FOREWORD

This book contains the papers presented at the 11th International Conference on Environmental Ergonomics in Ystad, Sweden on May 22-26, 2005. This type of conferences has been arranged since 1984. A list of the previous ones is found below.

The conferences provide a distinguished and recognized forum for presentation and exchange of new knowledge on subjects related to human interaction with the physical environment. New knowledge is reported on such topics as exercise, environmental physiology, ergonomics, extreme environments, firefighting, personal protective equipment, water exposures, prediction models and indoor air.

Conferences are intended for research scientists, ergonomists, industrial and occupational hygienists, safety engineers, safety and rescue services, product developers, physicians and other health care professionals as well as students of ergonomics and environmental sciences.

The conference in Ystad has attracted participants from more than 25 countries worldwide. A total of 176 papers were presented and they are published in these conference proceedings.

The organizers are much obliged to the members of the program committee for their support and review work, and the organizing committee for very practical assistance. We also wish to thank the sponsors and exhibitors that provided a valuable support of the conference. They enabled us to invite renowned speakers, but also to support participants that would not have been able to attend without funding.

On the following website you can obtain relevant information about the conference and also download the programme and a copy of the Proceedings in pdf format.
www.eat.lth.se/ICEE2005

Lund in May 2005
Ingvar Holmér Kalev Kuklane Chuansi Gao

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Previous ICEE Conferences

THE 1st INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Bristol or Cardiff, UK
No documents available.

THE 2nd INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Whistler Mountain, Canada
program in Annals Physiol. Anthrop. Vo1.5 No.3 1986
Selected papers in Environmental Ergonomics, Ed. I. Mekjavic,, EW Banister and JB Morrison, Taylor & Francis, London 1988

THE 3rd INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Helsinki, Finland and Viking Ferry Line 1988
Selected papers in Scandinavian Journal of Work, Envrionment and Health, 15, Supplement 1, 1989.

THE 4th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Austin, Texas, USA, 1990

THE 5th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Maastricht, The Netherlands. 1992
Procceedings published by TNO-Intstitute of Perception, Soesterberg, The Netherlands, 1992.
Editors W. Lotens and G. Havenith. ISBN 90-6743-227-X

THE 6th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Montebello, Canada, 1994
Proceedings published by Defense and Civil Institute of Envrionmental Medicine, Canada.
Editors J. From, M. Ducharme and P. Tikuisis. ISBN 0-662-21650-4-

THE 7th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
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Proceedings published by Freund Publishing house, Tel Aviv.
Editors Y. Shapiro, D.S. Moran and Y Epstein. ISBN 965-294-123-9

THE 8th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
San Diego, USA. 1998.
Proceedings published Environmental Ergonomics VIII
Editors Hodgdon JA, Heaney JH, Buono MJ. San Diego, 1999.
ISBN 0-9666953-1-3.

THE 9th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Dortmund, Germany, 2000.
Proceedings published as Environmental Ergonomics IX.
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ISBN 3-8265-7648-9

THE 10th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
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EFFECTS OF NORMOBARIC HYPOXIA ON THERMOREGULATORY RESPONSES IN HUMANS DURING LEG IMMERSION IN HOT WATER

Shuntaro SHIRABE, Tsuneyuki YAMAMOTO, Yutaka TOCHIHARA*

Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka, Japan
* corresponding author shirabe@gsd.design.kyushu-u.ac.jp

Introduction

Several reports have described the effect of hypoxia on thermoregulatory responses to cold at high altitude (1, 2). There are, however, few reports on the effects of hypoxia on thermoregulatory responses to heat stress at high altitude where core temperature rises due to exertion. Therefore, the present study aimed at examining the effects of normobaric hypoxia on thermoregulatory responses in humans.

Methodology

Subjects

Eleven healthy male students (22.7±1.1 yrs, 169.7±4.3 cm, 58.9±4.5 kg) were involved in this study. The purpose and procedure of the study were explained to each subject before the experiment, and they agree to participate in the study voluntarily. They wore only shorts during the experiment.

Procedures

A climate chamber in which oxygen concentration in air could be controlled under normal air pressure was prepared for the experiments. The conditions of oxygen concentration were set at 20.9 % (control) and 12.8 % (hypoxia) equivalent to 0 m and 4000 m above sea level, respectively. Ambient temperature, relative humidity and air pressure were set at 27 ℃, 50 % and 1013 hPa. Time protocol is shown in Figure 1.

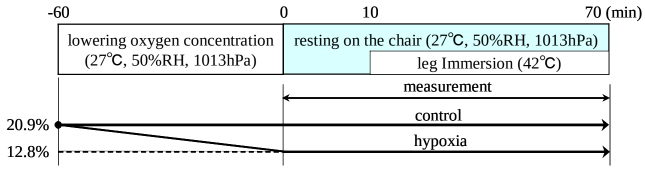

Figure 1. Time Protocol

Measurements

Measurements included rectal temperature (Tre), skin temperatures at 7 sites (forehead, chest, back, forearm, hand, thigh, and foot), laser Doppler flowmeter (LDF) on the forearm (LDFf) and back (LDFb) for cutaneous blood flow, forearm blood flow (FBF), local sweat rates on the forearm (Mswf) and back (Mswb), sweat lactate concentration and blood pressure. For measurement of Tre, the subjects inserted a thermistor probe at a depth of 12 cm from the sphincter muscle. Thermistors were taped onto specified sites with surgical tape to measure skin temperature. Data regarding Tre and skin temperature were recorded on a portable data logger (Gram, LT-8A) every second. Mean skin temperature ($\overline{T}_{sk}$) was calculated using the equation described by Shibasaki et al. (7). Local sweat rate was measured using a ventilated capsule instrument (K&S, AMU-100F4CH). LDF probes (omega flow, FLO-C1) were applied to adjacent sites to the ventilated capsules. FBF was measured using venous occlusion plethysmography (Horkkanson, EC-5R). A sweat sample was collected at 31, 44, 57 and 70 min using a modification of a disposable sweat collection device designed by Brisson et al. (3) from the forearm and back. Sweat samples were immediately analyzed using a YSI 1500 Sport Lactate Analyzer (Yellow Springs Instruments, Yellow Springs, OH). However in the case of a shortage of sweat, analysis was not performed.

Statistics

Data from time-lapse measurements were evaluated using repeated measures two-way analysis of variance (ANOVA) employing the data taken every one minute. The effect of oxygen concentration on sweat lactate was assessed by means of a t-test.

Results

Figure 2 illustrates time course of $\overline{T}_{sk}$. Two-way ANOVA revealed a significant tendency main effect of condition (p<0.1) and interaction between conditions and time (p<0.01) on $\overline{T}_{sk}$. Although $\overline{T}_{sk}$ decreased from the onset of sweating in both conditions, and then gradually increased during immersion, the increase in $\overline{T}_{sk}$ under hypoxia was larger than that of the control. There were no significant differences in the Tre (Fig. 3) and FBF (Fig. 4). Figure 5 illustrates the time course of Mswf. As the result of two-way analysis of variance, a significant interaction between condition and time was observed for Mswf (p<0.01). The increase in Mswf under hypoxia tended to be lower compared to that of the control. Sweat lactate at every measured time is shown in Table 1. A t-test revealed a significant difference in forearm at 31 and 57 min, in back at 31, 57 and 70 min, and a significant tendency in forearm at 44 min, respectively. During the above, sweat lactate under hypoxia was constantly higher than that of the control. Sweat lactate was the highest at 31 min both conditions and sites, gradually decreased and then maintained a constant level.

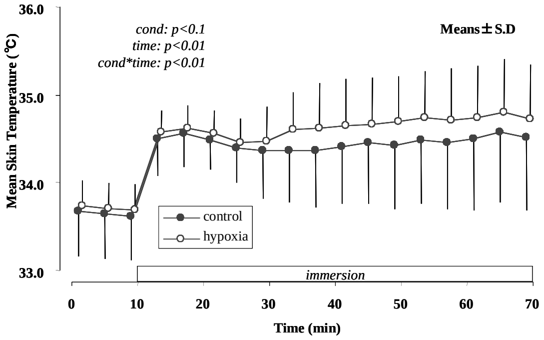

Figure 2. Time course of $\overline{T}_{sk}$ of control and hypoxia. Value are means±SD. "*cond: p<0.1*" indicates a significant tendency main effect of condition. "*time: p<0.01*" indicates a significant main effect of time. "*cond*time: p<0.01*" indicates a significant interaction between condition and time.

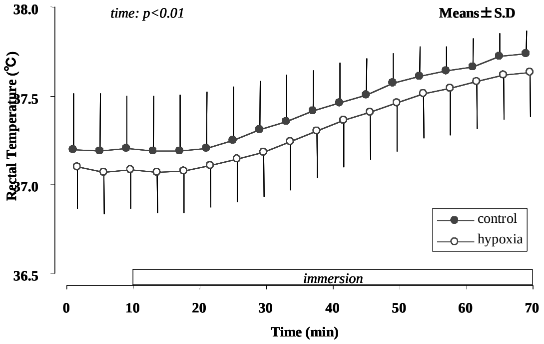

Figure 3. Time course of Tre of control and hypoxia. Value are means±SD. "*time: p<0.01*" indicates a significant main effect of time.

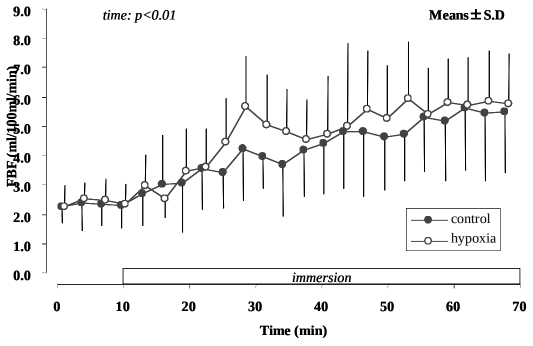

Figure 4. Time course of FBF of control and hypoxia. Value are means±SD. "*time: p<0.01*" indicates a significant main effect of time.

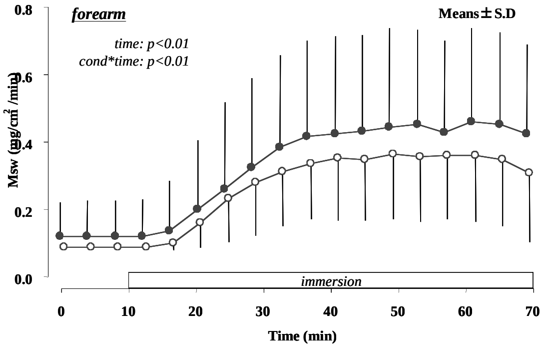

Figure 5. Time course local sweat rate on the forearm of control and hypoxia. Value are means±SD. “*time: $p<0.01$*” indicates a significant main effect of time. “*cond*time: $p<0.01$*” indicates a significant interaction between condition and time.

Discussion

A major point of interest in the present study regards the effects of normobaric hypoxia on sweat rate. In a previous study, DiPasquale et al. (4) showed that there was a 16 % lower sweat rate elicited by pilocarpine during hypoxia, whose concentration is 13.9 %, compared to sea level (p<0.006). In addition, they suggested sweating may be decreased under hypoxia because the mitochondria associated with sweat glands don’t receive

Sato (6) reported a major source of energy for sweat production is adenosine triphosphate (ATP) and sweat lactate is produced via glycolytic effects in secretory cells in sweat glands. In addition, Gordon et al. (5) suggested a decrease in blood oxygen concentration has aerobic metabolism falling in sweat glands and anaerobic metabolism rising. In the present study, there was a lower forearm sweat rate (p<0.01) as shown in Figure 3 and forearm sweat lactate showed a significant increase at 31 and 44 min under hypoxia compared to the control (Table.1). Moreover Figure 3 illustrated that as forearm sweat rate rose, sweat lactate tended to rise under hypoxia. These results showed evidence that sweat lactate is produced more by glycolytic effect when the ATP necessary for sweat production was produced. So the mechanism of a decrease in sweat rate under hypoxia may be the following: lack of oxygen to sweat glands caused a lack of ATP necessary for sweat production, which made sweat glands produce ATP through the glycolytic effect which, therefore, elicited an increase in sweat lactate and a lower sweat rate due to lack of oxygen.

In the present study, $\overline{T}_{sk}$ under hypoxia maintained lower level than did the control as shown in Figure 2, and increase in Mswf was smaller under hypoxia compared with the control (Fig. 5). Since there were no significant differences in the Tre (Fig. 3) and FBF (Fig. 4), it was estimated that dry heat loss was approximately equal in each condition. Therefore, high $\overline{T}_{sk}$ under hypoxia may be induced by a lower increase in sweat rate.

time	31 min	44 min	57 min	70 min
forearm				
control (mmol/L)	18.86±3.30 (n=6)	18.02±3.62 (n=7)	16.72±2.34 (n=7)	17.19±2.57 (n=4)
hypoxia (mmol/L)	24.08±4.58** (n=7)	20.84±4.51† (n=7)	20.81±4.99* (n=7)	19.33±5.67 (n=4)
back				
control (mmol/L)	18.32±2.61 (n=6)	16.42±2.43 (n=10)	14.69±1.94 (n=11)	14.25±1.65 (n=9)
hypoxia (mmol/L)	21.03±3.81* (n=6)	17.47±2.92 (n=10)	18.30±3.49** (n=11)	17.39±3.59** (n=9)

Table 1. Sweat lactate concentration at each time. Value are means±SD. **Different from the control values, p<0.01. *Different from the control values, p<0.05. †Different from the control values, p<0.1. numbers shown to “n” are sweat sample data.sufficient oxygen to provide the energy necessary for sweat production.

Conclusions

In the present study, these results suggest exposure to normobaric hypoxia does not affect thermoregulatory skin blood flow but elicits an inhibition of the sweating response, that is to say a inhibition of sweat production, which inhibits evaporative heat loss and maintains a high skin temperature.

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AN ALTERNATIVE VIEW OF VASCULAR THERMOREGULATION IN MAN

Leif Vanggaard and Gordon Giesbrect[2]

[1] Arctic Institute, Strandgade 100 H, DK 1401, Copenhagen K, Denmark < arctic@dpc.dk>
[2] Health, Leisure & Human Performance Research Inst. University of Manitoba, Winnipeg, Canada

INTRODUCTION

Experiments conducted in 1968 in Sweden at the Defence Research Establishment (FOA) by Wedin, P.O.Granberg and Leif Vanggaard (unpublished) demonstrated that when semi - nude subjects moved from an ambient temperature of 30 °C to 15 °C, hand and foot temperatures rapidly approached 15 °C while head, torso and upper part of the extremities only fell to values that would have been expected if there had been no change in skin conductivity even during a prolonged severe cold stress.

Vanggaard[1] has shown that during a moderate cold stress the arteriovenous anastomoses (AVAs) in fingers and toes close, resulting in a fall in extremity temperature corresponding to that seen during a complete arterial occlusion. In a warm or thermoneutral person the finger and toe temperatures are high and actually show the highest skin temperatures on the person.
One of the conclusions drawn from these experiments is that no thermo physiological experimentation should be carried out before ensuring that the AVAs are initially open, in order to ensure that the person is in a warm or neutral thermal condition.

The conclusions from these experiments were:

1. Skin temperature measurements on the torso, head and upper part of the extremities show that during cold stress, there is no active vasoconstriction in the skin, or if there is, it does not change the overall conductivity of the skin and subcutis.

2. The only vascular reaction to cold stress was that seen in the areas of the body where local skin temperature is governed by the blood returning from the AVAs to the body core via the superficial venous rete in the skin of the fingers, hands and lower part of the extremities.

The implications of these findings were that the old and generally accepted concept of an average skin temperature as originally proposed by Hardy & Dubois[2] had to be abandoned. This is shown in

In the original work of Hardy & Dubois[2], the authors mentioned that: concerning the measurements of hand and feet temperatures (the only skin temperatures that really determined the curve) the temperatures measured after one hour of exposure were used, as the temperatures here never stabilized!

We examined this forgotten statement and the earlier experiments where measurements were taken of skin temperatures on the extremities and the torso as ambient temperature was decreased from 30 °C to 10 °C in steps of 5 °C (unpublished observations).

METHODS

Two male test subjects were exposed, seated clothed in bathing suits, in a climatic chamber capable of rapid changes in temperature. Skin and room temperatures were measured with Cu/K thermocouples and continuously recorded.

Figure 1, where the original measurements of Hardy & DuBois are represented together with measurements from the 1968 and 2004 work

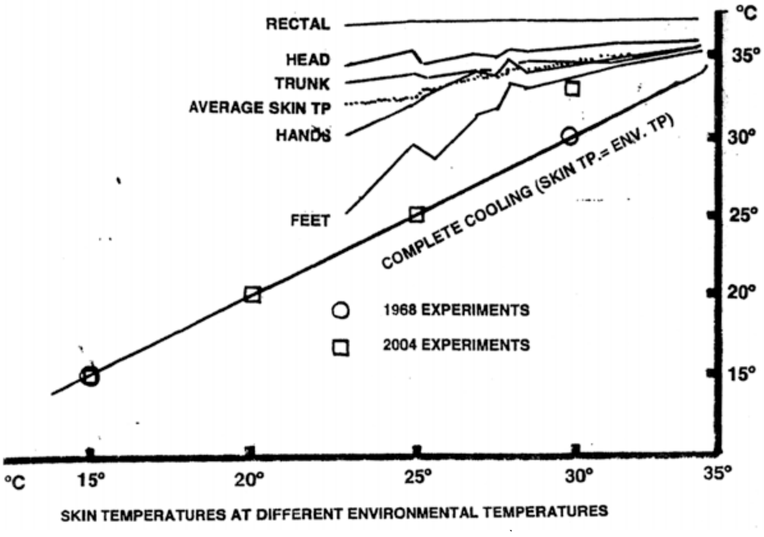

FIGURE ONE. The original Hardy & Dubois (1937) curve (upper right) on which the concept of the "average skin temperature" was based and later the commonly used concept of "area weighted skin temperatures" evolved. The values obtained by LV and others in 1968 after 2 days at 15 °C and the 2004 findings are shown, demonstrating that hand and feet temperatures only represent the results of a complete ("Newtonian") cooling.

The experiments started after opening of the AVAs was verified by high finger temperatures.

At the start of the experiment, an environmental temperature of 30 °C was chosen as being thermally neutral and not high enough to evoke a sweating response (which would result in an evaporative cooling of the skin). According to the conclusions from earlier experiments[1] that all physiological temperature research involving human subjects, the functional (open or closed) state of the arteriovenous anastomoses should be noted, it was found necessary to increase the heat production of the subjects by performing a moderate work on an ergometer cycle until the finger temperature rose rapidly, indicating the opening of AVAs, and ensuring that the subjects were in a comparable and well defined thermal state. This is obvious from Figure 2, where at the start of the experiment the finger temperature is seen falling, showing that the person has closed AVAs and, thus according to our earlier statement, is to be classified as cold stressed (see below).

When stable initial values were observed, the room temperature was lowered by 5°C. The same procedure was repeated until a room temperature of 10 °C was reached.

RESULTS AND DISCUSSION

Figure 2 indicates that *the finger temperature* drops rapidly from the initial 35 °C to that of the room (25 °C). This is in accordance with the expected closure of AVAs in the fingers due to cold stress and in accordance with earlier findings[1].

The initial *abdominal skin temperature*, stable at around 33 °C did not respond to the work-induced opening of the AVAs, indicating that the workload was sufficient to open the AVAs but not to elicit any detectable sweating in the skin, which would have shown itself as a fall in abdominal skin temperature. On the subsequent lowerings of the environmental temperature, the corresponding falls in abdominal temperature all show an identical response.

This is interpreted as experimental evidence of a constant insulation of the torso skin. General cold exposure (here naked at 10 °C) and even accompanied by low environmental temperatures does not elicit any change in skin insulation.

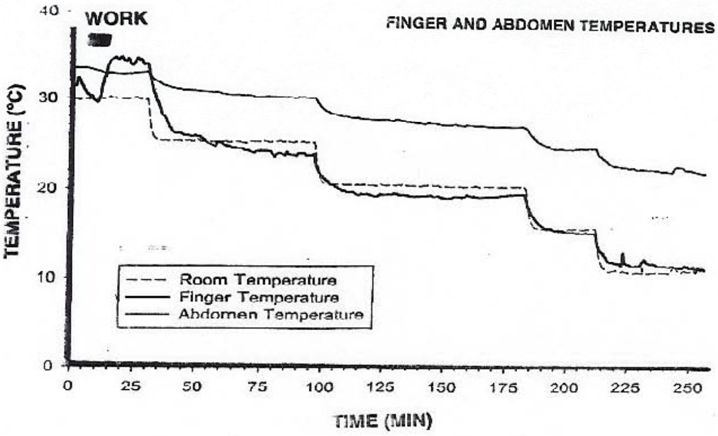

FIGURE TWO. Temperatures of room, finger and abdomen during subsequent 5°C lowerings of the environmental (room) temperature.

An explanation of this controversial statement could lie in the vascular arrangement in the skin. The skin in thermoregulatory sense includes the ectodermally derived skin and the mesodermally derived subcutaneous structures down to the superficial muscular fascia.

The temperature of the skin in the "AVA dependant areas" is completely governed by the blood flow through the AVAs and the subsequent return of warm arterial blood via the superficial venous rete of the fingers, hands and forearms.

The local skin temperature measured in the "non AVA- dependant areas" (the torso, head and upper arm and thigh, is due to the anatomical arrangements of the blood vessels in the subcutis and skin. Here the veins on their return course from the skin surface follows the arteries closely. As the veins generally have a larger transsectional area, the blood will have a lower linear velocity and thus greater possibilities for exchanging heat with the surroundings. This means that in these areas the physical arrangement of the vessels favours an effective heat exchange, not only in a counter-current heat exchange system between artery and vein but also, and of greater significance, between the returning blood and the surrounding subcutaneous tissues. This might explain why the skin and subcutis responses are consistent with the laws of passive cooling, and do not show any effect of a possible vasoactivity.

CONCLUSIONS

The following conclusions are relevant for a person exposed to a cold environment. The relevance of AVA functioning and its influence during body heating and subsequent sweating is not covered in the following conclusions:

- Only those skin areas where local temperature is dependant upon the functional state of the AVA (open or closed) show an influence of body cooling upon skin temperatures, and the changes are related to the thermoregulatory on-off actions of the AVAs.

- The lowering of skin temperatures measured in the non AVA dependant areas during cooling do not represent a regulated reaction to cooling (vasoconstriction) but is due to the constant insulative properties of the skin.

- The much used concept of an "area weighted average skin temperature" should not be used when referring to responses to a person's thermal state.

- The functional state (open or closed) of the arteriovenous anastomoses should be stated at the beginning and during experiments involving responses to cold.

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THERMOREGULATION DURING CYCLING- AND ARM CRANKING-EXERCISE WITH SAME ABSOLUTE OXYGEN UPTAKE AND %HR$_{max}$

Masafumi Torii, Muneyuki Hayashida, Shinji Hamada, Kohtaro Umeda, Emiko Morimoto

Division of Physiological and Biochemical Adaptation, Department of Biological Functions and Engineering, Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Kitakyushu Japan

Introduction

It is important to examine human thermoregulatory responses during muscular work, particularly comparing upper- and lower-body work. Upper-body work has many applications to the rehabilitation and maintenance of thermophysiological responses of individuals who are unable to work their lower body. It is not clear how thermoregulatory function adapts to the specific hemodynamic loads associated with this form of exercise bout (1). The purpose of the present study is to compare thermoregulatory responses between upper- and lower-body work of two different criteria, same level of oxygen uptake (VO_2) and same percent of maximal heart rate (%HR$_{max}$).

Methods

We conducted two series of the experiments according to following protocols. None of subjects took any medication at the time of the study. After careful oral and written explanation, written consent was obtained from all subjects and all of the experimental protocols were approved by the Ethical Committee of our Institute. The subjects were hea1thy and untrained men. There was significant difference in peak oxygen uptake (VO_{2peak}) in *Protocol 1* and no difference in maximal heart rate (HR$_{max}$) in *Protocol 2* between arm cranking (AC) and bicycle (BE) exercise tests (see Table 1).

Protocol 1: Arm- and leg-work due to the same level of VO_2

Two to three days after a preliminary test, the subjects, wearing trunks only, exercised for 40 min AC or BE. All experiments were carried out in a climatic chamber in which the ambient temperature was controlled at 32.5±1.4°C (relative humidity of 50±1.1%). In those cases, there was no significant difference in VO_2 (BE: 1.23±0.07 $l\cdot\text{min}^{-1}$, and AC: 1.19±0.08 $l\cdot\text{min}^{-1}$, $P>0.05$).

Unilateral tympanic (attached on the membrane of right ear, T_{ty}) and skin (T_{sk}) temperatures, skin blood flow (SkBF), local sweat rate (SR), VO_2, and heart rate (HR) were continuously measured. T_{ty} and T_{sk} were spontaneously recorded every minute by a thermistor recording system (Hybrid Recorder K380, Technoseven Co.) throughout the experimental period. HR was continuously recorded by an electrocardiography with a telemeter system (Life Scope 6, Nihon Kohden). SkBF was continuously determined by a laser Doppler flowmeter (ALF21, Advance Co.) at rest and during exercise after the beginning of exercise. The location of the censor probe for determining SkBF was on the cervical vertebra aspect of the back. Local SR at the location as well as the censor probe for determining SkBF was continuously determined by the ventilated capsule method using a hygrometry (Kenz-Perspiro OSS-100, Suzuken). VO_2 was measured via open-circuit spirometry by using an automated metabolic analysis system (Benchmark, 505 Type, Morgan). Measurements were obtained at rest and during exercise at 1-min intervals, breath by breath. Calculation of metabolic rate (M) and mechanical work efficiency (ME) were described in our previous work (2).

Protocol 2: Arm work and leg work with identical %HR$_{max}$

The subjects were randomly divided into cycling (n = 8) and arm cranking groups (n = 9) (See Table 1). Except for local SR, we basically measured thermophysiological variables according to Protocol 1. We measured local SR by filter paper modified Ohara's technique (3). Subjects completed three consecutive sessions (rest, 34±3% [1st W] and 65±4% [2nd W] of %HR$_{max}$) of 10 min in a climatic chamber with an T_a of 34°C (rh, 45%). T_{ty}, T_{sk}, SkBF, local SR and HR were continuously measured.

Results and Discussion

Protocol 1 In the latter period of exercise, T_{ty} increased linearly for both tasks. The change of T_{ty} (ΔT_{ty}) began to be suppressed at the 25th - 35th min after the beginning of the BE, and the 20th to 25th min after the beginning of the AC. The ΔT_{ty} was significantly higher in the AC (0.81±0.13°C) than in the BE (0.67±0.11°C) (one-way ANOVA, $F[1,39]=11.345$, $P=0.017$).

During the AC T_{sk} was relatively elevated in both tasks. At the end of the AC and BE, it was 35.4±0.2°C and 35.8±0.3°C, respectively. No significant differences were finally observed in T_{re} or mean T_{sk} between the AC and the BE.

As soon as the subjects started, a rise in sweat secretion was observed in all subjects. No significant difference was observed for local SR at the initial stage (exercise start to 10th min) in the AC (2.03±0.28 $mg\cdot cm^{-2}\cdot min^{-1}$) *vs.* the BE (2.00±0.40 $mg\cdot cm^{-2}\cdot min^{-1}$). Local SR in the AC (2.63±0.48 $mg\cdot cm^{-2}\cdot min^{-1}$) *vs.* the BE (2.52±0.53 $mg\cdot cm^{-2}\cdot min^{-1}$) did not significantly differ at the final stage ($F[1,19]=1.88$, $P=0.186$).

ΔSkBF increased quickly the 1st min at the onset of the exercise in the both tasks, especially in the AC, and it accumulated progressively until the 10th min in the BE, but not in the AC. ΔSkBF reached a steady state in the BE, but ΔSkBF in the AC increased progressively until the end of the exercise. Finally, mean ΔSkBF was approximately 1.5- and 5.8-fold against that at rest in the BE and AC, respectively.

The final HR was significantly higher ($P<0.05$, paired *t*-test) during the AC (156±9 bpm) than the BE (137±8 bpm). VO_2 and M during both tasks increased more rapidly in the BE than in the AC at the initial stage (paired *t*-test, $P<0.05$). No significant differences were finally observed in VO_2 or M. In contrast, ME was significantly higher in the BE (27.3±1.1%) than in the AC (16.3±1.1%) (paired *t*-test, $P<0.05$,).

As we estimated $\%VO_{2peak}$ in each subject, the values of $\%VO_{2peak}$ were significantly higher ($P<0.05$, paired *t*-test) in the AC than in the BE (see Table 1).

Protocol 2 HR was not significantly different between the tests. Namely, this means that HR_{max} as a relative index of physical stress was the same in both tasks. No difference in ΔSkBF was observed when BE was compared with AC. However, the ΔSkBF in the AC was higher than in the BE at 2nd to 4th min from the initiation and at the end of the exercise (unpaired *t*-test, $P<0.05$, all).

T_{ty} (37.7±0.06°C, mean±SE, n=9) in the BE was significantly higher than that (37.4±0.10°C, n=8) in the AC. T_{sk}, in the BE was significantly higher than that in the AC. T_{sk} during the BE increased progressively to 35.4±0.09°C, and the rate of T_{sk} change (ΔT_{sk}) during the BE rose gradually to 0.7±0.2°C at the end of the exercise ($P<0.05$).

Local SR in the BE was significantly higher ($P<0.05$) than that in the AC at the 6th to 16th min from the initiation of the exercise. However, no significant difference ($P>0.05$) in local SR was observed when the BE was compared with AC at the end of the exercise.

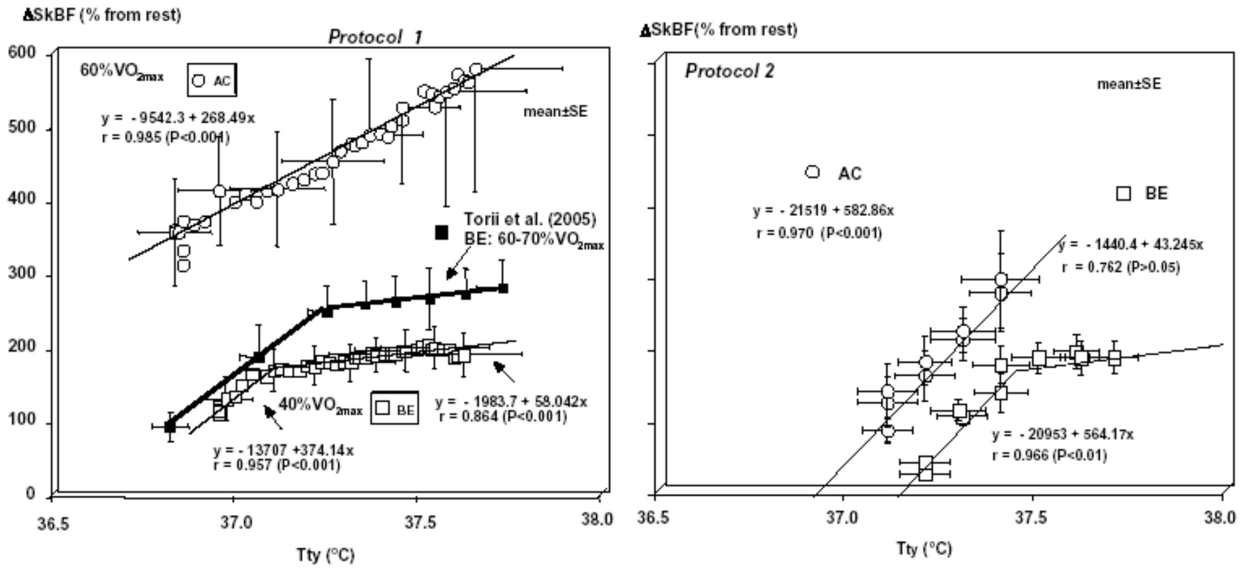

Figure 1. Change from rest control of skin blood flow (ΔSkBF, % from rest) as a function of tympanic temperature (T_{ty}) during BE (open squares) and AC (open circles). The closed squares in the left panel indicate our previous data (Torii *et al*., 2005).

Table 1. WR, cardiorespiratory parameters, %VO_{2prak} and HR_{max} during leg- and arm-work

Protocol 1 (n=7)	BE	AC	*Protocol 2*	BE (n=9)		AC (n=8)	
				1st W	2nd W	1st W	2nd W
VO_2 ($l \cdot min^{-1}$)	1.23±006	1.20±0.07	%HR_{max}[a]	34±3	65±3†	34±3	65±4†
%VO_{2peak}	40.4±1.7	58.5±3.8*	HR(bpm)	114±2	158±4	116±2	160±4†
VO_{2prak} ($l \cdot min^{-1}$)	3.09±0.19	2.17±0.16 *	WR (watts)	82±5*	125±5*†	30±2	58±3†
VO_{2prak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	46.3±3.3	32.6±3.0 *					
WR (watts)	95±5	55±5	HR_{max} (bpm)	189±3		185±4	

Data represent mean±SE. See text for abbreviations. [a] %HR = (HR_{submax} – HR_{rest})/(HR_{max} – HR_{rest}) x 100 (%).

* *P* < 0.05, Significantly different, BE *vs.* arm AC and †, *P*<0.05, significantly different, 1st W *vs.* 2nd W.

T_{ty}-to-SkBF and -to-SR relations in both Protocols

In both *Protocols*, the slope (%·°C^{-1}) of the regression equation between ΔSkBF and T_{ty} in the AC failed to show a significant difference in comparison with the BE of hypothermia side. As neared T_{ty} 37.3 to 37.5°C the slope of the ΔSkBF-to-T_{ty} relation suddenly decreased in the BE (by co-variance analysis, *F*[1,66]=203.44, *P*<0.0001 in *Protocol 1* and *F*[1,12]=30.337, *P*<0.001 in *Protocol 2*). The intercept is shown as a parallel shift (Figure 1, in both *Protocols*).

A significant positive correlation was found between T_{ty} and local SR in both exercises (AC; r=0.920 and BE; r=0.969 in *Protocol 1* and AC; r=0.964 and BE; r=0.944 in *Protocol 2*). In both *Protocols*, we observed there were no significant differences of (slope, sweating sensitivity) and threshold in the local SR-to-T_{ty} relation between BE and AC (*P*>0.05).

The present study demonstrates that for the SkBF-to-T_{ty} relation in the AC, the intercept of the regression equation shifts to upper side, as compared with the BE. SkBF-to-T_{ty} relation was characterized by a reduction of the slope (sensitivity, %·°C^{-1}) in the BE as T_{ty} neared 37.3°C, but not in the AC at 60%VO_{2peak}, as the results with our estimation of peak aerobic power in upper- body work (see Table 1). In contrast, subjects performed the BE at 40%VO_{2peak}, too.

A laser-Doppler flowmetry measurement provides an index of SkBF that is important in the assessment of thermoregulatory effector function (4). As core temperature (T_c) increases during exercise and/or heat stress, SkBF to the cutaneous vasculature increases proportionately. Exercise limits cutaneous vasculature to dilate and, as core temperature approaches 38°C, SkBF levels off even as T_c continues to increase (5). Nadel *et al*. (1980)(6) reported that at any hydration level the slope of T_c-SkBF relation fell at 38°C of T_c. It is this relationship that was of interest in the present study. We have observed this phenomenon. Moreover, we made the same observations in BE at 60-70%VO_{2peak} in our previous study (7): The SkBF-to-T_{ty} relation slope was significantly reduced over 37.5°C T_{ty}. The intercept of regression line in SkBF-to-T_{ty} relation was markedly different in BE, as compared with AC.

Brengelmann *et al.* (1977)(5) have notified that variations in skin blood flow would lead to differences in the volume of blood displaced into cutaneous veins (i.e., variation in stroke volume and cardiac output) and variations in arterial blood pressure and thus in vasoconstrictor drive to skin. They have used cycle erogometry, but not arm ergometry. In this case, the slope of core temperature (T_c)-to-skin blood flow relation was markedly reduced at increasing T_c (>38°C in esophageal temperature) during cycle exercise at 90 to 150 watts with oxygen consumption at 50% of VO_{2peak}. The reduction of the T_c-to-SkBF relation slope may be related to relative work intensities. Main heat loss in exercising humans is likely to change from skin blood flow to loss body heat content to wet-heat loss due to sweating, as shown in Figure 1.

Next, we must discuss that this phenomenon occurs in the leg-work but not occur in the arm-work. Sawak (1986) (1) has pointed out factors possibly limiting aerobic performance for upper body exercise, as compared with lower body exercise. He focus on 3 points of muscle physiology and metabolic aspects, reduced potential to generate muscular tension, reduced oxidative capacity, and reduced blood perfusion of skeletal muscle. There were no significant differences in the slope (sensitivity, mg·cm^{-2}·min^{-1}·°C^{-1}) or intercept (threshold temperature, °C) in the local SR-to-T$_{ty}$ relation. It seems likely that absolute with intensity is regulated whether work is upper or lower. The present study suggests that there are differential thermoregulatory effector responses between the upper- and lower-body work. Non-thermal factors rather than thermal factors may take part in reduction of the slope in skin blood flow-to-T$_c$ relation.

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QUANTITATIVE ANALYSIS AND DATA-BASED MODELLING OF SPATIAL SWEAT PRODUCTION OF HUMAN HEAD AND HEART RATE DURING EXERCISE

*Jan Welkenhuyzen [1], Jean-Marie Aerts [1], Jos Vander Sloten [2], Jan Goffin [3], Ignace Verpoest , Daniel Berckmans [1]**

[1] Laboratory for Agricultural Buildings Research, KULeuven, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium
[2] Biomechanics and Engineering Design, KULeuven, Celestijnenlaan 200A, 3001 Heverlee, Belgium
[3] Experimental Neurosurgery and Neuroanatomy Section, KULeuven, Herestraat 49, 3000 Leuven, Belgium
Metallurgy and Materials Engineering, KULeuven, Kasteelpark Arenberg 44, 3001 Heverlee, Belgium
* corresponding author daniel.berckmans@agr.kuleuven.ac.be

Introduction

Thermal comfort has a key factor in human behaviour, or even more specific in human safety. Every year, many cyclists die as a consequence of an unfortunate tumble or a traffic accident in which they suffer from a severe head injury. Most of these head injuries could be avoided or strongly reduced by wearing a cyclist crash helmet (1). However, a lot of cyclists still do not like to wear a crash helmet because of the thermal discomfort that comes along with wearing it, especially in the summertime when cycling is popular (2).

The human head plays an important role in the thermoregulation of the body. Up to 50% of the produced heat (latent and sensible) is transferred via the head, causing high temperatures and sweat production on the head (3). This is an important fact that has to be taken into account during headgear design. The current research aims at quantifying and modelling these thermal parameters of the head and to obtain a predictive three-dimensional simulation model of the head. In a next step this model can be used to develop new helmets.

In this paper the local sweat production of the head is studied, together with the heart rate during exercise. It is known that, on whole body scale, the amount of sweat production differs from body part to body part (4-5) and that the distribution of the total sweat production changes with changing effort level and environmental conditions (6-7). Measurement of the heart rate gives an indication of the supplied effort during exercise. The obtained data is not only quantitatively analysed but also processed using a dynamic data-based modelling approach.

Methods

Subjects & experimental conditions

Six students performed all the experiments (1 female, 5 males). The mean (SEM) physical characteristics of the subjects were: 22 ± 0.5 yr of age, 21.2 ± 0.7 of BMI and 3.57 ± 0.16 $l \cdot min^{-1}$ maximum oxygen consumption (VO_{2max}). They performed a step experiment under two different environmental conditions (see table 1) in a climate chamber of 3.65x2.35x2.40 m. During the second series of experiments (condition 2) also an air velocity of 2.4 m/s was maintained in the climate room. Each experiment was repeated three times to get statistical relevant data. The experiments had a total duration of 30 minutes and started after the test subject was acclimatised to the environmental conditions (air velocity, environmental temperature, relative humidity). In total 36 experiments were conducted (6 x 2 x 3).

Table 1. Experimental conditions

		Troom (^oC)	**Relative Humidity (%RH)**
Condition 1 (hard)	**mean**	28.26	37.60
	SEM	0.10	0.51
Condition 2 (moderate)	**mean**	16.06	45.01
	SEM	0.14	0.62

Experimental protocol

Each subject completed six step experiments. During one experiment, the subject started cycling for 10 minutes at 80W (50W for females), followed by a step to 150W (125W for females) which was maintained for 20 minutes. The experiments were performed on a cycle ergometer (Tunturi T8 Alpha 300 Cycle). Heart rate was measured using a heart rate monitor (Polar, using T-ware interface). Sweat production of the head was measured at three places on the head (left and right temple, forehead) using the Skinos sweat monitor (SKD4000), based on the method of ventilated sweat capsules (8). The obtained data are processed using a data-based modelling approach and is also analysed quantitative.

Results and discussion

Quantitative steady state analysis

a) Heart rate

For the quantitative analysis of the heart rate four cases are considered, namely the steady state heart rate before and after the step (corresponding to respectively the initial low effort level and the high effort level afterwards) and this for both conditions (figure 1). Figure 1 gives an indication of the differences between the cases: higher effort level gives higher heart rates (case 3 and 4 compared to respectively case 1 and 2); moderate conditions give lower heart rate (case 2 and 4 compared to respectively case 1 and 3). A statistical analysis reveals that those differences are also statistically significant (p-value < 0.05).

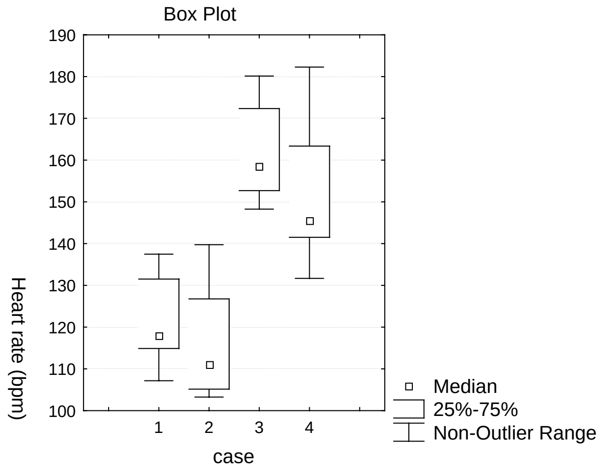
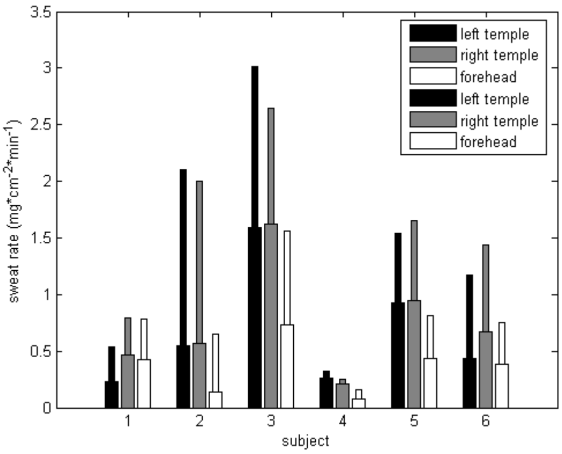


figure 1: Box plot for the different cases (1 = condition 1, before step / 2 = condition 2, before step / 3 = condition 1, after step / 4 = condition 2, after step)



b) Sweat rate

Sweat rate was measured at three places on the head (left and right temple, forehead). Steady state sweat rate after the step is significantly higher under condition 1 then under condition 2, for all local measurements. The sweat rate in moderate circumstances (condition 2) was on average 50% of the sweat rate during more severe circumstances (condition 1). Furthermore local differences in sweat rate were found: sweat rate of the temples is significantly higher than the sweat rate of the forehead, as depicted in figure 2. This is so for both experimental conditions, except for subject 1, who had a different sweat pattern.

figure 2: sweat rate for different experiments (thin bar = condition 1, thick bar = condition 2)

Data-based modelling

a) Heart rate

Once a set of usable input-output time-series data is generated, a reduced order, linear model can be identified that describes the system in a sufficiently accurate way for control purposes. In order to identify and model the heart and sweat rate, it is preferable to perform experiments in which the input (effort level) is changed sharply in a 'sufficiently exciting' manner (9). The continuous-time SRIV (Simplified Refined Instrumental Variable) algorithm (10-11) is used to identify the linear TF model between the input effort level and the output heart/sweat rate, with the YIC identification criterion employed as model structure identification criterion (12).

An example of a modelled heart rate signal is shown in figure 3 (left). Looking at the model orders reveals no statistical differences in heart rate response between the conditions or individuals. Simple first

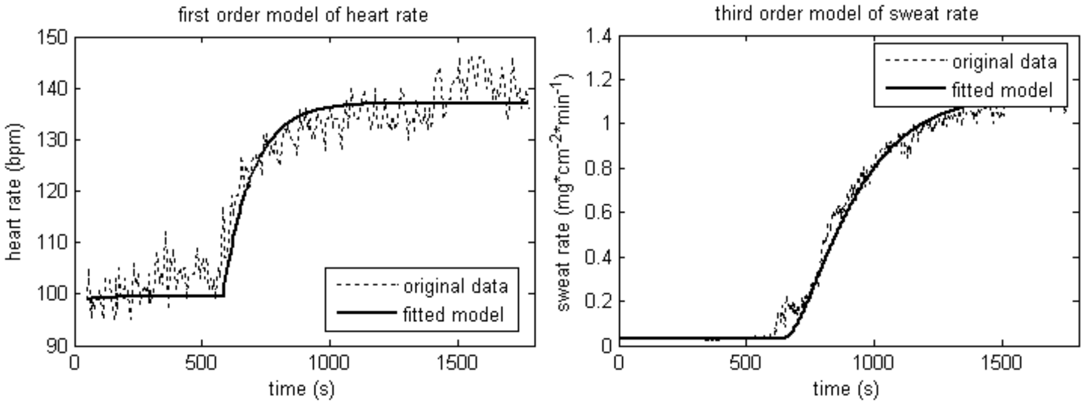


figure 3: modelled data of heart rate (left) and sweat rate (right)

Conclusions

The obtained results indicate the possibilities to model and predict biological responses to step inputs. They also reveal that a simple step in effort level causes high increases in heart rate and sweat rate. These broad ranges of sweat rate have to be taken into account when designing new protective headgear. Further research will concentrate on sweat rate but also on temperature distribution and environmental variables.

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THE METABOLISM OF ADVENTURE RACING

James D. Cotter[1], Nancy J. Rehrer[1], Patrick Manning[2], Samuel J.E. Lucas[1], David F Gerrard[2], Jörn W. Helge[3]*

[1]School of Physical Education and [2]School of Medicine, University of Otago, Dunedin, New Zealand
[3]Department of Medical Physiology, University of Copenhagen, Denmark
*corresponding author jcotter@otago.ac.nz

Introduction

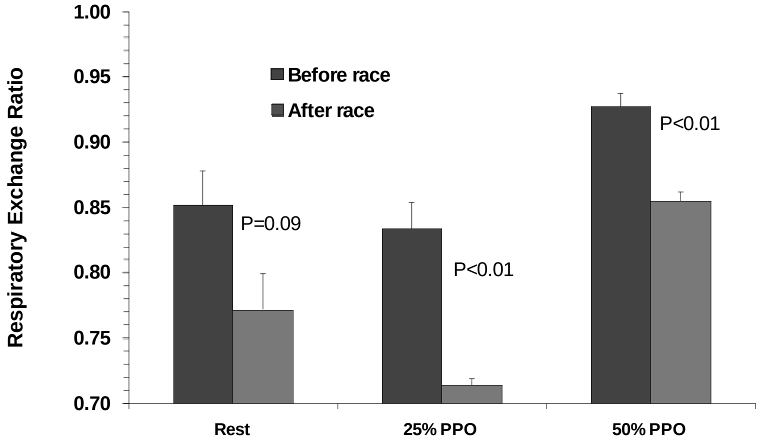
Adventure racing typically involves multiple days of competitive, almost continuous exercise, in which athletes compete in teams, concurrently, across wilderness terrain in multiple sporting disciplines. Energy is likely to derive increasingly from intramuscular and extramuscular triglycerides across the first several hours of racing, concomitant with declining muscle and liver glycogen stores. Yet sustained carbohydrate availability would remain important for oxidation of fatty acid derivatives, central nervous system metabolism and bursts of higher power demand. The purpose of this study was to examine energy substrate availability and utilisation during a multi-day adventure race.

Methods

Metabolic data were obtained from eleven athletes competing in the 2003 Southern Traverse (96-126 h duration). Vastus lateralis was biopsied 2-5 wk before the race and within 3 h after completing it. Respiratory gases were sampled at rest and while cycling at 25 and 50% peak aerobic power output (PPO) following each biopsy. Fat mass was estimated by four-frequency, eight-electrode bioimpedance, 1 d before and 1 d after racing (fasted and rested). Blood glucose was measured continuously (5-min intervals) during racing in two athletes.

Results

Blood glucose remained above 4 mmol/l throughout 90% of the 158-h of data recorded. As shown in the figure (M ±SE for *n*=9), the Respiratory Exchange Ratio decreased across the race, markedly so at the 25% workload. Plasma FFA following this exercise was 3.5 times higher after the race (298 ±74 to 1407 ±118 µmol/L; *p*<0.01). Muscle glycogen content fell 50%, from 554 ±28 to 270 ±25 nmol/g d.w. (*p*<0.01; *n*=7), and was <200 nmol/g d.w. in only one athlete who had been ill for 2 d while racing. Muscle triglyceride dropped inconsistently, from 32 ±5 to 22 ±3 nmol/g d.w. (*p*=0.14; *n*=7), whereas body fat mass dropped 1.6 ±0.4 kg (11%; *p*<0.01; *n*=9). Citrate synthase activity was stable across the race (92 to 93 µmol/g d.w./min; *p*=0.83; *n*=7), as was HAD (108 to 111 µmol/g d.w./min; *p*=0.58; *n*=7).



Conclusions

Competitive exercise, when performed almost continuously for 96-125 hours, did not appear to induce hypoglycemia or muscle glycogen depletion, so these may not have been the principal limiting factors. There was a marked increase in fat oxidation during exercise, associated with increased plasma fatty acid availability and reduced adiposity.

COGNITIVE FUNCTION IS MINIMALLY IMPAIRED DURING 100 HOURS OF EXERCISE AND SLEEP DEPRIVATION

*Samuel J.E. Lucas**, *James D. Cotter, Craig D. Palmer, J. Greg Anson*

School of Physical Education, University of Otago, Dunedin, NZ
* corresponding author slucas@pooka.otago.ac.nz

Introduction

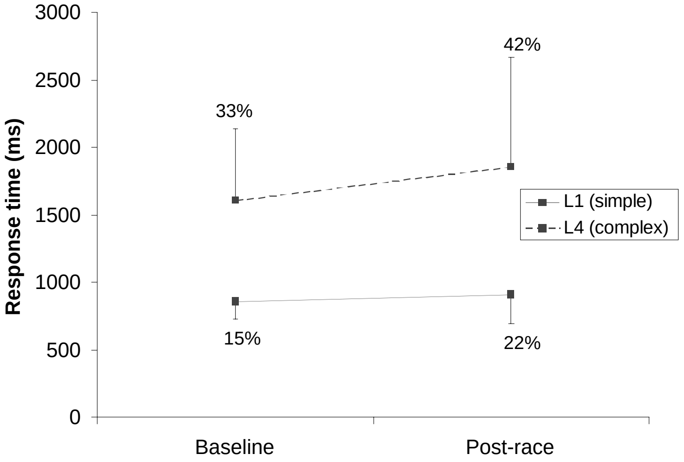
Adventure racing has several cognitive demands, including navigation through novel terrain. Research on the effects of exercise and sleep deprivation on cognitive function has produced diverse results. This diversity may be due to the variety of exercise parameters (mode, intensity, frequency, duration) and cognitive performance measures employed. Furthermore, most studies induced a maximum of 1 to 3 days sleep deprivation, were lab-based, and typically had regular periods of rest during each 24 hour period. Effects on cognitive performance of combined sleep deprivation and exercise sustained for longer periods are unknown. The purpose of this study was to measure speed and accuracy of decision making as an indicator of cognitive performance during ~100 hours of competitive exercise, undertaken as continuously as tolerated.

Methods

A computerised Stroop test was used to measured cognitive performance. Blocks of twenty trials at four levels of complexity were administered. Participants (*n*=9) completed the task before, during and after the 2003 Southern Traverse adventure race (96-125 h). Speed, accuracy and consistency of responses were analysed.

Result

Post-race simple response time increased by 50 ms (6%; *p*=0.27) compared to baseline (see figure), and the average within subject coefficient of variation (numbers in figure) increased by 50% (*p*=0.04). Complex response time increased by 250 ms (16%; *p*=0.04), and the average within subject coefficient of variation increased by 29% (*p*=0.11). During the race, average response times across all participants and all test periods increased by 40 ms (5%; 860 to 900 ms) for the simple task, and by 80 ms (4%; 1610 to 1690 ms) for the complex task. Consistency of responses was affected; within subject coefficient of variation increased by 66% (15 to 24%) and 17% (33 to 37%), respectively. Individual differences were evident both within and between teams. On average, accuracy of decision making was impaired at a rate of 1 error·day^{-1} for simple, but was improved by 1 error·day^{-1} for the most complex task. However changes were variable, and statistical differences were not evident (*p*=0.90 and 0.20, respectively).



Conclusion

Speed and accuracy of decision making is affected by ~100 hours of almost continuous exercise and sleep deprivation, but not in a consistent manner. Potentially, the greatest influence on speed and accuracy of decisions may be the ability to attend and concentrate on a task when sleep deprivation is extended, as has been observed previously.

MUSCLE TISSUE TEMPERATURE TRANSIENTS DURING AND FOLLOWING LIGHT AND MODERATE INTENSITY EXERCISE

Glen P Kenny[1], Paul Webb[1,2], Pascale Otis[1], Michel B Ducharme[1,3], Dragan Brajkovic[3], Mark L Reardon[1,], and Frank D Reardon[1].*

[1]J.W. Snellen Memorial Calorimetry Laboratory, University of Ottawa, Ottawa, Ontario, Canada
[2]Yellow Springs, Ohio, USA
[3]Defence Research and Development Canada - Toronto, Ontario, Canada
[4]Faculty of Medicine, University of Ottawa, Ottawa, Canada
*corresponding author gkenny@uottawa.ca

Introduction

A number of studies have investigated the effect of thermal stress on the temperature profile of muscle tissue during rest and exercise. Early studies focused mainly on the possible relationships between changes in muscle temperature and the capacity for work, the effect of exogenous heating prior to exercise (2) and muscle blood flow distribution at rest (3). Subsequent studies focused primarily on tissue temperature transients and heat loss responses during exercise (1,8,9). To our knowledge, the study by Saltin et al. (9) is one of the few early studies that examined intramuscular leg temperature following low to intense exercise (25-75% Vo_{2max}) performed in a range of ambient temperatures (10 to 30°C). Recent studies examining tissue temperature exchange during uni- and bilateral knee extension exercise suggests that the rate of core temperature decay following exercise is significantly influenced by convective heat transfer between muscle and core (6,7).

Tissue temperature at any given time is ultimately determined by the relative rates of heat production and heat loss. For example, regional muscle temperature at any point in time is the result of regional differences in metabolic rate, conductive heat loss to adjacent tissue and peripheral convective blood flow (4). Disturbances in deep and peripheral circulation, and therefore convective heat exchange, associated with blood pressure regulation and blood flow distribution has been shown to significantly influence the kinetics of tissue heat exchange, especially in the postexercise period (5). As such, it would be expected that the rate of temperature change would differ during resting, exercise and postexercise recovery. The following study examined core and active and non-active muscle tissue temperature transients during and following dynamic exercise.

Methods

Nine healthy subjects (4 males, 5 female) consented to participate in the study. Mean values (± SD) of the subject's age, height, body mass, VO_{2max} during incremental cycling ergometer test and body fat content were 30 ± 5 years, 1.7 ± 0.5 m, 65.6 ± 6.1 kg, 40.0 ± 2.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and 22.1 ± 2.3%.

In each trial, esophageal temperature (T_{es}) was measured using a thermocouple temperature probe inserted through a nostril, into the esophagus to the level of the heart. Regional muscle temperature of the vastus lateralis (T_{VL}), lateral head of triceps brachii (T_{TB}), and upper trapezius (T_{UT}) was measured by using a flexible thermocouple probe inserted ~30 mm perpendicular to the surface. The implant site for: 1) the vastus medialis was approximately midway between, and lateral to, a line joining the anterior superior iliac spine and the superior aspect of the center of the patella, 2) the triceps brachii was approximately midway between, and lateral to, a line joining the greater tubercle of the humerus and the superior aspect of the olecranon of the ulna, and; 3) the upper trapezius was approximately ~20-30 mm superior to the superior angle of the scapula.

With the use of aseptic technique, the skin, subcutaneous tissue, and muscle were anesthetized to a maximum depth of 40 mm by infiltrating ~3 ml of 2% lidocaine with epinephrine. With the use of the use of the anesthetic needle as a guide, an 18-gauge, 45-mm non radiopaque FEP polymer I.V. catheter (Medex Medical Ltd) was then inserted into the anesthetized tract to the required depth. The anesthetic needle and the catheter stylet were then withdrawn, and the temperature probe was inserted in the catheter shaft. The probe assembly including the catheter shaft, was secured to the skin with sterile, waterproof transparent dressing.

Skin temperature was monitored at 12 sites using Type T thermocouples integrated into heat-flow sensors (Concept Engineering, Old Saybrook, CT). The area-weighed mean skin temperature ($\overline{T}_{sk}$) and heat flux ($\overline{H}F_{sk}$) were calculated (6,7). Temperature and heat flux data were collected and digitized (Hewlett Packard data acquisition module, model 3497A) at 15-s intervals, simultaneously displayed and recorded in spreadsheet format on a hard disk (Hewlett Packard, model PC-312, 9000).

The experimental trials were conducted in the morning following a 24 h period without heavy or prolonged physical activity. Upon arrival at the laboratory at 0715 h, subjects were appropriately instrumented. Subjects then rested in a semi-recumbent position for 60 min at an ambient temperature of 30℃ of which the final 10 minutes were recorded as representative of the baseline resting values. Subjects then exercised for 60 min on a semi-recumbent cycle ergometer at either 70 W (LIE: light intensity exercise) or 140 W (MIE: moderate intensity exercise) followed by 60 min seated resting recovery.

Results

Baseline T_{es}, T_{re} and $\overline{T}_{sk}$ for LIE (36.69, 36.76 and 33.36°C respectively) and MIE (36.83, 36.76 and 33.45°C respectively) were similar (Fig. 1). No differences were measured for muscle temperature between conditions with T_{VL}, T_{TB}, and T_{UT} for LIE equal to 34.39, 34.68 and 35.49°C respectively and 34.42, 34.65 and 35.34°C for T_{VL}, T_{TB}, and T_{UT} respectively for the MIE trial.

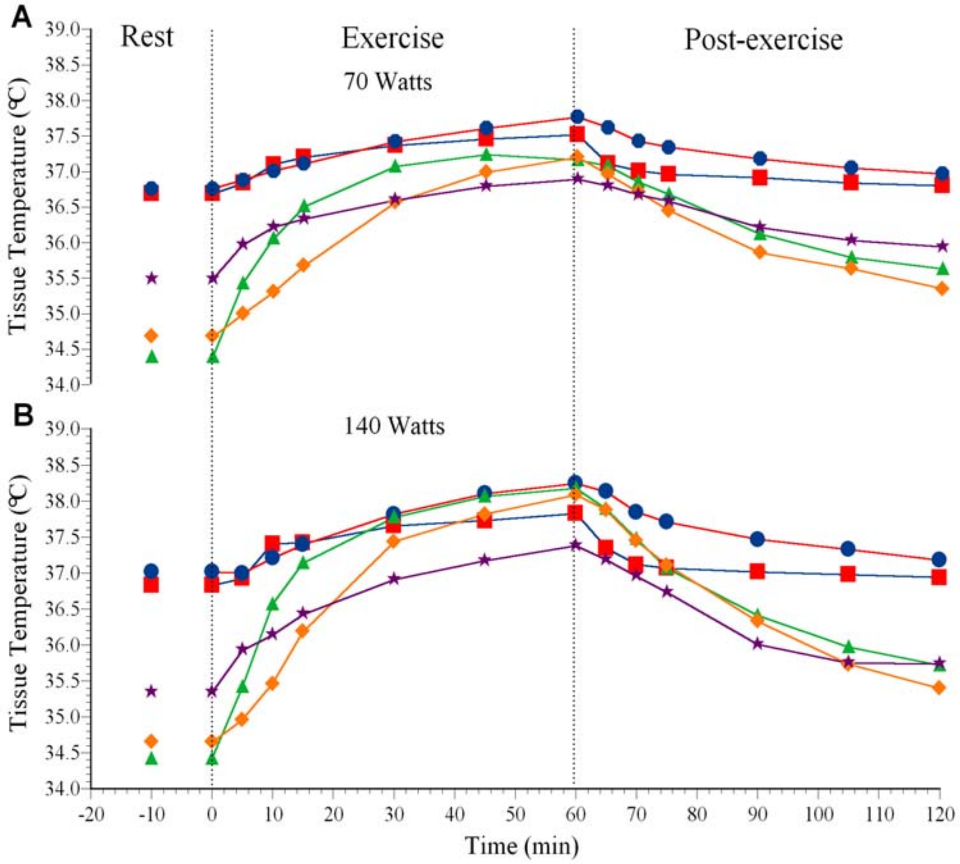


Figure 1. Mean rectal (●), esophageal (■), and muscle temperatures (▲, vastus lateralis; ◆, triceps brachii; and, ★, upper trapezius) during baseline resting, exercise and postexercise recovery for light (top, *A*) and moderate (bottom, *B*) intensity exercise.

Following the onset of exercise, both T_{es} and T_{re} remained relatively stable for the initial ~5 min of exercise after which both T_{es} and T_{re} showed a more rapid increase over the subsequent 5 minutes (T_{re}: 0.025 and 0.056°C/min; T_{es}: 0.052 and 0.096°C/min for LIE and MIE respectively). Thereafter, the rate of temperature increase was lower. The rate of T_{es} and T_{re} increase in the final 15 minutes were 0.004

and 0.005°C/min and 0.005 and 0.006°C/min for LIE and MIE respectively. Muscle temperature for all sites increased rapidly during the initial 30 minutes of exercise (T_{VL}, T_{TB}, and T_{UT}: 0.089, 0.063 & 0.037°C/min for LIE, and; T_{VL}, T_{TB}, and T_{UT}: 0.112, 0.093 & 0.052°C/min for MIE). The rate of change in muscle temperature during the final 15 minutes were -0.005, 0.063 & 0.037°C/min for T_{VL}, T_{TB}, and T_{UT} during LIE and at a rate of 0.008, 0.018 & 0.013°C/min for T_{VL}, T_{TB}, and T_{UT} during MIE. Similarly, both $\overline{T}_{sk}$ and $\overline{H}F_{sk}$ increased gradually over the initial 30 minutes of exercise thereafter reaching stable values for the duration of the exercise.

Exercise resulted in a T_{es} and T_{re} increase of 0.8 and 1.0°C respectively for LIE and 1.0 and 0.8°C respectively for MIE. Muscle temperature increased by 2.8, 2.5, 1.4 °C T_{VL}, T_{TB}, and T_{UT} respectively for LIE and 3.8, 3.4, 2.0 °C T_{VL}, T_{TB}, and T_{UT} respectively for MIE.

All tissue temperature measurements showed a rapid decrease in the initial 15 minutes of recovery. A reduced rate of temperature change was recorded for the duration of exercise. Both T_{es} and T_{re} returned to baseline resting values by the end of the 60 minute recovery. In contrast, muscle temperatures remained significantly elevated above resting values (1.2, 0.7, 0.5 °C T_{VL}, T_{TB}, and T_{UT} respectively for LIE and 1.3, 0.8, 0.5 °C T_{VL}, T_{TB}, and T_{UT} respectively for MIE).

Discussion

The aim of the present study was to measure intramuscular and core temperatures and heat flow transients during semi-recumbent cycling exercise in order to develop a better understanding of postexercise changes in compartmental body temperature. These data lend support to our previous findings in which we demonstrated that single leg knee extension exercise produced an increase in the resting contralateral muscle temperature suggesting that convective heat transfer by the blood to inactive tissue may significantly affect the rate of change in T_{es} during and following exercise (6).

In the present study both T_{TB} and T_{UT} increased significantly above baseline resting values. Interestingly, T_{TB} increased to values similar to those temperatures recorded in the active muscle (T_{VL}). Although core and skin temperature had returned to near baseline values by the end of the 60 minute recovery period, inactive and active muscle temperatures remained significantly elevated. Our observation of a prolonged sustained elevation in postexercise muscle temperature, despite a return of core and skin temperatures to baseline resting values, demonstrates that there remains significant heat retention in the body.

Conclusion

Our results demonstrate that changes in muscle heat content, and therefore the inclusion of a third compartment, must be considered for the modeling of heat storage.

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THE EFFECT OF A HOT CLIMATE AND EXTERNAL COOLING ON GRADED CYCLING PERFORMANCE

Niels Bogerd[1], Ronald Heus[2], John Willems[2]*

[1] Faculty of Human Movement Science, Vrije Universiteit, Amsterdam, The Netherlands
[2] Department of Product Ergonomics, TNO Science and Industry, Eindhoven, The Netherlands
* corresponding author ronald.heus@tno.nl

Introduction

If heat production exceeds heat loss, heat storage will occur which eventually will lead to an increased core temperature – or hyperthermia. Hyperthermia is recognized as a major factor limiting endurance performance[4]. Arngrímsson et al.[2] for example investigated the effect of different climates (e.g. 18 vs 26°C WBGT) on graded exercise test (GXT) performance of runners. They found a reduced maximum oxygen uptake ($\dot{V}O_{2\max}$) due to a hot climate.

Applying external cooling to an endurance athlete during exercise is known to reduce heat strain[5] and to improve subjective perception[3]. However, applying external cooling on the skin might also have a detrimental effect on the thermoregulatory response of the body. It is sometimes found to reduce sweat production[6] and to increase vasoconstriction of blood vessels in the skin[1].

The goal of this study is to quantify the deterioration of endurance performance, expressed in time to exhaustion and maximum oxygen uptake, due to a hot climate. If so, to test whether the performance deterioration can (partly) be counterbalanced by application of external cooling on the skin.

Figure 1. A subject on the cycle ergometer wearing the cooling garments.
Photo: TNO Defence, Security and Safety.

Methods

Eight male cyclists voluntarily participated in one standard GXT (sGXT) and three individualized GXTs (iGXT), which were separated by at least 5 days. From the sGXT maximum external power (P_{max}) was obtained. The following protocol was used for the iGXT; 10 min warming up period at 30% P_{max} outside the climatic chamber, which was followed by body weight determination after which the subjects entered the climatic chamber. In the climatic chamber the individualized GXT was conducted on a cycle ergometer, starting at 30% P_{max} and increased every minute with 3.5% P_{max} until exhaustion. The following trials were randomly assigned:

9.1°C WBGT (T_a=10°C and 85% RH) cold no cooling (CN);
16.9°C WBGT (T_a=35°C and 19% RH) hot no cooling (HN);
16.9°C WBGT (T_a=35°C and 19% RH) Hot with cooling (HC).

The absolute water vapor pressure was the consistent throughout all trials (1.04 kPa). Therefore sweat could evaporate with the same ease if skin temperature was equal.

In all conditions the subjects wore a water perfused long sleeved shirts and trousers (Delta Temax, Med-Eng Systems, Canada, size M and L, figure 1). In condition C the shirt and trousers were connected to separate cooling circuits consisting of insulated tubes and a thermostat bath with an intergraded pump (Tamson TLC 3, Tamson, The Netherlands).

During the trials exercise time, oxygen consumption, skin temperature on four locations ($\overline{T}_s$), rectal temperature (T_{re}), heart rate (HR) and weight change were recorded, along with temperature and velocity of in and out flowing cooling water in both circuits and 4 subjective scales were scored (rating of perceived exertion, perceived comfort, perceived temperature and perceived wetness). Average body temperature ($\overline{T}_b$), heat storage (S), wet heat loss (E) and cooling power of the garment (P_c) were calculated.

An ANOVA repeated measures was used to test the overall results and the average values from t=0; 4; 8; 12; 16 and end min. Significance was reached if p<0.05. The study was approved by a medical ethical committee.

Results

A malfunction of the humidity regulator occurred, causing a large variation in RH of the cold trials (table 1).

Table 1. Average climate characteristics.

Trial	Subgroup	WBGT (°C)	T_a (°C)	RH (%)
CN	Overall	7.8	12.5 (±1.6)	56.1 (±24)
	Low RH	11.2	13.1 (±2.3)	78.1 (±5)
	High RH	3.6	11.9 (±0.4)	34.1 (±10)
HN		14.2	35.1 (±0.5)	12.7 (±4)
HC		13.2	34.7 (±0.8)	11.3 (±2)

Table 2. Observed differences between conditions

		Trial		
		CN	HN	HC
Variable	Unit	Mean (sd)	Mean (sd)	Mean (sd)
$\Delta\overline{T}_s$	°C	1.09 (±1.09)	3.76 (±0.63)	2.74 (±1.49)
Effect		HN↑ HC↑	CN↓	CN↓
$\Delta\overline{T}_b$	°C	0.67 (±0.34)	1.32 (±0.27)	1.03 (±0.34)
Effect		HN↑ HC↑	CN↓ HC↓	CN↓ HN↑
Storage	$W*m^{-2}$	74 (±38)	145 (±28)	113 (±35)
Effect		HN↑ HC↑	CN↓ HC↓	CN↓ HN↑
Evaporation	$W*m^{-2}$	240 (±43)	332 (±42)	288 (±47)

Effect	HN↑	CN↓ HC ↓	HN↑
Perceived temperature	2.6 (±1.3)	3.8 (±0.5)	2.9 (±0.9)
Effect	HN↑	CN↓ HC ↓	HN↑

Overall effect

Time to exhaustion was similar for CN (21:17 ±1:04), HN (20:23 ±0:50) and HC (20:38 ±1:13). Moreover, no difference was found in time to exhaustion nor in $\dot{V}O_{2\max}$. The rectal temperature reached maximum values of 38.1 (±0.3), 38.4 (±0.2) and 38.1 (± 0.2)°C respectively. Observed differences between CN, HN en HC are shown in Table 2.

Time effect

The average development of $\overline{T}_s$ is shown in figure 2. $\overline{T}_s$, $\overline{T}_b$ and S showed a significant different development in the first 8 min after onset of the iGXT, whereby HN increased more rapidly than HC which, at its turn, increased more rapidly than CN.

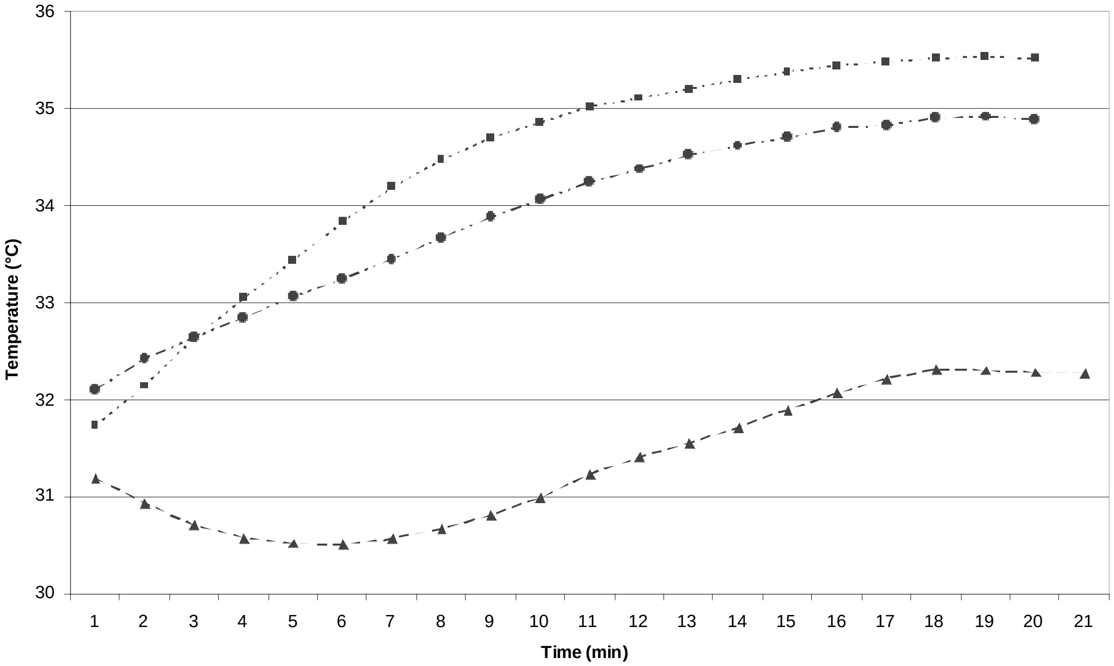

Figure 2. The average skin temperature (n=8) in all three conditions CN (▲), HN (■) and HC (●).

Cooling system

Based on the temperature difference between suit inlet and outlet temperature and rate of flow it was calculated that the heat gain of the water in the cooling suit was 319 (±24) W. The cooling power of the suit was consistent throughout the iGXT. This resulted in a significant lower heat storage in the body of 30 W*m^{-2}, compared to condition HN. Therefore the cooling efficiency was 19%.

Discussion

No influence of a hot climate or application of external cooling was found on graded cycling performance. An explanation is that the climate and exercise protocol did not result in high core temperatures. The core temperature is generally recognized as the cause of performance deterioration in a hot climate[4].

However, the heat storage was reduced due to the application of external cooling. Therefore it increases the heat buffer of the body and might, under more severe conditions, result in a reduced core temperature increase. External cooling also resulted in a favorable perceived temperature. A negative effect of the external cooling was observed in a reduced wet heat loss, which is consistent with other research[6].

Partly due to the reduced wet heat loss a cooling efficiency of only 19% was observed. Thus it will be hard to substantially improve endurance performance in a hot climate with functional sports clothing based on external cooling. However, in elite sports performance marginal advantages can result in the gold medal or no medal at all.

From the time analysis it became clear that cooling was most effective in the first 8 min of exercise, while metabolic heat production was low. Therefore it remains unclear if applied cooling would benefit elite endurance performance while these athletes have a consistent high heat production.

It is recommended that more research is conducted on the effect of external cooling on endurance performance during a simulated race in controlled conditions. The cooling efficiency is another point of interest for future research since this could be the key in development effective and functional performance enhancing sportswear. Moreover, it has to be taken into account that active cooling is currently hard to realize in sport events, improved designs may lower the threshold for use.

Conclusions

The external cooling applied in this study resulted in reduced heat storage in the body and a favorable temperature sensation. Therefore it holds the potential of enhancing endurance performance in a hot climate. Unfortunately, a cooling efficiency of only 19% was observed. More research is necessary, particularly to gain more insight in how to optimize cooling efficiency.

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[#] Department of Comfort and Performance, TNO Defence, Security and Safety (NL)
*Faculty of Human Movement Science, Vrije Universiteit (NL)

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ENVIRONMENTAL ERGONOMICS: WHENCE-WHAT-WITHER

Ralph F. Goldman.

Comfort Technology, Inc. 7 W. Trevor Hill, Plymouth, MA 02360, USA

The poet John Donne's "no man is an island" is particularly true for scientists; we build on the research of our predecessors. In considering how "environmental ergonomics" evolved, it seems appropriate to begin with the general concept of ergonomics, unfortunately skewed by my greater familiarity with US studies.

ORIGINS

Although derived from the Greek words "Ergos" meaning work and "Nomos" meaning surroundings or rules, and found in the Bible (Gospels according to Paul), Ergonomics is a relatively new science, dating to E.B. Jastrobowski's 1857 paper "An essay on ergonomy, or science of labor based on the laws of natural science". Studies in U.S. steel mills (F. W. Taylor's "Principles of Scientific Management", on the size of the coal shovel and its effect on the physical work, etc.) during the 1890s and in Russia by I. Sechenov on "Physiological criteria of the length of the work day" in 1897, served as a prelude to the classic studies of Frank Gilbreth on "Methods Time Measurement" (MTM) during the 1900s. The beginning of modern ergonomics may be dated to shortly after the end of World War II when, in July 1949, ten researchers[1] met at the British Admiralty in London. This group initiated steps to establish a research society, culminating in a January 14, 1950 meeting vote where "The Ergonomics Research Society" (apparently proposed by Hywell Murrell) was selected as its name.

However the process termed "ergonomics", perhaps most simply described by the title of Grandjean's classic text "**Fitting the Task to the Man**", predates human existence. Primates use twigs inserted into termite mounds to extract the occupants; Australo-pithecus used animal bones as spears; also, the advances from the "Mousterian" stone tools of eanderthal Man, who appear not to have use of an opposed thumb, to the "Aurignacian" tools of Cro-Magnon man who did, certainly was an ergonomic advance, albeit driven by genetic modifications ~ 50,000 years ago. The "classic" ergonomic studies appear to have been driven by a number of related goals; I will address these in writing this paper: **1) productivity**, studied initially by rulers, then early human factors engineers and recently by psychologists; and **2) human work capacity and load carriage,** physiologically based studies originally in response to concerns by the military of various countries; **3) comfort**, largely the domain of HVAC engineers; and subsequently, particularly as troops were able to be moved rapidly across time zones to unfamiliar climates, the primary focus of ICEE which is on **4) environmental ergonomics**, although I will only present the last two at Ystad.

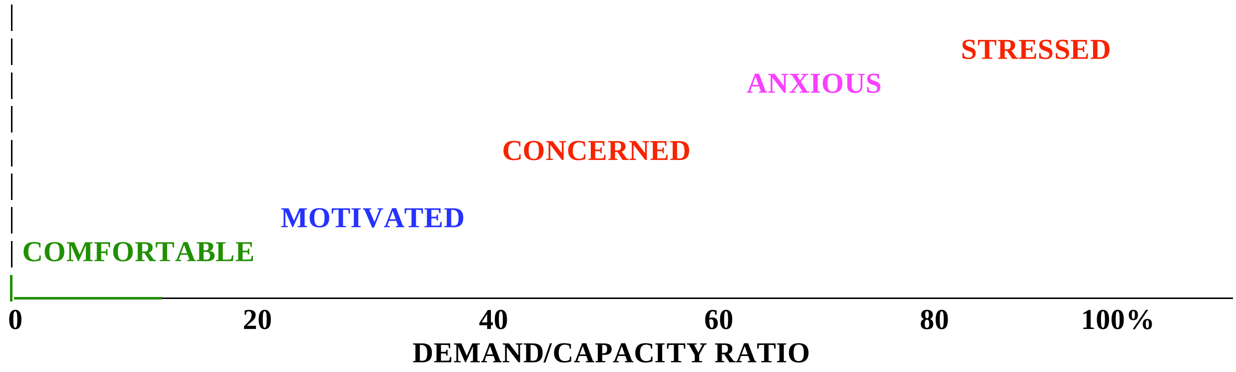
A) COMFORT and its COMPLEXITIES

The, misleadingly simple, term "comfort" is defined as "a state of mind"; "cozy", "warm" and " at ease" are suggested as synonyms. An 1896 paper by Eisert on "The Cooling of Closed Rooms" called for 10 tons of refrigeration and an air supply of 23 cfm/person. In 1910 Lyle presented a paper on "Relative Humidity and its Effects on Comfort & Health. In 1913 New York funded $50.000 for a Commission on Ventilation; it concluded that at rest, an air temperature of 75ºF (23.9ºC) and 35% RH, with 45 cfm/person (21.2 L/sec) was preferable to all others. In 1920, following up on Harvard Professor Ellsworth Huntington's linking of death rates to climate, Hill & Aberly indicated that the lowest death rates occurred at a 60ºF (15.6ºC) wet bulb temperature. The pioneering studies by Houghton, with Yaglou, in 1923 established the "Comfort Zone, and the Effective Temperature scales at the ASHVE (American Society of Heating and Ventilating Engineers) in Cincinnati, OH and by Rohles, McNall, Nevins et al at Kansas State U. after the Cincinnati facilities, now ASHRAE's, were turned over to Kansas State Un. used the classic 7 point comfort vote (PMV-predicted mean vote) approach. This 7-point scaling may have been derived from one by von Guericke in the 1650s which ran from extreme cold to extreme heat. Gagge and his colleagues at the John B. Pierce Foundation used the ASHRAE scale, but worked primarily from the physics of heat transfer. Many years later, Fanger in Denmark rotated the 7-point scale to a +3 to 0 to -3 scale, and carried out additional comfort studies. However, many factors modify comfort; e.g., physical, physiological, psychological, social, financial, etc. Most of these modifiers are so interactive, and humans are so variable in their evaluation of comfort, that it is an extremely difficult subject for study. Even the limited term “thermal comfort” has so much inherent human variability that ASHRAE (the American Society of Heating, Refrigerating and Air-conditioning Engineers) has had great difficulty establishing a standard (ASHRAE Standard 55-95 on Thermal Comfort) to identify environmental conditions which are acceptable for more than 80% of the occupants of an air conditioned space, despite studies involving over 3000 subjects conducted over the last 75 years. Comfort is most easily studied (and best understood), as a state where discomfort is not reported even when specifically questioned. Comfort is not a simple “state variable; there is seldom a single factor that equates with “comfort”. In general, comfort can be treated as a balance point between a variety of “demands ” (D), and the ”capacities” (C) to meet them. These demands, and capacities, can be physical, physiological and/or, to the extent that we can define them, psychological. One can consider comfort in terms of this D to C ratio; different D/C percentages represent comfort, discomfort, performance decrements, limited tolerance times and, finally, a high risk of damage. In physical/physiological domains, a D/C < 20% is usually comfortable.

The 20, 40, 60, 80% hypothesis

A personal example may help illustrate this hypothesis. Suppose you have $100 to last you for the week. If your brother needs a loan of $20 until he is paid, if he has repaid such loans on time in the past you would probably be reasonably comfortable lending him the $20. If he asked for $30 to $40 you would be less comfortable; if he wanted $60 or more it would definitely limit what you could do. If he really needed $80, that could be a real problem for you. Of course if you had $1,000 to work with, the relative impact of these requests would be quite different; even $100 could be easily met. This simple D/C ratio scale appears to apply across a wide range of physical and physiological factors. It may also apply to psychological factors, but it is frequently impossible to assign numbers to these Demands or Capacities.

Figure 1 presents this D/C ratio approach in general terms.



Thermal Comfort

This 20, 40, 60, 80% hypothesis can be applied to physical work (where the capacity is 4 kg of force per square centimeter of muscle cross section) and the demand is the force required (e.g., weight to be lifted and accelerated). It applies even more easily to physiological work (where the capacity is the, more easily measured, “maximum oxygen uptake”); a <20% demand is too low to be considered productive. Between 20 and 40% appears optimal (with a 33% demand about the highest that can be sustained for a five-day period). Working in the range of 40 to 60% of capacity one should expect some performance decrements, while 45% represents the self paced, voluntary hard work level unconsciously selected for 3 to 4 hours of hard work, tolerance time at 60% is about one hour, and at 85% is about 15 minutes. Thermal comfort can also be treated in terms of D/C ratios. However, the six key factors involved in thermal comfort must be defined, and the physiological and behavioral mechanisms humans have available to regulate their thermal comfort must be identified, to understand the role of clothing.

The Six Key Factors

ENVIRONMENTAL:
1. Air Temperature ($\mathbf{T_a}$);
2. Air Movement (**WV**);
3. Humidity (RH), or more correctly, Vapor Pressure ($\mathbf{P_a}$);
4. Mean Radiant Temperature (**MRT**).

BEHAVIORAL 5. Body heat Production (**M**)
6. Clothing (**Clo,** and under some conditions, **Im** & **p**)

While the first and second factors (T_a and WV) are more important under cold conditions, and the third and fourth (P_a and MRT) are of major concern in warm conditions, behavioral options like body heat production (M) and clothing (Clo) worn dominate thermal comfort.

"Normal" Thermal Comfort

The normal conditions for comfort (Monograph For Practical Applications of ASHRAE Research: Thermal Comfort Conditions. J. Am. Soc. Heating, Refrigerating & Air-conditioning Engineers Jan: 90-92,1974) were established for sedentary (resting) subjects (3000 students) focused to vote their thermal comfort (PMV) using the 7 point Comfort Vote Ballot: **1=COLD; 2=COOL; 3=Slightly COOL; 4=NEUTRAL; 5=Slightly WARM; 6=WARM; and 7= HOT.** Fanger rotated this 7-point scale, about a zero midpoint and thus ranging from –3 to +3. Either because PMV forces judgment beyond the human ability to discriminate, or humans vary greatly in their thermal sensitivity, the Std Deviation for PMV appears to be one full scale unit, so a 95 % confidence interval (mean +/- 2 S.D.) for a comfort vote of 4 (neutral) includes all votes between 2 (cool) and 6 (warm).

The Thermal Comfort Range

The research suggested thermal comfort (PMV=4) was a 3.3ºC (6ºF) wide air temperature band whose boundaries were set by the other 5 factors. This band runs from 22.2 to 25.6ºC (72-78ºF), **but only when the other 5 factors are:** a) RH is 40%; b) WV is 0.2 m/s (40fpm); c) MRT = T_a; d) Clo = 0.6; and e) M = 1 Met.

Environmental and Behavioral Trade-offs

An informal ASHRAE committee (Ralph Nevins, Pharo Gagge and Ralph Goldman) suggested trade off could be made between these factors with respect to their effects on human comfort. Note that, while relative humidity (RH) is useable in the comfort range of air temperatures, the important variable is not the relative humidity but the actual vapor pressure of the air (P_a). As air temperature drops below 10ºC, RH is seldom less than 100% (since the water holding capacity of cold air is very low). But sweat evaporation, ignored in the comfort zone (so Im can be ignored) but the major avenue for body heat loss in the heat, can occur at 100% RH.

Table I. Perceived equivalence of changes in the various comfort factors.

a) RH - an 18% change in RH can be offset by 0.5 ºC change in T_a
b) WV - a 0.18 m/s change in WV is equivalent to 1 ºC ; max offset is 3ºC)
c) MRT - a 1ºC change in MRT can be offset by a 1 ºC change in T_a
d) Clo - a change of 0.18 clo has the effect of a 1 ºC change in T_a at up to 2.5 Met, and of 2 ºC at higher levels of metabolic heat production.
e) M - each 15 kcal/hr increase in M equates to a 1 ºC increase in T_a

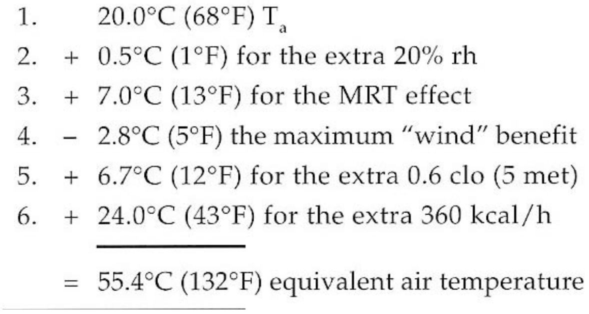
In conclusion, so long as sweating is primarily associated with discomfort, and thus ignored in the comfort zone, the extent to which changes in ambient air temperature can be offset by simply adjusting the clo value of the clothing worn (or changing the metabolic heat production) is easily estimated, as shown below.

Soldiers wearing typical combat clothing (2.0 Clo), working at the usual self paced hard work level (425 kcal/hr) in full sun are particularly susceptible to the effects of heat during military operations even under otherwise "comfortable conditions (e.g., at Ta = 20 ℃ (68 ℉), 60% RH with a high wind), as shown by the following "trade-off analysis, a stepwise arithmetic process.

The moisture permeability index (Im), a non-dimensional ratio representing the maximum evaporative cooling allowed from the sweating skin, through the clothing, to the ambient environment, divided by the maximum evaporative cooling from a ventilated wet bulb thermometer in the same environment [as well as the permeability index ratio (Im/Clo) which defines the % of the available sweat evaporative cooling that can be obtained by the body in any ambient environment] can be ignored in the comfort zone or, if of concern, can be estimated by assuming Im ≈ 0.45, which is generally the case unless water repellent treatments or special barrier materials are used in the clothing.

Having explained the key terms involved in comfort, and the fundamentals of the human heat balance equations, it is now easy to proceed outside the comfort zone to include other zones of thermo-regulatory effort. Within the “comfort” zone the primary physiological mechanism for temperature regulation involves vaso-motor control of blood flow from the body core (at deep body temperature, usually measured as rectal temperature = Tre) to its shell (at “Mean Weighted Skin temperature (Ts) as described above. When raising or lowering skin temperature (by adjusting the blood flow from the, normally warmer, core to the skin) is insufficient to balance body heat production with body heat loss to the environment, two additional physiological mechanisms are available.

Production of sweat, ***if*** the sweat can be evaporated, is the major defense against heat having to be stored in the body, while shivering heat production, ***IF*** it can be retained in the body, is the major defense against heat being lost from the body in the cold. Thus, we can identify a sweat compensable zone of temperature regulation against heat being added to the body heat content, and a shivering compensable zone against heat being removed from the body. The two highlighted ***If***s above suggest that there are



1. 20.0°C (68°F) T_a
2. + 0.5°C (1°F) for the extra 20% rh
3. + 7.0°C (13°F) for the MRT effect
4. – 2.8°C (5°F) the maximum “wind” benefit
5. + 6.7°C (12°F) for the extra 0.6 clo (5 met)
6. + 24.0°C (43°F) for the extra 360 kcal/h

= 55.4°C (132°F) equivalent air temperature

limits to the effectiveness of both these physiological defenses and suggests two more zones of temperature regulation. An incompensable heat zone, where body heat storage is increasing (increasing body temperature by about 1 ºC for each 60 kcal of heat added to the body of a 70 kg human), and an incompensable cold zone, where body heat storage is decreasing (decreasing body temperature by about 1 ºC for each 60 kcal of heat removed from the body of a 70 kg human). The boundaries between the compensable and incompensable zones are set by the 6 key factors as shown below.

B) ENVIRONMENTAL ERGONOMICS

The fatal effects of heat appear in the Bible (Samuel). The original name for heat stroke, “Siriasis” is derived from the “Dog star, Sirius” whose annual appearance in the sky, according to Homer, marked the onset of that season bringing madness to dogs and intense distress to humans. Sophisticated heating systems were developed in Rome and China before the Christian Era. During the Tang Dynasty (618-907 AD) the Emperor’s throne room was air conditioned by a large fan blowing air through a continuously wetted fabric. A large fan was installed on the roof of London’s “Newgate” debtor’s prison, to ventilate the noxious humors believed to be killing the prisoners. But this was not until in 1750, after the law was changed to allow gentlemen and even nobles to be imprisoned for debt.

Early reports, suggested that humans could tolerate very high, hot temperatures; in 1760, French scientists attempting to see whether the temperature in a very large, beehive, baking oven might be hot enough to kill grain weevils were unable to get a reading, so a female bakery worker, thereafter termed the “Lizard of Rochefoucalt”, carried the thermometer into the oven and stayed for 12 minutes until she noted a steady temperature of 142ºC (288ºF). That was, obviously, dry heat; Benjamin Franklin noted the effects of high humidity in making heat intolerable in the early 1700s. Joseph Banks & Dr.Blagden carried out the first scientific study on the effects of heat on man in January 1775 in England; their “climate chamber” was a 12’ x 14’ (3.6m x 4.2m) room heated with a pot-bellied stove and flues in the floor to about 212ºF (100ºC), which they entered carrying a small steak in a pan. They noted their own profuse sweating, and the fact that the steak cooked quite rapidly. In April, they observed the effect of air motion on their discomfort and on the rate at which the steak cooked. Some years before, Mr. Banks, and a Professor Solander, accompanied Captain Cook on his first voyage around the world, and reported on the effects of extreme cold exposure in Terra del Fuego, South America, and observed the importance of maintaining a high level of activity in the cold, reporting the death by freezing of several negro servants whom he could not keep from falling asleep in the cold.

I. INCOMPENSABLE HEAT ZONE
(Ereq > Emax)
(Ereq/Emax)

PMV 100% *f*[clothing permeability (Im/Clo);(Ps-Pa); wind]
- -

80
II. SWEAT EVAPORATION COMPENSABLE ZONE
7 hot **60** **q = 440kcal.m^2.hr**
(E_{max}= 1L/hr = 700 watts)
6 warm **40**
- -
5 sl. warm **q = 230**
20 **VASODILATION**
6
4 neutral **q = 72**
(M)
III. VASOMOTOR CONTROL ZONE
100 Watts VASOCONSTRICTION q = 23
3 sl. cool extremity cooling

2 cool
- -
200 skin cooling **q = 7**

1 cold 3 00 **IV. SHIVERING COMPENSABLE ZONE**

400 (M_{max}= 525 watts)

- -
f[clothing insulation(clo);(Ts-Ta);WIN D]

The Five Zones of Physiological Temperature Regulation

Reports on the effects of heat (and dehydration) and cold were documented in military reports from ancient Greece and Rome onwards, with reports of Dr. Larrey, Napoleon's chief surgeon, documenting the decimation of the Grand Armee from heat as it marched toward Russia, and from cold as it retreated back to France after the onset of winter providing classic accounts. However, aside from investigations of severely adverse working conditions in some industries (e.g., mining), major construction projects in desert or arctic regions (e.g., the Boulder Dam in Nevada, studied by Dill) or epidemic deaths associated with sustained heat waves (India, China), overcrowded confinement of prisoners (the "Black Hole of Calcutta"), or mass visitations of holy sites (e.g., Mecca), there was limited support for research in environmental ergonomics until the 1930s.

A great deal was known about environmental heat transfer by 1900; at USARIEM, the classic "Energy needs of the body" by Rubner published in 1902, was translated from the original german to English. I occasionally assign reading it to graduate students, and ask what we know today that disagrees with his findings (very little). The considerable body of experience by European troops in various expeditions during the 1800's led to a number of "remedies", some of which persisted well into the 20th century. The intense environmental and solar heat load in India led the British to adopt wear of the Solar Topee, actinic orange underwear, and a solar resistant spine pad as part of their uniform. In Germany, even today one can find references citing the need for a lambs-wool stomacher or kidney pad wrap to protect vital organs against severe cold. The ability of some Peruvian natives to function well at very high altitudes, observations by Darwin of nearly unclad Tierra del Fuego natives paddling their canoes alongside the Beagle apparently without discomfort from cold rain or sleet, and reports of the ability of some African and Arabian workers to work in hot climates which Europeans could not tolerate were also noted, and some degree of natural acclimation/selection was recognized. But the experience of the Arabian-American Oil Company (ARAMCO) when it began to develop the oil fields in Bahrein with primary reliance on a local native work force and suffered large numbers of heat injuries, proved quite a puzzle until someone remembered Noel Coward's verse "Mad dogs and Englishmen go out in the mid-day sun";

it appears that the native workers did not, as should have been recognized from the prevalence of the regular after noon siesta in many tropical countries. As late as 1920 there was a wide spread belief that Europeans or North Americans sent to work in sub-tropic and tropical regions had to be rotated back to their homeland regularly to avoid having them become ineffective. Indeed, a distinguished Harvard University Professor, Ellsworth Huntington, argued in 1924 that the molding effects of having to adapt to yearly climate cycles between heat and cold played a major role in any pre-eminence of northern cultures over tropical ones.

The recovery from the financial depression at the end of the 1920's and the turmoil of the decades pre WW-II, may be considered the era which gave rise to environmental ergonomics as we know it today. Castellani, the Chief physician of Mussolini's forces invading Ethiopia in 1935, demonstrated the contribution that even the simplest environmental ergonomics could make to troops moving into hot climates to fight; reduction of loads carried, reduction of the physical work required of combat soldiers by use of special labor battalions, avoidance of forced marches during the heat of the day, etc., all proved their merit. In 1939, E.F. DuBois published his classic on "Heat Loss from the Human Body" which, with Alan Burton & Otto Edholm's 1955 "Man in a Cold Environment", L.H. Newburgh's 1949 "Physiology of Temperature Regulation and the Science of Clothing", and A.P Gagge's earlier introduction of the Met and Clo units, established the fundamentals of environmental ergonomics.

In Britain, Otto Edholm headed a very active group of researchers, and Passmore and Durnin appear to have measured and/or collated the energy cost of almost any imaginable human activity. With British troops based in the middle and far east, a laboratory was set up in Singapore headed by Frank Ellis, and staffed by young researchers on temporary assignments from England, (e.g., Nelms, Lind, et al) carried out many studies on the effects of heat stress and the nature of heat acclimatization. In Canada, Professor Alan Burton established many of the basic physical and biophysical relationships that are basic to modern environmental ergonomics. William Ladell, in West Africa, studied the effects of dehydration, and contributed the dictum that there was ~ a 2% float of body water before dehydration should be of concern.

In the US, the Harvard Fatigue Lab (cited earlier in the section on physiological ergonomics) was staffed during the 1930s by scientists like Robinson, Dill, Forbes, Belding, Turrell, Pitts, Consolazio, Johnson, Brouha and Horvath to study the effects of work in heat and cold and at altitude. Margaria of Italy, subsequently known for his studies at altitude, spent an extended period there, and arriving mid-morning each day to find everyone else already long at work running studies, would disappear into the library; he spent his time mining the extensive files of laboratory study notebooks and wrote and published the results of a many of these studies. With the entry of the US into the war in the 1940s, the Harvard Fatigue Lab staff provided the cadres for many newly established US military laboratories. Spurred by rumors that Rommel had been studying the effects of heat on tank crews in hot chambers in pre-war Germany, the U.S. Armored Medical Research Laboratory was established at Ft. Knox Kentucky in 1942, staffed by Ashe, Eichna, Keats, Shelley, Beane, Horvath, et.al; E.F. Adolph, at the U. of Rochester, NY ("Man in the Desert") interacted with them. The loss of far greater number of troops from cold injuries than Japanese attackers in the Aleutian chain and Alaska led to the establishment in 1942, of the U.S. Army Climatic Research Laboratories (CRL) in Lawrence, MA where a very large cold chamber able to reach - 70℉ (-57℃) built by Pacific Mills, a wool processing company, to de-fat wool, was "drafted"; Belding was the first Scientific Director, and John Talbott, Jere Meade, and faculty members from the New England medical schools served as the cadre; the CRL was moved to Natick, MA, merged with Quartermaster elements from Chicago (food/nutrition), Virginia (geography/meteorology/anthropology), et al, to become the QM Natick Research & Development Command in 1955 (when I joined it). The staff included Paul Siple, Austin Henschel (who later left to head the environmental group at the National Institute of Health (NIOSH) in Cincinnati), David Bass, E.R. Buskirk (who eventually went to head a sports research group at the U. of Pennsylvania), Pat Iampietro (who later joined the Civilian Aviation Research Institute (CARI) in Oklahoma, Clark Blatteis, arctic explorer Sir Hubert Wilkins, Paul Baker, Robert White, Russ Newman, Alan Woodcock (who developed the Im permeability index), Bob Breckenridge, et al . This QM group supported a number of extra-mural researchers under contract, two of whom I served as the project officer for: Woodie Belding (who had invented the heated Copper man and was working with Eli Kamon on prescriptive heat indices) and Gene Wissler (who developed elaborate, physically based, models for human heat transfer, and whose contract I terminated when, despite my insistence that he attempt to validate them against some human data, he started more elaborate modeling, using Bessel functions of the jth order; but not to worry, the US Navy then funded his work, until they gave up, whereupon Sally Nunnally at the Air Force Lab at Brooks AFB in El Paso, TX continued it). The Environmental Protection Research Division of the

Quartermaster Labs and the Armor Research Lab of Ft. Knox (with T.R.A. Davis, et al) were merged to establish the US Army Research Institute of Environmental Medicine in 1961. In 1942 the US Aero-Medical Research Laboratory was established at Wright Patterson AFB in Ohio (Jim Veghte, et al), and the Arctic Aeromedical Lab (Charlie Egan, who converted Siple's windchill index from a "still air" (0 m/s) wind velocity base to the current 4 mph [1.79 m/s] baseline, Murray Hamlet, Jim Veghte, et al) was established at Ft. Wainwright, Alaska, the U.S. Navy Medical Laboratory was established in Washington, DC, US Navy Laboratories were established at Pensacola, FL and in Pennsylvania (where Alice Stohl and her group produced an elegant basis for the study of burn injuries), the US Naval Medical Research Institute at Betheda, Maryland (Ed Beckman, Elizabeth Reeves) and the U.S. Marine Medical Field Research Laboratory was established at Camp LeJeune, North Carolina. A laboratory was established at the US Army Edgewood Arsenal (Frank Craig, E Cummings). Extensive, sometime collaborative/overlapping, research along various environmental ergonomic lines of study were carried out in all these locations.

In the UK, extensive environmental research was conducted at the Army Personnel Research at Aldershot (Ted Renbourne, John Nelms, et al) and the Institute of Aviation Medicine across the road at Farnborough (Peter Whitingham, Jack Alan et al), at the Chemical Research Establishment at Porton, and at a number of Navy research Institutions.

In Canada, studies on white-out and cold injury were carried out in the Northwest Territories, Arthur Custance at the Defence Research Establishment in Ottowa (at Shirley Bay) developed the sweat measuring technique during studies on the effects of protective clothing on the wearer, and Sid Livingston studied heat loss in sleeping bags, while at the Defense Civil Institute of Environmental Medicine in Downsview, Ontario, Manny Radomski, John Frim, Peter Titsuikis, Michel duCharme , et al conducted a wide range of environmental ergonomic studies in collaboration with British, French and American colleagues, a practice still being continued by Michel duCharme, Gordon Giesbrech, et al.

In Europe, a number of german scientists were captured at the end of the war, cleared of Nazi involvement ("paper clip" Nazis, like Karl Shaeffer, Otto von Buettner, Otto Benzinger) and transported to the US to continue their research careers. There was also a fluorit of environmental/ergonomic research in a number of European countries and Canada. In France, the Centre des Recherche du Sante de Service des Armees in Lyon (Henane, et al), the Centre'dEssais en Vol in Bretagne sur Orge (where Jacque Boutelliere summarized some of their research and produced a superb review of the effects of cold water immersion for NATO); eventually, Bernard Metz set up a Center for Climatological studies in Strassbourg (J Vogt, et al); at the TNO in Holland (Wouter Lotens, et al); Ove Wilson at Lund, and Bertil Wedin, et al at FUOA in Sweden; Friederich Behmann in Coblenz, Germany; Leif Vangard in Denmark; and, in Russia, my counterpart Colonel Vladimir Igorovitch Krichyagin. There was, and continues to be, considerable environmental research in the far East; the series of studies in the early 1950s by Yashimura and Iida on cold induced vaso-dilation is fundamental to our concepts of cold injury, but a language barrier has limited our ability to benefit from much of the Japanese and Chinese work until recently. A number of Israeli scientists are at work in this field, some (e.g., Baruch Givoni, Eli Kamon, Yair Shapiro, Dani Moran, Yoram Epstein, et al) spent time at USARIEM, as did some UK (Mike Haisman, H deV Martin, W.P. Colquhoun), South African (John Stuart) and New Zealand scientists (Stephen Legg). The continuing collaborative studies between members of ICEE are most promising for growth in our knowledge.

A number of establishments were set up to conduct research, development, test and evaluation of military personal clothing and life support equipment (PCE), and these often supported extensive collaborative studies of interest to ICEE: the US Quartermaster R&D Labs at Natick (Steve Kennedy, Ted Bailey, Jan Vanderbie, et al); the Canadian Defense Research Establishment, Ottowa (Gerry Holmes, Ken Kenchington, Doug Soper, et al); the UK Clothing and Equipment Research Establishment in Colchester, UK (John Morris, Alf Stokes, et al); in Germany, in Coblenz among other sites; in India the Defence Institute of Physiology and the Allied Sciences (DIPAS – Mangel Malhotra, et al); in Malaysia, a Quartermaster Institute (Tan, Tong Tek, et al). The Technical Reports from many of these establishments often provide in depth reviews of topics relevant to environmental ergonomics. Other Conferences also are an extremely valuable source of information for our field, particularly the British run Commonwealth Conference on Operational Combat Clothing and Equipment (OCCE), which I attended in Melbourne, Australia in 1965, Nairobi, Kenya in 1968, Kingston, Ontario, Canada in 1971, Delhi, India in 1975, Accra, Ghana in 1978 and Kuala Lumpur, Malaysia in 1981. The NATO Combat Clothing and Equipment Working Group, which I and a number of European colleagues were involved in from 1970 to1978 agreed on an Allied Publication "Heat Transfer and Physiological Evaluations of Clothing," in

1978. Subsequently Lief Vangaard was able to establish Panel VIII of NATO Research Study Group 7; meetings in 1981 in Farnborough, U.K., in Soesterberg, Netherlands in 1982, in Koblenz, FRG in 1984, in Natick, MA in 1985 and Lyon, France in 1986, culminated in publication of a manual on "Biomedical Aspects of Military Clothing". This summarized the work in this area since Newburgh's 1947 text "The physiology of Temperature Regulation and the Science of Clothing" (which summarized US work up to and post WW II).

I apologize to the many colleagues whose contributions to our field have been omitted from this "history", but this was written primarily from memory in Naples, FL far from my reference files.

I would like to conclude with a few "Lessons Learned" from my 50 + years in this field:

1. Humans are not like inbred laboratory white rats; instead, they have very large individual variability as a result of both nature (genetics) and nurture (environmental experiences).
2. You need a minimum of 6 subjects to get to a 5% level of statistical significance; using 8, if one of them respond in the opposite direction of the rest, you can still reach a $p < .05$.
3. Never be an "equal opportunity" subject user initially; study a select population (e.g., all fit, 20 to 30 year old, lean (BMI < 24) males, conditioned **and** acclimatized before testing). After you establish their responses, and only then, expand to other ages, fitness and gender.
4. Never run physiological studies of humans to see what happens. Inevitably you will have an "inadequate" forcing function; i.e., differences in response to the various test conditions will be too small to detect reliably **– OR –** you will have an excessive forcing function and not all (or perhaps none) of the Ss will be able to complete the scheduled exposure.
5. If you have to use statistics to understand your results, your study design was not great; you should use statistics to establish the validity of your results.
6. Use the following 5 levels of analysis, starting with physics of the exposure first, then use biophysical analyses to build models predicting the outcome of various exposures; use models to select adequate forcing functions and, indeed, to design your research program.

THE FIVE LEVELS OF ANALYSIS

Physical analysis of problem elements considered is carried out; e.g., fabrics, environment, load lifted or carried. No subjects are required, the costs are minimal and the information obtained is usually extremely helpful.

Biophysical analysis of the items (e.g., garments fabricated from new fabrics) is carried out. Prediction **modeling** to identify probable differences under various conditions, is a key element at this level. Again, no human subjects are involved although models, mock-ups, manikins, etc. may be, but these cost far less than human subject studies.

Human physiological (small scale with 6 to 8 Ss), "**validating**" studies under tightly controlled conditions (e.g., in climatic chambers, on treadmills, stopwatch paced, etc.) are carried out to confirm that the projected differences do indeed occur. These are unlikely to be successful unless Level 2 modeling was used to select an appropriate forcing function (work rate, rest/work/recovery cycles, exposure duration, environmental conditions).

Controlled field trials, modest in scale (~20 to 50 Ss), are conducted; the items are used by the intended users in the actual conditions of proposed use, but under conditions that Level 3 suggested would be neither excessive nor inadequate. Relatively expensive, but introduce "real world" variability; any surprises mean back to Level 3 for study.

User trials ("test marketing" in the civilian community, "user wear/operational trials" in the military) are the final step; these are usually large scale, time consuming and expensive, and may well prove fruitless or provide dubious information unless levels 3 and 4 preceded them.

This progression of test levels decreases in scientific information yield and reproducibility, and increases in cost and possible confounding from level one to level five. Many new approaches and/or ideas can be eliminated even at level one, with enormous savings of subsequent research effort. Still more may be eliminated at level two, but the real savings here comes in the selection of "adequate forcing functions" (i.e., optimal test conditions) for demonstrating supposed differences in user response to the test item. If the essential "background" studies of levels one and two are conscientiously carried out, there should be few surprises during level three testing. Real world factors, which might otherwise confound laboratory results, can usually be dissected out in level four studies. Finally, user acceptance or resistance can be rationally assessed, although the real merit of the item versus the claims made for it may not be detectible at level five. Of course, that is if one is looking for practical, meaningful differences rather than statistically significant ones, at least from level three on up.

Finally, read the literature –even the older stuff not on the web. ICEE is putting the proceedings of its meetings (1984-Bristol; ’86-Whistler, Canada; ’88- Helsinki; ’90 ‘Austin, TX; ’92-Maastricht, NL; ’94-Montebello, CDA; ’96-Jerusalem; ’98-San Diego, US; 2000-Dortmund; ’02-Fukuoka; and ’05-Ystad). I would like to propose next we try to get at least the index of publications from as many relevant institutes as possible on our Website (e.g., US: Harvard Fatigue Lab, CRL, ARIEM, US AMRL; UK: APRE, AORG, IAM; Comm. Conf. on OCCE) etc. and also a listing of key institutions that could be visited by our younger associates in conjunction with travel; I learned more from such one day visits than a year at home.

AN APPROACH TO EVALUATE THE THERMAL PERFORMANCE OF LIQUID CIRCULATING GARMENTS

Jinkai Wang, Jean-Philippe Dionne, Aris Makris*

Department of Research and Development, Med-Eng Systems Inc, Ottawa, Ontario, Canada
* corresponding author fwang@med-eng.com

Introduction

Personal Cooling Systems (PCS) are designed to mitigate the effects of heat stress resulting from wearing protective clothing ensembles, the harsh environmental conditions, and/or high metabolic efforts. PCS employing Liquid-Circulating Garments (LCG) have been demonstrated to provide an effective solution to mitigate the heat stress (1-3). LCG integrate a flow network within a fabric material structure, and are used as a component of liquid-based PCS. They function as a heat sink to body heat dissipation and environmental heat source.

The capability of an LCG to remove physiologically produced heat depends on a number of variables such as LCG area, cooling liquid temperature and flow rate, temperature of the skin covered by the LCG, and the heat transfer effectiveness between the cooling liquid and the body surface. The heat transfer effectiveness can be represented by the overall Heat Transfer Coefficient (HTC) of the LCG, evaluated at unit LCG coverage and the temperature difference between the body surface and the mean temperature of the cooling liquid. The purpose of this study was to investigate how the cooling liquid temperature, flow rate, outer-garment type and sweating condition at the skin surface affect HTC. The HTC can be used as an experimentally determined attribute for predicting the heat removal capability of an LCG in various environmental and cooling liquid conditions using the thermal network approach, which is outlined in the discussion section of the paper.

Methods

Thermal manikins are valuable tools for quantitatively evaluating the performance of protective clothing ensembles and PCS. Experiments were conducted with both “dry” and “sweating” thermal manikins, to consider the two extremes of possible skin moisture conditions. Actual skin wetness in humans can vary between these two extremes, depending on the heat stress condition. An LCG of vest configuration, consisting of tubing network sewn into the fabrics, was used, and supplied with cooling water in all tests. The area coverage of the LCG used in dry manikin tests was 0.52 m^2, while that in sweating manikin tests was 0.66 m^2.

The dry manikin tests were performed at Med-Eng Systems using a thermal manikin torso, as described in a separate study (4), and used to investigate the sensitivity of the HTC to cooling liquid temperature, flow rate, and outer-garment type. The water temperature ranged from 8 to 24°C and flow rate from 0.35 to 0.65 L/min (LPM). HAZMAT Level B suit and Fire Fighting Gear (FFG) were used as the outer-garments in the dry manikin tests. The sweating manikin tests were performed at the U.S. Army Soldier and Biological Chemical Command (SBCCOM), Natick Soldier Center, Massachusetts, and used to investigate the effect of moisture condition at skin surface on HTC. The outer-garment for the sweating manikin tests was a Selectively Permeable Membrane (SPM – providing Chemical-Biological protection), which offers similar dry resistance and permeability characteristics as compared to the HAZMAT Level B suit. Different combinations of water temperature and flow rate were used in the sweating manikin tests.

All tests took place in a chamber of 35°C, which was also the controlled temperature at manikin surface. Setting the manikin and chamber temperatures equal eliminated the effect of dry heat exchange between the manikin and the surrounding environment in the area uncovered by the LCG. In the case of dry manikin tests, the power input to the manikin became, at steady state, the direct heat transfer from the manikin to the cooling water, namely the heat removal rate. For the sweating manikin tests, a baseline test was necessary to account for the evaporative heat transfer, even in the absence of cooling from the LCG, since the manikin surface was set to be fully wet at all time whereas the relative humidity of the environment was controlled at 30%. This baseline heat transfer value was subtracted from the manikin power input to isolate the heat removal rate of the LCG.

The heat removal rate of an LCG can be described, on a macroscopic scale, as:

$$Q = KA\left(T_s - \frac{T_{out} + T_{in}}{2}\right) \quad (1)$$

where Q (W) is the heat removal rate, A (m^2) is the area covered by the LCG, T_s (°C) is the manikin surface temperature, T_{in} (°C) is the water temperature at inlet, T_{out} (°C) is the water temperature at outlet, and K (W/m^2·°C) is the HTC. All parameters needed for determining the HTC using Equation (1) were measured from the tests.

Results and discussion

Influence of the variables on HTC

Experimental results from the dry manikin tests and the sweating manikin tests are presented in Tables 1 and 2, respectively. Listed are the temperature of the cooling water entering and leaving the LCG, flow rate of the water, the heating power required by the manikin to maintain its surface temperature at 35°C, water heat absorption rate, and LCG efficiency, defined as the ratio of the heat removal rate to the heat absorption rate of the cooling water.

Table 1. Detailed results for dry manikin tests.

Outer garment	Inlet temp. (°C)	Outlet temp. (°C)	Flow rate (LPM)	Heat abs. (W)	Heating power (W)	LCG efficiency
HAZMAT	8.18	15.48	0.350	178.24	126.99	0.713
HAZMAT	14.18	19.65	0.350	133.78	102.51	0.766
HAZMAT	20.13	24.40	0.349	104.17	76.26	0.732
HAZMAT	8.07	13.46	0.502	188.81	135.53	0.718
HAZMAT	14.03	18.15	0.502	144.35	108.14	0.749
HAZMAT	19.90	23.07	0.500	110.70	81.99	0.741
HAZMAT	8.25	12.42	0.656	191.12	137.20	0.718
HAZMAT	14.16	17.42	0.650	147.79	112.10	0.759
HAZMAT	19.97	22.44	0.652	112.52	81.36	0.723
FFG	7.97	12.92	0.501	173.07	132.95	0.768
FFG	14.06	17.92	0.500	134.60	104.34	0.775
FFG	19.97	22.84	0.502	100.48	79.29	0.789

Table 2. Detailed results for sweating manikin tests.

Outer garment	Inlet temp. (°C)	Outlet temp. (°C)	Flow rate (LPM)	Heat abs. (W)	Net heating power (W)	LCG efficiency
SPM	7.77	23.44	0.255	278.76	253.79	0.910
SPM	23.89	30.38	0.256	115.70	104.96	0.907
SPM	10.26	17.49	0.635	320.93	283.80	0.884

Figure 1 compares the HTC at different water temperatures and flow rates in the dry condition. It can be seen that, for all water temperature levels, the influence of the flow rate on the HTC was limited. The difference in HTC as a result of varying water flow rate was no more than 0.33 W/m^2·°C, or less than 3% of the average value at each temperature level. The results also showed that the influence of water temperature was insignificant. The difference in HTC was no more than 0.97 W/m^2·°C, or less than 8.9% of the average value at each flow rate level. The overall difference in HTC among the 9 tests shown in

Figure 1 was within 1.13 W/m^2·°C, or less than 10.2% of the average value of 11.08 W/m^2·°C. Figure 2 compares the HTC results for two different outer-garment types. Small differences in HTC as a result of outer-garment type were observed in the three temperature levels from 8 to 24°C. The maximum difference was no more than 0.46 W/m^2·°C, or less than 4.6% of the average value at each temperature level. The average HTC of the 3 tests with FFG outer-garment was 10.74 W/m^2·°C. The results for the dry manikin tests showed that the HTC was, in general, insensitive to water temperature, flow rate, and outer-garment type.

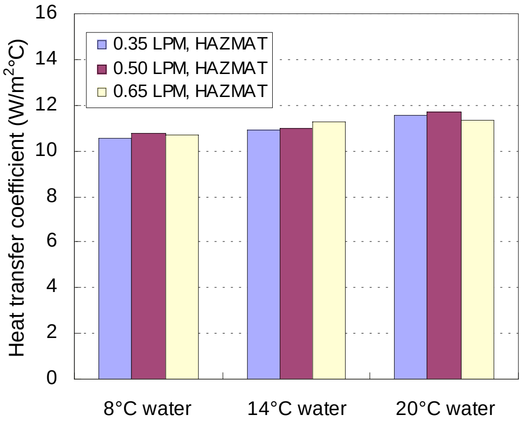


Figure 1. Influence of water temperature and flow rate on heat transfer coefficient.

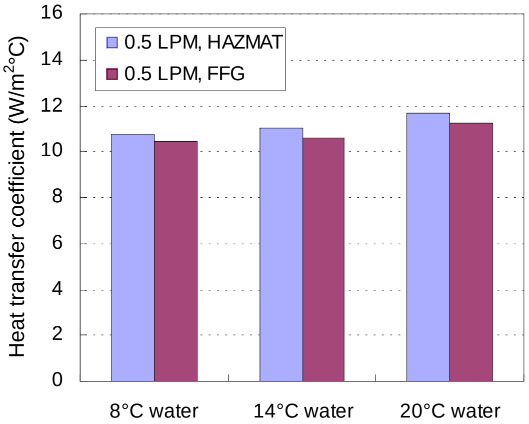


Figure 2. Influence of outer-garment on heat coefficient.transfer

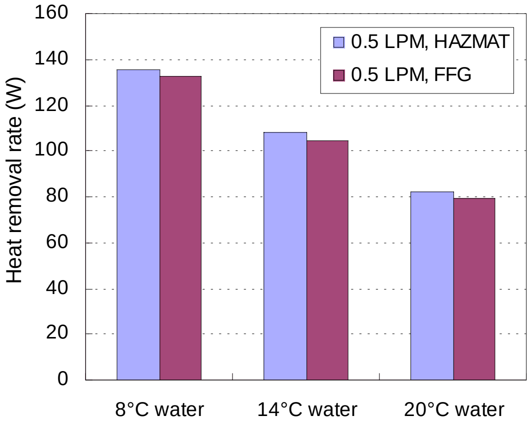


Figure 3. Influence of outer-garment on heat removal rate

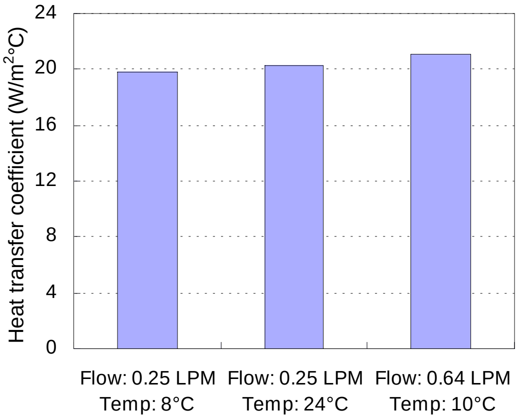


Figure 4. Heat transfer coefficient in sweating condition.

Figure 3 compares the heat removal rate at three temperature levels, and the influence of outer-garment type. As expected, the heat removal rate depends significantly on the water temperature. However, the influence of outer-garment type on the heat removal rate at each temperature level remained small. The maximum difference was no more than 3.8 W.

Figure 4 shows the measured HTC from the sweating manikin tests. The difference in the HTC among the three combinations of water temperature and flow rate was 1.29 W/m^2·°C, or less than 6.3% of the average value of 20.39 W/m^2·°C. Therefore, it can be concluded that the HTC was insensitive to water temperature and flow rate in both dry and sweating conditions. On the other hand, it was obvious that the HTC was significantly dependent on the moisture condition at manikin surface. The greater the moisture content at skin surface, the higher the HTC. Moreover, the impact of the outer-garment on the HTC in sweating condition is expected to be relatively less than that in dry condition, since the HTC in sweating condition is significantly higher. Although sweating is an indicator of heat stress level, it also helps increase the heat transfer effectiveness of LCG. The LCG efficiency can also be improved as a result of sweating condition, as shown by the results presented in Tables 1 and 2.

Prediction of LCG cooling capability

Since the HTC appeared insensitive to water temperature, flow rate and outer-garment type, the range of HTC may be identified at a recommended water condition and typical outer-garment type through dry and sweating manikin tests. This range can then be used to project the range of heat removal capability of an LCG at different environment, cooling water, and clothing conditions. Figure 5 illustrates a simplified thermal network for the purpose of projecting LCG cooling capability, which may be used to analyse the impact of environmental temperature (T_e), solar radiation (Q_r), heat transfer coefficient at outer-garment surface (K_e), insulation of outer-garment (K_{clo}), water temperature (T_f), and skin temperature (T_s) on the LCG performance. Figure 6 shows an example of how the heat removal capability of a vest LCG changes with water temperature and moisture condition at skin.

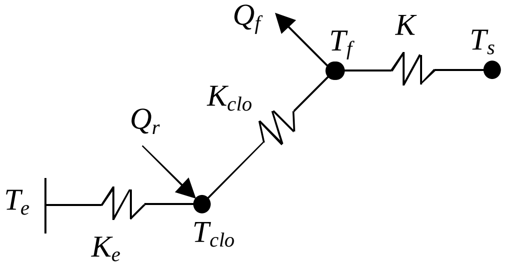
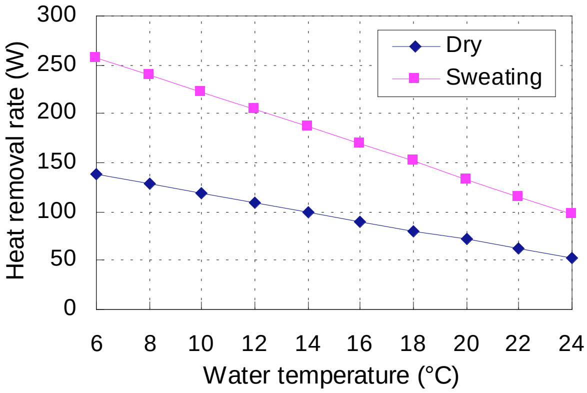


Figure 5. Simplified thermal network



. **Figure 6.** Projected relation of heat removal capability to water temperature.

Conclusions

The test results showed that the HTC was not significantly sensitive to the water conditions in both dry and sweating manikin tests. In dry manikin tests, the results also showed that the HTC was not sensitive to the outer-garment type either. A comparison of the results revealed that the HTC was strongly dependent on the moisture condition of the manikin.

The experimentally determined HTC may be used for predicting the heat removal capability of an LCG using a thermal network approach, which may be used to analyze the impact of environmental, sweating, water conditions as well as outer-garment types on heat removal capability of the LCG.

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THE EFFECT OF 30-MINUTES OF UPPER BODY COOLING (ICE VEST) ON SKIN AND CORE TEMPERATURES DURING REST IN A COMFORTABLE ENVIRONMENT (T_A = 22 ^{O}C)

Loren G. Myhre[1], Ian Muir[1]*

[1] Nike Sports Research Laboratory, One Bowerman Drive, Beaverton, Oregon U.S.A. 97005
*corresponding author loren.myhre@nike.com

Introduction

Metabolic heat stress can become uncompensable during prolonged exercise in warm/hot environments. Fatigue during exercise in the heat is related to achieving a critically high internal body temperature, e.g., core temperature (T_c) that may range from ~39^o to ~40^o C, but which is remarkably constant for a given individual (1,2). For given exercise and environmental conditions, initial T_c becomes a significant factor in determining the time required to reach one's tolerable level for T_c (1). Several methods for pre-cooling the body to better prepare for work in the heat have been reported, and most provide evidence for a favorable result. Cooling vests are among the most attractive methods selected, but there remains some controversy regarding the selection of the heat sink, e.g. ice @ $\leq$ 0^o C vs. phase-change materials that solidify @ $\geq$ 7^o C. Issues include safety (e.g., risk of cold injury) and the challenge of delivering conductive cooling to the skin without inducing vasoconstriction that could be counterproductive for deep body cooling. The purpose of this study was to develop a cooling vest that would position packets of ice in contact with most of the surface area of the upper body and then to test the effectiveness of a specific pre-cooling regimen for optimally preparing the user for a sustained bout of work in a warm/hot climate.

Methods

Eight heat acclimated males (mean $\pm$S.D. age 31$\pm$3 yrs; weight 80.7$\pm$3.8 kg) wearing only shorts rested for 30 minutes in a comfortable environment (T_a 22^o C; RH 40%). After donning a short-sleeved T-shirt they entered an environmental chamber where they proceeded to perform 30 minutes of intermittent rest and light exercise (treadmill) in a hot environment (T_a 35^o C; T_g 41^o C; 50% RH). On another day in a counterbalanced order design the subjects wore an ice vest *(IV)* weighing 3.45 kg over the same shirt during both the rest and the warm-up exercise scenarios. Heart rate, upper body skin temperatures (T_{sk}) at six sites, and rectal temperature (T_r) were monitored continuously

Results

From Figure 1 it can be seen that mean T_{sk} immediately prior to beginning the 30-minute rest averaged 33^o C for all experiments. Following the 30-minute "pre-cool" phase, mean $T_{sk\ (upper\ body)}$ averaged 23.5^o C and 31.0^o C with and without the *IV*, respectively. Lowest skin temperature observed for any site under any of the ice packs was 9.7^o C. During the subsequent 30-min warm-up period with and without the *IV* mean T_{sk} averages ranged from 24-26^o C and 34-35.5^o C, respectively.

Core temperature responses to these experimental conditions with and without the *IV* are presented in Figure 2. Initial $\mathbf{T_r}$ averaged 37.35 ^{o} C for all experiments and changes during the 30-minute "pre-cool" period were remarkably small and similar decreasing approximately 0.05^o C and 0.10^o C for the IV and bare skin experiments, respectively. The rate-or-rise in T_r during the warm-up exercise in the heat was slightly, but not remarkably greater for the T-shirt experiments with average values rising 0.6^o C vs. 0.52^o C for the IV during this 30-minute period.

Heart rate responses to the rest and warm-up phases of these experiments (See Figure 3) were identical for both treatment conditions as observed during both the rest and warm-up phases of these experiments.

Discussion

Thirty minutes of rest with the *IV* proceeded without shivering and upper body mean skin temperature was maintained approximately 8^o C lower than that for the T-shirt condition during this pre-cooling period. However, this had no apparent effect on T_c, probably due to peripheral vasoconstriction. Mean upper body skin temperatures remained about 8^o C lower with the *IV* during the warm-up exercises in the heat as well, but still, this had no obvious effect on T_c. Again, it is conceivable that upper body skin blood flow was little if any affected by the modest increases in T_{sk} and T_c during 30 minutes of intermittent rest and light exercise in the heat. Surely, if an increase in blood flow to the significantly cooler upper body skin areas with the *IV* had occurred, it should have been manifest in a delayed rise in T_c. It was not. Since it has been reported that the application of ice for 85 minutes can reduce the temperature of underlying tissues to a depth of 7 cm by 5° C (3), 60 minutes of ice vest contact with the skin must have had a similar albeit somewhat lesser effect.

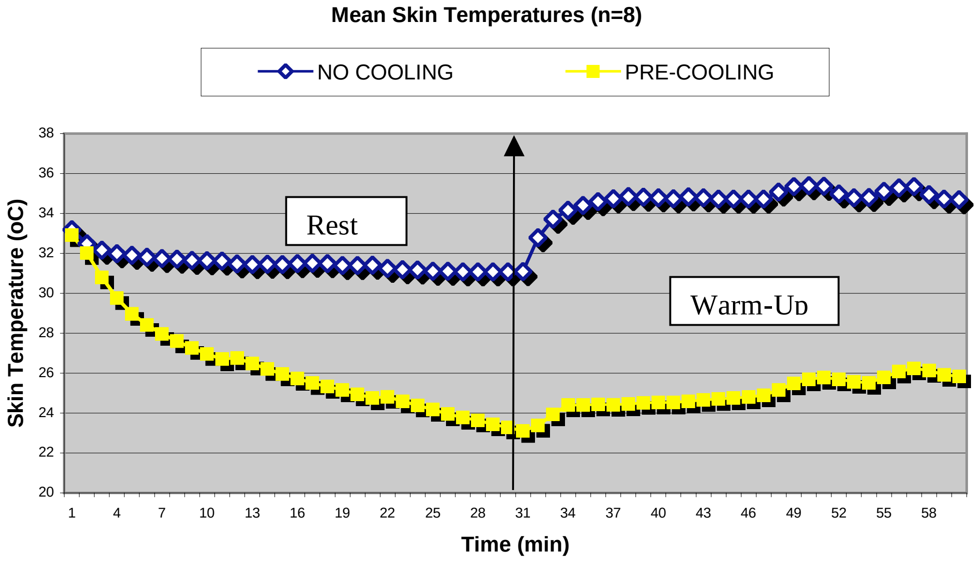


Figure 1

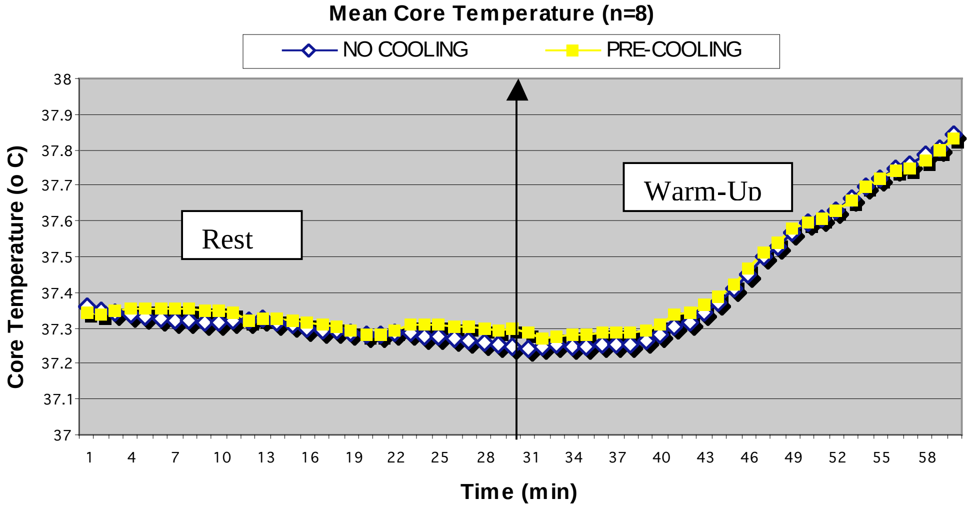
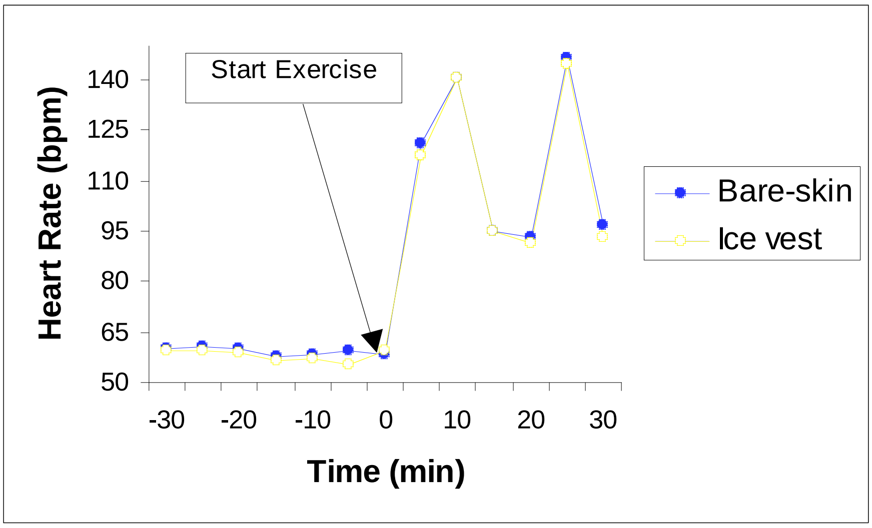


Figure 2 (up);

Conclusions

An ice vest can be worn over a light T-shirt during a period of 30 minutes at rest in a comfortable environment (T_a 22° C; RH 40%) without risk of cold injury while effectively lowering underlying skin temperature by an average of 8° C. This relative cooling effect can continue during a subsequent 30-minute period of intermittent rest and light exercise in a hot environment (T_a 35° C; T_g 41° C; 50% RH) without any remarkable effect on T_c. It is concluded that the heat sink produced by the cooling of deep tissues in these experiments had yet to be exposed to an increase in skin blood flow which would eventually occur as both in T_{sk} and T_c increase with continued exercise in a hot environment.

Figure 3 (down)



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THE EFFECT OF 60 MINUTES OF UPPER BODY PRE-COOLING (ICE VEST) ON EXERCISE/WORK TOLERANCE TIME IN THE HEAT.

Muir, I.H., and Myhre, L.G.

Nike Sports Research Laboratory, One Bowerman Drive, Beaverton, Oregon U.S.A. 97005.
ian.muir@nike.com

Introduction

Athletic performance and work activities in hot environments are often compromised by an increased rise in core temperature above that exhibited in more temperate climates. A number of studies have demonstrated that high body temperature is a key element of fatigue and that time to exhaustion is strongly related to initial core temperature and the rate at which heat is stored during exercise (4,6). Various pre-cooling strategies have thus been developed to try and increase the heat storage possible before reaching body temperatures associated with fatigue (6). A number of these different strategies have been used before exercise of varied intensities, in diverse environments, and have yielded results that leave some questions with regard to the most effective and practical uses of pre-cooling for athletes. Whole body cooling using either water immersion or cold air exposure has been shown to significantly increase time to exhaustion in temperatures ranging from 24 to 40°C (4,5). However, for some athletes this type of pre-cooling may not be a practical strategy. A more viable alternative could be the use of some degree of upper body pre-cooling, although use of this modality has exhibited varied results (1,2,3). Cheung and Robinson (2) showed no effect on power output when using an upper body liquid cooled garment for 30 minutes prior to exercise. During the 30 minutes of exercise in this moderate environment core temperatures were not raised above 38°C and were consequently unlikely to limit performance. Duffield *et al*. (3) examined the effect of 5 minutes of upper body pre-cooling and rest period cooling on intermittent exercise in a more challenging environment. Although general thermal comfort was improved no effect on performance was seen. Upper body pre-cooling during an active warm-up has been effective in improving 5 km running time, most notably with an increase of pace during the last two-thirds of the run (1). It seems apparent from these and other studies that some general principles apply for upper body pre-cooling of this type to be effective in enhancing both comfort and performance. The pre-cooling period must be sufficient for skin temperature to be lowered for a suitable duration, allowing an effective heat sink to be available during exercise. In addition, to truly see the value of the pre-cooling, core temperatures must rise to levels where they are known to be a key element of fatigue. The purpose of this study was to assess the use of an ice vest for pre-cooling during both a rest period in a thermoneutral environment, and an active warm-up in the environment that the athlete was preparing to compete in. It was hypothesized that this combination of upper body pre-cooling would enhance performance in the heat by increasing tolerance time at a sustained workload.

Methods

Subjects:

Subjects were eight heat-acclimated recreational and/or competitive male athletes. Physical characteristics: Age – 31±3.4years, weight – 80.7±3.8 kg. All subjects had previously been involved in research in the laboratory and a speed on the treadmill at 0% grade set that would elicit a workload equal to 70% VO_2 max.

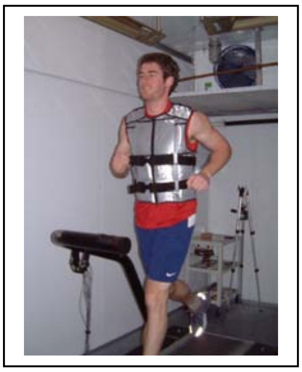
Procedures:

The study was designed to investigate the effect of a total of 60 minutes of upper body pre-cooling. The ice vest was specifically designed to increase skin surface area coverage, with the use of flexible packs placed in 18 pockets. Buckle straps allowed each subject to adjust the vest for the tightest fit desired. The outside of the vest utilized a reflective fabric intended to reduce the impact of radiant heat. Total weight of the vest was 3.35 kg. (Figures 1 and 2).

On two separate occasions separated by at least 48 hours subjects performed identical testing sessions under two experimental conditions. On one occasion subjects wore the ice vest *(*PC) during 30 minutes of rest (T_a 22° C) followed by 30 minutes of light warm-up exercise in a hot environment (T_a 35° C; T_g 41° C; 50% RH). While remaining in the heat, subjects removed the vest and donned a short-sleeved t-shirt before beginning a continuous run on a treadmill at a pace set to elicit 70% of VO_2 max. On a different day in a counterbalanced order design the subjects performed the same protocol without any cooling (NC), wearing the short-sleeved t-shirt throughout the pre-cooling, warm-up, and treadmill run. On both test occasions the treadmill exercise continued until core temperature reached 39.5°C, or volitional exhaustion. The duration of time from the end of the 60-minute pre-cooling period to termination of the test was recorded as total treadmill run time.

Figure 1.
Pre-cooling period wearing the ice vest (PC)

Figure 2.
Warm-up period wearing the ice vest (PC)



Test protocol:
Subjects reported to the laboratory at the same time of day for each testing session. Subjects' unclothed and clothed body weights were measured on a precision platform balance for the determination of sweat production and sweat loss (Ohaus Corp). Subjects were instrumented with five skin thermistors on the upper body (chest, scapula, abdomen, rib, and lumbar) and a rectal thermistor for the measurement of core temperature (YSI). A heart rate monitor was worn throughout the test (Polar, Inc). Subjects underwent two test sessions as detailed above. At minutes 10 and 20 during the pre-cooling phase subjects stepped slowly for one minute at a pace set by a metronome to simulate any movements or stretching that the athlete might make during this period. The warm-up consisted of bouts of walking and running at speeds ranging from 1.5 to 7.5 mph. Core and skin temperatures were measured continuously with a computerized system (Biopac Inc.) and recorded every minute. A rating of thermal comfort on a 9-point scale (0=unbearably cold, 4=comfortable, 8=unbearably hot) and heart rate was recorded every 5 minutes.

Data analysis:
Statistical analyzes were carried out with Statistica 6.1 (StatSoft Inc.). Results are reported as mean±SD. A dependent samples *t*-test was used to determine significance of differences between conditions. Statistical significance was set at $p<0.05$.

Results and discussion

The use of the ice vest during 30 minutes of seated pre-cooling and a 30-minute active warm-up was effective in increasing exercise tolerance time in this environment. Mean total run time was increased to 41.3±16.3 minutes in PC compared to 34.8±11.6 minutes in NC. This difference equated to an increase of 19%. Table 1 details the differences in mean total run time, sweat rate, heart rates and ratings of thermal comfort between the two conditions. Sweat rate was significantly lower for PC. Mean heart rate during the warm-up period was not different but mean heart rate during the run at 70% VO_2 max approached a statistically significant level at close to 4 beats per minute lower for PC ($p=0.058$).

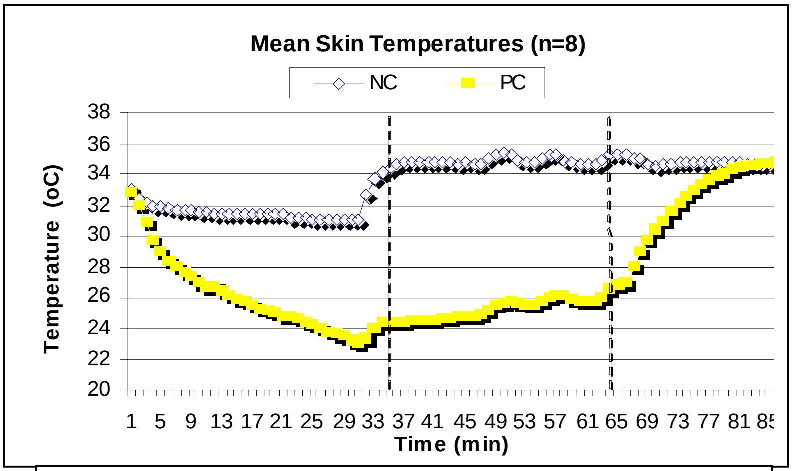
Figure 3 displays the changes in mean skin temperature throughout the test period. Following the pre-cooling period mean skin temperature for NC was 35.33°C compared to 26.82°C for PC. Mean skin temperatures did not become equal until 18 minutes into the treadmill run at 70% of VO_2 max. At the start of this run mean core temperature for PC was 37.97±0.3°C and did not differ significantly from 38.00±0.3°C for NC. Twenty minutes into the run period mean rise in core temperature for PC was 0.69°C compared to 0.83°C for NC (Figure 4). Mean rating of thermal comfort was lower for PC during the seated pre-cooling period and remained lower during both running sections in the hot environment, importantly remaining lower following the warm-up when the vest was not being worn (Table 1).

Table 1. Difference between conditions for total run time, sweat rate, heart rate, and rating of thermal comfort.

	NO COOLING NC	**PRE-COOLING PC**
Total run time (min)	34.85±11.6	41.34±16.4*
Sweat rate (g/min)	52.34±8.0	45.89±6.5*
Heart rate / warm-up (bpm)	107.3±10.3	106.0±10.9
Heart rate / run at 70% VO_2 max (bpm)	148.5±15.5	144.8±15.6
Rating of thermal comfort (warm-up and run)	5.48±0.5	4.71±0.6

(Values are means±SD)* Significant difference between NC and PC (p<0.05).

Figure 3. Mean skin temperatures throughout the test period for PC and NC.
(Mean skin temperature is reported as the un-weighted average of all five skin sites).



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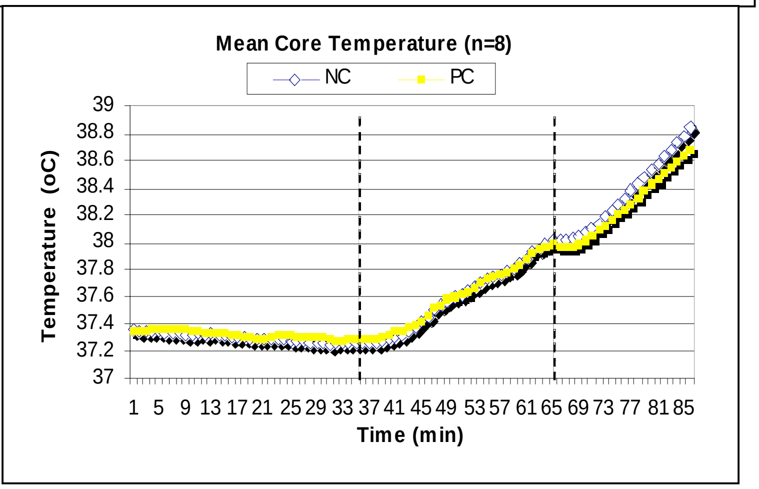

Figure 4. Mean core temperature throughout the period for PC and NC.

Data is reported up to the point (minute 85) where all subjects were at a core temperature of below 39.5℃ in both conditions.

The combination of rest and warm-up pre-cooling during this testing was sufficient enough to lower mean skin temperature by 8 to 10℃ for a period of approximately 40 minutes. This sustained difference in mean skin temperature would seem to have provided enough of a heat sink to impact the rise in core temperature and increase time to exhaustion in the heat. This occurred without a noticeable difference in core temperature during the pre-cooling period. Moreover, sweat rate was significantly lower for PC and although not statistically different both heart rate and rating of thermal comfort were positively impacted for PC.

Conclusions

This study demonstrated that a period of upper body pre-cooling with an ice vest capable of lowering skin temperature for an extended period is a practical method of increasing tolerance time in the heat.

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EXTENDING SAFE WORKING TIMES IN THE HEAT BY COMBINED USE OF HAND COOLING AND ICE-VESTS

Jim House, Heather Lunt, Jason Lyons*

Environmental Medicine Unit, Institute of Naval Medicine, Alverstoke, PO12 2DL, United Kingdom
* corresponding author ssophys@inm.mod.uk

Introduction

Previously we modelled the effectiveness of two cooling techniques, hand immersion (HI) in cool water and an ice-based cooling-vest (CV), for reducing heat strain whilst personnel wear encapsulating personal protective equipment (PPE) and working intermittently in a hot climate[1]. The study predicted that both CV and HI in 10 °C water would increase safe working endurance, with HI (during rest periods) being more effective than continuous wear of a CV. The modelling study was unable to model the effect of using HI and CV simultaneously, or using HI in water colder than 10 °C due to a lack of such human data. We might expect that greater cooling would occur with HI with colder water as the temperature gradient is larger. Cooling is more effective when HI water temperature is lower over the range 10 °C and 30 °C[2,3], and 0 °C water should cool more so. However, colder water could cause peripheral vasoconstriction and the cooling rate, which depends upon skin blood flow (SkBF), would be reduced. In subjects with a normal core temperature (T_c) SkBF is low with a skin temperature (T_{sk}) lower than 30 °C[4]. With a raised T_c (>37.5 °C) we have seen only slight vasoconstriction in hands immersed in 10 °C water[5], and it is possible that further cooling to 0 °C would not cause significant vasoconstriction. We hypothesised that: hand immersion in 0 °C water would cool hyperthermic subjects more quickly than hand immersion in 10 °C; and that combining hand immersion in 0 °C water with ice-vests would cool personnel more quickly than hand immersion alone. The later of these hypotheses assumes that cooling a larger surface area of the body (hands and torso) does not significantly increase vasoconstriction at a particular T_{sk}.

Methods

Following external ethical approval ten medically fit male volunteer subjects gave written informed consent for their participation. The experiment was conducted in 36.3 °C (SD 0.3 °C) dry bulb temperature (T_{db}), 25.3 °C (0.2 °C) wet bulb temperature (T_{wb}), giving a wet, bulb, globe temperature (T_{wbgt}) of 28.6 °C (0.2°C) and a relative humidity (RH) of 55 %. Subjects were dressed in Royal Navy CBRN PPE[†] and stepped using a 22.5 cm box at 12 steps per minute following a continuously repeating cycle of 10-minutes work and 5-minutes rest for a maximum of three-hours. On each day, the subjects undertook one of five experimental conditions: control (C) (no-cooling), hand immersion in 10 °C or 0 °C water during rest periods (HI_{10}, HI_0), and combined hand immersion (during rest) with a CV (continuously) (HI_{10}+CV & HI_0+CV). The conditions were undertaken in a balanced randomised order according to a latin-square design. During the experiment the subjects were provided with water *ad-libitum* through the respirator drinking system. Subjects were stopped, seated and commenced their resting condition (HI_o *etc*.) hand immersion *etc*.) if rectal temperature (T_{re}) exceeded 39.0 °C, or heart rate (HR) was within 10 beats per minute ($b.min^{-1}$) of predicted maximum (220-age). Subjects recommenced work at the start of the next scheduled work period providing that the variables given above had fallen below the stopping limits. Mean skin temperature (T_{msk}) was estimated from a weighted mean of T_{sk} recorded by thermistors at four sites (shin, thigh, upper arm and chest)[6]. Mean body temperature (T_b) was taken to be the weighted mean of $0.9T_{re}+0.1T_{msk}$. Changes in body heat strorage (S) were calculated as follows: $S = Cm\Delta T_b$, where C is the specific heat capacity of the body ($3.47\ kJ.kg.°C^{-1}$), m is the mass of the body (kg) and ΔT_b is the change in mean body temperature. Heart rate (HR) was recorded from a telemetry electro-cardiograph system (MIE Instruments, UK). Metabolic rate was assessed using indirect calorimetry during work periods. The experiment followed a repeated measures design of five conditions within a linear additive model of main effects (conditions and subject). An additional analysis of four

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[†] Underpants, socks, boots, S10 respirator, two-layered flame retardant coverall, CBRN protective smock & trousers, cotton inner gloves, rubber outer gloves and rubber overboots. CBRN – chemical, biological, radiological and nuclear.

conditions (all except C) corresponded to a factorial design with ‘conditions’ decomposed into two factors, HI water temperature and CV use. The overall statistical model was a linear additive model of main effects for subject, HI temperature and CV, plus the interaction term for the latter two factors. Analysis of variance was used to identify any significant factors and differences in T_{re} and mean body temperature (T_b) between the conditions.

Results

Nine subjects completed the experiment, the tenth withdrew for reasons unconnected to the experiment. The mean (SD) metabolic rates measured during stepping were similar across conditions at 1.14 (0.22) $L.min^{-1}$. All subjects in the C condition were withdrawn between 30-105 minutes whereas in the HI and CV conditions 21 of the 32 tests continued until the scheduled stop time of 180 minutes. The number of subjects completing the three-hour exposure, and mean (SD) final T_{re} are given in Table 1.

Table 1. Cumulative mean (SD) body heat storage (kJ)

Condition	Number completed 3 hours	Mean (SD) final T_{re} at 180 minutes
C	0	38.7 (0.3) (between 75-105 minutes)
HI_{10}	7	38.4 (0.3)
HI_0	6	38.3 (0.5)
HI_{10}+CV	7	38.2 (0.8)
HI_0+CV	7	38.0 (0.4)

As the subjects were progressively withdrawn from experiments at different times because they reached safety thresholds, it is difficult to represent the mean responses from all subjects graphically. To overcome this, the mean responses from six subjects who participated in all five conditions for at least 75 minutes on each occasion were used to represent the data graphically (Figure 1). The data are presented as changes from time point zero rather than absolute values, to minimise the spread of data due to inter-subject variability and clearly show the changes due to the cooling interventions. Statistical analysis was conducted on all available absolute data from the nine subjects.

Over the first 60-minutes T_b rose more quickly in C than in the four HI and CV conditions (P<0.01) (See Figure 1). After 75 minutes mean T_{re} was significantly lower in all of the cooling conditions than C (by between 0.35 °C to 0.73 °C) (sed 0.09 °C, P<0.01). After 75, 105 and 120 minutes T_{re} was 0.16 °C to 0.27 °C lower when 0 °C rather than 10 °C water was used (sed 0.10 °C, P<0.05). When an ice-vest was used T_{re}

Table 2. Cumulative mean (SD) body heat storage (kJ)

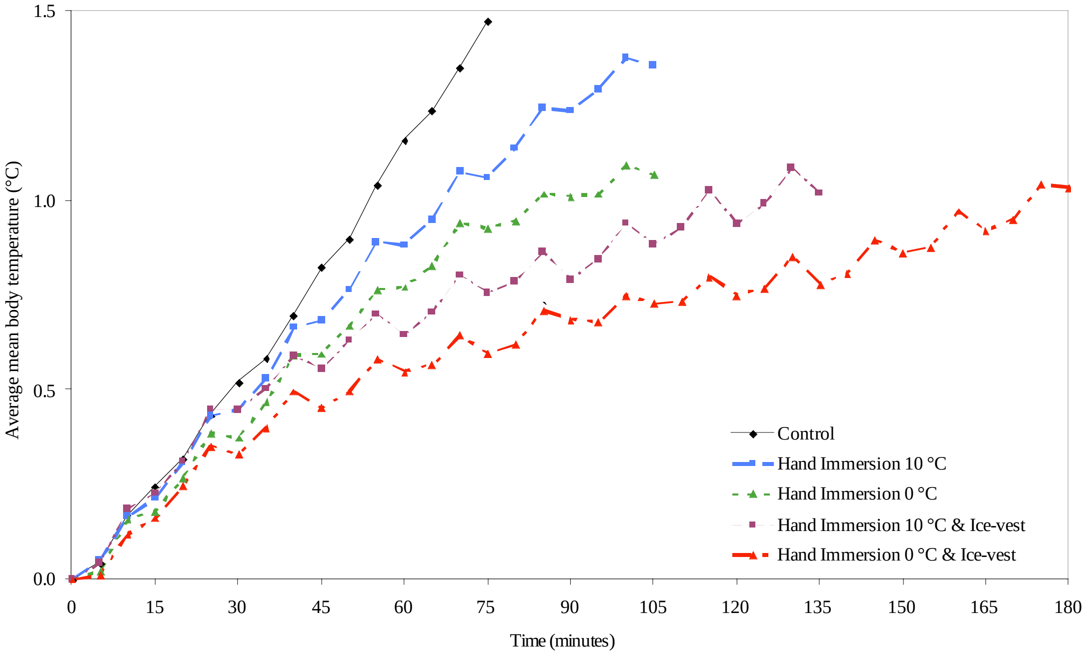
Time Period (minutes)	Condition (n=9)				
	C	HI_{10}	HI_0	HI_{10}+CV	HI_0+CV
30 (n=9)	144 (64)	125 (40)	107 (51)	116 (40)	114 (64)
60 (n=8)	352 (99)	261 (97)	241 (74)	183 (51)	163 (73)
90 (n=6)	520 (105)*	376 (149)	295 (76)	230 (72)	194 (84)

* n=4

Differences in the changes in mean body heat storage across conditions equate to cooling powers of 25 W for HI_{10}, 31 W for HI_0, 47 W for H_{10}+CV and 53 W for HI_0+CV.

was further reduced at all time points by 0.22 °C to 0.27 °C (sed 0.10 °C, P<0.05).

Figure 1. Average increase in mean body temperature during work and rest periods (n=9)



Changes in mean body heat storage are given in Table 2.

Over the period 0-60 minutes HR rose more quickly in C compared with three of the four cooling conditions ($P<0.01$) (except HI_{10}). For the period 60-120 minutes the rise in HR was not significantly different between the cooling conditions, although there was an indication that the CV helped to attenuate the rise in HR ($P<0.1$) – there were insufficient data to compare to the C condition.

Although the subjects felt that the CV offered cooling only for the first hour, chest T_{sk} indicated that the full cooling benefit was maintained often up to 90-minutes, before the ice-packs started to increase in temperature. In most cases the vest seemed to offer some cooling benefit throughout the three-hour period (as evidenced by reduced chest T_{sk} and T_b). When the CV was removed, the cooling packs remained ‘cool’ to touch, despite the volunteers being unable to sense this under the PPE. There were no reports of finger numbness or loss of dexterity due to HI and all personnel were able to remove their own PPE without difficulty.

Discussion

Using HI in 10 °C or 0 °C water significantly extended personal endurance in relation to heat strain, as described by T_{re}, Tb and HR. Heat strain was further reduced when a CV was also worn. CVs were not tested in isolation (without HI) as previous work showed that fire fighters were cooled more effectively using intermittent hand immersion than continual use of ice-vests[8] and therefore the use of CV alone is not advised, if HI techniques are possible.

Although the rates of change data do not indicate a significant advantage to using 0 °C compared to 10 °C water for HI, analysis of the body temperatures at discrete time points showed that temperatures were lower when ‘iced’ (0 °C) water was used. An advantage of ‘iced’ water is that practically it is easier to make. If a bucket contains a mixture of liquid water and solid ice that is not melting appreciably, it can be assumed that the water is close to 0 °C and can be described as ‘iced’. Trying to obtain water at a specific temperature, say 10 °C, requires the temperature to be measured and monitored.

Using CVs in conjunction with HI further enhanced body cooling and extended personal endurance to at least three hours (in terms of T_c and T_b), and might extend this period further. Using CV enhanced overall cooling and resulted in lower T_{re}, T_b and HR. Although the subjects report that the CVs had lost their cooling power between 45 and 90 minutes, the data suggests that a cooling benefit was maintained for up to three hours. In summary, the CV provided a considerable benefit in addition to HI and cooling appears to have been maintained well for up to three hours.

Conclusions

In conditions where work capacity was limited by heat strain using HI in 10 °C water during intermittent rest periods significantly lowered heat strain and increased work endurance times. Using CV in conjunction with HI further reduced heat strain and extended personal endurance, often to the maximum 3-hours. Using 0 °C ('iced') rather than 10 °C water further reduced heat strain. Using 'iced' water also has the advantage that it is easy (away from the laboratory) to ascertain the temperature, whereas, to obtain water at 10 °C requires measurement and control.

Acknowledgements

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EVALUATION OF THE EFFICIENCY OF LIQUID COOLING GARMENTS USING A THERMAL MANIKIN

Xiaojiang Xu[1*], *Thomas Endrusick*[1], *Julio Gonzalez, Brad Laprise*[2], *Walter Teal*[2], *William Santee*[1], *Margaret Kolka*[1]

[1]US Army Research Institute of Environmental Medicine, MA, USA
[2]Natick Soldier Center, MA, USA
[*]Corresponding author: xiaojiang.xu@us.army.mil

Introduction

Liquid cooling garments (LCG) absorb heat from both the human body and the environment. The cooling efficiency is influenced by the configurations of the LCG and clothing ensembles worn over the LCG (outer clothing, e.g. personal protective equipment), and environmental conditions. Thermal manikins (TM) have been used to evaluate the performance of LCG systems and to determine the amount of heat that a LCG can extract from a TM (1-4). However, effects of the outer clothing's insulation on cooling efficiency have not been investigated. The purpose of this study was to use a TM to investigate the relationship between LCG efficiency, insulation of the outer clothing, and water inlet temperature (T_{in}).

Methods

Three ensembles consisting of a cooling vest (CV) only, CV plus battle dress uniform (CVB), and CVB plus battle dress overgarment (CVBO), were tested on a sweating thermal manikin. The TM has 18 independently heated thermal zones plus an additional heated guard zone at the neck mounting plate. Sixteen of the zones are wet zones with an integrated sweating dispenser. The setpoints for water flow in each zone are adjusted to keep the TM skin saturated. The TM is covered with a cotton skin layer to distribute water over the zone surface. The ThermDAC software (Measurement Technology Northwest, Seattle, WA) controls, records data, and displays real time numerical and graphical plots of section temperatures. The software also calculates thermal resistances and evaporative resistances.

TM tests were run dry (i.e. no sweating) and wet (i.e. manikin sweating). The TM surface temperature was maintained at 33°C during all tests and the environment in the climatic chamber was 30 ± 0.5°C, and 50 ± 5% rh. After the clothing ensemble was placed on the TM, baseline values were measured without any perfusate flow through the LCG. The cooling system was then turned on to circulate cool perfusate. The perfusate inlet temperatures (T_{in}) were 15, 20 and 25°C respectively, and the flow rate was 0.5 liter/min. The LCG heat removal from the TM (Q_{tm}) was calculated using the difference between the power input to the TM with and without the perfusate flow. The fluid side heat gain (FSHG) was calculated from the flow rate and the temperature rise of perfusate flow. LCG heat removal from the environment (Q_{en}) was calculated by subtracting Q_{tm} from FSHG. The cooling efficiency (CEF) was defined as:

$$CEF = \frac{Q_{tm}}{FSHG} = \frac{Q_{tm}}{Q_{tm} + Q_{en}} \tag{1}$$

Results and Discussion

Table 1 represents the thermal and evaporative resistances of the three clothing ensembles with and without perfusate. Thermal resistances were reduced by 10-15% when perfusate filled the CV, as the perfusate inside the tubes increased heat conduction from the TM to the environment. Evaporative resistances were only measured with no perfusate, as perfusate inside tubes does not affect vapor transfer from the TM surface to the environment.

Table 1 Heat transfer properties of the LCG ensembles as measured on the TM

	thermal resistance (m^2°C/W)		evaporative resistance (m^2Pa/W)
	no perfusate	with perfusate	no perfusate
CV	0.28	0.24	43.11
CVB	0.39	0.35	65.25
CVBO	0.60	0.51	101.45

Table 2 shows LCG cooling efficiency measured in dry and wet experiments with different water inlet temperatures. As expected, thermal resistances of outer clothing affected the cooling efficiency. Insulated outer clothing (i.e. higher thermal resistance) increased heat removal from the TM and decreased the heat removal from the environment, and consequently the cooling efficiency increased. The cooling efficiency was increased from ~0.45 with no outer clothing to ~0.70 with the added insulation of outer clothing (i.e. CVBO). Reducing T_{in} from 25 to 15°C increased both the heat removal from the TM and the heat removal from the environment, but the cooling efficiency remained nearly constant. A similar phenomenon was also observed by Dionne and his colleagues (1).

Table 2 Cooling efficiency during dry and wet experiments

	dry manikin			wet manikin		
	T_{in} 15°C	T_{in} 20°C	T_{in} 25°C	T_{in} 15°C	T_{in} 20°C	T_{in} 25°C
CV	0.45	0.44	0.46	0.50	0.53	0.56
CVB	0.62	0.58	0.52	0.63	0.64	0.63
CVBO	0.71	0.66	0.73	0.77	0.77	0.82

Cooling efficiency for wet experiments are higher than for dry experiments, and LCG heat removal from the TM in wet experiments was about 2 times as much as in dry experiments. There are two mechanisms which contribute to this increase: (1) the cooling vest fabric was absorbing “sweat” in wet tests, thus enhancing heat conduction from the TM surface to flowing perfusate; (2) water vapor from the TM skin condensed onto the perfusate tubes, then evaporated and diffused into the clothing and the environment.

Dionne and his colleagues used TMs to compare the performance of various personal cooling garments (1). The outer clothing in their studies had thermal resistances similar to our CVBO ensemble. They observed efficiencies of ~0.9, which were higher than our values. The TM skin temperature in their study was 2°C higher than the TM skin temperature in our study. Given that the heat removal from the TM increases when the TM surface temperature increases(1), cooling efficiency would also be expected to improve.

Understanding the impact of outer clothing on cooling efficiency serves several purposes: (1) the cooling efficiency relationship can be used to improve mathematical simulation of human responses with LCG/outer clothing combinations; (2) in physiological studies, by estimating the LCG heat removal from human by the fluid side heat gain, knowledge of the cooling efficiency equation components can improve heat balance analyses; and (3) the information on cooling efficiency can help personal protective system design engineers convert the physiological cooling requirements into requirements for cooling unit performance.

In this study, tests were conducted with one set of environmental conditions (i.e., constant values for temperature, humidity, and wind speed) without any adjustment for solar radiation. The addition of a solar component could significantly impact the efficiency of LCG system. Further tests and theoretical analysis would be required to investigate how this might affect the cooling efficiency in an operational scenario.

Conclusion

This study used a sweating thermal manikin to systematically investigate the impacts of outer clothing and water inlet temperature on LCG efficiency. The insulation of an outer clothing ensemble reduces

LCG heat removal from the environment and thus increases the LCG efficiency. The water inlet temperature had minimal influence on the cooling efficiency of the LCG.

Disclaimer

We thank Mr. Gary N. Proulx for his technical assistance in setting up the cooling system. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or service of the organizations. Approved for public release; distribution is unlimited.

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CLOTHING HEAT EXCHANGE MODELS FOR RESEARCH AND APPLICATION

George Havenith

Environmental Ergonomics Research Group, dept. Human Sciences, Loughborough, UK
* corresponding author g.havenith@lboro.ac.uk

Introduction

The regulated exchange of heat from the human body to the environment is essential in human survival. This exchange is adjusted by our physiological response mechanisms. We are able to sweat profusely to cool the body in exercise and heat exposure, and are able to fine-tune our body temperatures in moderate environments through variations in skin circulation.

In slightly cool environments, we reduce blood flow to our extremities and skin and use our fat layer insulation to conserve central body temperature. We can increase our heat production by shivering and can create a small insulating air layer around our skin by pilo-erection. However, when temperature goes down further, we cannot sustain our body temperature in the long run without behavioural adjustments that include putting on clothing or using heated dwellings. In this context, clothing has allowed mankind to expand its habitat around the world and has had a positive influence on its development.

Today, clothing is worn for various reasons. Apart from its functional aspects (insulation, protection), it has a strong cultural and social aspect as well. The latter are on occasion counterproductive in terms of the first. A business suit for instance is hardly functional in a tropical climate, nor is a ladies evening dress in a cold environment. Also, when the function of the clothing is not only protection against heat or cold, as e.g. is the case with chemical protective clothing, the barriers introduced in the clothing to achieve the required protection can cause a conflict between the protective function of the clothing and the thermal functioning of the body. These conflicts can lead to discomfort, but also to physical strain and in extreme cases can put the person at risk from heat or cold injury or illness.

In order to understand these relations and conflicts, we need to study not only what happens in terms of thermoregulation in the body, but also how heat is transferred from skin to environment. For heat loss from the body, between skin and environment, several pathways are available. For each pathway the amount of transferred heat is dependent on the driving force (e.g. temperature or vapour pressure gradient), the body surface area involved and the resistance to that heat flow (e.g. clothing insulation):

$$Heat\ \ Loss = \frac{gradient \cdot surface\ area}{resistance} \qquad \mathbf{<1>}$$

Usually the descriptions of the heat exchanges are confined to conduction, convection, radiation and evaporation. A minor role is normally taken by conduction, which is usually only referred to when people are in contact with solids. More important for heat loss is convection. When air flows along the skin, it is usually cooler than the skin. Heat will therefore be transferred from the skin to the air around it. Also heat transfer through electro-magnetic radiation can be substantial. When there is a difference between the body’s surface temperature and the temperature of the surfaces in the environment, heat will be exchanged by radiation. Finally, the body possesses another avenue for heat loss, which is heat loss by evaporation. Due to the body’s ability to sweat, moisture appearing on the skin can evaporate, with which large amounts of heat can be dissipated from the body.

In most calculations and description of these heat losses, clothing is represented as a resistance to dry heat loss and as an evaporative heat resistance. However realistically many more parameters are required to fully describe clothing heat transfer, leading to rather complex descriptions or models. Both approaches will be discussed here.

Detailed models

In order to describe the heat transfer through clothing fully one needs to include a number of processes. If we assume clothing built up of a number of textile layers with a still air layer on their surfaces, and possibly mobile air layers on top of those, the following heat transfer processes may take place:

Dry:

Conduction: dry heat is transferred by conduction through the still air layers that are found on the surface of the textile layers, as well as through the air within the textile layers and through the textile fibres. Conductivity of textile fibres is much higher than that of still air, indicating the importance of trapped air within garments to the conductive heat loss (Table 1).

Convection: where the air is not held still by textile fibres, and is able to move due to natural convection (rising of warmed air) or is forced to move by forced convection (wind, body movements creating a bellows effect) heat will be transported with the air moved defined by its enthalpy.

Radiation: heat can be transported between the environment and the clothing surface by electro-magnetic radiation. This also occurs between clothing layers, and finally radiant heat transport can take place between the fibres within a textile, through the entrapped air. The more fibres, the less radiant transfer, though an optimum for overall conductivity of a textile is based on the balance between radiation and convection (denser → less radiation but more conduction through the fibre content).

Wet:

The water vapour molecules of evaporated sweat, having ‘absorbed’ around 2430 J.g^{-1} of heat at the skin, can be transported to the environment in various ways:

Table 1: Thermal conductivity of various textile fibres (1)

Material	$W \cdot m^{-2} \cdot {}^{\circ}C^{-1}$
Wool	0.19
Silk	0.21
Linen	0.29
Cotton	0.29
Polyamide	0.23
Polyester	0.18
Polyacryl	0.18
air	0.026

Diffusion: the movement of water vapour molecules through still air and textiles allows moisture to be lost from the skin and keeps the microclimate dry enough to allow more sweat evaporation.

Convection: similar to dry heat loss by convection, moving air will take with it the moisture contained in the microclimate, which can then be replaced by fresh air if the convective stream actually leaves the garment (ventilation). If not, it will have an equilibrating effect on local microclimate conditions.

Absorption (adsorption): water vapour travelling through textiles may be absorbed by the textile fibre. All materials, when allowed to absorb vapour until an equilibrium is reached, have characteristic absorption levels (expressed as regain), which increase with relative humidity and are typically higher for natural versus man-made fibres. With this absorption heat is released in the textile, composed of the heat of condensation and the heat of swelling, raising the local temperature. If liquid is absorbed, only the heat of swelling is released.

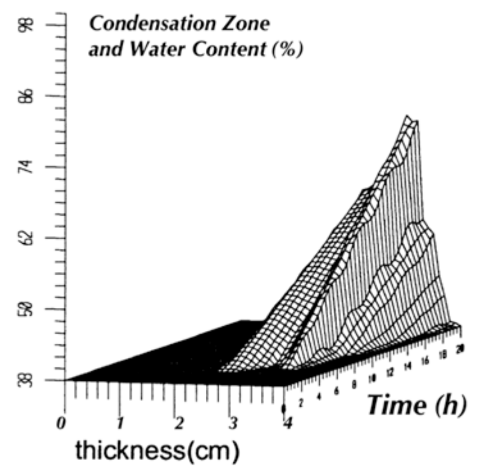


Fig. 1 Example of finite element modeling calculation showing distribution of condensed water in a wool batting (adapted from (2)).

Desorption: Any water bound to the textile fibres may be released as vapour again and take with it the heat of swelling plus the heat of evaporation, i.e. the reversal of absorption. This will reduce the local temperature.

Condensation: In most situations a temperature gradient as well as a water vapour gradient is present from the skin to the environment. This drives the transport of heat and moisture. These two interact however, as with reducing temperature along this temperature gradient, also the dewpoint of the local air is reduced. This dewpoint limits the water vapour concentration at that location, and if that is exceeded, condensation of moisture with a release of heat will occur at that point, raising the local temperature.

Models that study heat transfer processes in clothing in detail will need to incorporate these factors. Various approaches are possible with numerical or analytical solutions. Good examples are the models developed by the groups around Jones,

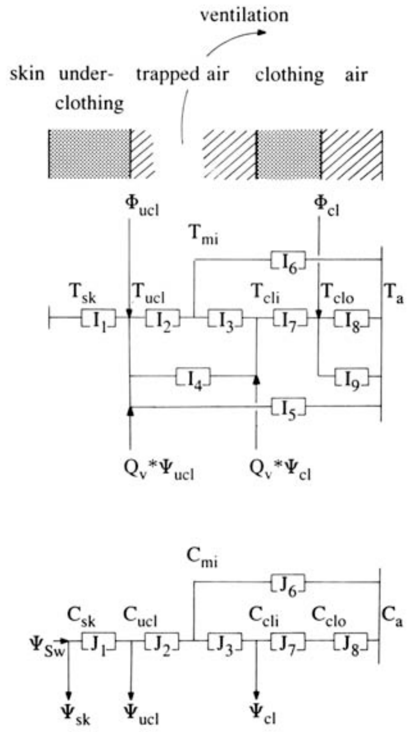


Figure 2, four layer clothing model and related heat and vapour resistance network (6)

Li, Fan, Ghali, Ghaddar and Lotens (2, 3, 4, 5, 6). Much of this work is based on Henri's work from 1939 (7).

Many of these modellers revert to finite element modelling for their simulations, as the analytical solutions are almost impossible without simplifications (2). In essence this divides all clothing and air layers into a matrix of elements and heat and moisture transport etc. between all adjacent elements is calculated in short time increments. Given the complexity of even this exercise, most of these models are only one dimensional in space. However they do allow in depth analyses of all relevant processes over time in a cross section of the clothing (Figure 1).

These models are mainly used by material and textile engineers for basic research. They have not found wide acceptance in the research area of environmental ergonomics due to their mathematical complexity, which makes them difficult to work with for a major part of that research community.

The problems with this complexity, and the debate whether this level of complexity is needed for most applications of these models has led some researchers to simplify these models. E.g. by representing clothing layers not as multinode structures with interaction of heat and moisture transfer in each node but by describing them with fixed values for heat and vapour resistance and reducing the number of nodes dramatically. This was the approach taken by Lotens (6). A schematic drawing of Lotens' model is provided in Figure 2. He has reduced the clothing to a representation by 4 layers, underclothing (including the skin air layer), microclimate between underclothing and outer clothing, the actual outer clothing layer and the outer surface air layer. He did include radiation, convection, diffusion and ventilation and only within three nodes he allows interaction of heat and moisture transfer. Farnworth (8) took the simplification one step further using a simple description with fixed values for heat and vapour resistance. The advantage is a drastic simplification; the disadvantage is that processes, like pumping effects and ventilation, are neglected as well.

Lumped models

In the area of environmental ergonomics there is a large group of practitioners and researchers for whom the detailed analysis of heat transfer processes in clothing is not essential. Rather they are interested in the overall influence the clothing has on the wearer. Examples can be found in the areas of heat (9) or cold stress (10) prediction, or in the area of indoor climate research looking at thermal comfort (11). For these applications the complex models are not practical, as with their large numbers of parameters that can be set and changed, understanding of the implications is soon lost. For these applications a calculation of the overall human heat balance is the main basis for the analysis, and hence these can work with very simplistic models of clothing heat transfer, which in some applications goes down to representing the clothing as a single heat resistance with all other parameters derived from this (e.g. (11)). This approach has led to the development of ISO 9920 (12) and ISO 15831 (13), describing the clothing as a single heat and a vapour resistance, combined with those of the surface air layer (Fig. 3).

This allows the calculation of heat loss from the skin for steady state situations, but does not allow study or calculations of transients, changes in insulation due to moisture accumulation, increased ventilation etc. This standard has become tremendously popular with practitioners (climate assessment; building HVAC designers) as it provided examples of the heat resistance values of many different clothing ensembles, which could be used in calculations without the need to measure the actual insulation worn. The standard provided extensive data on heat resistance of clothing and limited data on vapour resistance, obtained on thermal manikins. The latter was usually treated as having a direct relation with heat resistance (Lewis relation) allowing its deduction from it. Especially for comfort conditions this approach appeared to be satisfactory.

For other work conditions, where more stressful conditions were present this approach was found to be overly simplistic. It did not take proper account of increased air speeds, radiation effects on specialised clothing, rain protective clothing etc. etc. Some of these factors are now addressed in the revision of ISO 9920, expected to be published at the end of 2005.

Given the popularity of this approach, the following sections will look into this in more detail and identify some areas that are currently under discussion or require more attention in future research.

The f_{cl} factor

The classic equation for calculation the clothing insulation that relates to Figure 3 is:

$$I_{\mathrm{T}} = I_{\mathrm{cl}} + \frac{I_{\mathrm{a}}}{f_{\mathrm{cl}}} \qquad \mathbf{<2>}$$

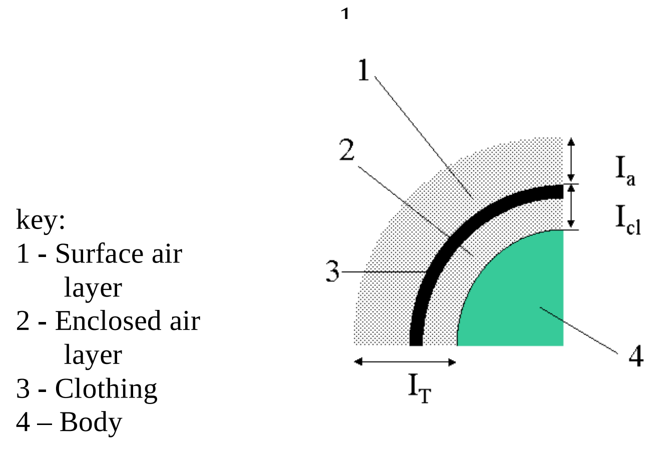
with:

I_{T} = Total Insulation provided by clothing and surface air layer; I_{cl} = Intrinsic clothing insulation, I_{a} = surface air layer insulation, and f_{cl} = clothing area factor; ratio of the outer surface area of the clothed body to the surface area of the nude body

While I_{cl} and I_{a} can be measured or looked up in tables, f_{cl} has to be determined by photographic or body scanning techniques (14). But as this is highly labour intensive, f_{cl} is usually calculated using one of various regression equations proposed in literature. (15). During the revision phases of ISO 9920 and ISO 7730, these equations were criticised for predicting too large f_{cl} factors, and new research initiated to look into this. A problem with the regression equations available is that they were based on only a weak relation between f_{cl} and I_{cl}, and this within a domain of I_{cl} of 0.2 to 1.7 clo only (aiming at office clothing and light to medium workwear). So they were not designed for cold weather clothing and a large error for individual ensembles can be expected. However, when the sensitivity of the calculation of I_{T} for different f_{cl} calculations is investigated, it can be demonstrated that the impact of an error in f_{cl} is small. If I_{T} values in relation to I_{cl} values for the current f_{cl} prediction in ISO 9920 ($f_{cl} = 1 + 0.28\, I_{\mathrm{cl}}$), are compared to those for two equations with largely deviating coefficients (0.13 and 0.43 instead of 0.28; much larger than any found in literature), it can be seen that even for such extreme deviations, the final impact on the insulation calculation is small. Difference are all less than 4.5%, even for such extreme f_{cl} changes.

Radiation

Data collected in ISO 9920, are all based on measurements where no added radiant load is present, so ambient temperature (T_a) = mean radient temperature (T_{mrt}) = operative temperature (T_o). In case radiation is present, the representation of insulations of Figure 3 only provided limited opportunity to incorporate this in the calculations. If the clothing's outer surface reflectivity is known, and one assumes that only reflection or absorption of radiation takes place at the clothing surface (i.e. no penetration/transmission), it is possible to calculate convective and radiant heat transfer from the clothing surface to the environment correctly, with all heat transfer inside the clothing assumed to have a fixed radiant component that does not change in radiant exposures. So, though this allows a first order approximation of radiation effects, it is not a complete model for this



2. Figure 3 — Schematic representation of insulation definitions. I_{cl} = Intrinsic clothing insulation; I_{a} = outer surface air layer insulation, I_{T} =total insulation.

purpose as in radiation exposures also radiant fluxes inside the clothing or interior microclimate are bound to change. In various ISO standards for the assessment of heat stress, such conditions, and/or specialised clothing, are deemed to be outside of the scope for this reason.

Currently a European Union Research Project called ‘THERMPROTECT’, dealing with these issues is under way, and first results will be discussed at this conference.

Air speed/pumping effects

Apart from not including radiation issues, the model used for insulation in ISO 9920 also does not intrinsically contain effects of body movement or wind penetration, which both can cause ventilation of the clothing microclimate with outside air. As the insulation from skin to clothing surface is treated as one fixed value, no extra pathway for ventilation is included (see Fig. 2 for model that does include this). These wind penetration and pumping effects can have substantial effects on the insulation provided by the clothing, however, with reductions for light clothing going towards 40% of total insulation (16). Rather than making the model (Fig. 3) more complex, the standardisation group dealing with ISO 9920 has now chosen to provide correction equations to users of the standard, that allow them to use the static values from the ISO 9920 tables and convert these to dynamic value for activity and wind (Fig 4, [17, 18]).

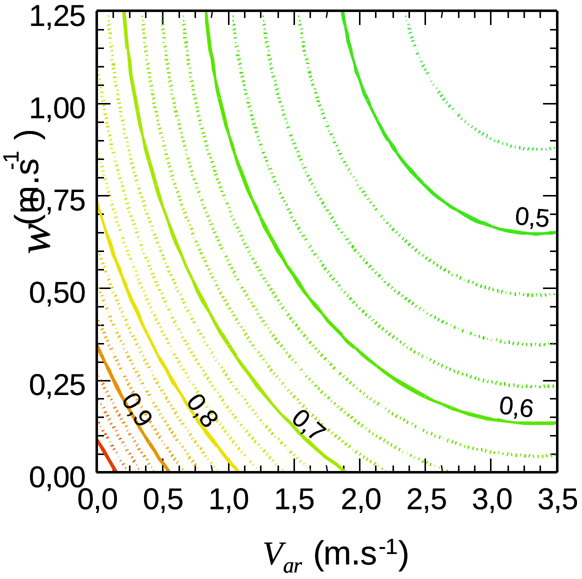


Figure 4 — Correction factor ($I_{T,r} / I_T$) for dressed subjects; validity up to 1,2 m·s^{-1} walking speed (w) and 3,5 m·s^{-1} relative wind speed (v_{ar}) (source[18]).

Different experimental and calculation methods for manikin data

The various standards describing the measurement of clothing insulation with a thermal manikin and those providing example data for various clothing ensembles have been developed with different applications in mind. While ISO 9920 and related manikin based data tables have been initiated with human heat balance analysis as goal (application of ISO thermal comfort and climatic stress standards; initially focussed on office worker’s clothing and from there has expanded to workwear), other standards, like the cold weather clothing standard (EN342, (20)) and the manikin standard EN ISO 15831 (13), have been developed from the clothing testing, evaluation and certification viewpoint. This has caused a difference in methods for the manikin measurement of clothing insulation, most notably a difference in the wind speed used. While the data in ISO 9920 are almost exclusively obtained at wind speeds below 0.2 m.s^{-1} (most around 0.1 m.s^{-1}), the other standards work at 0.4 m.s^{-1}. Though the difference in wind speed seems small this can have a substantial effect on the insulation measurement of up to 12% for light clothing, less for heavier clothing. Hence this should be accounted for when getting data from different sources.

Apart from the issue with reference wind speeds mentioned above, another problem has been introduced in the interpretation of insulation data due to development of different standards in parallel. This issue relates to the calculation of the overall heat resistance provided by clothing from the data obtained from a multizone manikin. In the simple case of a single zone manikin, the insulation is simply calculated by dividing the temperature gradient between skin and environment by the total heat input to the manikin. This is also possible for multizone manikins, but another method has been proposed as well (21, 13)

Three calculation methods are in use:

1 – The general formula for defining whole body resistance, best fitting the insulation definition of ISO 9920:

$$\text{with } \alpha_{\mathrm{i}} = \frac{\textit{surface area of segment } i}{\textit{total surfacearea of manikin}}$$

$\overline{t_{sk}}$ = average skin temperature

t_i = temperature of segment i

t_a = ambient temperature (if mean radient temperature differes from ambient, replace by operative temperature)

H_i = heat loss of segment i

$$I_{\mathrm{T}} = \frac{\overline{t_{sk}} - t_a}{H_{sk}} = \frac{\sum \alpha_i.t_i - t_a}{\sum \left(\alpha_i.H_i\right)} = \frac{\sum \alpha_i.(t_i - t_a)}{\sum \left(\alpha_i.H_i\right)} \qquad \textbf{<3>}$$

2 – If one makes the assumption that skin temperature is uniform over the body, i.e. $t_i = t_{sk}$ = constant, then equation <3> becomes :

$$I_{\mathrm{T}} = \frac{\overline{t}_{\mathrm{sk}} - t_a}{\sum \left(\alpha_i.H_i\right)} \qquad \textbf{<4>}$$

or:

$$\frac{1}{I_{\mathrm{T}}} = \frac{\sum \alpha_i.H_i}{\overline{t}_{\mathrm{sk}} - t_a} = \sum \alpha_i.\left(\frac{H_i}{\overline{t}_{\mathrm{sk}} - t_a}\right) = \sum \alpha_i.\frac{1}{I_{\mathrm{T},i}} \qquad \textbf{<5>}$$

This is adding up resistance according to a **parallel model**, used in ASTM F1291, ISO9920 and ISO/CD15831 (19, 20, 13).

3 – If the assumption is made that local heat flux is uniform over the body, i.e. $H_i = H_{sk}$ = constant, then equation <3> becomes:

$$I_{\mathrm{T}} = \frac{\sum \alpha_{\mathrm{i}}.(t_i - t_a)}{\sum \left(\alpha_{\mathrm{i}}.H_i\right)} = \frac{\sum \alpha_{\mathrm{i}}.(t_i - t_a)}{H_{sk}} = \sum \alpha_{\mathrm{i}}.\frac{t_i - t_a}{H_{sk}} = \sum \alpha_{\mathrm{i}}.I_{\mathrm{T,i}} \qquad \textbf{<6>}$$

This equation is adding up resistances according to a **serial model**, used in ENV342, EN13537, and ISO15831 (20, 21, 13).

In practice most measurements of clothing or sleeping bag insulation are made with constant skin temperature (EN ISO 15831) as this takes a lot less time. Mostly this is done with equal skin temperatures all over the body pointing to the parallel method, but even if temperature of hands and feet is lowered as suggested for some applications, it would be very seldom that the condition of uniform heat loss is approached. If this assumption is not met however, the calculation of the serial model becomes highly error prone. With uneven distribution of insulation (e.g. nude hands and head in cold weather clothing), the serial method will produce much higher total insulation values than the parallel method and, if used in total body heat balance models, the serial method based insulation values will give unrealistic results in such cases. E.g. if we would highly insulate a single body compartment it is possible to drive up the local insulation dramatically. In the serial model this will than also push up overall insulation proportionally. This is illustrated in Figure 5. Putting on several pairs of socks and gloves on top of each other causes the large change in total insulation with the serial method on the left of both graphs. In reality total body heat loss will only change minimally. If we would use the whole body serial value to calculate backwards how much heat input the manikin required, a large discrepancy with the actually observed value would be observed. For the parallel method this is not the case.

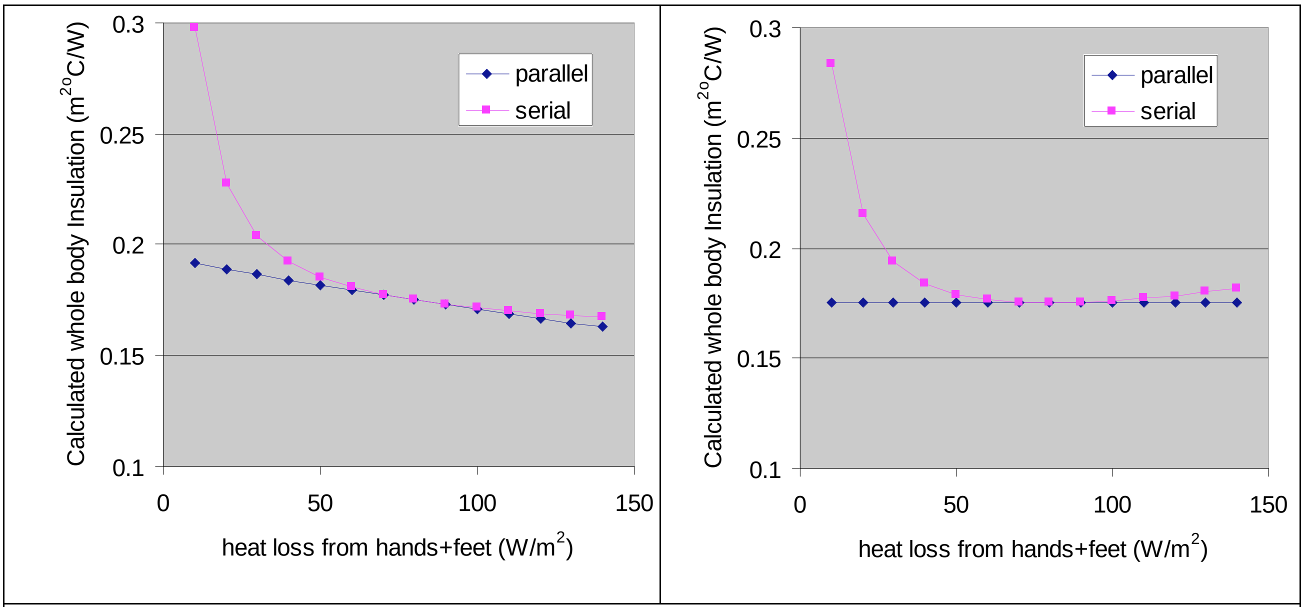


Fig. 5, total body insulation calculated with both the parallel and the serial model in light clothing. Left: heat loss from hands and feet (i.e. the insulation) is varied while the heat loss from other zones is constant at 80 W/m^2. Right: a fixed total body heat loss is assumed of 80 W/m^2, with a varying insulation on hands and feet.

One requirement for the parallel method is however that the ensemble is representative for the use situation. Leaving off gloves from a highly insulative ensemble would have a huge effect (as it would in real life), which cause could be easy overlooked in the application of the data.

With the development of manikins with more and hence smaller zones, this issue becomes more relevant, as a malfunction of a single, small, zone would offset the result of the serial calculation heavily with small impact on the parallel one.

Conclusions

A choice of clothing models is available for simulations and estimations of clothing heat and vapour transfer. For the study of the actual heat and moisture transfer in textiles, models tend to be multinode and mathematically complex, creating a barrier to their widespread use. Several attempts to simplify the approach have been successful for use in practical applications. The most simplified model, as used in ISO 9920, has received widespread use in climate assessment and clothing assessment and certification. However, the simplicity comes at a cost of requiring a number of empirical correction factors to be used to account for effects of movement, wind and radiation. Also development of different methods for calculation of insulation values based on this model has introduced a source for confusion.

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INFRARED RADIATION EFFECTS ON HEAT LOSS MEASURED BY A THERMAL MANIKIN WEARING PROTECTIVE CLOTHING

Peter Bröde[1], Kalev Kuklane[2], Emiel den Hartog[3], George Havenith[4] and THERMPROTECT[5] network*

[1] Institut für Arbeitsphysiologie an der Universität Dortmund (*IfADo*), Germany
[2] Department of Design Sciences, EAT, Lund University, Sweden
[3] Department of Performance & Comfort, TNO Human Factors, Soesterberg, The Netherlands
[4] Department of Human Sciences, Loughborough University, Loughborough, UK
[5] V. Candas, H.A.M. Daanen, B. Griefahn, G. Havenith, I. Holmér, H. Meinander , M. Richards
* corresponding author broede@ifado.de

Introduction

The main objective of the EU funded research project THERMPROTECT is to provide basic data and models on "Thermal properties of protective clothing and their use" for improving the assessment of heat stress (3). One work package studies the effects of thermal radiation utilising a stepwise experimental approach comprising flat plate material tests, manikin experiments and human trials.

This paper deals with manikin experiments on the effects of far infrared heat radiation (FIR), considering aspects related to the reflectivity of the clothing, the number of clothing layers and the radiated body surface area.

Methods

The Swedish heated thermal manikin TORE (5) was operated with a constant surface temperature of 34 °C standing in a climatic chamber at *IfADo*. That chamber allows for the application of high intensities of FIR while keeping the other climatic parameters constant and thus enabling the presentation of the results as (changes in) measured heat loss.

To ensure reliable operation of the manikin's heating mechanism under radiant heat load the experiments were carried out at a low air temperature (t_a) of 5 °C, with 50% relative humidity (rh) and air velocity (v_a) of 0.5 m/s. Mean radiant temperature ($\overline{t_r}$) was varied between 41.3 and 62.5 °C, and a homogeneous reference condition with $\overline{t_r} = t_a$ was included.

Generally, FIR with semi-cylindrical geometry was frontally applied, but in order to consider the effects of the radiated surface area semi-cylindrical lateral and cylindrical all-side radiation with identical mean radiant temperature $\overline{t_r}$ =50 °C were also studied.

Coveralls made of different outer materials (cotton, Nomex®) and colours (black, white, orange) as well as an aluminised reflective suit and a black Nomex® coverall with inside lamination as wind protection were combined with polypropylene underwear (Helly Hansen Super Bodywear 140 g/m^2, HHS). Three layer ensembles were also studied by adding a wool/polyamide single piece long underwear (Ullfrotté Original overall 400 g/m^2, ULF) as a middle layer.

The manikin wore socks and gloves, and the head, hands and feet were shielded against FIR with aluminium foil. Steady state values of heat loss were calculated for the whole body (excluding head, hands and feet), frontal and back torso taking the surface area into account. All conditions were measured twice.

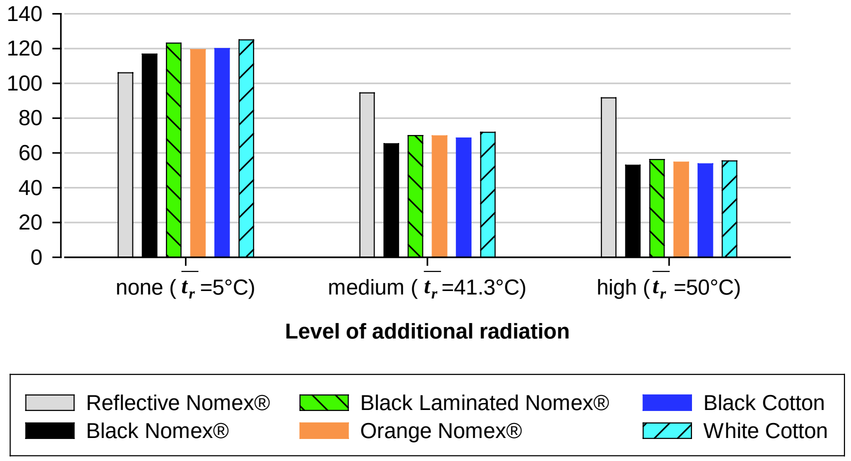

Figure 1. Manikin whole body heat loss (head, hands, feet excluded) at the applied levels of additional radiation for different outer layer materials. Bars represent averages of replicated measurements obtained with HHS underwear at t_a=5 °C, v_a=0.5 m/s, rh=50%.

Results

FIR effect in relation to the reflectivity of the garment material

The results showed a decrease in whole body heat loss, i.e. heat gain for the conditions with radiant heat stress compared to the reference (Figure 1). Except for the reflective suit that showed a higher insulation at the reference condition and minor FIR effects compared to the other suits, the influence of the material and colour of the outer garment was small.

Effect of additional insulating clothing layer

The left panel of Figure 2 compares the whole body heat losses for some two layer ensembles depicted from Figure 1 to those with an additional layer (ULF). Again, the orange and black Nomex® suits showed nearly identical decreases in heat loss, that seemed to be linearly related to the difference $\bar{t}_r$ - t_a and appeared to be flatter for the three layer ensembles.

Extrapolation indicates that the 2 and three layer curves would intersect at higher radiation intensities, when the total heat loss might turn into heat gain (that could not be directly measured by the heated manikin) and that a user would benefit from the thicker 3 layer system as protection from the incoming heat.

The percentage decrease of heat loss caused by adding the ULF layer, corresponding to the relative increase of clothing insulation, was nearly unaffected by the radiation intensity and outer garment material (Figure 2, right panel). Though there was an increase observable for the orange Nomex® at higher radiation intensities, the fluctuations were lower than 5% about the grand average.

FIR effect in relation to the radiated surface area

Figure 3 shows that the whole body heat gain induced by radiation ($\bar{t}_r$ =50 °C), i.e. the difference in heat loss to the reference condition, was similar for frontal, lateral and all-side radiation, but that frontal radiation affected differently the frontal and back torso, thus causing inhomogeneous spatial distribution of heat gain. Similar relations were found for lateral radiation and the left and right extremities (data not shown).

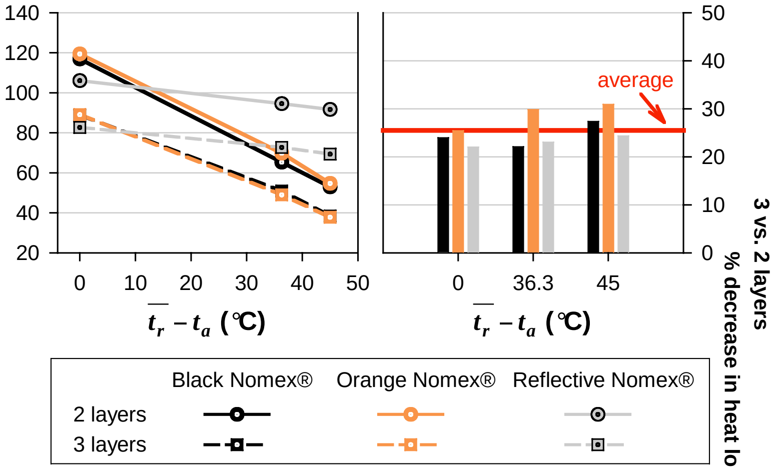

Figure 2. Left panel: Connected averages of whole body heat loss vs. $\overline{t_r}$ - t_a for ensembles with 2 layers (depicted from Figure 1) and an additional layer (ULF). Right panel: Effect of additional ULF layer as percentage difference in heat loss to the two-layer condition related to outer layer and radiation intensity. The reference line denotes the grand average (25.5%).

Relation to FIR intensity

Figure 4 presents the individual measurements, that proved to be highly repeatable, of whole body heat gain under frontal and all-side FIR in dependence to FIR intensity.

The heat gain was well fitted by a linear function of $\overline{t_r}$ - t_a (Figure 4). Again, with the exception of the reflective suit, the regression lines were nearly identical for the different Nomex® materials.

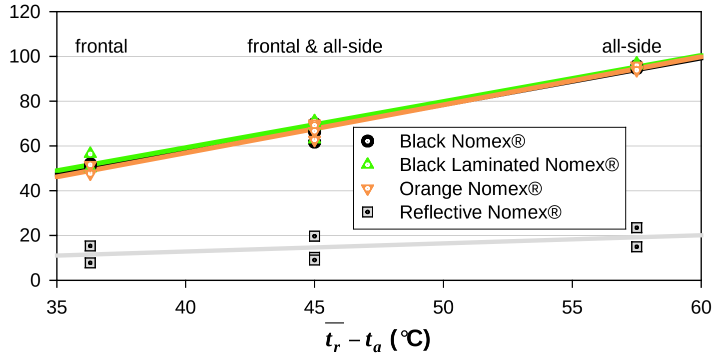

Figure 3. Effect of frontal, lateral and all-side FIR at $\overline{t_r}$ *=50 °C* expressed *as heat gain (i.e. difference to heat loss at* $\overline{t_r}$ *=* t_a*=5 °C,* v_a=0.5 m/s, rh=50%*) for different body parts and outer layer materials.*

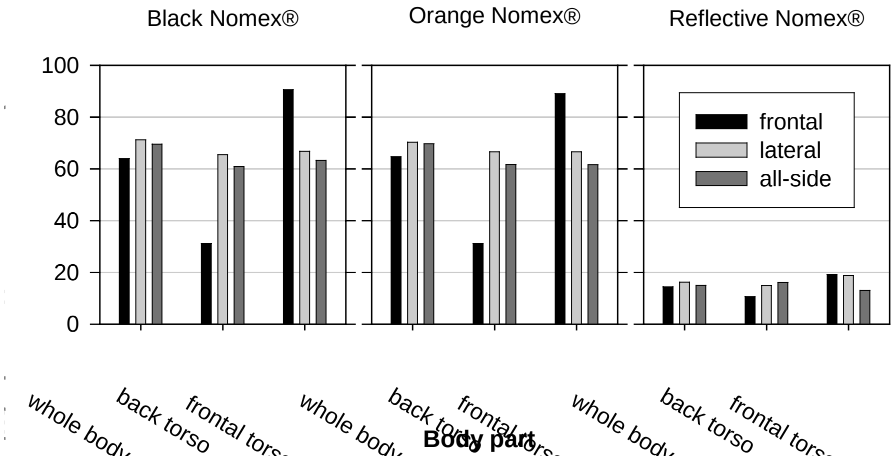

Figure 4. Linear regression of FIR effect (whole body heat gain) on $\overline{t_r}$ - t_a for different outer layers. The points represent the single measurements for frontal and all-side radiation used for this combined analysis.

Discussion and conclusions

The results confirm the linear dependence of FIR effects on radiation intensity for clothes with higher insulation, that had been observed earlier for lighter clothing (1;2). They also indicate the suitability of the difference $\overline{t_r}$ - t_a for the description of radiation intensity in heat stress assessment (3).

As long as special shielding material is not considered, the colour and material of the outer garment proved to be of minor importance. Extrapolation of our results suggests that additional insulating clothing layers may be useful to attenuate FIR induced heat gain at higher intensities.

The small effects of radiated surface area on whole body heat loss were accompanied by locally increased heat gain and higher inhomogeneity in its spatial distribution that may be responsible for the greater impairment of physiological and psychological responses to frontal FIR observed in human trials (4).

In the THERMPROTECT project this research will be complemented by further experiments on the probable influence of colour on the effects of radiation in the visible spectrum (1) and by considering the interaction with convection and wet underclothing, where differential material effects related to air and vapour permeability are expected.

Acknowledgements

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EFFECTS OF MOISTURE ON THE HEAT TRANSFER THROUGH PROTECTIVE CLOTHING

Mark Richards[1] and THERMPROTECT network[2]*

[1] Empa Materials Science and Technology, CH-9014 St. Gallen, Switzerland
[2] P. Broede (D), V. Candas (F), E. den Hartog (NL), G. Havenith (UK), I. Holmér (S), H. Meinander (FIN) and W. Nocker (D)
* corresponding author mark.richards@empa.ch

Introduction

The EU research project THERMPROTECT aims to provide data and models to be used to improve standards for the use of personal protective clothing/equipment (PPC/PPE). One of the objectives of this project is to study the effects of moisture on the heat transfer through PPC in relation to the location of the moisture, the vapour resistance of the clothing and the climate.

Heat and moisture transport through clothing involve complex processes and are coupled through evaporation, condensation, sorption and desorption of moisture (1). Standards for predicting heat and cold stress (2) do not consider this coupling and define the total heat exchange of the skin as being the sum of its dry and evaporative heat exchanges. These heat exchanges are estimated using the dry thermal resistance and water vapour resistance (or permeability) values of the clothing worn, which have been measured without the presence of additional moisture. However additional moisture is often present in clothing, particularly from sweat accumulated during and following exercise. Such moisture reduces the effective thermal insulation of the clothing, can increase the effective water vapour resistance and, under cold conditions, increases the total heat loss from the wearer (3-5).

In the study presented here the effect of moisture due to body sweat on the effective heat loss of selected PPC is investigated using a thermal manikin under cold conditions.

Methods

Two layer clothing systems were investigated in this study to cover a range of PPC with different moisture transport properties. The underwear materials have very different absorptive properties, namely hydroscopic (CO, 100% cotton, Swiss army ‘Gnägi’), hydrophilic (PES, 100% polyester) and hydrophobic (PP, 100% polypropylene, Helly Hansen Lifa Active). Outer layer materials were selected with different water vapour permeabilities, namely impermeable (IMP, Swiss army rain wear, polyamide with PVC coating), semi-permeable (SEMI), permeable (PERM) and very permeable (OPEN). Intrinsic dry thermal insulation (I_{cl}) and water vapour resistance ($R_{e,cl}$) values for these materials (measured using EN 31092/ISO 11092 (6)) and calculated water vapour permeability values (i_{mt}) are listed in table 1.

For the results presented here, the Sweating Agile thermal Manikin (SAM) (7) was used to measure the average heat loss without and with sweating. Sweating is simulated by water distributed over the surface of the manikin. SAM was operated with a constant surface temperature of 34°C. The climate was maintained at an air temperature of 10°C (equal to the mean radiant temperature) and 80% relative humidity, with an air flow of 0.5±0.1 m/s.

Underwear consisted of long-sleeved T-shirts and long johns. Outer layers were confectioned into overalls without pockets. Clothing fit was kept as constant as possible.

Table 1: Underwear and outer layer materials. See text for the definition of the values listed.

Code	**Material**	**Moisture property**	**I_{cl} (m^2 K/W)**	**$R_{e,cl}$ (m^2 Pa/W)**	**i_{mt}**
CO	100% Cotton	Hygroscopic	0.024	4.2	0.34
PES	100% Polyester	Hydrophilic	0.029	3.4	0.51
PP	100% Polypropylene	Hydrophobic	0.026	3.7	0.42
IMP	PA webbing with outer PVC coating	Impermeable	0.007	∞	0
SEMI	hydrophilic layer with outer PTFE membrane	Semi-permeable	0.023	18.6	0.07

PERM	hydrophobic layer with inner PTFE membrane	Permeable	0.025	5.6	0.25
OPEN	PERM without membrane	Very permeable	0.008	1.1	0.44

Measurements of the dry heat loss were made with the manikin not sweating over 1 hour and of the wet heat loss with the manikin simulating a constant sweat rate of 200 g / (m^2 h) over 2½ hours (allowing sufficient time for heat loss to reach steady state). For each clothing system and condition, the average total steady-state heat loss for all body parts excluding the hands, feet and head of the manikin was determined from the last 10 minutes of three tests.

Results

The moisture collected within the clothing layers is shown in figure 1. As expected the total moisture which collected is strongly dependent on the water vapour permeability of the outer layer, with most moisture collecting in clothing with the IMP outer layer. For a given outer layer, the moisture accumulation within the underwear is dependent on its absorptive properties, with the most moisture collecting in CO (being very hygroscopic) and the least in PP (being hydrophobic). The moisture within the tight-fitting skin on the manikin surface is dependent on the underwear layer, being greatest for CO and least for PP for a given outer layer. For the IMP results, almost all the water sweated in 2½ hours collected within the clothing. Some water dripped down and was collected below the manikin and some evaporated sweat (about 20% of the total 550g sweated) could escape through the collar of the overall which was not completely closed.

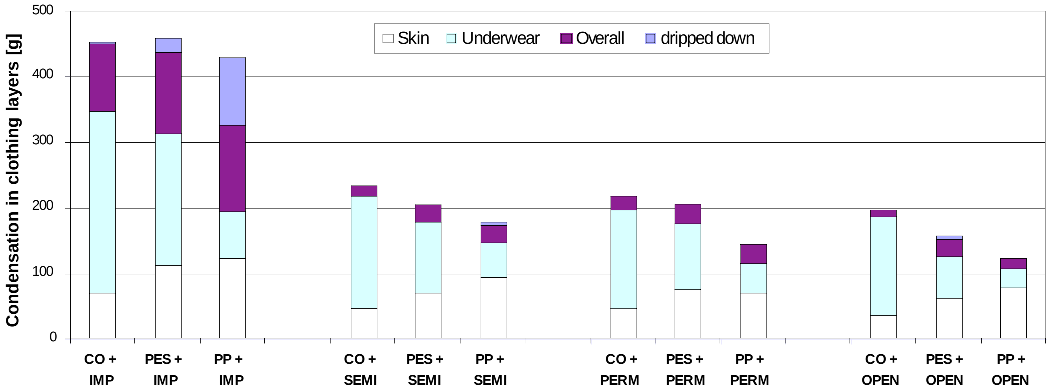

Figure 1 Moisture condensed in clothing layers during 2½ hours of sweating at 200 g / (m^2 h). Clothing layers are indicated with codes for underwear + outer layer.

Average dry and wet heat losses for the clothing combinations are shown in figure 2. The dry heat losses did not vary greatly between the clothing measured. Combinations with IMP and OPEN gave slightly higher dry heat losses (105-110 W/m^2 and 114-124 W/m^2) than for the other outer layers (99 – 104 W/m^2) due to the lower insulation values of IMP and OPEN and possibly due to the high air permeability of OPEN.

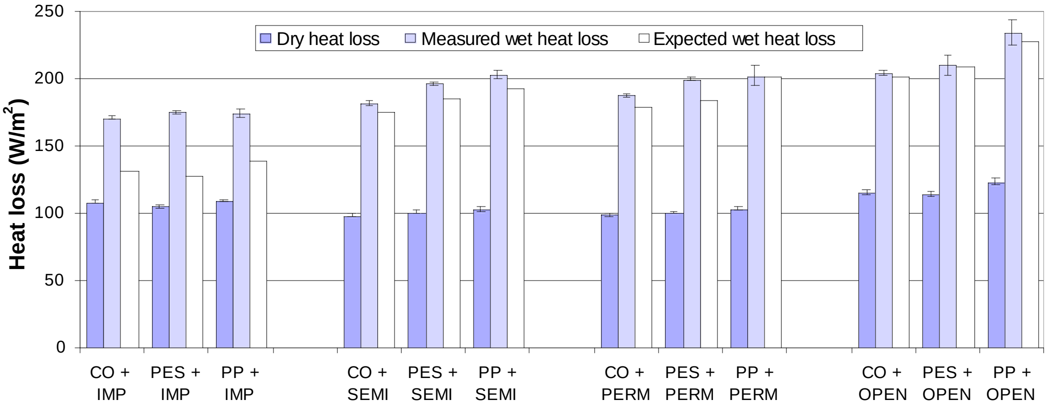

Figure 2 Average heat losses (excluding head, hands and feet). Error bars indicate ±1 SD for dry (not sweating) and wet (sweating at 200 g / (m^2 h) heat losses. The expected wet heat loss is calculated by adding the heat loss due to evaporation to the dry heat loss. Climatic conditions are 10°C, 80% relative humidity with an air flow of 0.5 m/s. Clothing layers are indicated with codes for underwear + outer layer.

The measured wet heat loss is primarily dependent on the permeability of the outer layer, with IMP giving the lowest wet heat losses and OPEN giving the highest. For a given outer layer, the total wet heat loss tends to be lowest for CO and highest for PP underwear.

Figure 2 also shows the expected wet heat loss, which is calculated by adding the heat loss due to evaporation to the dry heat loss. Here the evaporation rate was estimated by subtracting the total water condensed (equal to the increase in weight of the individual clothing layers plus dripping) from the total water sweated. As can be seen, the measured wet heat loss is greater than expected for all clothing except for combinations with OPEN. This is most evident for combinations with IMP, where the difference in wet to dry heat loss is 2 to 3 times greater than the estimated heat loss due to evaporation. This discrepancy is mainly due to condensation occurring at the outer layer as discussed below.

Discussion

Dry heat transfer (due to conduction, radiation and convection) and evaporative heat transfer through clothing are often treated as taking place independently. This assumption has been taken when calculating the expected (total) wet heat losses here.

Although absorption of water vapour raises the temperature of clothing locally and affects heat loss temporarily, it does not affect heat loss when steady state is reached (5).

Moisture within a clothing layer increases its conductivity (e.g. from 0.08 to 0.37 W/mK for CO when fully saturated) and reduces its intrinsic thermal resistance. However, as the clothing layers studied here were thin (only ~1mm thick) and were not saturated, the intrinsic thermal resistances of the fabrics are small compared to those of the air layers present (5), so additional conduction due to moisture will not greatly affect the total heat loss.

Condensation occurs within clothing at locations where the saturated vapour pressure is reached. Under cold conditions condensation causes the inner surface of an impermeable outer clothing layer to heat up by several degrees (4, 5). Such increases of inner surface temperature were observed for the overalls measured here (up to 4.5°C for IMP and up to 3.3°C for SEMI). For IMP and SEMI, assuming that all heat generated by condensation in the outer layer was lost to the environment, on average 73% of the unexpected heat loss could be accounted for. Thus it is reasonable to assume that the unexpected heat loss is predominately due to condensation occurring in the outer layer for IMP and SEMI.

Comparing figures 1 and 2, the moisture collected within the overall correlates ($R^2 = 0.878$) with the difference between the wet heat loss expected and measured. This also indicates that the unexpected heat loss is mainly due to condensation at the inner surface of the overall.

Further work is in progress to study the effect of moisture on heat loss for pre-wetted underwear and pre-wetted outer layers. Additionally results obtained from different laboratories and manikins shall be compared. As well as manikin measurements, a series of human subject trials shall be carried out on a subset of these PPC systems.

Conclusions

Generally the presence of moisture within clothing reduces its total effective thermal insulation and causes an increase in the heat loss from the wearer under cold conditions. The majority of this increased heat loss is due to evaporation for semi-permeable and permeable clothing. However not all of this increase can be accounted for by evaporation.

Additional heat loss is caused mainly by condensation heating up the outer clothing layer. This additional unexpected heat loss is dependent on the water vapour permeability of the outer layer, being highest for clothing with an impermeable outer layer. Accumulation of moisture within the clothing is dependent on both the water vapour permeability of the outer layer and the absorptive properties of the underwear.

Reduction of the effective thermal insulation due to moisture will affect heat and cold stress particularly for impermeable clothing and this should be considered in future standards.

Acknowledgements

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THE EFFECTS OF PROTECTIVE CLOTHING ON METABOLIC RATE

Lucy Dorman, George Havenith and THERMPROTECT network*

Human Thermal Environments Laboratory, Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU, UK.
* corresponding author l.e.dorman@lboro.ac.uk

Introduction

There are many industrial sectors where workers are required to wear personal protective clothing and equipment (PPC/PPE). Although this PPC may provide protection from the primary hazard, for example heat or chemicals, it can also create ergonomic problems. The growing concern regarding health and safety of workers has generated regulations and standards, as well as research and development in the area of PPC/PPE (1). Although these have helped to improve the quality of the PPC and increase the safety of the workers, information on the effect of the clothing on the wearer and the interactions between PPC, wearer and environment are limited. Most PPC is designed for optimal protection against the hazard present, however the protection in itself can be a hazard.

There are important side effects to protective clothing and typically with increasing protection requirements, the ergonomic problems increase. The problems of protective clothing can be split into thermal and metabolic issues. By creating a barrier between the wearer and the environment, clothing interferes with the process of thermoregulation, particularly reducing dry heat loss and sweat evaporation. Protective clothing also increases the metabolic cost of performing a task by adding weight and by otherwise restricting movement. The binding or hobbling effect of bulky, stiff or multilayered clothing adds measurably to work (2) .

Current heat and cold stress standards consider the balance of heat production and loss but focus on environmental conditions, clothing insulation and work rate metabolism. They also assume workers are wearing light, vapour permeable clothing. By failing to consider the metabolic effects of actual protective clothing, the standards can underestimate heat stress or overestimate cold stress; therefore current standards cannot be accurately applied to workers wearing PPC.

The effects of protective clothing on workers has been studied across a number of industries but studies have emphasized the thermal effects of clothing, such as heart rate, core temperature responses to different garments and performance decrements in the heat. Very few studies have considered the metabolic effects. Multilayered clothing ensembles have been reported to increase oxygen uptake by an amount significantly in excess of that which can be accounted for by the increases in the clothed weight of the subjects. Teitlebaum and Goldman (1972) walked subjects on a treadmill either wearing an additional 5 layers of arctic clothing over their standard fatigues or carrying the 11.19kg weight of the five layers as a lead-filled belt. In conclusion, the authors suggest the significant increase on average of approximately 16% in the metabolic cost of working in the clothing compared to the belt can most probably be attributed to ‘friction drag’ between the layers and/or a ‘hobbling effect’ of the clothing (3). Duggan (1988) investigated the effect using a bench stepping task in military chemical protective clothing, with long underwear and quilted thermal jackets/trousers as extra layers. When corrected for clothing weight, VO_2 was greater by an average of 9% (4).

In order to obtain data on a wider range of PPC and further investigate this possible ‘hobbling effect’ an experiment was performed on an extensive set of protective clothing ensembles with a focus on the metabolic effects.

Methods

14 protective garments were tested from a range of industries; firefighter’s suits, general workwear suits, chemical protective suits, cold store suits as well as garments for chainsaw and welding protection. A number of military garments were also tested including a nuclear, biological, chemical protective ensemble, body armour and a waterproof jacket. All protective garments were worn with army boots and cotton work trousers and t-shirt or sweatshirt underneath, apart from the army clothing which was worn with the appropriate base layers or combat fatigues. For the control condition trainers were worn, with cotton tracksuit trousers and a t-shirt which were provided.

Metabolic rate was measured with a MetaMax 3B (Cortex, Germany) portable breath-by-breath analyser, which was calibrated before each session for pressure, gas and volume. A laptop running the Metasoft software allowed for real-time monitoring of participants, included heart rate for which a compatible sensor belt (Polar Electro, Finland) was worn.

After dressing and instrumentation, data collection was started. Participants rested for 3 minutes and then completed 4 minutes of walking on a treadmill (Tunturi T-track Gamma 300, Finland) at 5km/hr and 4 minutes of stepping at a rate of 25 steps/min on a 20cm step (Reebok aerobic step) separated by a 3 minute rest period. Participants presented at the laboratory for 7 sessions on different days, in each session they completed the test in 2 protective garments separated by a control condition. The session time was limited to reduce any thermal effects from the clothing or the exercise. The protective garments were paired (A,B) and then the order of the pairs randomised in a Latin square, within the pairs participants 1–3 completed garment A first then a control then garment B, while participants 4–6 completed garment B first then a control then garment A.

The data was exported into Microsoft Excel files for analysis, and the percentage increase in metabolic rate when wearing the protective garments from the control condition was calculated. In order to establish if walking and stepping in the protective garments significantly increased the metabolic rate above a control condition, single sample t-tests with a test value of 100 (control equals 100%) were carried out for each garment.

Results and Discussion

6 participants (3 males, 3 females, age 23±0.25years, height 176±6.5cm, weight 71±8.5kg) completed the test in 14 protective garments. The average environmental conditions for the room were 18.7°C ± 1.1 °C and 40.1% ± 4% relative humidity.

The percentage increases in metabolic rate have been plotted for the 14 protective garments and the results for walking and stepping are presented in Figures 1 and 2 respectively. Figure 1 shows that the garment with the highest percentage increase when walking was a ‘Grey Fire’ suit which caused a 21% increase in metabolic rate, the lowest increase was 4% for a Mountain Rescue uniform. Increases in the metabolic rate of 12% or above proved to be significant ($p<0.05$) although it is difficult to give a specific threshold as there is a gap from the ‘Army+ waterproof’ (jacket only) at 12% to the next lowest, ‘Army+vest’ (body armour) which caused a 9% increase.

For the stepping task, illustrated in Figure 2 values ranged from a 20% increase in a Workwear (2 layer) suit to just 3% for a Mountain Rescue uniform, with values recorded as significant ($p<0.05$) with an 8% increase or above.

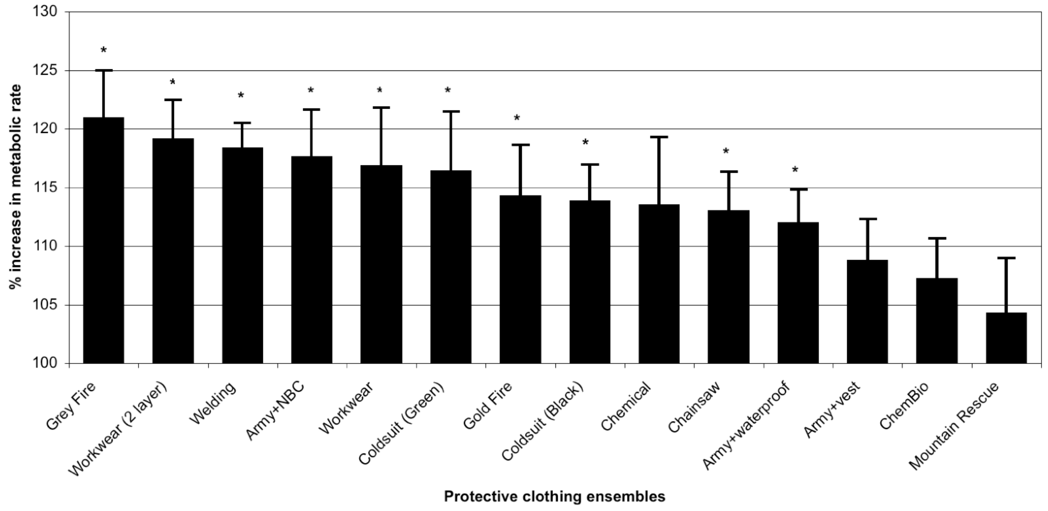

Figure 1. Average (n=6) percentage increase (100%=control value) in metabolic rate when wearing protective clothing during treadmill walking at 5km/hr. Significance of $p<0.05$ indicated by *.

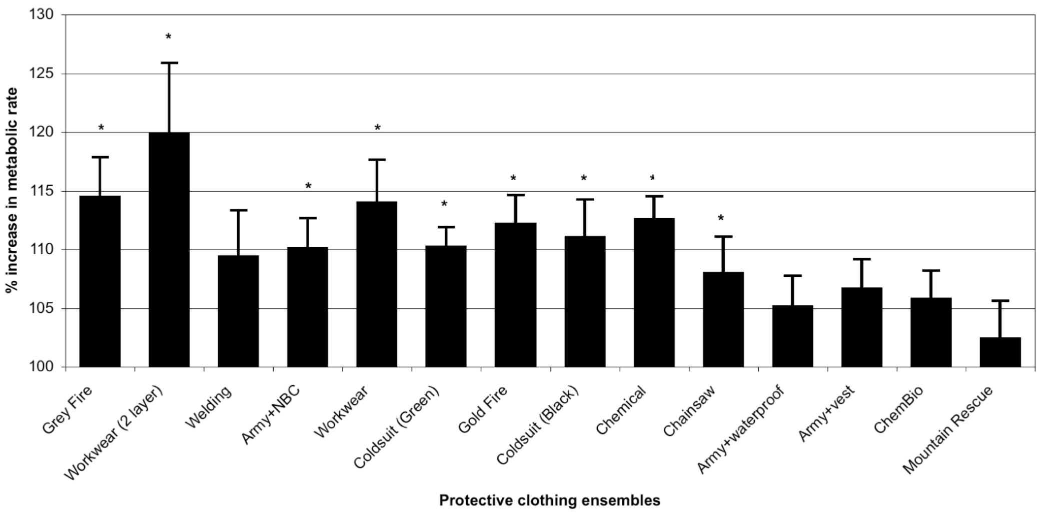

Figure 2. Average (n=6) percentage increase (100%=control value) in metabolic rate when wearing protective clothing during stepping (25 steps/min, 20cm step). Significance of $p<0.05$ indicated by *.

The two fire suits (Grey and Gold) worn in this study had significant ($p<0.05$) effects on the metabolic rate of the wearer and they were the two heaviest garments to be tested. Walking in the Grey suit (7.00kg) elicited a 21% increase, 14% in the Gold suit (6.66kg), whilst stepping increased the metabolic rate by 15% in the Grey suit and 12% in the Gold suit. These figures are similar to those reported by Graveling and Hanson (2000) from laboratory trials where standard firefighter clothing typically increased physiological cost (oxygen consumption) by 15% over control sessions (5).

The 'Army+NBC' and 'Army+vest' garments also showed interesting results. The 'Army+NBC' ensemble was made up of a norwegian shirt, combat trousers and army boots with NBC jacket and trousers over the top plus overboots and gloves, total weight 5.27kg. The 'Army+vest' ensemble was made up of base layer (top and bottoms), combat trousers, norwegian shirt and army boots and weighed 5.32kg. Even with very similar clothing weights the percentage increase values for the 'Army+vest' ensemble were only 9% when walking and 7% when stepping compared to the significant ($p<0.05$) increases of 18% when walking and 10% when stepping in the 'Army+NBC' ensemble. Despite the large body of knowledge on the performance effects of chemical protective clothing, little quantitative information exists about the energy cost. Patton *et al.* (1995) completed a laboratory study wearing standard BDU (battledress uniform) or CP clothing (chemical protective clothing with a mask, overgarment, gloves and boots) in very similar conditions, 18-22°C and 40-55% relative humidity. VO_2 corrected for differences in clothed weight was 6-11% greater in CP clothing across a range of exercise intensities again suggesting that factors other than clothing weight were responsible for the increase (6).

The significant values recorded in this study also fit in with the results of two studies highlighted in the introduction that found a 16% increase in metabolic cost during walking (3) and 9% increase in VO_2 during stepping (4).

Conclusions

It has been shown that protective clothing ensembles worn in a variety of industries increase the metabolic cost when walking and stepping. Increases of 8% and above compared to a control condition were significant ($p<0.05$). The increases cannot solely be explained by the added clothing weight. Analysis of the clothing properties such as bulk and stiffness could be carried out and further work is needed to fully understand the significance of the 'hobbling effect'.

Acknowledgements

This work was funded as European Union GROWTH programme project "THERMPROTECT, Assessment of Thermal Properties of Protective Clothing and Their Use", contract G6RD-CT-2002-00846, with participation by P. Broede (D), V. Candas, (F), E. den Hartog (NL), G. Havenith (UK), I. Holmér (S), H. Meinander (FIN), M. Richards (CH).

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AN OVERVIEW OF THE RECENT DEVELOPMENTS IN MATERIALS FOR PROTECTIVE CLOTHING

Roshan Shishoo

Shishoo Consulting AB, Askim, Sweden
roshan.shishoo@shishooconsulting.se

INTRODUCTION

Millions of people world-wide have working environment which exposes them to specific risks from which their bodies need protection. In many industrial sectors, military and energy services, hospital environments, human beings are subjected to various types of risks and each sector has its own requirements for protective clothing.

The performance requirement of all types of protective clothing often demand the balance of widely different properties of drape, thermal resistance, liquid barrier, water vapour permeability, anti-static, stretch etc. The seemingly contradictory requirement of creating a barrier e.g., towards heat, cold, chemicals, bacteria, and breathability in high functional clothing has placed challenging demands on new technologies for producing fibres, fabrics and clothing design. Among the contributing factors responsible for successful marketing of such products have been advances in polymer technology and production techniques for obtaining sophisticated structures of fibres, yarns and fabrics.

Improved fibre spinning techniques in melt spinning, wet spinning, dry spinning and new techniques such as gel spinning, bicomponent spinning, microfibre spinning, have made it possible to produce fibres with characteristics more suitable for use in protective clothing. [1]

INNOVATIONS IN FIBRES

The evolution of fibre developments have gone through the phases of conventional fibres, high-functional fibres and high-performance fibres. Today a wide range of high performance fibres is commercially available for technical and industrial applications. Among the speciality fibres already established can be mentioned the following types.

- Aramid fibres
  - p-aramid fibre to provide high strength and ballistics.
  - m-aramid fibre to provide flame and heat resistance.
- Ultra-high tenacity polyethylene fibres (UHMWPE)
  Gel spun, ultra-high molecular weight polyethylene fibres with extremely high specific strength and modulus, high chemical resistance and high abrasion resistance.
- Polyphenylene sulphide fibres (PPS)
  Crystalline thermoplastic fibre with mechanical properties similar to regular polyester fibre. Excellent heat and chemical resistance.
- Polyetheretherketone fibres (PEEK)
  Crystalline thermoplastic fibre with high resistance to heat and to a wide range of chemical.
- Novoloid (Cured phenol-aldehyde) fibres
  High flame resistance, non melting with high resistance to acid, solvents, steam, chemical and fuels. Good moisture regain and soft hand.
- Polybenzimidazole fibres (PBI)
  Moisture regain 15%, high resistance to chemicals especially at elevated temperatures.

Melamine-based Fibres

Basofil (BASF), a high temperature and fire resistance fibre, is a melamine-based staple fibre which has a LOI of 31-33 with no melt dripping and a continuous service temperature of about 200ºC.

PBO Fibres

PBO fibre, p-phenylene-2, 6-benzobisoxazole, has strength and modulus far exceeding than any of the known fibres. PBO fibre has the decomposition temperature of 650ºC, tenacity 5-8 Gpa and modulus of 180-250 Gpa. (1,2)

Novel Yarn Spinning Technology

Novel yarn spinning technologies are commercially available today for producing hybrid yarns for various applications including protective clothing.

One can thus combine the functions of two different fibre qualities to produce fabric of varied functions. For example the core can be made of p-aramid, the sheath of m-aramid, cotton or polyester. Sensitive core-materials can be protected by the sheath fibres.

HIGH FUNCTIONAL AND HIGH PERFORMANCE FABRICS

Multifunctional textile structures

Some of the most interesting developments lie in the production of multi-layer knitted and woven constructions. A multi-knit fabric of 2 or 3 layered structure using 100% polyester and polypropylene yarn has characteristics of quick water absorption, ability to evaporate water and a dry touch, being capable of transporting perspiration from the skin to the outer surface and then quickly dispersing it.

Breathable coated multifunctional fabrics

Following the earlier developments of microporous coated and laminated fabrics, some very interesting commercial developments have taken place as regards multifunctional coated or laminated fabrics for different applications.

GORE-TEX anti-static is a functional textile for protective clothing which combines several functions: permanent full-surface antistatic protection, weather protection, heat and flame protection. Additionally this garment provides the wearer with excellent wear comfort.

This innovative, durable, anti-static protection is based on nano-technology, a field which has not been applied in functional textiles before.

GORE-TEX Airlock is a functional textile which was developed by Gore for the special needs of fire fighters. This is the first time that a single product combines an effective heat shield with a moisture barrier and high physiological comfort due to its inherent breathability. The concept of this product is to eliminate the conventional, bulky, thermal insulation layer and substitute it by a protective air cushion. Dots consisting of foamed silicone are discontinuously applied to a fibre substrate and anchored within the microporous GORE-TEX membrane. They measure only a few millimetres in height, creating a defined air cushion between the adjacent flame-retardant face fabric and the inner lining. Fire fighting clothing made from this material is considerably more comfortable to wear than conventional constructions due to significantly improved breathability, perspiration transport, absorption and quick dry properties. (3)

MARMOT – MEMBRAIN is a waterproof and breathable polyurethane coating. Laminated with a textile fabric, this material is self-regulating in that it responds to changes in the body’s temperature and adapts to the wearer’s activity level. As the body’s temperature rises, there occurs a molecular chain rearrangement in the coating layer resulting in the laminated fabric becomes more porous and therefore more breathable. This allows more moisture vapour to pass through the fabric. As the body cools, the pores in the membrane close, thereby trapping heat.

NONWOVEN PROTECTIVE CLOTHING

Protective coveralls, suits, gowns, lab coats and accessories are used in industry and institutions to protect workers from exposure to hazardous materials and to protect sensitive products from human contamination. Nonwoven are used for limited use protective clothing and as components in reusable clothing. Spunbonded olefins are the leading materials used and are often used in composites with barrier films.

Tyvek 1431N, nonwoven structure made of 100% HDPE offers excellent particle hold and properties down to particle size of 3 microns. For protection from particles smaller than 3 microns, DuPont recommends the coated fabric Tyvek C and laminated fabric Tyvek F.

For dust protection, spunbonded nonwoven fabrics using multidenier fibre assemblies are a new group of innovative products.

INTERACTIVE TEXTILE MATERIALS FOR PROTECTIVE CLOTHING

Shape Memory Polymers

The shape memory effect is observed in metal alloys and polymers and results in an object reverting to a previously held shape when heated. Early shape memory polymers were blends of glassy thermoplastics and elastomeric materials.(4,5)

In effect, the shape memory polyurethanes are thermoplastic elastomers that can have glass transition temperatures within an unusually interesting range. For instance, this includes ambient temperatures (about 25ºC), the temperature of the human body (37ºC) and the temperature of boiling water (100ºC).

The prototype design is a laminated film consisting of:

a film of shape memory polymer having a glass transition temperature of 25ºC;

a layer of a compatible elastomeric, a thermoplastic polyurethane having a much lower glass transition point..

The films can be made on an extrusion/ calendering line and the laminates can be compression moulded in conventional equipment. To promote the circulation of air and moisture vapour within the interstitial space, as well as reducing the weight of the film, holes and cut-outs can be made in the laminate.

On cooling below 25ºC, the shape memory layer should shrink linearly by some 3% and become rigid while the conventional elastomer remains largely unaltered. As a result, an out-of-plane deformation of the laminate is expected to occur.

It is anticipated that deformed films of these laminates will provide a reversible response to cold conditions.

Phase Change Materials (PCM)

For the past 20 years, investigators at Triangle Research and Development Corporation at Research Triangle Park , North Carolina, USA have pioneered the research, development and application of micro-encapsuled phase change materials. This programme was undertaken for among others NASA, US Air Force and US Navy.

The PCM, are encapsulated in small spheres in order that they are contained when in a liquid state. The microcapsules possess approximate diameter of 1-10 μm and are resistant to abrasion, pressure, heat and chemicals. At present this-technology is only applicable to acrylic fibres using the wet-spinning process.

For coating applications, the PCM microcapsules are dispersed in e.g. a polyurethane coating which is then applied to a fabric.

For foam applications, the PCM microcapsules are dispersed in a polyurethane foam matrix. These foams are often laminated to a fabric.

Textile structures with PCM microcapsules for protective clothing have following interactive functions:

absorption of surplus body heat;

an insulation effect – caused by heat emission of the PCM into the textile structure;

a thermo-regulating effect – which keeps the microclimate temperature nearly constant.

Protective textiles with microencapsulated Phase Change Material are now commercially available, e.g. Outlast Technologies. The PCMs used in this technology consists of carbohydrates with different chain lengths, whose phase change take place in a temperature range close to that of the human skin. (6,7)

Exothermic Functions in Clothing

For many years, Japan has been an innovation gateway in the man-made fibre high-tech and high performance textile sectors.

The technique of producing sheath/core melt spun conjugate fibres has been commercially exploited for producing added value fibres. Unitika produced the first heat-regenerating conjugate fibre with a core containing zirconium carbide (ZrC). Since ZrC absorbs sunlight (visible and near-infrared radiation) and emits far-infrared radiation, one feels warmer when one puts on a jacket made from such fibres. Other types of heat generating fibres contain ceramic micro-particles.

Reactive Materials for Flame and Heat Protection

These types of materials are designed to provide minimal insulation during normal wear, but maximum insulation when the heat threat impinges (8,9).

Among the novel treatments can be mentioned:

Intumescent treatments - these would normally be in the form of thin, low insulation coatings on a lining fabric. Some of the established intumescents are based on ammonium polyphosphate, melamine phospahates and pentaerythritol derivatives. When activated by excessive heat or flames the formulation swells instantly to form an inert insulative char, protecting the wearer.

Shaped Memory Alloys - are metals which can assume different shapes when the temperature is changed. One wishes to establish a large air gap during the threat phase. This can be achieved by using a coil spring between two fabrics layers which adopts a flat conformation during normal operations, but which rapidly forms an extended helical shape when the heat threat arrives.

BIOMIMETICS AND TEXTILES

The structure and functions of natural biological materials are precise and well defined. The imitation of living systems, "biomimetics" could make it possible in future to replicate the molecular design and morphology of natural biological materials once their structure and functions are related. Already in many laboratories around the world, R&D work is going on in the field of biomimetic chemistry and fibre formation. A typical example is the development of water and soil repellent fabrics produced by imitating the surface structure of a lotus leaf.

NANOTECHNOLOGY AND PROTECTIVE TEXTILES

In textiles, practical uses are being found for nanotechnology in order to offer greatly enhanced or novel properties in fibres and in yarns and fabrics made from them. The first developments on the use of nanotechnology in textiles have been made by Nano-Tex, a subsidiary of US- based Burlington Industries and Swiss-based textile company Schoeller The fabrics made using these technologies are waterproof, soil-resistant and comfortable.(10)]

In May 2003 the US Army Research Office and the Massachusetts Institute of technology (MIT) opened the Institute for Soldier Nanotechnologies (ISN). ISN’s goal is to give US military personnel an edge on the battlefield by combining basic and applied research in nanoscience and nanotechnology.(11) ISN’s vision is to explore “smart” functionality with a view to create a multi-functional battle uniform that can monitor health, ease injuries, and communicate automatically. Examples of “ smart” functionality that may be explored at the institute include materials and systems that:

- provide chemical and biological protection;
- provide protection against ballistic and shrapnel impact;
- automatically administer medicines and transmit a soldiers vital signs to medics, such as heart rate and respiration;
- weave radio communication materials directly into the fabric of a soldier’s uniform;
- incorporate built-in sensors, enabling a soldiers physical condition and position in the battlefield to be monitored from command post; and
- change the colour of uniforms on command in order to camouflage soldiers.
-

The knowledge developed within the research activities of ISN would eventually be used for other types of clothing such as fire-fighters uniforms, protective clothing for severe environments and highly functional garments.

Direct Nanofiber Coatings on Protective Fabrics

Electrospinning is a fiber spinning technique that produces extremely fine fibers of submicron diameters. Electrospinning occurs when a polymer solution or melt is electrically charged. Voltages of 5kV to 30 kV are sufficient to overcome surface tension forces of the polymer, and a free surface of charged particles will produce fine jets of liquid that are rapidly drawn towards a grounded target. The fiber is collected as an interconnected web of small filaments on the surface of a grounded target. Development work is going on , among other places, at the U.S. Army Natick Soldier Center , in the field of using electrospun nanaofiber coatings for the enhancement of aerosol protection of protective fabrics.(12)

Other application areas for nanofiber technology are protection against dust, bacteria virus ; ballistic products, fiber- reinforced composites, membranes for coating and laminating, and medical textiles.

Silver Coated Protective Fabrics

The applications of silver coated fabrics for protective clothing including anti-static garments for military, medical, electronic, police, fire fighters where there are risks for electrostatics or discharges; uniforms for soldiers against microwave detection; and in smart clothing incorporating alarms and sensors for soldiers and civil persons.

SMART TEXTILES AND WEARABLE TECHNOLOGY

Smart textiles are defined as textiles that can sense and react to environmental conditions or external stimuli, from mechanical, thermal chemical, electrical, magnetic or other sources. Very smart textiles can sense, react and adapt themselves to environmental conditions or stimuli. Three components may be present in smart textiles- sensors ,actuators and controlling units.(13)

The optic fibres sensors can be used to sense various battle field hazards in real-time, such as chemical and biological warfare threats, above normal field temperatures, and other toxic substances.For example, polyurethane-diacetylene copolymer can be used as thermochromic material for temperature sensor application. Polyaniline can be used as the photo-chemical polymer for chemical sensor application. The smart uniforms could have significant applications for protective clothing for fire-fighters, hazardous material workers and other personnel exposed to toxic agents in the workplace. Smart shirts or vests have been developed embedded with sensors for electrocardiogram (ECG), heart rate, respiration, voice etc. All information is collected by sensors from various parts of the body, then routed to a device attached to the waist portion. The biometric information is wirelessly transmitted to a PC and the Internet.

In addition to the two dimensions of functionality and aesthetics, if “intelligent” can be embedded or integrated into clothing as a third dimension, it would lead to the realisation of protective and safety clothing as a personalized wearable information infrastructure.(14)

CONCLUDING REMARKS

Safety & protection, performance materials and electronics & information technologies are named by many leaders of the textile industry as being the top sectors for the sustainable growth in the 21st century.

The driving technology force in material development for safety and protective clothing has been spear-headed by advances in fibres, polymers, chemical technology and fabric/web forming technologies. The technological trends and challenges ahead will be determined by market pull demands, increasing environmental awareness, personal safety and comfort, and performance requirements. The advances in materials and technologies including nanotechnology should lead to products with sought-after characteristics e.g., laminates able to meet multiple functional requirement, coating which can be tailored for specific end-uses, fibres and fibre-blends for demanding applications and sophisticated fibrous structures., and smart textiles and clothing.These technological developments provide vast opportunities for developing products which demonstrate a good balance between the protective and barrier advantages on one hand and the user functionality in terms of physiological and mechanical comfort, ease of movement, fit, drape etc.

For many applications the technical challenges still remain but the availability of new knowledge should make it highly possible to meet these challenges.

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STUDY ON BINDING SENSATION FROM CLOTHING

*Wenbin Zhang, Jun Li**

Fashion Institute, Donghua University, Shanghai 200051, People's Republic of China
*corresponding author lijun@dhu.edu.cn

Introduction

Clothing ergonomics is an important factor in apparel design [1, 3]. Binding sensations from clothing pressure is one complaint given by consumers. Analyzing the factors that effect binding sensation will supply information to optimize the parameters in apparel pattern making [2], and provide an understanding of how to design and develop more comfortable clothing.

In this study we analyzed the factors effecting the binding sensation of trousers. Physiological indices such as energy metabolism rate, psychological sensation of binding feeling created by the trousers, as well as physical features of the trousers including fabric properties, clothing pressure, and clothing tolerance were measured and evaluated with subjects wearing the test trousers at rest and exercise. By comparative analysis of the test results, the affecting factors of these three aspects are described.

Methods

In this study, two types of trousers were made, one with thick fabric and one with thin fabric. These are indicated as 'thin' and 'thick' with three kinds of tolerances for the subjects. The subjects were healthy, 40 year old men. They had an average height of 170 cm, average breast girth of 92 cm, average waist girth of 85 cm, average hip girth of 97 cm, and average body mass of 70 kg. In wear trials each garment had two moist conditions including dry and water holding rate 55%. In the climatic chamber with temperature 25°C, humidity 55%, and air velocity lower than 0.1 m/s, subjects were monitored wearing test trousers first at rest (sitting and standing), then at exercise. When resting in both standing and sitting postures the subject's clothing pressure at the front abdomen, side abdomen, front knee, side knee, back waist, and hip was measured by the AM-7102 clothing pressure measuring apparatus. In resting and exercising status the consumed oxygen content was measured by the METS900-SA respiration metabolism measuring apparatus. Subjects were asked to evaluate their binding sensation at the waist, hip, and thigh, as well as their total binding sensation on the following scale: 0 = very comfortable, 1 = comfortable, 2 = no special, 3 = tight, 4 = very tight. These evaluations occurred at rest, both sitting and standing, and two minutes after starting exercise.

Results and Discussion

The results in Table 1, 2, and 3 were reported as an average of three independent replications.

Table 1. Pressure at specific body locations from trousers in dry status.

Fabric type	Posture	Tolerance (%)	Pressure at the body locations (10^3Pa)					
			Front abdomen	Front knee	Side abdomen	Side knee	Back waist	Hip
Thin type	Standing	0	0.36	0.15	0.31	0.10	0.22	0.47
	Sitting	0	1.12	2.65	2.10	1.03	1.00	3.40
	Standing	10	0.07	0.12	0.07	0.05	0.13	0.11
	Sitting	10	0.34	2.08	2.07	0.76	0.38	2.49
	Standing	20	0.01	0.05	0.06	0.03	0.12	0.04
	Sitting	20	0.02	1.00	0.16	0.44	0.34	1.10
Thick type	Standing	0	0.35	0.79	1.38	0.05	0.72	0.90
	Sitting	0	1.88	4.31	3.03	1.38	0.64	3.71
	Standing	10	0.25	0.35	0.15	0.02	0.60	0.18
	Sitting	10	0.51	3.54	2.07	0.67	1.50	2.87
	Standing	20	0.23	0.20	0.06	0.02	0.51	0.05
	Sitting	20	0.46	2.66	1.01	0.13	1.01	1.48

Clothing pressure

Table 1 presents the results of pressure from trousers at specified body locations in dry status.

The pressure from the trousers relates to the curvature radius of the body joints, such as the knees. The perpendicular pressure from the trousers has inverse proportion with the curvature radius of knee joints. The side knee with a large curvature radius has a smaller perpendicular pressure than the front knee with a small radius. Pressure from the trousers relates to subjects posture. For both thin and thick trousers, the pressure when sitting is much higher than in standing posture. Each body sections' pressure increases as the fabric thickness increasing.

The relationship between energy metabolism rate and clothing pressure

In the climatic chamber the subject's respiration was monitored and analyzed by the METS900-SA respiration metabolism measuring apparatus, and the consumed oxygen content was recorded. The energy metabolism rate RMR is calculated as

$$RMR = (VO_2(\text{in exercising}) - VO_2(\text{in resting}))/VO_2(\text{basal metabolism}). \quad (1)$$

The results of VO_2 and RMR are shown in Table 2. After calculation it is known that the correlation coefficient between the energy metabolism rate RMR and the clothing pressure in standing posture is 0.6367 and the correlation coefficient between RMR and the clothing pressure in sitting posture is 7393.

Table 2. Results of VO_2 and RMR in each testing conditions.

Fabric description	Thin, dry			Thin, wet		
Tolerance (%)	0	10	20	0	10	20
VO_2(resting) (l)	5.23	4.90	4.25	4.27	4.50	4.26
VO_2(exercising) (l)	10.08	10.20	9.36	9.41	9.46	9.08
RMR	2.43	2.37	2.28	2.29	2.21	2.15

Fabric description	Thick, dry			Thick, wet		
Tolerance (%)	0	10	20	0	10	20
VO_2(resting) (l)	4.12	2.90	3.90	3.89	4.19	3.60
VO_2(exercising) (l)	10.03	8.63	9.13	10.20	10.92	9.55
RMR	2.64	2.56	2.33	2.82	2.74	2.66

Binding sensation's correlated factors

The results of the binding sensations evaluated in each testing conditions are listed in Table 3.

Table 3. Results of the binding sensations evaluated in each testing conditions.

Fabric description	Tolerance (%)	Evaluating point	Sensation at the body locations				
			Total	Side waist	Hip	Thigh	Calf
Thin, dry	0	Rest in standing	1	2	2	0	0
		Rest in sitting	1	2	3	1	0
		2 min since exercising	2	2	4	3	1
	10	Rest in standing	0	1	1	0	0
		Rest in sitting	0	1	1	0	0
		2 min since exercising	1	2	2	2	1
	20	Rest in standing	0	1	0	0	0
		Rest in sitting	0	2	1	0	0
		2 min since exercising	1	2	2	3	3

Table 3 continued.

Thin, wet	0	Rest in standing	3	3	3	2	1
		Rest in sitting	3	4	4	3	2
		2 min since exercising	3	3	4	3	3
	10	Rest in standing	1	1	1	1	1
		Rest in sitting	1	1	2	2	1
		2 min since exercising	2	2	2	2	1
	20	Rest in standing	1	1	1	1	1
		Rest in sitting	2	1	2	2	1
		2 min since exercising	2	2	2	3	1
Thick, dry	0	Rest in standing	2	2	3	3	2
		Rest in sitting	2	3	4	3	2
		2 min since exercising	3	3	4	4	2
	10	Rest in standing	0	1	1	1	1
		Rest in sitting	0	1	1	1	1
		2 min since exercising	2	2	2	2	3
	20	Rest in standing	-1	0	0	0	0
		Rest in sitting	0	1	1	1	0
		2 min since exercising	1	2	1	1	2
Thick, wet	0	Rest in standing	3	3	4	2	1
		Rest in sitting	3	4	4	3	3
		2 min since exercising	3	4	4	4	3
	10	Rest in standing	2	2	2	2	1
		Rest in sitting	3	2	3	3	2
		2 min since exercising	3	2	3	3	2
	20	Rest in standing	1	1	1	1	1
		Rest in sitting	1	2	2	2	1
		2 min since exercising	1	2	2	2	2

By statistical data analysis the correlated factors to the binding sensation are concluded as clothing pressure, tolerance, fabric thickness and dry/wet state [2].

The regression equation between the binding sensation and the clothing pressure is

$$F_A=-0.3504-0.1617P_1+0.5082P_2-0.0802P_3+1.2632P_4-0.1008P_5+0.0486P_6; \quad (2)$$

$$F_B=0.4616+0.0931P_1-0.0569P_2+0.0017P_3+0.1127P_4+0.0920P_5-0.0098P_6. \quad (3)$$

Where F_A is the binding sensation in standing posture, F_B is the binding sensation in sitting posture,P_1,P_2,P_3,P_4,P_5,P_6 is the clothing pressure at the front abdomen, the front knee, the side abdomen, the side knee, the back waist, and the hip, respectively.

The regression equation between the binding sensation and the clothing pressure, tolerance, fabric thickness, dry/wet state is

$$F_A=0.3552+0.2786P_A-0.0225R-0.1776H+0.6447C; \quad (4)$$

$$F_B=-0.7898+0.1128P_B+0.0065R-0.1781H+0.6765C. \quad (5)$$

Where P_A is the clothing pressure in standing posture, P_B the clothing pressure in sitting posture, R is the clothing tolerance, H is fabric Thickness, and C is the fabric state (in dry state C=0,in wet state C=1).

The regression equation between the energy metabolism rate RMR and the clothing pressure, tolerance, fabric thickness, dry/wet state is

$$RMR=1.5155-0.0634P_A+0.0534P_B+0.0160R+0.0995H-0.1856C. \quad (6)$$

Conclusions

In the research the relationship among physiological index, physical features, and psychological sensation were focused on, and the research results show apparel design, especially pattern making, closely relates to ergonomics. The binding sensation is mainly due to the clothing pressure caused by some pattern making parameters, such as tolerance. We found that the affecting factors on the binding sensation are concluded as clothing pressure, tolerance, fabric thickness and dry/wet state. The quantitative relationship between binding sensation and clothing pressure, tolerance, fabric thickness, and dry/wet state; and the quantitative relationship between energy metabolism rate *RMR* and the clothing pressure, tolerance, fabric thickness, dry/wet state are described as the regression equations.

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TESTING AND DEVELOPMENT OF A NEW MC-UNIFORM FOR THE NORWEGIAN POLICE SERVICE

H. Færevik, R.E. Reinertsen

SINTEF Health Research, 7465 Trondheim, Norway

Introduction

MC-drivers in the police service are on duty at all seasons, and they are exposed to different climatic conditions. A MC-uniform should be comfortable and functional during a normal work situation and at the same time protect against cold, wetness and physical hazards when driving at high speeds in cold weather. To provide optimum solutions for protective clothing for different environmental conditions the main purpose of this study was to develop a new MC-uniform for the police service. Stage one of this project included a survey of the MC-drivers in the police service in Norway (1). This study demonstrated that the highest prioritized requirements to an MC-uniform are: 1) the need for protection of the driver during an accident, 2) thermal comfort at high and low temperatures and protection against wet environments, 3) functionality and good moving flexibility during all driving situations (1). The next stage in this project was to develop good test methods, establish technical requirements, select, test and evaluate materials and develop new prototypes on the basis of the end-users requirements. This paper presents the some of the results from the testing of the new MC-uniform prototypes, which aimed to give a tool to decide which MC-uniform to select.

We hypothesized that is possible to develop an optimum solution for a MC-uniform during different environmental conditions.

Methods

First, test-methods were developed on the basis of end-users requirements, technical and standard requirements of the police department. Secondly, laboratory and field test of existing clothing concepts were performed. Third, selection of materials and clothing were made and new prototypes were designed. The new prototypes included the whole clothing concept; underwear, bullet proof west, shoes, gloves and the MC suit. The new prototypes were thereafter tested after the same test protocols using human subjects.

Clothing

Totally eight different combinations of clothing ensembles were tested. First, tree outer wear MC suits (the original leather suit and two different Goretex suits; YOKO and Stadler Factor) were tested to find differences between the leather and Goretex material in the MC-suit. On the basis of these tests, one of the Goretex suits was selected and tested in combination with tree different underwear concepts. Two different bullet-proof waistcoats were included in these tests. The same helmets and boots were used for all the tests.

Subjects

Six male subjects were selected to participate in the tests. The mean (± SD) age, weight, height of these six subjects is shown in table 1.The Ethical Review Committee of the Faculty of Medicine at the Norwegian University of Science and Technology approved the experimental procedure. The subjects were free to withdraw from the experiment at any time.

Test protocol

The test protocol was designed to compare the thermal properties of the different prototypes during exposure to different climatic conditions: 1) Summer (23°C), 2) Autumn (5°C and rain) 3) Winter (-15°C). In all condition the test subjects was exposed for 5 m $\cdot$sec^{-1} wind. Subjects reported to the preparation room at least one hour before the test and weight and height were registered. The subjects were then fitted with thermistors and heart rate recorder, and humidity sensors were fitted between each clothing layer. Sweat accumulated in the clothing was determined by weighing each individual clothing component before and after the test. To provide baseline measurements of skin and rectal temperature, humidity and subjective evaluations, the subjects sat quietly outside the climatic chamber for 20 minutes. The subjects were then moved to the climatic chamber where they performed the following protocol for 120 minutes: 20 minutes cycling on ergometer cycle (30% VO_{2max}), 20 minutes rest (sitting quietly), 20 minutes tasks (carry boxes, writing, moving markers) (50% VO_{2max}), 20 minutes cycling on ergometer cycle (50% VO_{2max}), 20 minutes rest (sitting quietly), 20 minutes tasks (carry boxes, writing, moving markers), (50% VO_{2max}). After the test each clothing layer and the test subject was weighted again to decide total sweat production and moisture accumulation in each clothing layer. A questionnaire about design, fit and freedom of movement of the clothing was answered after each test.

Table 1. Anthropometric data for the subjects.

Subject	Age (years)	Height (cm)	Weight (kg)
1	36	175	78
2	28	188	101
3	27	180	90
4	27	183	80
5	28	180	82
6	22	181	61
Mean	28	181.2	82
SD	4.5	4.3	13.3

Statistical analysis

Time-dependent changes in rectal temperature, mean skin temperatures, humidity and heart rate were assessed by two-way analysis of variance for repeated measures (ANOVA). Differences in ratings on thermal comfort and thermal sensation sweat production and accumulation was assessed by Student's *t*-test for paired samples. SPSS 10.0 (SPSS inc. Chicago, USA) and Excel 97 were used for processing the data.

Results and discussion

The results demonstrated that subjects was significant warmer when wearing the leather MC suit at summer temperatures (23°C), and also colder at winter temperatures (-15°C) compared to the two Goretex suits. The Stadler Factor Goretex suit gave significantly poorer protection against rain compared to the YOKO-suit. A questionnaire about ergonomic and design factors sent to the MC-drivers, concluded that the YOKO MC-suit fulfilled more requirements than the Stadler Factor MC suit. This influenced the selection of YOKO as the supplier of MC-suit. Tree different combinations of underwear, and two different bullet-proof waistcoats was then tested in combination with the YOKO MC-suit to give recommendations about which underwear and bullet-proof waistcoat to select.

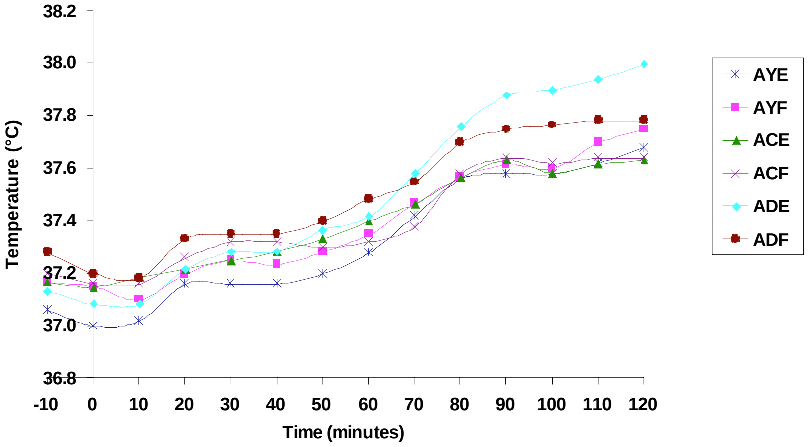

Figure 1. Mean rectal temperature (n=6) when wearing the YOKO MC-suit in combination with tree different underwear concepts underwear concepts and two different bullet-proof waistcoats at the summer protocol (23°C).

In the summer protocol (23°C) one layer of underwear was used, and in the rain (5°C)- and winter (-15°C) protocol two layer of underwear was used. The results demonstrated that the underwear had an effect on the skin and core temperatures, relative humidity between the clothing layers, accumulation of sweat and thermal comfort of the subjects. Figure 1 demonstrates the results from the rectal temperatures measures, where a combination of wool underwear and NFM bullet proof waistcoat (AYE) was the significant warmest concept. The CoolMax underwear (AYE) is the underwear that results in the least increase in core temperature.

The amount of wool in the underwear is of vital importance for how much sweat that accumulates in the underwear (Figure 2). The more wool, the more sweat accumulates in the underwear, and this is demonstrated at all environmental temperatures. However, even though more sweat accumulated in the wool underwear at low temperatures, the subjects did not feel any colder. Polypropylene is recommended at the highest temperatures.

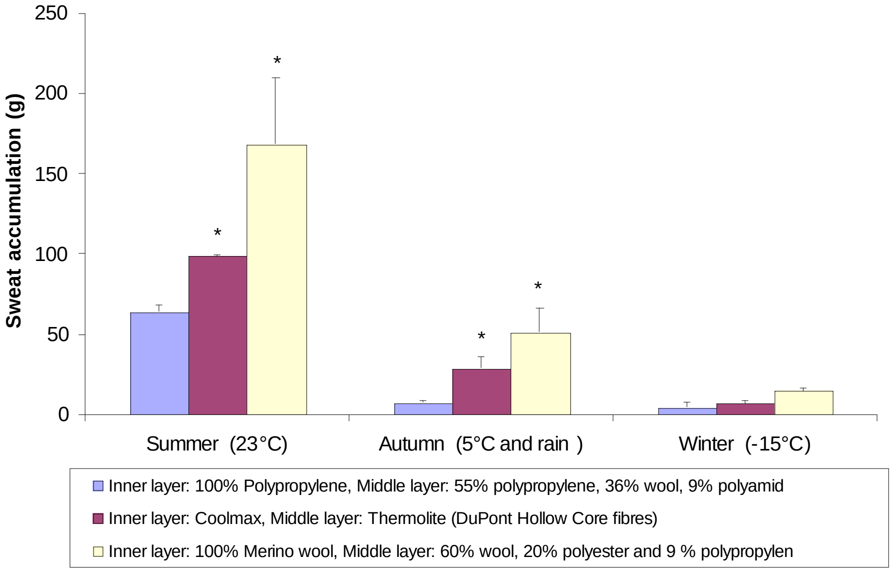

Figure 2. Mean accumulation of sweat in the underwear at the tree different exposures, summer (23°C), autumn (5°C and rain) and winter (-15°C) (n=6). *) demonstrates significantly more sweat accumulation in the underwear as compared to the other underwear concepts (n=6).

Figure 3. The new MC uniform for the Norwegian police service

Conclusions

YOKO was selected as the new MC uniform for the police service after thorough testing. This was the MC uniform that best satisfied the user requirements; 1) protection 2) thermal comfort 3) functionality and good moving flexibility. The study also gave recommendations about which underwear to use at different environmental temperatures; polypropylene at high temperatures and combinations of wool and synthetic fibres at low temperatures.

THERMAL INSULATION OF COLD PROTECTIVE CLOTHING: STATIC AND DYNAMIC MEASUREMENTS WITH A MOVABLE THERMAL MANIKIN

A. Virgílio M. Oliveira[1], Adélio R. Gaspar[2], Divo A. Quintela[2]*

[1] Departamento de Engenharia Mecânica, Instituto Superior de Engenharia de Coimbra, Instituto Politécnico de Coimbra, Rua Pedro Nunes - Quinta da Nora, 3030 – 199 Coimbra, Portugal
[2] Departamento de Engenharia Mecânica, Universidade de Coimbra, Pólo II, 3030 – 201 Coimbra, Portugal
* avfmo@mail.isec.pt

Introduction

The thermal insulation provided by clothing is one of the most important parameters that must be taken into account whenever the evaluation of human thermal environments is foreseen. Accordingly, the main objective of the present work is the assessment of the thermal insulation of different types of clothing, both in static conditions and considering the effect of body movements. The study is focused on the experimental evaluation of nine clothing ensembles used by people working in refrigeration and freezing chambers in Portuguese industries. The total insulation was calculated using the three main methods for manikin clothing insulation, under static and dynamic conditions, and the results indicate that the serial method always presents higher values. In addition, the differences between the methods are sometimes significant, normally associated to an uneven distribution of the thermal insulation. The results also put in evidence the decrease in insulation due to walking.

Experiment

The experiments were carried out with a thermal manikin in a climate chamber (CC). The thermal manikin is articulated and divided into 16 parts, each of them controlled according to the relation between dry heat losses and skin temperature of the human body within thermal comfort conditions (Fanger, 1972). An original pneumatic system was developed to simulate the walking movements at different step rates. The CC with 4,5m×4,5m of floor area and variable ceiling height (3m in this work) has capabilities to control air temperature, humidity and air velocity in a wide range of conditions. As the objective of the tests was restricted to the influence of the walking movements under calm conditions, the indoor environment was imposed through control of the inner wall temperatures, so the air velocity within the CC was lower than 0,15 m/s. The air (t_a) and operative (t_o) temperatures were measured with a Thermal Comfort Meter from Brüel & Kjær.

Each experimental session didn't take more than 45 minutes. The parameters were continuously monitored on the manikin's computer, enabling an easy check of the steady state situation. Data acquisition was started after achieving this condition and lasted for 20 minutes, from which just the last 10 minutes were considered for analysis. During the acquisition period, the heat flux and the skin temperature of each body part were recorded every minute.

Methods

The main mechanisms of sensible heat transfer between the human body and the environment are convection (C) and radiation (R). The resistance to this heat flow transferred from the skin surface/clothing to the environment is called Thermal Insulation of the Boundary Air Layer, I_a. It is often assumed that it can be measured by operating the thermal manikin nude.

The total clothing insulation, I_T, i.e., the insulation from the skin surface to the environment, including the effect of the increased surface area (f_{cl}) and the resistance at the surface of the clothed body, the effective clothing insulation, I_{cle}, consisting of the difference between I_T and I_a, and the intrinsic or basic clothing insulation, I_{cl}, defined as the insulation from the skin to the clothing surface, are calculated by the equations:

$$I_T = \frac{\bar{t}_{sk} - t_o}{\bar{\dot{Q}}_S} \quad ; \qquad I_{cle} = I_T - I_a \quad ; \qquad I_{cl} = I_T - \frac{I_a}{f_{cl}} \ [\mathrm{m^2.^oC/W}]$$

where $\bar{t}_{sk}$ [°C] and $\bar{\dot{Q}}_S$ [W/m^2] are the mean skin temperature and the sensible heat flux obtained by area weighing. The f_{cl} factor is calculated according to the following expression:

$$f_{cl} = 1 + 1{,}97 \times I_{cl} \qquad [\mathrm{m^2.^oC/W}]$$

For the calculation of clothing insulation we consider for the present analysis three methods. The ***Global*** method performs an overall calculation and defines a whole body resistance, i.e., the area-weighted of all heat losses and skin temperatures of each body segment are summed up before the insulation is calculated, like if we have a manikin with only one segment. This is the conventional method called in the literature as parallel. The ***Serial*** method makes use of the skin temperature and heat flux from each segment to calculate the local resistances which are then summed according to a serial model. From a physical point of view and taking into account the analogy between heat transfer and electrical circuits, the relative position of the local resistances over the human body is far from corresponding to a serial system. Although it isn't a true parallel system, because of contact between body parts and the fact that the heat flux is not unidirectional (Havenith, 2002), this configuration is closer to the reality.

It is important to remark here that the parallel method mentioned in the literature doesn't correspond to the calculations of the equivalent resistance according to a parallel model. For this reason we renamed it here as ***Global***, assigning the designation ***Parallel*** to the method that corresponds to a real parallel system. The three methods just defined are compared in the present paper. The corresponding equations are:

$$\underbrace{I_T = \frac{\sum\left(f_i \times \bar{t}_{sk,i}\right) - t_o}{\sum\left(f_i \times \dot{Q}_{s,i}\right)}}_{Global\ \ Method} \; ; \; \underbrace{\frac{1}{I_T} = \sum f_i \times \left(\frac{\dot{Q}_{s,i}}{\bar{t}_{sk,i} - t_o}\right) = \sum f_i \times \frac{1}{I_{T,i}}}_{Parallel\ \ Method} \; ; \; \underbrace{I_T = \sum_i \left(f_i \frac{\bar{t}_{sk,i} - t_o}{\dot{Q}_{s,i}}\right)}_{Serial\ \ Method}$$

where f_i represents the relationship between the surface area of section *i* of the manikin, A_i, and the total surface area of the manikin A ($f_i=A_i/A$).

Results and discussion

During visits to more than 30 food industries in Portugal, the authors realized that people working in cold environments worn ordinary winter cloths, namely shoes, thick socks, briefs, trousers, long-sleeve flannel shirt and a sweater. Generally, the protective clothing is provided by the enterprises but it is usually restricted to a jacket that sometimes is not suitable to the activities being performed and without thermal insulation specifications in the label. To make up the common ensemble, referred hereafter as ensemble 0, a classic piece of each garment was selected. In addition, 8 cold protective jackets kindly made available by 4 food industries were analysed. Therefore, we had a group of 9 typical ensembles used by Portuguese workers often exposed to cold environments. The experiments were carried out with the head of the manikin uncovered (i.e. no hair) and no gloves.

Table 1. Intrinsic and total clothing insulation.

		I_{Static}			$I_{Dynamic}$			**Global/Serial**	
		Global [clo]	Serial [clo]	Parallel [clo]	Global [clo]	Serial [clo]	Parallel [clo]	Static %	Dynamic %
Ensemble 0	I_{cl}	0,79	1,02	0,73	0,73	0,98	0,66	22,5	25,5
	I_T	**1,44**	**1,64**	**1,38**	**1,32**	**1,56**	**1,25**	**12,2**	**15,4**
Ensemble 1	I_{cl}	1,28	2,11	1,15	1,16	1,92	1,04	39,3	39,6
	I_T	**1,85**	**2,6**	**1,73**	**1,68**	**2,37**	**1,55**	**28,8**	**29,1**
Ensemble 2	I_{cl}	1,64	2,74	1,47	1,40	2,55	1,21	40,1	45,1
	I_T	**2,17**	**3,17**	**2,01**	**1,88**	**2,95**	**1,71**	**31,5**	**36,3**
Ensemble 3	I_{cl}	1,5	2,37	1,35	1,4	2,34	1,22	36,7	40,2
	I_T	**2,05**	**2,81**	**1,91**	**1,88**	**2,79**	**1,72**	**27,0**	**32,6**
Ensemble 4	I_{cl}	1,47	2,54	1,32	1,27	2,2	1,12	42,1	42,3
	I_T	**2,02**	**2,99**	**1,88**	**1,77**	**2,63**	**1,63**	**32,4**	**32,7**
Ensemble 5	I_{cl}	1,27	2,05	1,14	1,17	2,04	1,04	38,0	42,6
	I_T	**1,84**	**2,54**	**1,72**	**1,68**	**2,48**	**1,56**	**27,6**	**32,3**
Ensemble 6	I_{cl}	1,19	1,85	1,07	1,1	1,84	0,99	35,7	40,2
	I_T	**1,77**	**2,36**	**1,66**	**1,63**	**2,3**	**1,52**	**25,0**	**29,1**
Ensemble 7	I_{cl}	1,26	1,94	1,11	1,19	1,92	1,03	35,1	38,0
	I_T	**1,83**	**2,44**	**1,7**	**1,7**	**2,37**	**1,55**	**25,0**	**28,3**
Ensemble 8	I_{cl}	1,78	2,88	1,59	1,52	2,64	1,34	38,2	42,4
	I_T	**2,29**	**3,31**	**2,12**	**1,99**	**3,04**	**1,83**	**30,8**	**34,5**

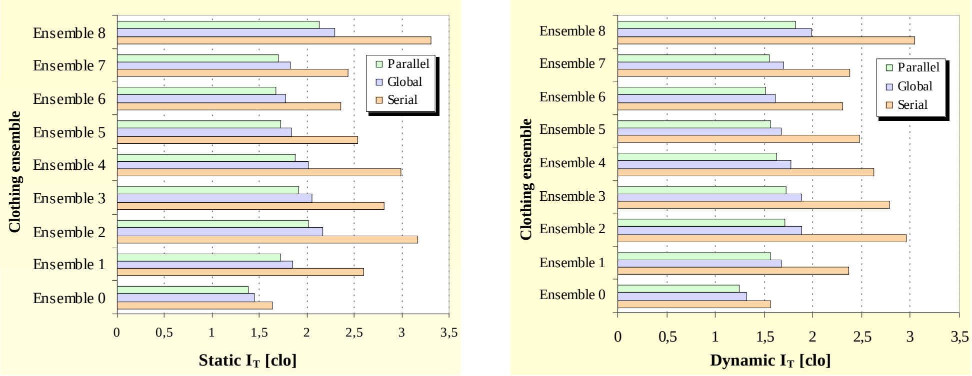

Figure 1. Static (left) and dynamic (right) thermal insulation calculated with the three methods.

In all the tests, the parallel and serial methods always present the lower and higher values, respectively, and the results of the global method are in between those two. For the static posture, the total clothing insulation ranged from 1,44 to 2,29 *clo* with the global method, from 1,64 to 3,31 *clo* with the serial method and from 1,38 to 2,12 clo with the parallel method. For the dynamic condition, the corresponding values varied from 1,32 to 1,99 *clo*, from 1,56 to 3,04 *clo* and from 1,25 to 1,83 *clo*. Considering the I_T values, the average difference between the parallel and global methods is 6,6% for the standing posture and 7,7% for the dynamic condition. The analogous differences for the global and serial methods are 26,7 and 30% respectively. It must be noted that the smaller differences are obtained with ensemble 0 (no cold protective jacket), which is the one with the most uniform clothing insulation. These results clearly demonstrate the influence that the uneven distribution of the clothing insulation has in the calculation methods, particularly for the serial. In fact, the head and hands were uncovered and with the jacket, the trunk and upper limbs obviously have more insulation than the remaining parts. Figure 3 shows the differences of thermal insulation by body parts for ensembles 0 and 8. As they have the lowest and highest total insulation values, the comparison can better illustrate the existing discrepancy. While ensemble 8 has a too extreme distribution of clothing insulation, ensemble 0 is more “homogeneous”. However, it is evident in both cases the higher values in the upper body parts.

Finally, Figure 4 compares the global results with the equations proposed by Nilsson and Holmér (1997), Holmér *et al*. (1999) and Nilsson *et al*. (2000). Since the tests were performed with an air velocity (v_a) close to 0,1 m/s and a regular walking speed (w_s = 0,51 m/s), these parameters were kept constant in the equations. The correlation proposed by Nilsson *et al*. (2000) overestimates de results while the others are seen to underestimate.

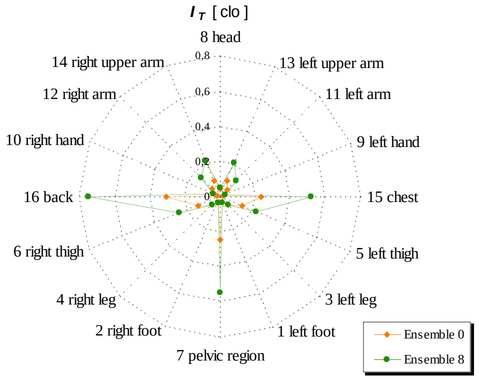

Figure 3. Total clothing insulation calculated with the serial method for ensembles 0 and 8.

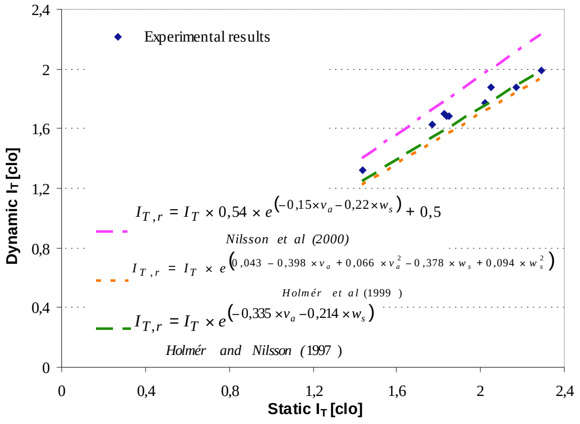

Figure 4. Total clothing insulation calculated with the global method: dynamic *vs* static results.

Conclusions

Regarding the comparison made with the three methods of calculation of the thermal insulation, the results obtained with the serial method were always higher. In contrast, the parallel method always presents the lower values. The differences between the global and serial methods were, in some cases, significant, and this discrepancy increases with non-uniform distribution. The mean difference for the static posture was 26,7% and for the dynamic condition was 30%. Besides the noticed non-uniform clothing distribution between the lower and upper parts of the body, the nude parts (head and hands) also contribute to these results. Uneven distribution in clothing insulation is rather a rule than an exception (McCullough, 2001), and so, for typical clothing, higher values should be expected when using the serial method. Definitely, the serial method does not give true values, certainly because it doesn't represent the physic system *clothing-human body*. However, extreme distributions of insulation should, whenever possible, be avoided because this condition may become uncomfortable for the wearer. When designing new protective clothing, special attention must be given to this requirement, in order to accomplish ensembles with the insulation evenly distributed over the whole body. The prediction that best fits the results is the one proposed by Nilsson and Holmér (1997). As a final remark, the authors believe that these contributions should be continued and promoted in order to get a representative dataset.

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PREDICTION OF CONDENSATION IN THE CLOTHING SYSTEM AT COLD ENVIRONMENT

Takako Fukazawa[*1], *Yutaka Tochihara*[*1], *Teruko Tamura*[*2]

[1] Faculty of Design, Kyushu University, Fukuoka-shi, Japan
[2] Faculty of Fashion Technology, Bunka Women's University, Tokyo, Japan
* corresponding author fuka@design.kyushu-u.ac.jp

Introduction

The heat and water vapour transfer from the body to the environment through clothing is one of prime factors in thermal comfort. If microclimate contains a lot of moisture, the body will be in discomfort. Especially, the condensation takes place when heat and mass transfer balance is lost in the clothing system. Then the body is suffered from intensive discomfort. Therefore, the condensation is not only a significant factor of the discomfort in the daily life but also in shiver environment, especially under cold condition, because the evaporation takes extremely large amount of heat energy away from our body.

In order to estimate the condensation rate in clothing system, Lotens et al. [1] and Lotens and Pieters [2] presented a set of heat and mass balance equations and solved them numerically. More recently, Fukazawa et al. [3] derived an analytical equation (FKTT equation or method, hereafter) for the condensation rate in the clothing system, enabling us the amount of condensation to be calculated from given conditions of body surface, clothing and environment. The validity of the equation has been confirmed through our previous studies [3, 4]. In this study, heat and water vapour transfer with the condensation in the clothing system at cold are analytically discussed using the developed FKTT method.

Methods

The environmental and the body conditions

The condensation under the cold environment at a high altitude of Mt. Fuji, which is the highest mountain (3,777 m) in Japan, is assumed. The average environmental conditions in the summer and winter at its summit are quoted from a data book [5]: in summer they are 279 K and 71 %RH with a wind velocity of 7 m/s and in winter they are 254 K and 51 %RH with an extremely high velocity of 16 m/s.

The skin surface temperature and the relative humidity are defined as 309 K with 100 %RH during the exercise, and as 306 K with 50-80 %RH during the rest.

To obtain the condensation just after and before the exercise, additional calculations are made for the body conditions during both the exercise and the rest with a low air velocity of 0.1 m/s.

The terms of estimation

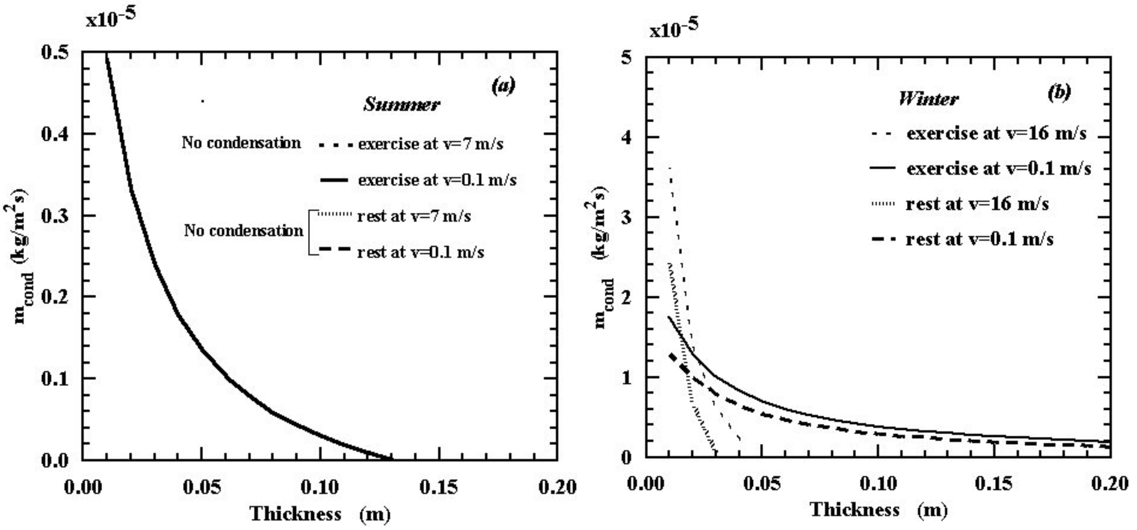
The packing factor of common clothing including those for high performance usually ranges from 10 % to 30 %: in another words, the clothing is consisted mainly by the air. According to Fourt and Harris [6], the water vapour resistance, R_v^* (m/s) increases proportionally to the increasing packing factor up to 30 %. Therefore, in calculating the condensation, the R_v^* at the standard condition (1 atm) is assumed to be equal to a value obtained using the water vapour diffusion coefficient in air (D_{air}, m^2/s) and the thickness of the clothing (d, m).

Based on some references [e.g., 7], a typical value of 0.029 W/m^{2}K, is employed in this study as the effective thermal conductivity of the clothing, because the influence of thermal conductivity of fibre upon the effective one of the clothing would be small even though the packing factor differs from that of common clothing.

Internal resistances of the thermal and the water vapour are determined by the linear relation between the thickness of the clothing and the thermal conductivity and the D_{air}, respectively. Additionally, regarding with the R_v^* influence of the pressure on the R_v^* [3, 9] is considered in the calculation.

The average mass transfer coefficient around the human body is approximated by the one around a circular cylinder. The heat transfer coefficient around a cylinder [8, 10] can be applied to the average mass transfer coefficients because of the analogy between the heat and mass transfer. Thus, the external water vapour resistance, R_{vs} (s/m), can be calculated with the following equation;

$$Sh_m = \frac{d_{body}}{R_{vs} \cdot D_{air}} = c\left(\frac{u_m \cdot d_{body}}{\nu_{air}}\right)^n Pr^{1/3}, \tag{1}$$



where $$Re = \frac{u_m \cdot d_{body}}{\nu_{air}} . \qquad (2)$$

Figure 1 Calculated condensed water vapour on the clothes plotted

In the equation, the *c* and *n* are the constant and the exponent which are dependent upon *Re* (Reynolds number, dimensionless). Their values are quoted from Holman [10] and Seki [8].

Re=4,000-40,000	c=0.193	n=0.618
Re=40,000-400,000	c=0.0266	n=0.805

Sh_m is the average Sherwood number (dimensionless), ν_{air} the kinematic viscosity (m^2/s), u_m the velocity (m/s), d_{body} the diameter of the cylinder or the body (m), and *Pr* the Prandtl number (dimensionless).

The external thermal insulation, $R_{\theta s}$(m^2K/W), can be obtained by the extended Reynolds-Colburn analogy [8, 10] for mass transfer as given by following equation.

$$R_{\theta s} = R_{vs} \frac{D_{air}}{\lambda_{air}} \left(\frac{Sc}{Pr} \right)^{1/3} \qquad (3)$$

where λ_{air} is the thermal conductivity of the air (W/mK).

Results and discussion

The condensation under cold at high altitude

Figures 1-a and 1-b show the calculation results with use of the FKTT equation for summer and winter, respectively. In both figures, x-axis is the thickness of the clothing and y-axis the condensed amount of the water vapour on the clothes. If a line is defined in the legend but not drawn in the figure, it means that the condensation does not take place in that case. Condensation in the clothing occurs when the body is in the exercise at the low wind velocity in summer. In winter, condensation takes place in the clothing under the lower wind velocity during both the rest and exercise, while the condensation can be seen in the clothing whose thickness is up to about 0.04 m under the high wind velocity, because in the calculation, the constant value of the skin surface temperature is employed as mentioned above. Actual condensation rate in the clothing might be smaller than the estimated values if a possible decrease in the skin surface temperature under the shivery condition is taken into account.

In discussing the estimated results, it can be considered that the condition during the exercise at the low air velocity is equivalent to the rest period (e.g. taking a rest in a tent) just after stopping the exercise, because the body still produces a large amount of heat and water vapour due to the exercise revelation. Furthermore, the condition during the exercise at the high air velocity can be also considered to be actual exercise condition exposed to the high air velocity.

In summer, thinner clothing; e.g. T-shirts or long sleeve shirts are employed in daytime at the altitude. Their total thickness is 0.005 m to 0.05 m at maximum. Thus, the estimation for the thickness up to 0.05

m is especially useful. The estimated condensation rate is plotted in Figures 2-a and 2-b. The figures indicate that no condensation will take place except during the exercise exposed to the low air velocity. Moreover, the amount of the condensation in that case is very small and it may not be sensible for the body through touch and observation. It is also of practical importance to recognise in which part of the body the condensation takes place. In instance of climbers, a great deal of the condensed water vapour is often recognised on the back of the body through the experiences. This is because the climber usually carries a package on his/her back and it causes a high thermal resistance between the back and the environment.

In winter, thicker clothes are always employed as an outer jacket to prevent heat release from the body. Their total thickness mostly ranges from 0.05 m to 0.15 m. The condensation mass fluxes for the thickness of 0.05 and 0.15 m are shown in Figures 3-a and 3-b. No condensation would appear under the high air velocity condition owing to the smaller external water vapour resistance. On the other hand, under the low air velocity condition, the condensation will take place on or in the clothes from the present estimation as shown Figures 1-b, 3-a, and 3-b. Especially, judging from the results during the rest under the low airflow in winter (see Figures 3-a and 3-b), the condensation will occur in the sleeping bag. This indication agrees well with the experiences during climbing in winter at high altitude. Furthermore, the difference in condensation between during the exercise and the rest under the low airflow is found to be very small. This means also that the condensation takes place in the microclimate under the low temperature and the low airflow condition, i.e., during the rest in a tent or a hole.

The condensation will take place just after the exercise and then the sweat will remain on the skin surface. Therefore, the body is cooled intensively due to the release of the evaporation heat, which will tend to cause the getting into hypothermia. As shown Figures 1-a and 1-b, the thicker clothes provide smaller or no condensation. According to existing reports [e.g., 11-13], woolen clothing can maintain the low water vapour concentration and prevent the occurrence of the condensation in the microclimate due to the high water vapour absorbability thanks to its own property. Their results indicates that even if a hydrophobic and a hydrophilic clothing are similar in their thickness, the water vapour resistance through the hydrophilic clothing become larger compared to the hydrophobic one. Hence, the combination of the present estimation and their results indicates that the condensation can be made negligible or prevented by adding another thick clothes made of hydrophilic materials.

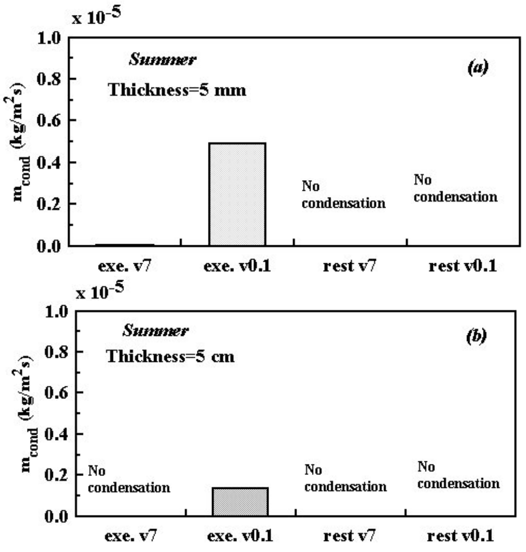


Figure 2 Effect of the thickness of the clothing upon the condensed water vapour in summer. Upper and lower figures indicate condensation mass flux in the clothing whose thicknesses are 5 mm (a) and 5 cm (b), respectively.

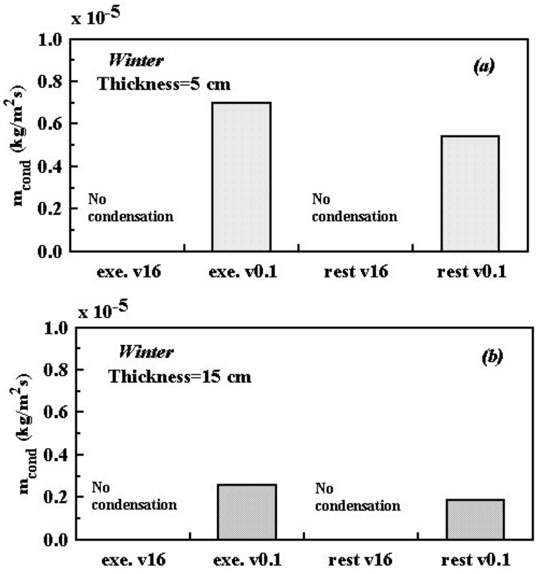


Figure 3 Effect of the thickness of the clothing upon the condensed water vapour in winter. Upper and lower figures are the condensed mass flux in the thinner (a) and thicker (b) clothing, respectively.

Conclusions

The heat and mass transfer with the condensation in the clothing system at cold are discussed using the developed estimation method. Larger amount of condensation is seen in thinner clothing than in thicker one. Occurrence of the condensation in the clothing can be neglected or prevented by means of adding another thicker clothing made of hydrophilic materials. The results also indicate that a larger amount of condensation will be seen during a rest in a tent just after stopping the exercise.

Acknowledgements

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PHYSICAL STRAIN AND COOLING DURING WORK IN A BOMB DISPOSAL (EOD) SUIT

E.A. den Hartog, C.L. Koerhuis

Dept. Human Performance, Business Unit Human Factors, TNO Defense, Security and Safety, Soesterberg, The Netherlands
* corresponding author denhartog@tm.tno.nl

Introduction

An important part of the Explosives Ordinance Disposal (EOD) Squad work consists of the handling and removal of unidentified packages or improvised explosives. In those situations, they wear the EOD suit. This is a protective suit of about 35 kg, that protects against blasts. The burden of wearing the suit is high and the work load may be high for unfit people. Next to the weight load, thermal load is high, in particular during hot summers. Thus, working times may be limited. TNO participated in a study to quantify the physical strain (thermal and biomechanical) on people working in an EOD suit. The project aimed to find ways to lower the strain and might lead to the setting of fitness levels of the employees in the future. As a part of this project, we tested two cooling systems under the EOD suit to study if these cooling systems would indeed increase working times in warm conditions. In this study a commercial water cooling garment and a PCM vest were used. To test the effectivity of the cooling vests we developed an exercise protocol that was typical in duration and exercise level for the actual working conditions of the EOD workers. In this paper the actual differences will be discussed in detail as well as the pros and cons for practical working in these two different cooling systems under these specific conditions.

Methods

Ten subjects from the EOD squad, experienced in wearing the EOD suit, entered the study. In an earlier phase of the project, the subjects performed a maximum exercise test to determine their fitness levels. From field visits during training and interviews with the employees we developed a protocol that was similar to the work performed in practice, but that could be performed in the climatic chamber (25 °C, 50% RH). The protocol of the study consisted of alternating series of activities according to Figure 1.

Time: 4’ - 1’ – 3’ - 2’ - 2’ - 1’ - 2’ - 1’ - 3’ - 1’

Task: Psion – rest – Walking – Crawling - Blocks – rest - Pins – rest – Walk - rest

Figure 1: Activity sequence in the protocol.

The Psion test was a simplified version of a cognitive task that is used in psychological studies (1). This test was meant to load subjects mentally, as opposed to the rest periods. The walking task simulated the walking back and forth from the command post to the bomb site in the field. The crawling task simulated some obstacles during the walking task. The “Blocks” and “Pins” simulated the fine motorical tasks close to the bomb. This sequence of events was performed twice in a condition, taking approximately 45 minutes. Then the subjects had a 30 minute rest period without the EOD suit, outside the climatic chamber.

The different conditions consisted of one without cooling (N), one with a water cooling system (W - going with the suit) and one with a PCM vest (P). During the experiments heart rate, core temperature (CoreTemp pill) and skin temperature (neck, hand, scapula and shin, (2) were measured. Furthermore thermal comfort (scale from –4 (very cold) to +4 (very hot)) and RPE scores were asked during the walking periods. Finally, the wearers gave a general judgement on these suits. All subjects performed three sessions during one day, and were within a day exposed to one or two no-cooling conditions and one or two cooling condition, either P or W. Thus, 30 exposures without cooling and 30 exposures with P or W cooling were tested. All data were analysed by a repeated measures ANOVA with Condition and Session as independent variables.

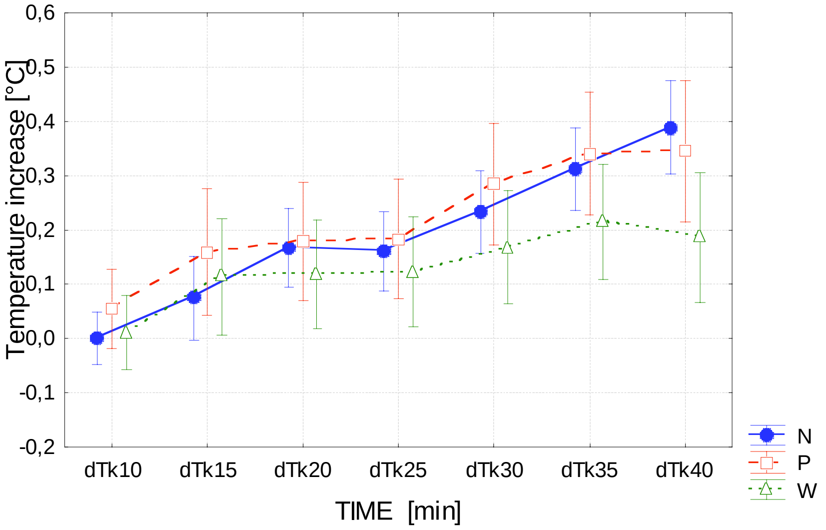

Figure 2: Increase in core temperature for the different cooling vests, N= No cooling, P = PCM cooling and W = Water cooling. On the x-axis time is shown in minutes and on the y-axis the increase in core temperature in °C.

Results

The protocol in this study was considered to be a representative example of a working routine. The subjects considered the work load as not too high and commented that they certainly encountered more strenuous exposures in terms of time and exercise level, but also often encountered 'easier' exposures in terms of physical load.

The results from the different days and sessions within the days were not different. Therefore, we analysed only the temperature changes over time between the three conditions (N,W,P). We obtained no significant effects of the cooling conditions on the RPE scores. Also, we found no effects in the performance on the Psion test, nor on the "Blocks" and the "Pins" tasks.
The results on the core temperature measurements show that the water cooling vest performed best in providing actual cooling to the wearer of the EOD suit. The average increase in core temperature was 0.4(±0.1)°C without cooling and 0.2(±0.1)°C with the water cooling (figure 2). The increase in core temperature was significantly lower in the Water condition than in the No-cooling condition (Time*Condition, p=0.002).

Although there was a significant difference (Time*Condition, p=0.02) in skin temperature, the differences were much smaller (on average 1°C) than expected. This was partly due to the fact that we used only four sites to measure skin temperature. The distribution of (cold) water over the body was not immediately related to the locations of the skin temperature measurements. Therefore, the actual measurements did not show very low temperatures (figure 3), whereas the subjects did complain about cold sensations at the start of the experimental sessions (figure 4). The votes on thermal comfort were significantly lower during the Water cooling condition compared to the No-cooling condition (p<0.001). For thermal comfort there was no significant interaction between time and cooling method (Time*Condition not significant). In all three conditions the thermal votes increased about 1.5 point , on a 9 point scale. The subjects all indicated that the suit was uncomfortably cold at the start of the session. Also, they all indicated that they considered the water cooling suit as impractical for use during their normal working routine.

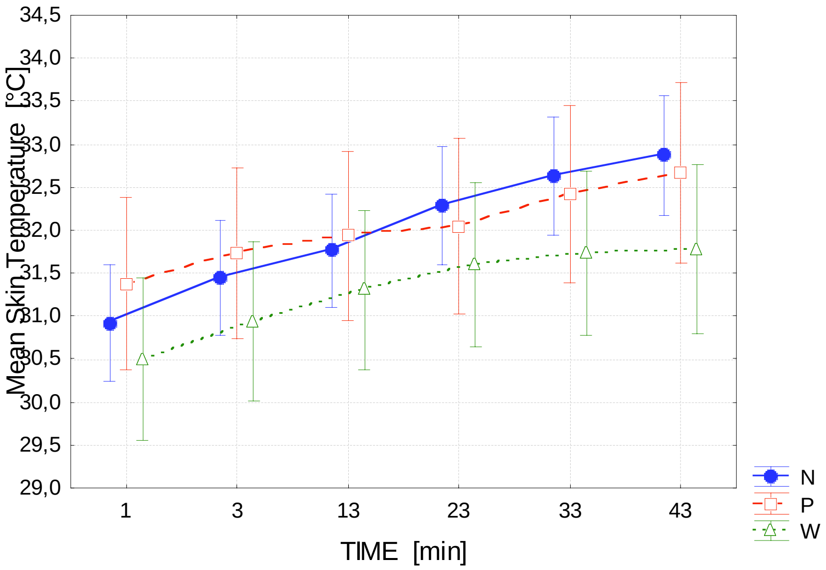

Figure 3: Mean skin temperature increase over time for the three different cooling conditions.

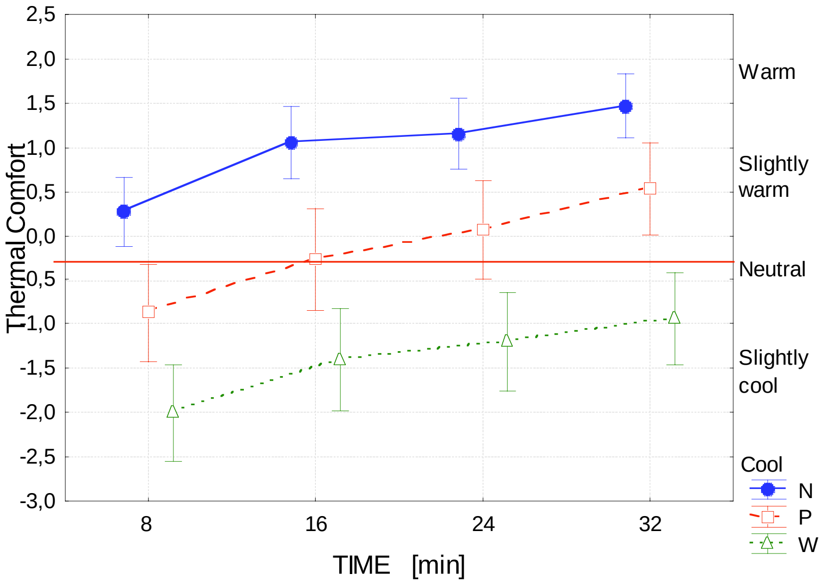

Figure 4: Thermal comfort versus time for the three different cooling conditions.

Discussion and Conclusions

The currently used protocol may be suitable as a representative scenario for testing EOD suits. Although the thermal load was relatively low, we found a significant thermal effect of the water cooling suit compared to the No-cooling condition. As this has been found before, it confirms the effectiveness of the water cooling suit (3). However, from the interviews during this project and the comments of the professional subjects we used during this study, we found out that the willingness to use the cooling suit in practice was low. Although the demonstrated effectiveness of the water cooling suit slightly altered this attitude, the subjects still considered it too unpractical for their normal use, and complained about the cold feeling at the start of the sessions. Based on the results of these experiments and an improved insight in the working methods of the Dutch EOD Squad, recommendations will follow on the use of cooling suits in the working practice. These results also contribute to the overall project in which the physical load of the EOD is analysed. Finally, some useful recommendations to improve the cooling suit may have come up, so that the wearers will use it more often.

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BODY ARMOUR. EFFECTS ON PERFORMANCE AND PHYSICAL LOAD

Ulf Danielsson, Ulf Bergh*

Swedish Defence Research Agency, Stockholm, Sweden, Div. of NBC-* corresponding author
ulf.danielsson@foi.se

Introduction

In regular military combat, fragments are the cause of 60 to 70% of the casualties, while high-energy projectiles account for approximately 20% (1). For police personnel, on the other hand, the threat is mainly coming from low-energy projectiles and knives. Body armour offers protection against all these weapons and safety has become an increasingly important issue in the modern society. Therefore, the use of various kinds of body armour as well as the demand for better protection has increased dramatically. This has been driving the development in the direction of thicker and/or larger armours. For example, the soft aramide armour is frequently enforced by ceramic, increasing the mass form about 3 kg to 10 or more, which inevitably will reduce comfort and perhaps also certain aspect of performance (2, 3)

Methods

Ten conscripts participated voluntarily in the study. Height ranged from 1,95 m to 1,64 m, average 1,80 m, and body mass ranged from 61 kg to 83 kg, average 76 kg. Main experiments were run during three consecutive days. The day before these experiments an endurance test (Cooper, 2000m) was performed. After the first day a strength test was performed on a cycle ergometer. Twenty five revolutions at maximum speed were requested with a braking load of 10% of nude body mass. The following activities were performed during the main experiments.
Climbing up and down a net. Measuring variables were time, heart rate (HR). Perception of (RPE) and body motion restriction (RPI) were rated.
Shooting was performed with assault rifle (AK5) in the prone position, without support. Shooting was done without prior exercise and after 200 m of running (twice). Ranges were 100 and 200 m. At each shooting occasion five shots were delivered within five seconds. Measuring variables were firing score, RPE, RPI and HR.
Hand grenade throwing was performed from a standing, kneeling, and prone position (two hand grenades in each position). RPE, RPI, and throwing length and lateral deviation were registered.
Repeated dashes back and forth (eight times) assuming kneeling fire position and turning each 25 m. Measuring variables were HR, RPE, RPI and time for each section.
Belly-crawl through an eight meter long tunnel. HR, time, RPE and RPI were registered.
Reach for five different body positions.

Equipment

During the first day three of the participants used combat equipment but without body armour (FU). Next three participants used combat equipment together with (soft) body armour (FUK) while the remaining four participants used combat equipment together and body armour with front and back ballistic inserts, ceramic plates (FUKP). Body armour used is shown in figure 1. During the next days the equipment was rotated between the three groups. Combat equipment was composed by field uniform including shirt, long underpants, stockings, boots, helmet, gloves, filled water bottle, hearing protection, rifle with three magazines and combat vest. The mass of the respective equipment alternatives are displayed in table 1. For the average subject the mass of FU, FUK and FUKP relative nude body mass was 25%, 31% and 39%, respectively.

Tabell 1. Mass (mean and s.d.) of the different equipments (kg), within brackets in relation to nude body mass (%).

	FU	FUK	FUKP
Vikt (kg)	19, 0±0,9 (25%)	23,6±0,8 (31%)	29,7±1,0 (39%)

Statistical analysis

Variance analysis was used for evaluating the results. If the analysis indicated significant differences, post hoc test were run to find between which equipment alternatives the difference referred to. In these cases the basic significance level, $p = 0,05$, was corrected according to

$p_1 = 1-(1-p)^n$, to avoid effects of repeated tests. For continuous data the variance test model with so called ”incomplete block design” has been used together with paired t-test. For discrete data Friedmans test has been used first and in case of significance Wilcoxons Signed Rank test was used.

Figure 1. Body armour used (left). Hard back and front plates when not inserted (right).

Results

Significance tests for RPE and RPI are shown in table 2. Shooting result was based on median data. The table shows that significantly different RPI values (pooled) were obtained for the various equipments. I respect of pooled RPE-values the differences were significant except between FU and FUK. Significance test in respect of HR indicate significant differences between FU and FUKP as well as between FUK and FUKP (table 3) but not between FU and FUK. Significance test results for pooled performance of shooting, belly-crawling, net-climbing, dashes and hand grenade throwing are shown in table 4. Significant differences were obtained between FU and FUKP as well as between FUK and FUKP. The pooled results from endurance and strength tests indicated no significant relation to the results of net-climbing, belly-crawling or dashes.

Table 2. Significance test of RPE and RPI with the critical value 0,017 (Wilcoxon Signed Rank Test, n.s. = not significant).

	FUK/RPE	FUKP/RPE	FUK/RPI	FUKP/RPI
FU	0,021 (n.s.)	0,005	0,004	0,004
FUK		0,013		0,014

Table 3. Significance test of HR with the critical value 0,05 (n.s.= not significant) for different equipments.

	FUK	FUKP
FU	0,16 (n.s.)	0,02
FUK		0,01

Table 4. Significance test of pooled performance (Wilcoxon Signed Rank Test with the critical value 0,017, n.s. = not significant)

	FUK	FUKP
FU	0,38 (n.s.)	0,008
FUK		0,016

Discussion

The pooled measure of physical load and performance respectively showed significant relations between the various equipments in respect of RPE (tables 2, 3 and 4) except between without (FU) and with soft body armour (FUK). This indicates that the subjects perceived a raising load when the ballistic inserts were added to the body armour whereas without hard plates the body armour was considered not more demanding than the equipment without body armour (table 2). Taking heart rate as a representative measure of physiological load a similar relationship could be expected and so was also the case (table 3). Significant heart rate differences were obtained except between FU and FUK. Statistical analysis of RPI gave the result that the differences between all three alternatives were significant. This means that the participants could feel the impact of the body armour and also that the motion restrictions increased when hard plates were inserted in the body protection. Altogether, these analysis indicate that the physical load increases when the hard plates are introduced but body motion is restricted as soon as the body armour is worn. Reach as well as RPI analysis support these conclusions. Just one movement, raising one’s knee, was hindered neither physically nor ”mentally” by the body armour. Obviously, the body armour is short enough not to get in contact with the thigh when rising the knee. Also the part of the body armour protecting the crouch seems to be flexible enough not to resist high knee rise as long as the right size is worn.

The opinion of the participants indicates that wearing body armour with hard plates is generally acceptable if the threat is substantial. Just one out of the ten participants was uncertain whether it was good to wear hard plates in a threatening combat situation or not. This could mean that the extra load introduced by these plates is considered neither negative for the physical or mental performance, nor that the load was found too obstructive. In a real situation when the carried burden might be 10 kg higher may give other priorities. The impact of body armour on the performance will depend on the tactical situation. In a peace keeping situation a body protection might not be that cumbersome while combat in e.g. urban terrain the soldier may prefer ammunition over carrying similar weight in the form of protective plates. Another question is whether active protection due to greater mobility when wearing lighter burden gives better protection than passive protection in the form of heavy plates.

The physical load is also related to the time body armour is carried. Hence, time until relief must be considered to reduce the load. Body armour may also be uncomfortable because of the thermal load it induces (e.g. 4). Impaired lung function due to body armour has also been reported (5). When sitting still the static load on shoulders may also be troublesome (6). It should be noted that body armour is not designed for women, which may result in greater load for this category (e.g. 7).

Conclusions

The carried equipment affects the wearer’s actual and perceived load as well as his physical performance. Altogether the study shows that:

- Body armour, with or without hard inserts, was perceived as more restricting (RPI) than when combat equipment was carried without body armour.
- Body armour with hard inserts was perceived as more restricting (RPI) than body armour without hard inserts.
- Body armour without hard plates did not add to physical load (RPE)
- Body armour with hard inserts caused greater load (RPE) than body armour without plates.
- RPE-conclusions were in line with measured HR.

Significant differences in performance between the three equipment alternatives were obtained for net climbing, belly-crawling, dashes and reach. However, the differences in result for hand grenade throwing and shooting were small and not significant. Yet, there was a clear correlation between perceived exertion (RPE) and shooting results (points and deviation) for the ranges 100 m as well as 200 m. Time consumed during net climbing (up and down, respectively) were linearly related to mass of the equipment. During the dashes, the time needed for each distance became increasingly longer. This result was more apparent when combat equipment was combined with body armour and hard inserts.

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SURFACE THERMAL INSULATION AND MOISTURE VAPOUR RESISTANCE OF HUMAN BODY UNDER VARYING ENVIRONMENTAL CONDITIONS AND WALKING SPEEDS

*Xiaoming Qian and Jintu Fan**

Institute of Textiles and Clothing
The Hong Kong Polytechnic University
Hung Hong, Kowloon, Hong Kong
* Corresponding author Email tcfanjt@inet.polyu.edu.hk

Introduction

Surface thermal insulation and moisture vapour resistance of human body are important parameters for predicting thermal comfort. While surface thermal insulation had been determined by experiments using human subjects or dry manikins (Fan and Keighley, 1991; Olesen, 1982), the surface moisture vapour resistance was estimated from surface thermal insulation based on Lewis relation. Such estimation was not validated by direct experimental measurements. Furthermore, the interaction of heat and moisture transfer at the surface of human body under varying environmental conditions and body motions has not been investigated.

In this study, the recently developed movable sweating fabric manikin – WALTER (Fan and Chen, 2002; Fan and Qian, 2004) was used to directly measure the surface thermal insulation and moisture vapour resistance simultaneously under various environmental conditions and “walking” motion. The relationship between the surface insulation and moisture vapour resistance under varying conditions are investigated.

Past related work

The heat and mass transfer through the air layer of outer surface of human body plays a very important role on the thermal comfort, heat and cold-stress analysis. Kerslake’s (1972) empirical formula,

$$h_c = 8.3\sqrt{V_0 + V_{wind}} \qquad (V_{wind} > 0.2 m/s) \qquad (1)$$

where, h_c : convective heat transfer coefficient, W/m^{2o}C,
V_0 : a lower limit related to natural convection, m/s,
V_{wind}: wind velocity, m/s.

is widely considered as the best practical estimation. When a clothed person is in activity in windy condition, the effect of body movement should be considered. Givoni and Goldman (1972) suggested using an equivalent air velocity V_{eff} corrected by body metabolic rate, which corresponds to the body activity level, to take into account the combined effects of wind and body motion. After analyzing the thermal insulation data measured on human subjects by Havenith et al (1990), Lotens and Havenith (1991) redefined the equivalent air velocity V_{eff} and proposed using V_{eff} instead of air velocity for predicting the surface thermal insulation for a man walking in wind as below:

$$V_{eff} = 0.11 + V_{wind} + \beta \cdot V_{walk} \qquad \beta = 0.67 \; for\ walking \qquad (2)$$

V_{walk} : walking speed, m/s

β is less than unity partly because the trunk of the human body is relatively immobile during walking and partly because walking motion is intermittent.

The radiative heat transfer coefficient h_r is dependent on the temperature and emission coefficients of clothing surface. The typical value of h_r is 4.5~5 W/m^{2o}C (ASHRAE 1989; Lotens and Havenith, 1991; McCullough et al, 1985, 1989).

The inverse of the heat transfer coefficient through the surface air layer is defined as the surface insulation I_a.

$$I_a = \frac{1}{h_r + h_c} \qquad (3)$$

Substitute the equations (1) and (2) into (3), and let h_r be 5 W/m^{2o}C, we have:

$$I_a = \frac{1}{5+8.3\sqrt{0.11+V_{wind}+\beta V_{walk}}} \qquad (4)$$

Due to the complexity and high cost of actual measurements of surface moisture vapor resistance as well as the difficulty in achieving a good accuracy, surface moisture vapour resistance is practically estimated from the surface thermal insulation according to Lewis relation, which assumes that heat and moisture transfer is in analogy. Lewis relation L_R can be expressed in

$$h_e = L_R h_c = 0.0165 h_c \qquad L_R = 0.0165^o C/p_a \qquad (5)$$

Applying Lewis relation to Equations (4), we have:

$$R_a = \frac{1}{0.0165\times 8.3\sqrt{0.11+V_{wind}+\beta V_{walk}}} \qquad (6)$$

However, since Lewis relation represents an ideal situation (Cengel,Y.A., 2003), its validity for predicting the surface moisture vapour resistance of human body should be evaluated.

Methods

The surface thermal insulation I_a and the surface moisture vapour resistance R_a of the air layer surrounding the nude manikin were measured on the sweating manikin-Walter (Fan and Chen 2002, Fan and Qian 2004) in a climatic chamber, in which temperature and humidity can be controlled at the range of 10 to 40°C±0.3°C and 30% to 80%RH±5%RH, respectively. There are nine axial fans in the chamber which can generate evenly distributed wind with the mean wind velocity varying from 0.22 m/s ±0.03m/s to 4.04 m/s±0.22m/s.

Results and discussion

The interaction between heat and moisture transfer

Temperature and moisture concentration gradient are the driving force for the heat and mass transfer, respectively. When they are present at the same time, they can affect each other (Cengel,Y.A., 2003). In order to clarify this interaction, the surface thermal insulation measured with the sweating manikin under the condition of 20 °C and 50%RH (i.e. having simultaneous heat and moisture transfer) with varying wind velocity is compared with that measured with the manikin covered with a non-sweating fabric skin (i.e. only heat transfer, but no moisture transfer); the surface moisture vapour resistance measured under the condition of 20 °C and 50% RH (i.e. having simultaneous heat and moisture transfer) with varying wind velocity is compared with that measured under the isothermal condition of 35 °C and 50% RH (i.e. only moisture transfer, no direct heat transfer). The results are plotted in Fig. 1(a) and 2(b).

In Fig. 1(a), the curve is the calculated surface thermal insulation according the equations (4) (The manikin was not in walking motion, $V_{walk}=0$). As can be seen, there is no significant difference between the surface thermal insulation measured on the non-sweating manikin and those measured on the sweating manikin, both agreeing well with the calculated values. This means that there is little effect of moisture transfer on the surface thermal insulation.

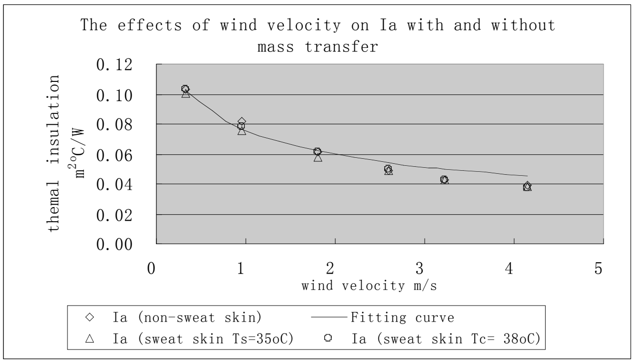

Fig. 1 (a) I_a measured with and without moisture transfer

In Fig. 1(b), the curve is the calculated moisture vapour resistance based on the equation (6). As can be seen, the R_a measured at 20 °C and 50%RH agree well with the calculated values, but much lower than those

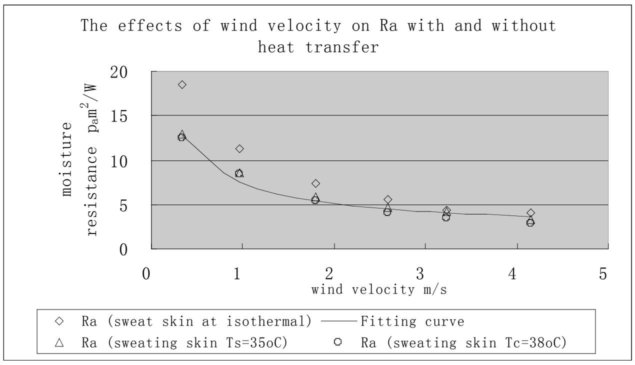

Fig. 1 (b) R_a measured with and without heat transfer

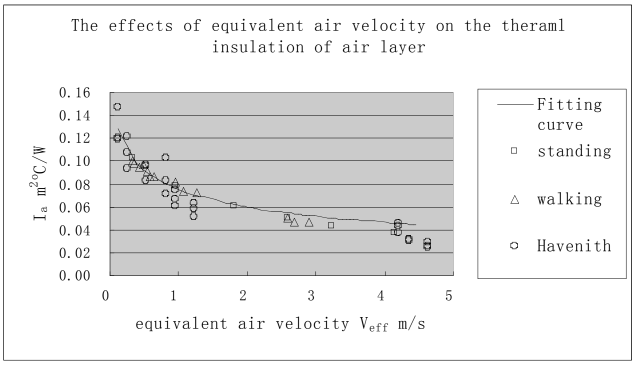

Fig. 2 (a) the effects of equivalent air velocity on I_a

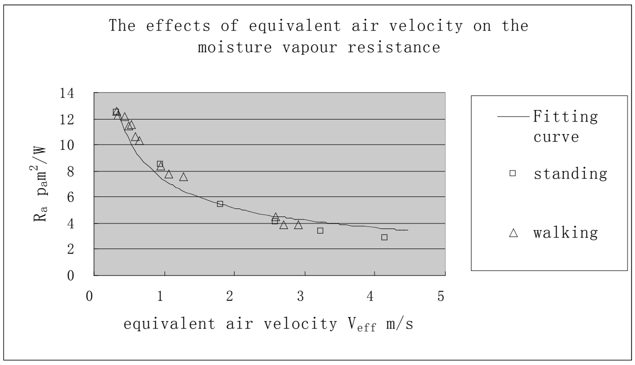

Fig. 2 (b) the effects of equivalent air velocity on R_{oa}

measured at the isothermal condition of 35 °C and 50%RH, when the wind velocity is less than 2.0 m/s. At high wind velocity, no significant difference exists between the R_a measured under non-isothermal and isothermal conditions and those predicted by formula (6). The higher values of R_a under isothermal conditions are likely due to the increase of surface air layer as a result of the absence of temperature gradients. At high wind velocity, such increase in surface air layer becomes insignificant. It is clear that Lewis relation is not valid under isothermal condition when the wind velocity is small. Under the isothermal condition, the effect of wind velocity on the surface moisture vapour resistance can be fitted with the following empirical equation:

$$R_a = \frac{1}{0.1 \times (V_0 + V_{wind})^{0.57}} \qquad (V_0 = 0.11 m/s, \quad V_{wind} \le 4 m/s) \qquad (9)$$

with the percentage of fit (i.e. R^2) being 0.99.

As can be seen in Fig. 1(a) and Fig. 1(b), at the small range of skin temperature varying from 33~35°C, there are no significant difference in I_a and R_a measured at constant skin temperature (accompanied with different core temperature of manikin) and at constant core temperature (accompanied with different skin temperature).

Combined effects of wind and "walking" motion on the surface thermal insulation and moisture vapour resistance

Surface thermal insulation I_a and moisture vapour resistance R_a were measured under the condition of 20^{o}C and 50%RH with varying wind velocity and the speed of "walking" motion. By fitting these datum using Eq. (4) and (6), we obtain $\beta = 0.45$ with the percentage of fit being 0.87 (i.e. $R^2 = 0.87$). Therefore, we have:

$$V_{eff} = 0.11 + V_{wind} + 0.45 \times V_{walk} \qquad m/s \qquad (10)$$

The surface thermal insulation and moisture vapour resistance are plotted against the equivalent air velocity V_{eff} in Fig. 2 (a) and (b), the curve is also the calculated thermal insulation and moisture vapour resistance based on the equation (4) and (6), respectively. The thermal insulation measured on human subjects by Havenith et al (1990) was also plotted on Fig. 2(a) for comparison. It can be seen that all data is much closed to the fitting curves.

The β value determined in our work is smaller than that proposed by Havenith (1990a) ($\beta=0.67$), who obtained it by analyzing the thermal insulation measured on human subjects. The smaller value of β could be due to the fact that, when human subjects are walking, the lower legs swing against the upper legs at the point of knee and the forearms swings against the upper arms at the point of elbow, whereas the entire arms and legs remain straight when our manikin was in "walking" motion.

Conclusions

Using the sweating fabric manikin-Walter, the surface thermal insulation I_a and moisture vapour resistance R_a adjacent to the skin were investigated under different environmental temperatures, humidity values and wind velocities and under varying speeds of "walking" motion. It was found that, (1) there is no significant difference between the surface thermal insulation measured on the non-sweating manikin and those measured on the sweating manikin, indicating the moisture transfer having little effect on the direct heat transfer through the surface air layer; (2) the surface moisture vapour resistances R_a measured under isothermal conditions tend to be greater than those measured under non-isothermal conditions, especially when the wind velocity is less than 2.0 m/s. The higher R_a under isothermal conditions is likely due to the increase of surface air layer with the absence of the temperature gradients. (3) The also study shows that Lewis relation holds under non-isothermal conditions, but does not hold under isothermal condition when the wind velocity is small. (4) The study further confirmed that the effect of "walking" motion can be regarded as an equivalent air velocity.

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ENHANCEMENT OF THE PHYSIOLOGICAL FUNCTION OF WATER AND AIR TIGHT PROTECTIVE CLOTHING IN HEAVY SWEATING SITUATIONS

Volkmar T. Bartels

Hohenstein Institutes, Department of Clothing Physiology, Boennigheim, Germany

Introduction

Water and air tight but water vapour permeable barrier textiles are used in many different applications like foul weather protective clothing, surgical gowns, chemical PPE, or fire fighter garments. A major property of this type of protective clothing is its wear comfort or physiological function. A great disadvantage of even “breathable” textile constructions is that they allow no liquid sweat transport in heavy sweating situations, because the barrier (membrane or coating) is liquid tight. As water tight protective clothing has frequently to be worn even while heavy sweating, the wear comfort in these situations is only poor.

In this work two new concepts are presented, which enhance the liquid sweat transport through water tight barrier textiles indirectly by a better transfer of the sweat to the membrane. They were part of research project, for which technical reports (in German) are available from the author [1, 2].

Methods

Textile samples

The first example presented here is foul weather protective clothing. Two 3-layer-laminates as well as a 2-layer-laminate with two different linings from a German manufacturer were investigated. The barrier textiles were provided with a) a conventional, hydrophobic lining and b) a new hydrophilic lining. Materials are characterised in table 1.

The second example is fire fighters protective clothing (see table 2). Here, a 2-layer-laminate with a liquid barrier is combined with different radiative heat protective textiles, for which a conventional nonwoven is compared to three newly designed 3D-spacer fabrics. The latter materials were produced by the Textilforschungsinstitut Thüringen-Vogtland (TITV), Greiz, Germany. The laminate and the nonwoven were purchased from an Austrian manufacturer of fire fighter protective clothing.

Table 1. Foul weather protective textiles investigated. All barrier textiles contain a hydrophilic PES-membrane. R_{ct} and R_{et} are the thermal insulation and the water vapour resistance, respectively, as measured according to EN 31092 or ISO 11092.

No.	Description	Lining	R_{ct} in 10^{-3} m^{2}K/W	R_{et} in m^{2}Pa/W
O1	3-layer-laminate	hydrophobic	14.7 ± 3.0	10.61 ± 0.51
O2	3-layer-laminate	hydrophilic	10.0 ± 3.0	7.18 ± 0.30
O4+F1	2-layer-laminate + lining	hydrophobic	17.9 ± 3.0	12.44 ± 0.60
O4+F2	2-layer-laminate + lining	hydrophilic	15.5 ± 3.0	12.35 ± 0.59

Skin Model tests

Apart from other tests (see [1, 2] for details), Skin Model measurements according to BPI 1.2 [3] were performed, leading to the following physiological parameters, which characterise the textile's management of liquid sweat:

The liquid sweat transport F_1, giving the amount of liquid sweat that is transported through the sample and can evaporate into the ambience.

The buffering capacity against liquid sweat impulses K_f, i. e. the ratio of liquid sweat transported or soaked up by the specimen over the total amount of liquid sweat that originally occurred on the skin. K_f ranges between 0 (all liquid sweat stays at the skin) and 1 (all liquid sweat is transported away from the skin).

Table 2. Protective textiles for fire fighters investigated. All materials are fire retardant. R_{ct} and R_{et} are the thermal insulation and the water vapour resistance, respectively, as measured according to EN 31092 or ISO 11092.

No.	Description	R_{ct} in 10^{-3} m^2K/W	R_{et} in m^2Pa/W
13	2-layer-laminate, 245 g/m^2, PTFE-membrane, 75 % meta-aramide, 23 % para-aramide, 2 % carbon	5.8 ± 3.0	4.85 ± 0.30
6	3D-spacer-fabric, 360 g/m^2, 3.3 mm thick, inside: polyester (74 %), outside: aramide + viscose (26 %)	69.4 ± 3.0	10.25 ± 0.49
7	3D-spacer-fabric, 422 g/m^2, 2.4 mm thick, surfaces: aramide (73 %), combining pile: aramide + viscose (27 %)	60.9 ± 3.0	10.61 ± 0.51
8	3D-spacer-fabric, 387 g/m^2, 2.0 mm thick, inside: aramide (80 %), outside: aramide + viscose (15 %), combining pile: polyester (6 %)	54.0 ± 3.0	6.39 ± 0.30
14	Nonwoven, para-aramide (50 %) + viscose (50 %). Stitched to lining meta-aramide (93 %), para-aramide (5 %), carbon (2 %)	115.1 ± 3.7	14.89 ± 0.71

Wearer trials with human test subjects

Wearer trials with human test subjects were performed in a climatic chamber. Test persons wore bike jackets made of the foul weather protective textiles O1 and O2, and a 2-layer functional underwear (U1), with a PES functional fibre at the inside and cotton at the outside. Three cycles of 30 min activity (riding on a bicycle ergometer) + 15 min rest periods (sitting) had to be performed. Ambient conditions were 20 °C temperature, 50 % relative humidity + slight wind. Details are described in [2].

Apart from other objective and subjective data, the overall wear comfort *WC* ranging from 1 "very good" to 6 "unsatisfactory" and the user's acceptance *A*, i. e. the amount of test persons, who would like to buy such a jacket, were determined by a questionnaire.

Results and discussion

Skin Model tests results

In fig. 1, the liquid sweat transport F_1 and the buffering capacity against liquid sweat impulses K_f of the foul weather protective textiles are shown. These Skin Model measurements clearly show the advantages of the new, hydrophilic lining construction: Firstly, the liquid sweat transport is significantly enhanced. In the case of the 3-layer-laminate, F_1 is more than doubled in comparison to the conventional, hydrophobic lining. For the 2-layer-laminate, the hydrophilic lining improves F_1 by 65 %.

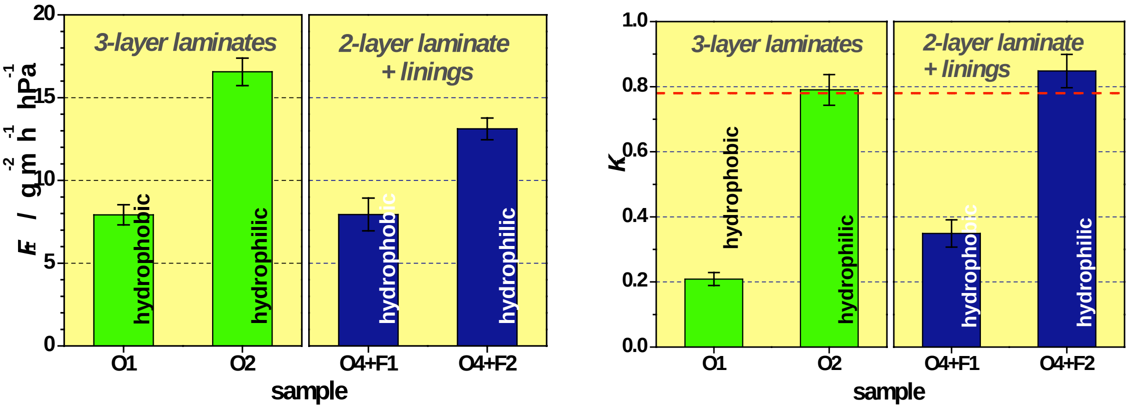

Figure 1. Skin Model measurements of foul weather protective textiles: Liquid sweat transport *F*1 (left) and buffering capacity against liquid sweat impulses *K*f (right).

Secondly, comparing the results for the buffering capacity K_f, only the hydrophilic versions of the foul weather protective textiles are able to achieve satisfactory results with $K_f \geq 0.78$ (red dotted line in fig. 1).

In fig. 2 the liquid sweat transport through the combinations of textiles for fire fighter garments is given. Here, all combinations with 3D-spacer-fabrics offer a better liquid sweat transport than that with the conventional nonwoven (13+14). In the best case (13+6), the enhancement amounts 51 % in comparison to the so far used materials. Hence, the 3D-spacer-fabrics offer a better wear comfort while heavy sweating situations than the nonwoven.

Wearer trials results

In fig. 3, the overall wear comfort *WC* perceived by the test persons and the user's acceptance *A* are given. It can be seen that *WC* is better (i. e. lower) for the hydrophilic variant by 0.75. Hence, the test persons were able to subjectively perceive its better wear comfort.

A huge difference occurs for the user's acceptance *A*: 75 % of the test persons would like to buy the jacket with the new hydrophilic lining, but only 25 % with the "old" hydrophobic one.

In conclusion, the Skin Model results are confirmed by the data from the wearer trials, exhibiting a better wear comfort and a higher acceptance by the test subjects while using the newly designed material.

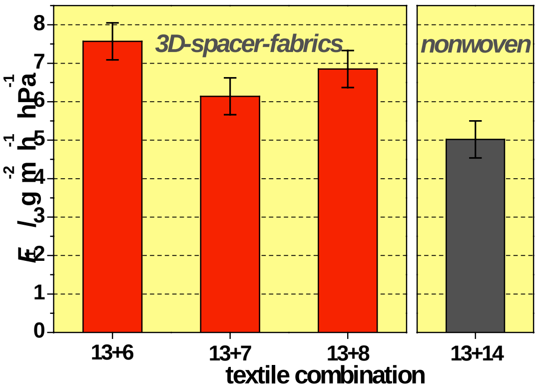

Figure 2. Skin Model measurements of combinations of protective textiles for fire fighter garments: Liquid sweat transport $F1$

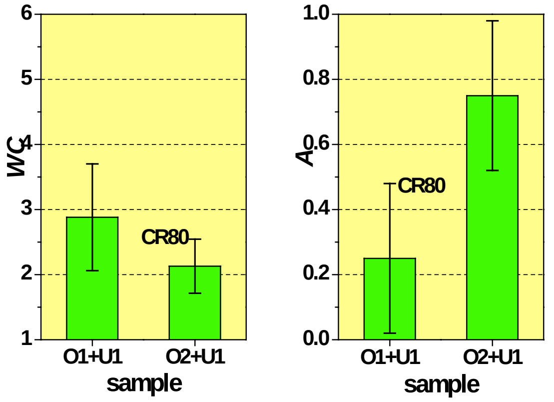

Figure 3. Wearer trials with human test subjects with foul weather protective textiles. Overall wear comfort *WC* (left) and user's acceptance *A* (right).

Conclusions

The wear comfort of water and air tight but water vapour permeable protective clothing in heavy sweating situations with the occurrence of liquid sweat can be improved:

For thin barrier textiles a hydrophilic lining is superior instead of a conventional hydrophobic one.

For thicker materials, offering also a thermal protection, three-dimensional spacer fabrics are favourable in comparison to so far used nonwovens.

Acknowledgement

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EFFECTS OF HEAT AND MOISTURE TRANSPORT IN FIREFIGHTER TURNOUT CLOTHING EVALUATED BY A SWEATING MANIKIN*

Jun Li [1,2*]**,** *Roger L. Barker* [2], *AND A. Shawn Deaton* [2]

[1] Fashion Institute, DonghHua University, Shanghai 200051, P. R. China
[2] Center for Research on Textile Protection and Comfort, College of Textiles, North Carolina State University, Raleigh, NC 27695, U.S.A
*corresponding author to lijun@dhu.edu.cn

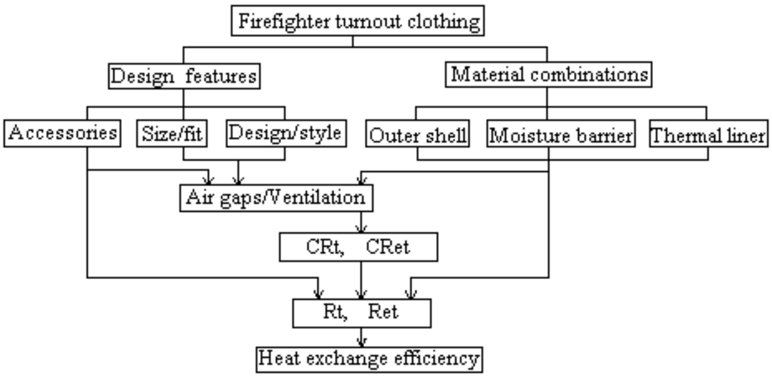
Introduction

The design of firefighter clothing is a compromise between protection and comfort (Veghte,1981). The extent to which the clothing affects the heat exchange between the fire fighter and the environment is a crucial parameter that should be considered when evaluating the effectiveness of fire protective clothing (Barker, 2000).

Clothing's heat and moisture transport performance is affected not only by many material characteristics, such as fabric thickness, weight, and air permeability, but also by design factors like style, size, accessory, and how a garment is worn (Yoo, 2000). The effects of the clothing design features therefore need to be understood. In this study, an advanced sweating manikin (Deaton) was used to evaluate firefighter turnout clothing's thermal insulation (*Rt*), moisture evaporative resistance (*Ret*). The purpose of this laboratory study was to develop a methodology to assess quantitatively the effects of clothing variables on heat and moisture transport performance of firefighter turnout clothing.

Evaluation model

In order to differentiate the effects of different clothing variables on heat and moisture transport in firefighter turnout clothing, an evaluation model was developed on the basis of the sweating manikin test, as shown in Figure 1. As the standard firefighter turnout clothing's three layers, outer shell, inner moisture barrier and thermal liner become three variables to define material system. From the design aspect, design/style, size, and accessory are summarized as another three explainable factors.



In sweating manikin tests (Deaton), *Rt* and *Ret* are regular output indices. For the air trapped between fabric's layers ventilation and diffusion are two ways to escape. In Figure 1, new indices *CRt* and *CRet* are introduced to describe the effects of ventilation on *Rt* and *Ret*. *CR*t and *CRet* are defined as the changing rates of *Rt* and *Ret* from the status of the clothing dressed on the manikin with openings unsealed (*Rtu*, *Retu*) to the openings sealed status (*Rts*, *Rets*), and can be calculated by the following equations:

$$CRt(\%)=|Rts-Rtu|/Rtu\times100, \qquad CRet(\%)=|Rets-Retu|/Retu\times100.$$

(Note: the lowercase "u" stands for openings unsealed; "s" stands for openings sealed.)

Under no sweating condition, little diffusion can occur because thick firefighter turnout clothing with a moisture barrier. Thus, *CRt* can indicate the size or style's effects on heat loss (Figure 1), and describe the contribution of ventilation to the heat exchange of clothing in dry state. Under sweating condition, even with openings sealed, the moisture diffused through material system can make a big difference on heat loss of different firefighter turnout clothing. Consequently *CRet* closely relates to the material properties, is also affected by clothing design features.

Experimental

Test garments

11 different firefight turnout clothing were selected as samples (Figure 2, Table 1, Table 2).


B1~6 G1 G2 G3 G4~5

Figure 2. Test garments.

Table 1. Clothing design features.

Sample ID	Design	Pocket	Enhanced/reinforced section	Other accessory	Size/Length (cm)
B1~6 Coat	Traditional	2 patch pockets; 1 liner pocket	Elbow with extra layer		44 /80
B1~6 Pant	Traditional (waist-length)	2 expansion slash pockets	Knee with extra layer		38 /73.7
G1 Coat	Traditional	2 expansion pockets; 1 liner pocket; 2 radio pockets; 1 mask pocket	Shoulders/Upper Back and elbows padded; elbows reinforced	Letter patch on back	42 / 89
G1 Pant	Traditional (waist-length)	2 expansion pockets; 2 front rear pockets	Thermal seat/knees padded with extra layer in liner, seat reinforced	Flashlight loop	36 / 71
G2 Coat	Same as G1	1 liner pocket	No		42 / 89
G2 Pant	Same as G1	No	No		36 / 71
G3 Coat	Jacket	2 expansion pockets; 1 radio pocket	Shoulders/Upper Back padded with extra layer in liner	Universal clip; Nomex hand guard	42 /81
G3 Pant	Bibbed pants	2 expansion pockets; 2 rear pockets	Back bib padding for SCBA; knees padded and reinforced		36 / 71
G4~5 Coat	Same as G3	2 Hand warmer Dual-Action Pockets; 1 liner pocket	Shoulders/Upper Back padded with extra layer in liner		42 / 89
G4~5 Pant	Same as G3	2 expansion pockets	Back bib; knees padded		36 / 71

Table 2. Material characteristics.

Sample ID	Component			Weight (g/m^2)	Thickness (mm)
	Outer shell	Moisture Barrier	Thermal Liner		
B1	255 g/m^2 ripstop weave, 60% Kevlar /40% PBI Blend	Barrier 1 PTFE laminated on aramid/para-aramid spunlace	Liner 1 238 g/m^2 aramid/para-aramid spunlace quilted to aramid facecloth	678.3	4.98
B2	Same as B1	Barrier 1	Liner 2 238g/m^2 para-aramid batt quilted to aramid facecloth	666.1	5.28
B3	Same as B1	Barrier 2 Polyurethane laminated fabric	Liner 2	673.9	5.08
B4	Same as B1	Barrier 3 Neoprene enduit/polycotton	Liner 2	926.5	4.17

B5	Same as B1	Barrier 1	Liner 3 Nomex-para aramid batt laminated to Nomex multifilament	663.3	4.90
B6	Same as B1	Barrier 2	Liner 1	686.5	4.88
G1~ G2	Same as B1	Barrier 3 PTFE laminated on 170 g/m^2 Nomex substrate	Liner 4 241.4 g/m^2 layer aramid/para-aramid spunlace quilted to aramid facecloth	666.4	2.70
G3~G4	Same as B1	Barrier 3	Liner 5 267 g/m^2 para-aramid batt quilted to aramid facecloth	666.4	2.70
G5	Same as B1	Barrier 4 polyurethane laminated to non-woven substrate 146 g/m^2	Liner 6 316 g/m^2 aramid batt, quilted to aramid face cloth	691.9	4.01

Test procedure

To simulate the real firefighter turnout protective clothing wearing statuses, test garments were dressed in the manikin by tightening the wrists, ankles, and the waist with threads; and sealing the neck with impermeable tape. On the other hand, garments were tested with openings unsealed.

The NCSU sweating manikin is capable of internally generating a controlled supply of moisture through 187 individually controlled sweat glands. The ability to precisely control sweating over lengthy test periods has been lacking in previous thermal manikin technologies. *Rt*, *Ret*, the permeability index *im*, and *im/It*, the coefficient of evaporative heat transfer, are calculated.

Results and discussion

The testing results were listed as an average of at least three independent replications in Table 3.

Table 3. The sweating manikin test results.

	B1	B2	B3	B4	B5	B6	G1	G2	G3	G4	G5
Rtu, m^2°C /W	0.297	0.326	0.320	0.322	0.273	0.317	0.349	0.294	0.375	0.346	0.377
Retu, m^2kPa /W	0.047	0.048	0.055	0.076	0.047	0.051	0.057	0.045	0.049	0.051	0.065
imu	0.379	0.402	0.353	0.256	0.347	0.376	0.370	0.396	0.463	0.405	0.350
Rts,m^2°C /W	0.359	0.395	0.384	0.386	0.329	0.380	0.390	0.348	0.412	0.388	0.426
Rets, m^2kPa /W	0.062	0.062	0.076	0.142	0.058	0.069	0.079	0.054	0.066	0.063	0.083
ims	0.351	0.383	0.305	0.163	0.344	0.331	0.295	0.386	0.380	0.363	0.309
imu/itu	0.198	0.191	0.171	0.123	0.197	0.184	0.164	0.209	0.192	0.181	0.144
ims/its	0.151	0.150	0.123	0.066	0.162	0.135	0.117	0.172	0.143	0.145	0.113
CRt, %	20.86	21.05	19.94	19.93	20.33	19.82	11.66	18.46	10.01	12.33	13.09
CRet, %	30.64	30.57	38.89	86.91	23.29	36.33	39.59	21.50	34.90	23.01	28.06

With openings sealed all garments' *Rt* and *Ret* increase significantly (confidence level a=0.05), while *im* decreased significantly, than with openings unsealed. As the main effect, sealing the openings makes heat loss more difficult from thick and heavy firefighter turnout clothing.

Effects of material components

The impermeable moisture barrier (Barrier 3) in B4 is inferior to the moisture permeable barrier in B2 (Barrier 1) and B3 (Barrier 2). Barrier 1 is better than Barrier 3 in B6, based on B1's higher *im/It* value. Impermeable moisture barriers greatly resist evaporative heat loss from the wearer, and moisture barrier's property has strongly affected on moisture permeability of test garments.

Considering *Ret*, it can be concluded that Liner 3 in B5 is a little superior to Liner 1 in B1, and B2's Liner 2 is not as good as Liner 3 in B5 and Liner 1 in B1, but their difference are not significant. Thermal liner affects heat and moisture transmission through firefighter turnout clothing, but the effect is not as strong as moisture barrier.

Effects of clothing construction features

With same design features the garments B1~6 have close *CRt* values. So do G4 and G5. In addition *CRt* of the B1~6 group are different to which of G4-G5 group, because the two groups have different style. The ventilation from B1~6 group garments contribute more to heat loss.

B1~6 have obviously different *CRet* individually. Different material combinations made big differences on *CRet* values due to their different moisture permeability. The garment with better moisture permeability (lower *Ret*) certainly had a lower *CRet*.

Traditional style test garments (except B4 with an impermeable barrier) have lower *Rt*, *Ret*, and *CRt* than G3, G4, and G5. It suggests traditional style has a comparative advantage over the style with bibbed pants on heat loss.

With much more accessories than G2, G1's *CRt* and *CRet* values are lower than G2's,while G1 has a significantly higher *Rt* and *Ret*. So do G3 and G4. Apparently accessory resists heat transfer, especially when moisture exists. Accessory reduces the heat loss form the wearer by changing the garment's thickness and surface area and restricting moisture evaporation.

B1~6's *CR*t are higher than which of G1 and G2, mainly because B1~6's size are larger than G1 and G2. All B1~6 with large size have higher *CRt* than G1-G2 with small size. Large size results in thick air gaps under clothing, which contributes to ventilation through openings.

Conclusions

By using a new generation sweating manikin, this research demonstrated the use of the methodology that can evaluate heat and moisture transfer performance of firefighter turnout clothing. From the clothing's point, outer shell, moisture barrier, and thermal liner in the aspect of material, design/style, size/fit, and accessory in the aspect of clothing design were concluded as six decisive factors. Their effects on heat loss of firefighter garments were described by responsible indices *Rt*, *Ret*, *CRt*, and *CRet*.

CRt, and *CRet*, the changing rates of *Rt* and *Ret* under two different dressing ways, with openings sealed or not, were introduced as new indices. *CRt* described the effects of clothing design variables on heat transfer through firefighter turnout clothing, while *CRet* was dependent greatly on which material prosperities (moisture permeability).

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THE OPTIMIZATION OF CLOTHING THERMAL COMFORT DESIGN, USING MULTIVARIATE ANALYSIS

Ana Cristina Broega, Maria Elisabete Cabeço Silva*

Departamento de Engenharia Têxtil, Universidade do Minho, Campos Azurém,
4800-058 GUIMARAES, Portugal
* corresponding author cbroega@det.uminho.pt

Introduction

Comfort is one of the most important aspects of clothing, mainly for next-to-skin garments such as trousers for summer. The perceived comfort of wearers of these garments depends to a great extent on the tactile and thermal-moisture properties of the fabrics. In addition, the environmental conditions and activity level of the wearers also influence the perceived comfort of garments [1]. From this point of view, we may suggest to classify comfort into three groups: Psychological, Sensorial, and Thermal Comfort.

Psychological comfort bears little relation to the fabric's properties and is mainly related to the fashion trend prevailing in the society [2].

Sensorial comfort is essentially a result of how much stress is generated in the fabric and how it is distributed over the skin and therefore has a strong relationship with both the mechanical and surface properties of the fabric.

Thermal comfort is related to the fabric's ability to maintain skin temperature and allow transfer of perspiration produced from the body. Factors affecting the thermal behavior of clothing will include the dry thermal insulation, transfer of moisture and vapor through clothing (sweat), heat exchange with clothing (conduction, convection, radiation, evaporation and condensation), compression (caused by high wind), pumping effects (caused by body movement), air penetration (through fabrics, vents and openings), subject posture, etc. [3].

In this study, concerning the woollen sector, the trends towards lighter and lighter fabrics have significantly influenced the recent evolution of the wool industry, the weight of traditional woven fabrics for jackets and suits has decreased in a probable irreversible way.

A typical example of that is the new class of products: “Italian Cool Wool”, a name that was firs introduced by a group of Biellese companies, with the aim of launching on the market a new kind of fabrics, the weight of which was comprised in the range of about 210 to 270 g/m.

One of wool's unique properties is its high hygroscopicity, which enables wool clothing to exhibit superior thermal comfort performance under various dynamic wear situations. Many researchers have investigated the influence of buffering by hygroscopic fabrics upon removal of moisture from the clothing microclimate [4,5,6].

Fabric mechanical and thermophysiological properties such as tensile, bending, shearing, compression and surface properties can be measured by the four modulus of KES-FB System and thermal conductivity, thermal diffusivity, thermal isolation can be evaluated by Thermolabo and Alambeta instruments. All these apparatus are generators of big amount of data which needs to be analyzed, and it takes a lot of time and experts in this area.

An approach to assessing the thermal behavior of clothing is given in this paper utilizing multivariate analysis techniques in order to reduce data and point out the most significant properties from the point of view of the thermal comfort.

Methodology

For this study we used light-weight wool woven fabrics for making men summer suits by comparing different commercially available wool fabrics of high quality, including Italian “cool wool” material (TD26 and PD26). We made two fabrics different in tactile properties, traditional “springly touch” fabric, (TD38 and PD38), made with yarns of 38,5 tex (2/19,3 tex), manufactured with wool material considered economically standard, fiber diameter of 21 μm. To give to this fabric a "fresh touch" we used yarns with twist and retwist Z, contrarily to all the other of materials that the yarns were manufactured by a traditional process of twist Z and retwist S, (it has also higher twist level comparing whit the others fabrics yarns). All the fabrics are made of plain weave structure.

The fabrics were finished in two different ways, piece dyeing (PD) and yarn top dyeing (TD) and the final dry finishing was the some for all the fabrics (Shearing, Continuous Decatizing, Kier Decatizing and Steaming). A summary of the characteristics of the fabrics used in this study is given in Table 1.

The fabrics properties (thermal, mechanical and transport properties) were measured, mainly by KES, Termolab, Alambeta, Air Permeability Tester and Water Vapour Permeability Tester.

Factor analysis technique was used to reduce the dimensionality of a large number of fabric mechanical and thermophysiological properties and to know the most important properties of these fabrics in the thermal-sensorial comfort context. Parameters used in the factor analysis for the thermophysiological properties are shown in Table 2.

Table 1: Fabric Specifications

Fabric COD	Composition	Warp Count (tex)	Weft Count (tex)	Mass per unit area (g/m^2)	Thickness (mm)	Finishing
TD20	Wool	10,9 x 2	18,2 x 1	130	0,402	TD
PD20	Wool	11,0 x 2	18,6 x 1	137	0,407	PD
TD25	Wool	12,5 x 2	12,5 x 2	137	0,408	TD
PD25	Wool	12,5 x 2	12,5 x 2	142	0,408	PD
TD26	Wool	13,2 x 2	13,2 x 2	142	0,411	TD
PD26	Wool	14,0 x 2	14,0 x 2	162	0,424	PD
TD31	Wool	15,7 x 2	15,7 x 2	152	0,412	TD
PD31	Wool	15,7 x 2	15,7 x 2	155	0,440	PD
TD38	Wool	19,3 x 2	19,3 x 2	189	0,557	TD
PD38	Wool	19,3 x 2	19,3 x 2	189	0,575	PD

Table 2: Factor analysis after rotation of the fabrics thermophysiological properties

	Factor		
Parameters	**F1**	**F2**	**F3**
AP – Air Permeability (l/m^2/s)	0,938		
WVPI - Water Vapour Permeability Index		0,979	
Qmax – warm/cold feeling (W/m^2)			
TC – Thermal Conductivity (W/mºk)	0,972		
TID – Thermal Isolation at Dry State (%)			
TIW - Thermal Isolation in presence of Moisture (%)			
CP – Compression properties (%)			
BD - Bulk Density (Kg/m^3)			-0,922
T – Thickness (mm)	0,951		
TD - Thermal Diffusivity (m^2/s)			
% of variance	49,445	23,627	14,169

The value for the KMO (Kaiser-Meyer-Olkin index) is 0,79 in our case, so we can proceed with the factor analysis.

The principal components method has been used to know how many factors we can fix, so we run the analysis choosing the option of finding factors with eigenvalues more than 1. This analysis is in some way a trial run to see how many factors there could be.

Applying the principal components analysis it shows that almost 87,2 % of the total variance is attributable to the three factors. The other factors together, account for only 12,8 % of the variance. Thus, a model of three factors may be adequate to represent the data. After fixing the three factors, the factor analysis techniques are been applied.

The factor matrix obtained in the extraction phase, of the factor analysis techniques, indicates the relationship between the factors and the individual variables; it is usually difficult to identify meaningful factors based on this matrix. Consequently we use the most commonly rotation schema the Laiser's Varimax rotation in our data analysis, to minimize the number of variables that have high loadings on a factor. The Table 2 shows the factors greater or equal to 0,75 after rotation.

Results and Discussion

Factor analysis techniques are been applied to the data and the results show that almost 87.2 % of the total variance is attributable to three factors. The other factors together, account for only 12.3 % of the variance. Thus, a model with three factors may be adequate to represent the data.

The first factor explains almost 50 % of the total variance and associates of this factor are the Air Permeability (AP), Thermal Conductivity (TC) and Thickness (T), the second factor is associated to the Water Vapour Permeability Index (WVPI) and explains 23,62 % of the total variance. Associated with the third factor is the Bulk Density (BD), so we can suggest those are the most important fabric's properties responsible for the thermal comfort. Therefore should be enough to interpret these parameters to conclude about the thermal comfort of these materials.

The results obtained from Air Permeability tester is given in Figure 1. The Air Permeability refers to the accessibility of void space interfibers in the yarns and/or interyarns of a fabric, depends upon the yarn count, yarn compact density, and fabrics constriction density (spicks/cm). Therefore, fabrics coded PD38 and TD38 made of thicker yarns count and higher twist level (twist and retwist Z) would give the highest fabrics permeability.

The transmission of heat through a fabric occurs by conduction through the fiber, by radiation and convection of the entrapped air. Practical method of test for thermal conductivity (TC) of a fabric, measure the total heat transmitted by the different mechanisms. We can relate this property with the Thickness properties (T) in order to calculate the thermal resistance (TR) or the isolation parameter Clo, and predict the thermal comfort of this kind of materials.

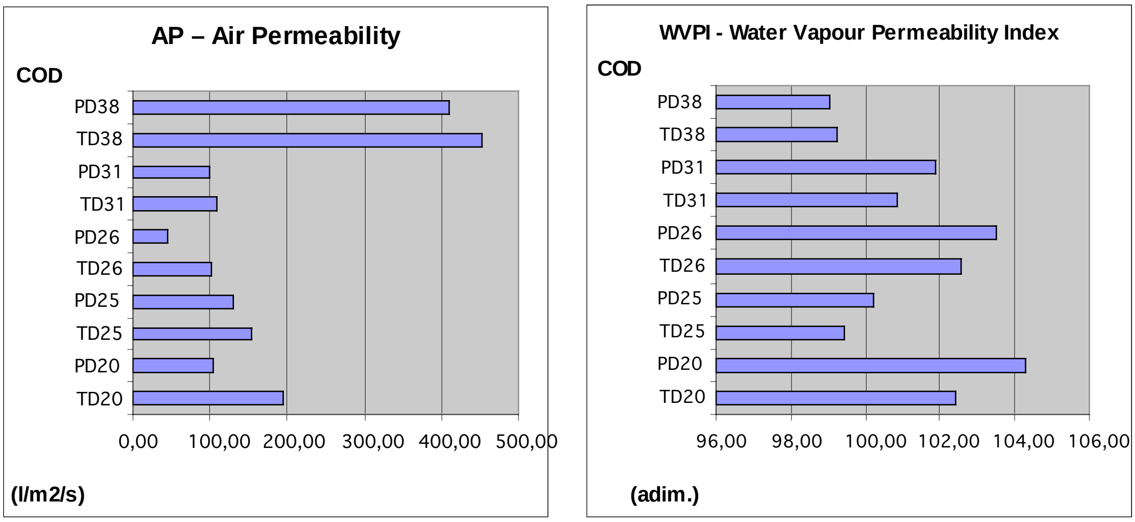

Figure 1: Results of the Air Permeability tester and the Water Vapour Permeability Index (WVPI)

In the Figure 2 is given the Predicted Mean Vote PMV of Fanger (1970), considered a men at metabolic rate (M) of a 1.2 Met (sedentary activity at office, home, school, laboratory), in *relative humidity* of 50% and 22ºC of Temperature [3].

Interpreting the thermal sensation of the PMV (with the scale: +3 hot; +2 slightly warm; +1 warm; 0 neutral; -1 Slightly cool; -2 cool; -3 cold), we can say that the lower is the PMV value the best will be the thermal comfort sensation of this fabric applied to making men summer suits (for hot-warm weather condition). The fabrics made from the finest yarns exhibits the lowest PMV and in this class, the Italian "*cool wool*" material (TD26 and PD26) present the best results.

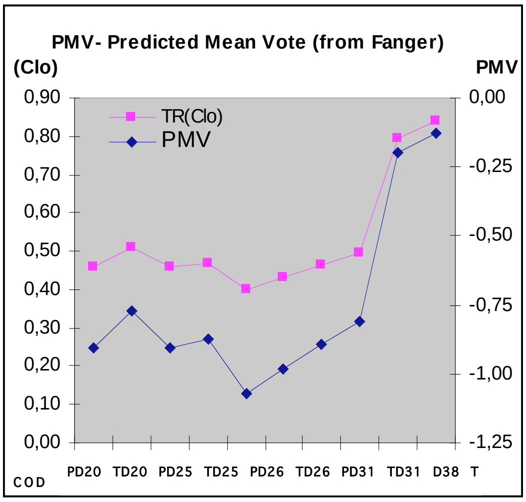

Figure 2: Results of the Thermal Isolation (Clo) andthe Predicted Mean Vote PMV of Fanger (1970)

The Water Vapour Permeability Index (WVPI) obtained from the water vapour permeability tester is presented in Figure 1. Under normal or stationary conditions, the human body produces little perspiration or saturated water vapour and the Water Vapour Permeability Index (WVPI) is the measure of moisture manageability of the fabric to remove this perspiration from the microclimate next to the skin, for that the wearer does not experience any significant discomfort.

High values of WVPI represent high level of water vapour transfer through the fabrics and good comfort performance of clothing. From this point of view we can say that the Italian "cool wool" material (TD26 and PD26) and the lighters ones (TD20 and PD20) have the bets results in terms of moisture manageability.

Conclusions

The application of factor analysis techniques to data permits to identify the most appropriate physical and mechanical properties to characterize the thermal comfort of the wool light fabrics, reducing the number of variables and time testing, which is becoming an essential part of clothing design and evaluation.

Although, the fabrics coded PD28 and TD28 had the highest fabrics air permeability witch can represent a high accessibility of void space inside the fabric, those present the lowest results in transport properties such as water vapour permeability and a high thermal resistance. Those last parameters responsible for the temperature exchanges and moisture flux through the fabrics, witch govern the cloth perceived comfort (PMV).

This fact can be explained by knowing that when a wool fibber absorbs moisture, a certain amount of heat is liberated. Moreover, the changes in fiber dimension caused by moisture absorption lead to changes in fabric thickness and permeability, hence thermal and moisture related properties and fiber characteristics are related to each other.

The results presented above strongly suggest that the Light-weight Wool Fabrics principally the Italian "*cool wool*" are the best in terms of thermal comfort, once they had the best results in terms of the Predicted Mean Vote and water vapour permeability index.

This work shows the potential of the data techniques, namely multivariate analysis and the comfort science, applied in textiles and apparel production, is a design powerful tool, permitting to identify the most appropriate physical and mechanical properties to define the textile comfort of the wool light fabrics, reducing the number of variables and time testing which is a big advantage for the wool industry.

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EFFECTS OF LAYER DESIGN ON CONDENSATION WITHIN COLD WEATHER CLOTHING ENSEMBLES

Shinjung Yoo,Eun Ae Kim*

Functional Textile System Research Laboratory, Department of Clothing and Textiles, Yonsei University, 134 Shinchon-dong Seodaemoon-gu, Seoul, 120-749, Korea
* corresponding author sjyoo@yonsei.ac.kr

Introduction

When water vapour concentration in a clothing system exceeds the saturation level for the local temperature, condensation takes place throughout the layers of the clothing system. Functional garments for cold weather are likely to be exposed to conditions conducive to condensation since they usually consist of several layers of high insulating textiles and a waterproof breathable fabric as an outer shell. Consequently, the vapour permeability of the clothing system easily deteriorates, and large temperature gradients are developed within the system. Accumulated moisture may then freeze and be trapped within the clothing system and cause a reduction in heat resistance as well as wearer discomfort. As such, it is critical that condensation in the clothing system be prevented, especially under cold weather conditions and when the clothing is used in high activity levels that raise production of sweat such as winter sports and other physical activities.

The moisture vapour transfer properties of a fabric are dependent not only on the water vapour resistance but also on the thermal resistance of the fabric. Several researchers have developed numerical models for heat and vapour transfer with or without condensation [1, 2, 5], and some studies focused on condensation and its effects on the water vapour permeability of waterproof breathable fabrics [6]. However, since a clothing system seldom consists of a single layer, especially for cold weather, the experimental data from an individual layer in a clothing system [3] is not relevant to the prediction of the performance of the fabric under real use conditions.

In this study, we investigate condensation on the individual layers of multilayer cold weather protective ensembles. To consider the effects of layer design, three different layer layouts comprised of identical fabrics are assessed and a series of experiments on combined heat and moisture vapour transfer through the clothing systems is performed. We examine the condensation profiles of individual layers in the three layouts as well as the effects of sweat amount on the condensation profile by applying a different amount of water to simulate light and heavy sweat rates.

Methods

We used a newly developed Human-Clothing-Environment (HCE) simulator [4] for the experiment. The HCE is comprised of a vertical type-sweating hotplate with multiple cartridges for fabric layers to simulate a clothing system and two independent climate chambers. Utilizing this device, we can monitor the effects of cyclic changes of environmental conditions if a test material is subjected to two different sets of conditions by attaching the vertical type hot plate to the both chambers alternately. In addition, the vertical type sweating hot plate provides effective simulation (better than what? Or do you mean “effective”?) of the heat and moisture transfer mechanism from the body surface through a clothing system to the environment. Further details of the simulator can be found in a previous paper [4].

For a cold weather clothing system, five layers of fabric were selected. A PET underwear fabric was utilized for the innermost layer and three identical PET fleece fabrics were employed for the 2nd to 4th layers. A waterproof breathable fabric was added as an outer shell. The properties of the PET fleece fabrics are 246.9g/m^2 weight, 1.63mm thickness, 103.33 ㎤/㎠/s air permeability, water vapour resistance R_{et}=11.68 m^2 Pa/W, and thermal resistance R_{ct}=0.083 m^2°C /W. The waterproof breathable outer shell is a 2-layer-laminate with microporous PTFE membrane and 100% PET surface layer, 120 g/m^2 weight, water vapour resistance R_{et}=7.29 m^2 Pa/W, and thermal resistance R_{ct}=0.019 m^2°C /W. The five layers of fabrics were mounted on the fabric frames and placed on the sweating hot plate in different layouts, as outlined in Figure 1. Between each fabric layer there are temperature and humidity sensors for real-time monitoring of the microclimate temperature and humidity within each layer.

For the test, the hot plate temperature was set at 33±0.5°C to simulate the human body’s skin temperature at a comfortable condition, and the plate was covered with an absorbent fabric to function as a sweat distributor. To simulate light and heavy sweating, 2 and 5ml of distilled water were applied respectively. These are approximately equivalent to 65 and 160 g /m^{2}hr of sweat rate. The test was conducted at -15±0.5°C, 20±5% to simulate cold conditions.

The data of the temperature and the relative humidity between each layer were collected and recorded every 30 seconds through a data logging system over a period of 1 hour and the vapour pressure profiles were calculated from the data. The amount of condensation on each layer was measured by weighing each fabric layer before and after the test for further analysis.

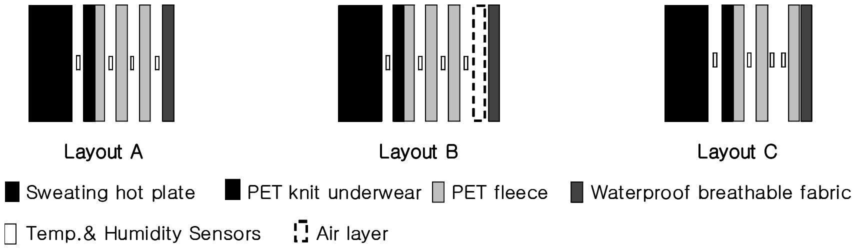


Figure 1. Five-layer cold weather clothing layouts
(Layout A: All separated; Layout B: separated with an extra air layer; Layout C: 4th and outer shell combined)

Results and discussion

Figure 2 shows the vapour pressure profiles between layers for the two different sweat amounts. In the case of light sweat (60g/m^{2}hr), vapour pressures between the skin and underwear fabric (innermost microclimate) and the 2nd and 3rd layers start to drop after about 30~40 minutes, indicating that most of the applied moisture on the skin moves toward the outer layers. In contrast, the vapour pressures of the heavy sweat condition were maintained at a high level throughout the test. Comparing the vapour pressures of the different layouts at the light sweating condition (Figure 3), layout “B”, which is identical to layout “A” except for an extra air layer between the 4th layer and outer shell, has the highest vapour pressure and layout “C” (4th and outer shell combined) dries more rapidly than the others. However, for the heavy sweating condition, a clear trend for the effects of layout on the vapour pressure profile cannot be found. Even though the extra air layer in layout “B” provides higher vapour pressure within the clothing system, it does not seem to affect moisture condensation. As presented in Table 1, while the total amount of condensation is similar for the three layouts, a slightly larger amount of condensation takes place within layout “A” and the smallest condensation level is found in layout “C”. This basic pattern recurs for the heavy sweat condition as well. However, it is clear that quite different behaviours are produced in individual layers as a function of the layer layout. The amount of condensation in the individual layers for three layouts at different sweat levels is presented in Figure 4. Most condensation takes place at the 3rd and 4th layers and more condensed moisture is trapped on the outer side of the 4th layer of layout “A” at the light sweat condition. On the other hand, in the case of layout “C”, for both sweat levels the largest portion of condensation takes places at the 3rd layer. Fukazawa et al. [2] have shown that condensation mass flux can be estimated by condensation potential and condensation resistance, which are a function of the moisture vapour and thermal resistance of a material. In this experiment, since we used identical fabrics and environmental conditions, the vapour and thermal resistances of the overall clothing systems might be very similar. Thus, the total amount of condensation could show little variation for the three layouts. However, the individual layers have different condensation profiles; layout “A” could have advantages in terms of wearer comfort because the condensed moisture is kept away from the body as compared to Layout “C”.

Conclusions

Because of the importance of condensation with respect to clothing comfort and thermal physiology, many researchers have attempted to predict condensation within cold weather clothing systems by using numerical models [1, 2]. We have shown that the layer layout of a multiplayer clothing system can alter the condensation profile within each garment layer, even if the total condensation mass flux is almost the same. When the insulating layer is separated from the waterproof breathable fabric, condensed moisture is kept away from the body efficiently. The results obtained here can provide useful insight into the layer design of cold weather protective gear.

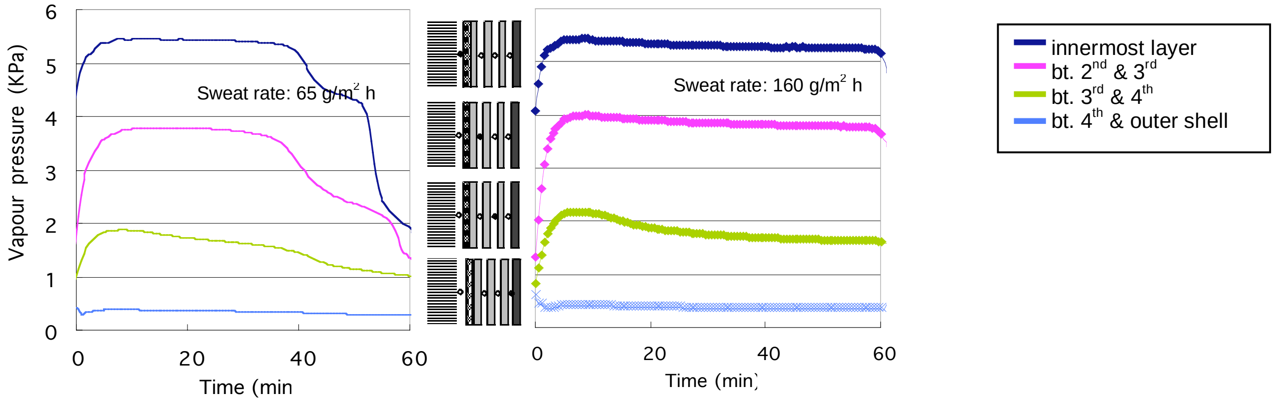


Figure 2. Microclimate vapour pressure between layers at different sweat rates (Layout A)

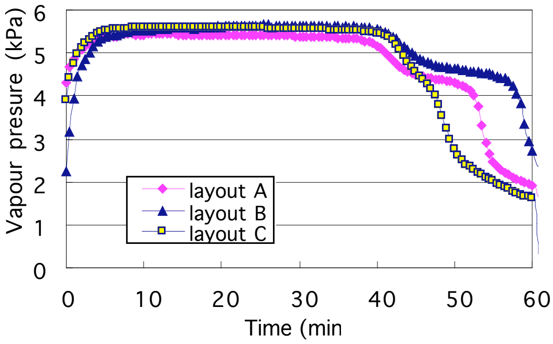
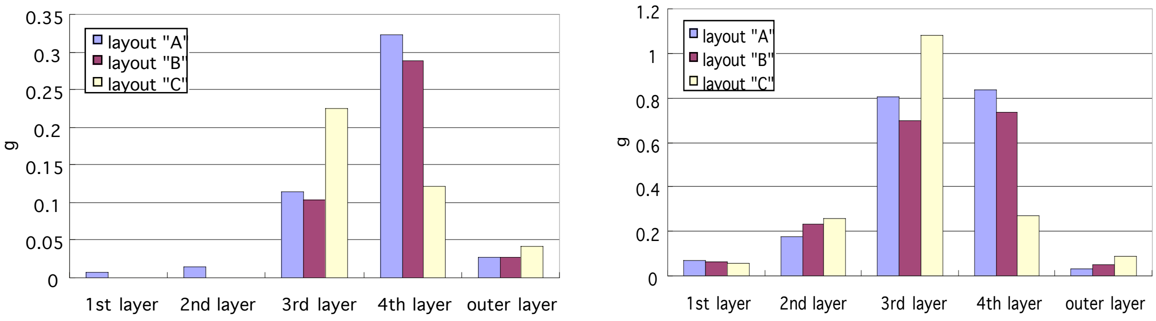


Figure 3. Microclimate vapour pressures of innermost layer for different layouts at sweat rate=60g/m^{2}h, Layout A:separated; B:separated with extra air layer; C:4th and outer combined.

Table 1. Total amount of condensation of different layer layouts of cold weather ensembles at two sweat rates

Layout	**Sweat Rate** **65 g/m^2 hr (light sweat)**	 **160 g/m^2 hr (heavy sweat)**
A	0.485	1.792
B	0.418	1.779
C	0.388	1.755



(A) Sweat rate 65 g/m^{2}h

(B) Sweat rate 160 g/m^{2}h

Figure 4. Amount of condensed moisture in each layer at different sweat rate

Acknowledgement

This work was supported by the Ministry of Science and Technology in Korea through the 2002 National Research Laboratory Program (M1-0203-00-0077).

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PHASE CHANGE MATERIAL IN HIKING BOOTS DOES NOT MINIMISE THE RISK OF COLD INJURY

Igor B. Mekjavic[1], Bojan Andlovec Korosec, Martin Tomsic[1], Petra Golja[2]*

[1]Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute,
Jamova 39, SI-1000, Ljubljana, Slovenia
[2]Nova Gorica Polytechnic, Kostanjeviska cesta 16, Pristava, SI-5000 Nova Gorica, Slovenia
*corresponding author: igor.mekjavic@ijs.si

Introduction

The present study compared the thermal insulation properties of hiking boots (Alpina d.d., Slovenia) containing a layer of either Sympatex® or Outlast® Phase Change Material (PCM). PCM contains paraffin filled microcapsules, which change their state of aggregation with changing temperature. In the process of being heated from a solid state, PCM liquifies and absorbs a certain amount of thermal energy. Conversely, during cooling, PCM changes from a liquid to a solid state and releases thermal energy. We therefore tested the hypothesis that the exothermal reaction of the phase change material during exposure to cold may provide better thermal insulation and thus offer greater protection against cold injury of the feet.

Methods

Twenty subjects (10 males and 10 females) participated in the study. The protocol of the study was approved by the National Ethics Review Committee (Republic of Slovenia).

Subjects participated in two trials separated by a minimum of 5 days. During each trial they wore the same clothing, with the exception of the hiking boots (Alpina d.d., Ziri, Slovenia). In one trial, the boots incorporated Outlast® as the thermal insulative layer and in the other Sympatex®. The study was a double blind study; namely both the experimenters and subjects were naïve regarding the boots tested. The external appearance of the boots was identical. Approximately 30 minutes prior to each experiment, the boots were wrapped in a polyurethane bag and immersed in a bath of water maintained at 30°C. Prior to donning the boots, the subjects left foot was instrumented with temperature and heat flux transducers. Once instrumented, both booted feet were then placed in the separate thin polyurethane bags and immersed to within 1 cm of the top of the boot in 30°C water for 20 minutes. Thereafter, the feet were immersed in a similar manner in bath of water maintained at 15°C.

During the immersion we monitored skin temperature of the upper arm (lateral aspect), chest (mid-clavilcular line, at the level of the 3rd intercostal), mid-thigh (anterior aspect), and mid-calf (lateral aspect) with YSI 401 thermistors (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Heat flux and skin temperature (Tsk, °C) was monitored with Concept Engineering Heat Flux transducers at six sites on the left foot: toe (bottom), arch, heel, top of toes, instep, lateral. All measurements were recorded at minute intervals. Skin temperature from the torso was recorded with a Biopac data acquisition system controlled by Acknowldege Software on a Macintosh computer. Foot skin temperatures were recorded with an Almemo data acquisition system (Ahlborn Mess-und Reglungstechnik GmbH, Holzkirchen, Germany). Tympanic temperature (Tty, °C) was recorded every 30 minutes with an infrared thermometer (ThermoScan IRT 3020, Braun, Kronberg, Germany).

The differences between the average regional skin temperatures and heat fluxes observed with the two prototype hiking boots were compared with a one way repeated measures ANOVA.

Results

Average unweighted Tsk and Tty were identical during the two trials. There were no statistically significant differences in any of the foot Tsk (Fig. 1 and 2) or heat fluxes between the two boots containing Sympatex® or Outlast®. Overall thermal insulations of the boots determined with a Thermal Foot Manikin were 0.167 m^2K/W and 0.163 m^2K/W for the Sympatex® and Outlast® boots, respectively. The difference was not significant.

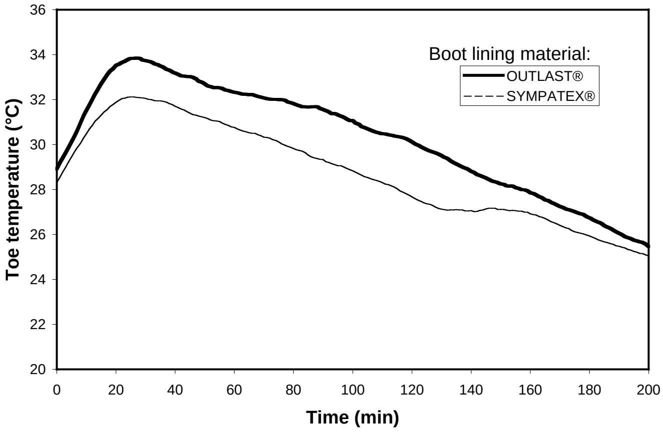

Fig. 1: Average toe temperature during 30 minutes immersion in 30°C water, followed by 3 hr immersion in 15°C water. Subjects wore hiking boots containing a layer of either Outlast® Phase Change Material (thick line) or Sympatex® (thin line).

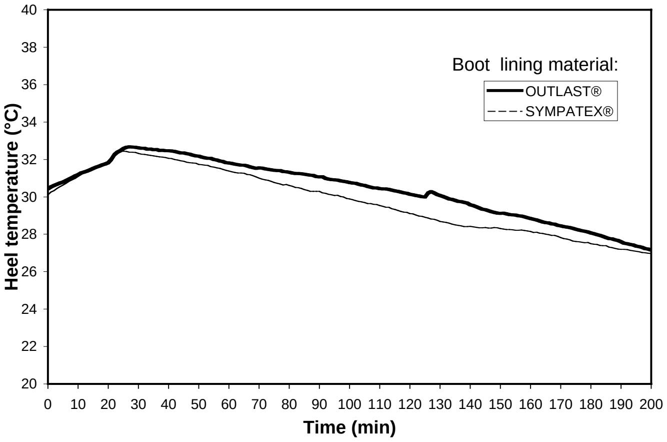

Figure 2: Average heel temperature during 30 minutes immersion in 30°C water, followed by 3 hr immersion in 15°C water. Subjects wore hiking boots containing a layer of either Outlast® Phase Change Material (thick line) or Sympatex® (thin line).

Conclusions

In contrast to the reported benefits of incorporating PCM in cold protective clothing (1), our findings concur with those of Endrusick et al. (2), namely that Outlast® Phase Change Material does not improve the thermal insulation properties of hiking boots.

Acknowledgements

Supported, in part, by a Science for Security and Peace grant (project no. M2-0018) from the Ministry of Defence (Republic of Slovenia), and by Alpina d.d. (Ziri, Slovenia).

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PROTECTIVE CLOTHING – RELATED HEAT STRESS ON FIREFIGHTERS IN JAPAN

Yutaka Tochihara[1]**, Mizuho Fujita*[1]*, Takahiro Ogawa*[2]

[1] Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka , Japan
[2] Japan Fire Retardant Association, Tokyo, Japan
* corresponding author tochi@design.kyushu-u.ac.jp

Introduction

Firefighters conduct dangerous missions. Firefighters' protective clothing should be designed with great heat, flame, and water-resistant properties to protect wearers (1). On the other hand, it must also be designed to alleviate physiological strain and discomfort. The strain and discomfort occur when wearing the protective clothing in conditions of great thermal storage by the body metabolism and heat stress from fire (2-4). Alleviating physiological strain and discomfort could result in firefighters' increased ability to concentrate on efficient firefighting. We conducted a questionnaire study with 796 Japanese firefighters to investigate their experience of heat illness during practice and firefighting work and their evaluation of their protective clothing.

Methods

Questionnaires about firefighters' training, work, and protective clothing were distributed to firefighters working in 16 fire departments in Japan. The questionnaires, completed individually, asked about their previous year's experience of heat illnesses during training and work and their own evaluation of their protective clothing from various points of view. Data were collected on 796 firefighters. Their average (range) of age, height and weight were 39.8 (18-60) years, 171.2 (157-188) cm and 69.1 (45-104) kg, respectively. This study was conducted in October and November 2004.

Results

Priorities for protective clothing selection

Firefighters ranked degrees of importance for protective clothing selection on 3 factors: protection and safety, ease of movement, and comfort (Figure 1). Ease of movement ranked higher than protection and safety, and comfort.

Difficulties experienced while firefighting

Firefighters were asked to describe difficulties they experienced while working (Figure 2). 48.6% had experienced feeling very ill because of heat during the previous year. The second highest (41.0%) response rate was experience of restricted movement while firefighting. 16.3% of the firefighters had experience of tearing their protective clothing.

Follow-up questions were asked to the 387 firefighters who had experienced heat illness. The number of times they had experienced heat illness was an average of 3, while about 30 firefighters had experienced it over 10 times. The questions on handling heat illness allowed multiple answers (Figure 3). During the year, 79.1% had gone on firefighting in spite of feeling ill, and 40.1% had stopped firefighting for a moment. 7.2% of them lay down for a moment. Symptoms of heat illness were dehydration for over 40% of firefighters and dizziness (33.1%) or nausea (23.0%). Heat illness was experienced most often in July (27%) and August (49.4%), between 1-3 pm (41.4%). The main jobs during which firefighters had experienced heat illness were hosing (38.8%) and rescue (23.5%).

Evaluation of protective clothing in current use

Firefighters were asked to rank their protective clothing in current use according to five grades. The questions involved the following aspects of protective clothing: ease of putting on and taking off, ease of movement, thermal sensations, and protective properties, etc. (Figure 4). Firefighters' evaluation indicated that they felt discomfort arising from heat and dampness while wearing protective clothing. A five-grade evaluation of protective clothing produced a response of

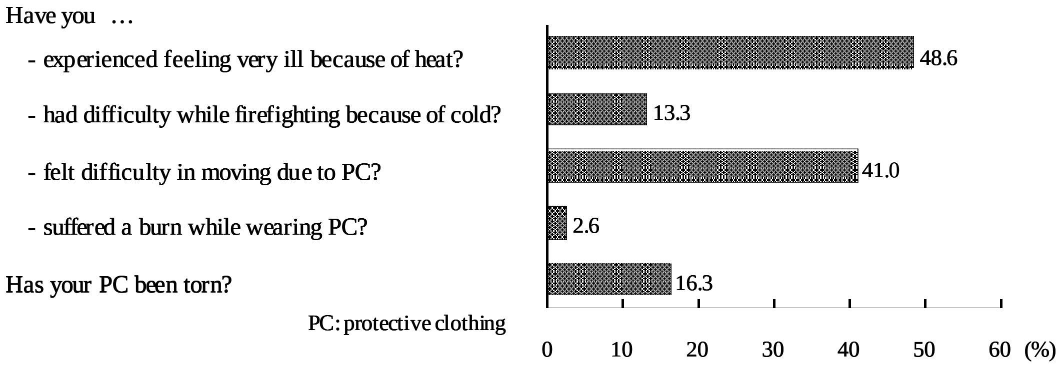

Figure 2. Difficulties experienced while firefighting.

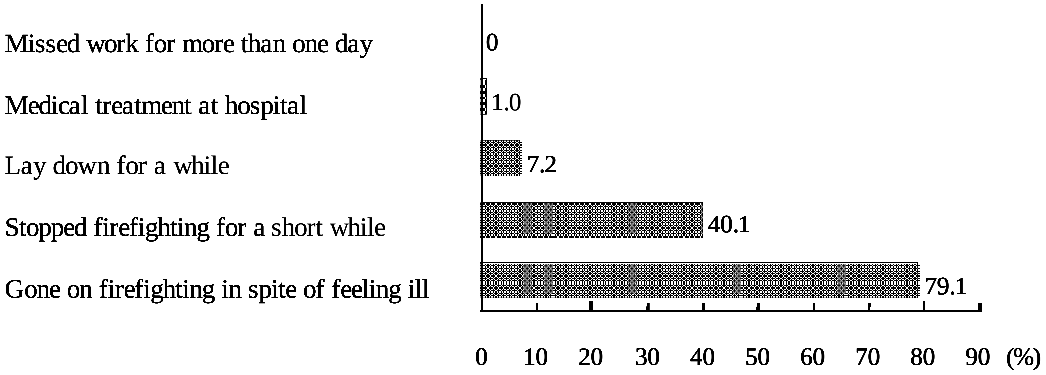

Figure 3. Handling heat illness

poor" or "somewhat poor" from over 70% of firefighters for heat and dampness. The next highest levels of complaints were ease of movement, weight, and stiffness of protective clothing, producing a response of "poor" or "somewhat poor" from about 40% of firefighters. Regarding ease of putting on and taking off protective clothing, flame resistance and thermal properties against cold, they evaluated their protective clothing 'poor" or "somewhat poor" at a rate of less than 30%.

A relationship between heat illness and characteristics of protective clothing and firefighters was found, in that the higher body mass index of firefighters, the higher the frequency of heat illness. Also, the frequency of heat illness rose as evaluation of protective clothing scored worse in terms of heat, dampness, and weight.

Discussion

Priority for protective clothing selection by firefighters ranked ease of movement during firefighting work higher than protection and safety, and comfort as shown in Figure 1. However, the most common difficulty (48.6%) experienced while working by firefighters was heat illness (Figure 1). Next, they also felt restricted movement while firefighting wearing protective clothing (41%). It was found that heat illness was induced during the hottest hours of the day in summer. About 80% of firefighters had gone on firefighting in spite of heat illness, while 40% of firefighters who had suffered more severe heat illness had taken countermeasures like short breaks (Figure 3).

These results suggested that firefighters tended to select protective clothing for work performance over their own comfort and safety during firefighting. This might cause a higher risk of heat illness, leading to wearers going on firefighting excessively. Firefighters also felt discomfort arising from heat and dampness while wearing protective clothing (Figure 4). Moreover, the frequency of heat illness rose as evaluation of protective clothing scored worse in terms of heat, dampness, and weight. Therefore protective clothing design must consider comfort and usability to avert the risk of heat illness and concentrate firefighters on efficient firefighting, in addition to protective properties to reduce heat stress.

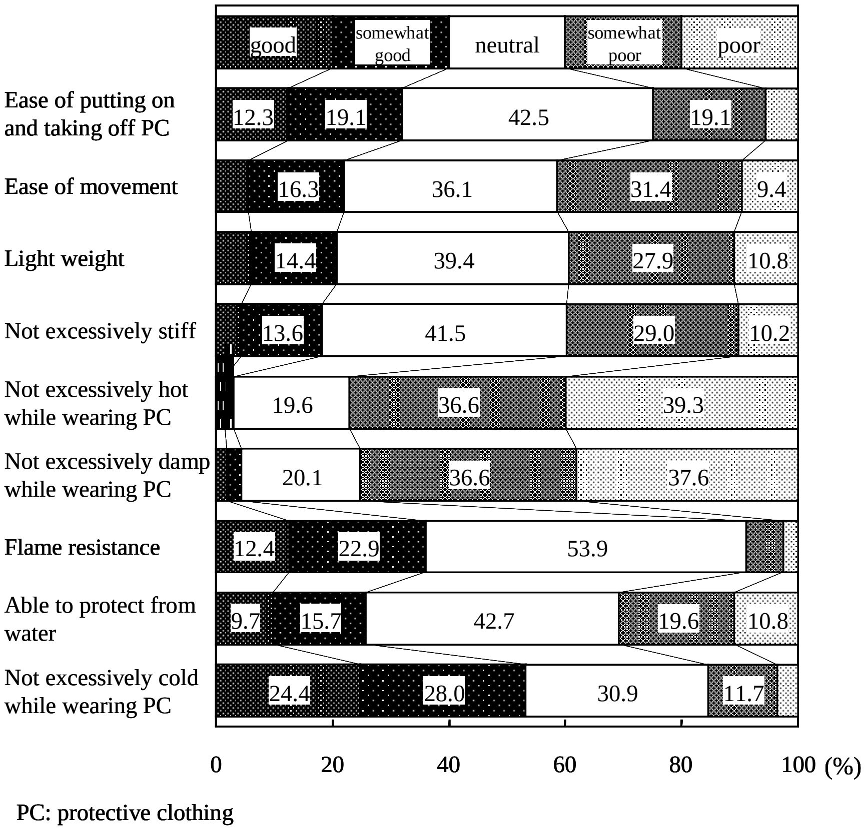

Figure 4. Evaluation of protective clothing.

Conclusions

Japanese firefighters suffer from heat illness very often in summer. The frequency of heat illness rises as evaluation of protective clothing scores worse in terms of heat, dampness, and weight. Therefore, further research on protective clothing to reduce thermal discomfort and accidents of firefighters is needed.

Acknowledgements

This study was supported in part by the Research Grant for Fire and Disaster Management in Japan.

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FITNESS STANDARDS FOR MARINE RESCUE OPERATIONS AROUND THE BRITISH ISLES

Tara Reilly[1]*, *Michael Tipton*[1]

[1] Institute of Biomedical & Biomolecular Science, Department of Sport & Exercise Science, University of Portsmouth
* corresponding author tara.reilly@port.ac.uk

Introduction

Occupational fitness standards provide the following benefits:

1. Enable the employer to fulfil a duty of care by decreasing the potential for injury.
2. Provide a selection method that is fair and unbiased and is based only on ability.
3. Determine if an individual retains the physical capability to continue safely. Such a test can therefore replace a compulsory retirement age.
4. Provide feedback on recovery, rehabilitation and return to work.
5. Encourage continued training, self-evaluation, healthy lifestyle and employee fitness (2,4).
6. Provide confidence within a team as the level of physical capability of all members has been established.

Alternatively, the consequences of employing physically unfit individuals for a physically demanding job can be costly, both in human and economic terms (8). Fitness standards for potential recruits have been employed within the police, fire fighters, industry, and defence (1,3,7,9,10,12).

These standards have been developed from one or a combination of:

1. Evaluation of work
2. Simulation of work
3. Surrogate physical selection tests (PST)

The Royal National Lifeboat Institution (RNLI) employs 5000 paid or volunteer crew for their 186 Inshore lifeboats (ILB), and 139 All-weather lifeboats (ALB). This paper describes the development of a task-related fitness standard for lifeboat crew, to ensure that they are capable of safely performing the most physically demanding generic critical tasks associated with rescue to a minimum acceptable standard, irrespective of age or gender.

Methodology

Questionnaires (640) and interviews (225) of lifeboat crew from 50% of the 233 lifeboat stations identified the most physically demanding, critical and generic tasks for ILB crew as: Man overboard (MOB) recovery, Anchor recovery, and Boarding the boat from water. For ALB crew the equivalent tasks were: Casualty handling, MOB recovery, and Salvage pump handling. The details of each task and method of best practice were specified by the RNLI to ensure repeatability and validity.

Field testing

28 ILB and 37 ALB lifeboat crew performed the most demanding generic lifeboat tasks, external load was increased incrementally until volitional failure. Maximum load achieved in each task was measured using load cells (Biometrics, UK) and recorded as the performance measure. As 4 of the 6 tasks require 2 people, the relative load lifted and carried by each team member was also recorded.

Simulations and physical strength measures

The force required to recover the anchor was measured with repeated trials under various sea states and wind conditions and averaged 14kg (range 10-17kg). As this task depends on field conditions, it was simulated for consistency; the performance measure was set as the time to recover 50 metres of anchor rope with an active resistance of 14kgs.

Crew members also completed a range of isometric and dynamic simulations of the critical tasks using a custom built rig. This rig replicated the posture of each task by employing a sponson and other equipment used during the actual tasks. All 3 ALB tasks were simulated isometrically and 3 trials of 5 seconds were performed at maximum effort by each subject. ILB tasks, anchor recovery (maximum pull to free anchor) and MOB recovery, were simulated isometrically. MOB recovery was also simulated dynamically with increasing load until volitional fatigue.

Subjects performed maximum isometric strength tests of the muscle groups responsible for the performance of these tasks (biceps, back, triceps, trapezius). Grip strength and grip endurance tests were performed at maximum effort using an electronic hand grip dynamometer (Biometrics, UK). Anthropometric dimensions (breadths, circumferences, lengths) and percent body fat were measured.

Relationships between performance on the field tests, simulations, and physical strength tests were examined using correlation and stepwise linear regression statistics, with the aim of identifying a set of simple-to-administer tests that predicted performance on the critical tasks.

The minimum performance requirements, set by the RNLI were

1. The minimum body mass of a man overboard or casualty would be 70kg, each crew member being responsible of recovering 35kg, and carrying 35kg a distance of 10m (length of boat deck) in a stretcher.
2. The salvage pump weighs 40kg, with each crew member being required to carry 20kg a distance of 10m.
3. Board a ILB via the stern
4. Recover a delta anchor (50m rope) in 45seconds

Results

Field testing of the lifeboat crew members revealed that 89% (MOB), 95 % (salvage pump) and 100% (casualty handling) of ALB crew, and 81% (boarding from water), 93% (anchor recovery time), 93% (MOB), and 81% (freeing anchor) of ILB crew could achieve the minimum performance requirements.

Simulation and Strength measures for ALB subjects

A correlation of >0.6 (R^2=0.36) was accepted as the criterion for the inclusion of a variable as a predictor of field performance, this is similar to the value used in the development of other occupational fitness test[8].

The stepwise linear regression identified the following variables as important for performance on ALB tasks and their simulations (task performance predicted):

Back Strength (casualty handling R^2=0.40, salvage pump handling R^2=0.44)

Grip Endurance (casualty handling R^2=0.62 (10 second) R^2=0.49 (30 second) MOB recovery R^2=0.40 (10 second), salvage pump handling R^2=0.38 (30 second).

The relationship between back strength and ability to carry 35kgs in the stretcher is estimated by the equation: ***Y=0.78(x) + 15.6*** Where x = body mass to be lifted.

Thus, if Y = 0.78(35kgs) the required back strength is 42.9kg ±1 standard error of the estimate (32-52kg). This process was repeated for 10 second (demonstrated in Figure 1) and 30 second grip strength.

Simulation and Strength measures for ILB subjects

The stepwise linear regression identified the following variables as important for performance on ILB tasks and their simulations (task performance predicted):

1. Back strength (anchor recovery time R^2=0.48)
2. Triceps strength (MOB isometric simulation R^2=0.57, anchor recovery time R^2=0.40)
3. Grip strength (anchor recovery time R^2=0.35, anchor freeing R^2= 0.47)

Discussion

On the basis of the individual associations established between these variables and performance, the minimum standards presented in Table 1 were recommended:

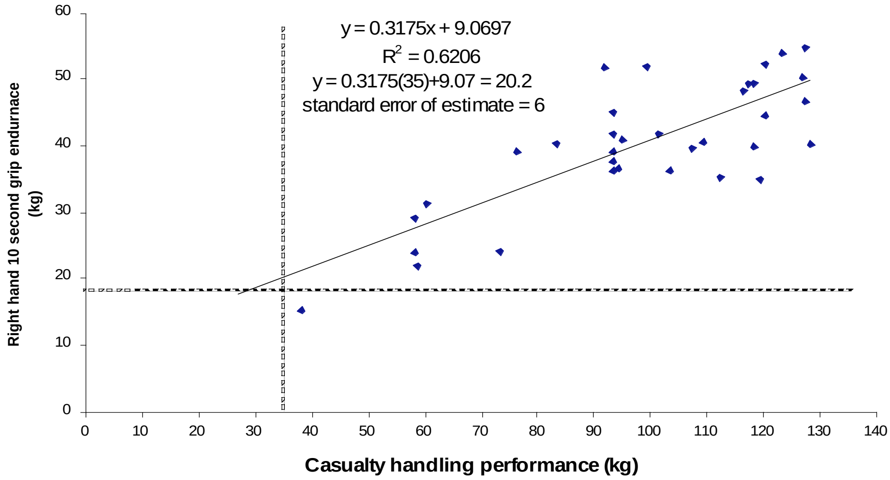

Figure 1. Relationship between casualty handling performance and 10s grip endurance (right) for ALB crew.

Table 1. Fitness standards for lifeboat crew.

Fitness requirements for the ALB boats:	Fitness requirements for the ILB boats:
1. 1.5m lift of 35kg using lifeline strops	1. Rescue a 35kg “dummy” over the sponson
2. 10m carry of 20kg, (right then left hand)	2. Anchor recovery with buoy attached
3. Stretcher carry for 10m with a resultant load of 35kg	3. Crew should be able to re-board the boat via the stern
4. Back Strength: 42kg (32-52)* (predicts casualty handling & salvage pump carry)	4. Back Strength: 64kg (50.4-77.6)* (predicts anchor recovery)
5. 10s Grip Endurance: 33kg (27-39)* (predicts casualty handling & MOB)	5. 10s Grip strength: 38kg (31.5-44.5)* (predicts anchor freeing)
6. 30s Grip Endurance: 14kg (11-17)* (predicts casualty handling & salvage pump carry)	6. Triceps strength: 44.2kg (33.6-54.8)* (predicts Anchor recovery)
*Use with potential crew	*Use with potential crew

The final fitness test for those wishing to join the RNLI is comprised of all strength measures (relevant to boat type) and field evaluations that do not require skill or technique; these traits will be learned and assessed during training. For existing crew members the fitness test is composed of field evaluations for the man overboard, stretcher carry, salvage pump carry, board the boat from water, and anchor recovery tasks. Existing crew members will also be required to perform the isometric strength tests (back, triceps, biceps, grip strength, grip endurance). The strength measures have been previously identified in the literature as important predictors of success on manual handling tasks (5,6,8,11).

Conclusions

The implementation of this standard will allow the retirement age of RNLI crew to be based on physical capability rather than chronological age. The strength tests also provide a simple to administer fitness test for selection of potential lifeboat crew members.

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MONITORING OF RISK ON SKIN BURNS OF FIREFIGHTERS DURING TRAINING IN REALISTIC WORKCONDITIONS

Ronald Heus [1]*, *Ed H.M. Schols* [1], *John W.M. Willems* [1],*Emiel A. den Hartog* [2]

[1]Dept. of Product Ergonomics, Business unit Design and manufacturing, TNO Science and Industry, Eindhoven, The Netherlands. [2]Dept. of Human performance, Business Unit Human Factors, TNO Defence, Security and Safety, Soesterberg, The Netherlands
* corresponding author ronald.heus

Introduction

Fire fighters and heat stress seems to be a logical combination. However, fire fighters in the Netherlands are only 5% of their working time exposed to heat and flames (1) and work even less time in indoor fire attacks. Own heat production during work is even a larger problem (2), accompanied by sweat production as a potential identified risk for skin burns, the so called "steam burns"(3). During realistic training, fire fighters are regularly exposed to high temperature environments. In these activities thermal, physical and mental stress can be (very) high. To study these risks on skin burns, we carried out measurements of various physical parameters during realistic training conditions. An important issue was that it was not allowed to hinder the fire fighters during their normal training activities and routines.

Figure 1. Example of a realistic training situation

Method

In November 2004 four different brigades of the Utrecht region in the Netherlands have participated in training sessions. The focus was to train in realistic fire fighting circumstances which was carried out at the Swedish Rescue Services Agency (SRSA) in Revinge (Sweden). Exercises implied various fires in cellars, apartments, houses and complex company buildings as well as flash over situations.

During various training sessions temperature and humidity were recorded at three sites (arm, breast and back) every 10 seconds. We collected data on four fire fighters of one brigade each day. So data of 16 subjects were collected at the end of the training week

The used sensors (Feuchte/Temperaturlogger DK 812, Driesen+Kern GmbH, Germany) were situated on the skin (using a very open harness) as well as on the underwear (fixed with tape) of the subjects. To have an indication of the workload during their jobs, heart rate was recorded every five seconds (Polar S 810, Finland).

Subjective findings of the fire fighters were noticed and occasionally reported in the project diary. However, it was not possible to question them in a structured way.

Results

Temperature humidity measurements and heart rates

Only data of the fire fighters who entered the burning buildings were analysed. Maximum reached temperatures of skin and underwear, maximum reached relative humidity on skin and underwear and heart rates of the subjects, averaged per exercise, are shown in table 1. The last column of the table shows the intensity of the complete action including time for instruction and time outside the building (i.e. not necessarily fire fighting actions).

Critical temperatures for potential skin burns were only seen in some of the exercises on the third and fourth day of the training week. These were exercises with complex situations in which some of the fire fighters were inside the building, near the fire for more then 30 minutes and during which skin temperatures were above 40ºC for about 5 minutes. These high temperatures were seen at all sites.

Table 1. Maximal skin and underwear temperatures, maximal relative humidity on skin and underwear, maximal heart rate and mean heart rate during exercises.

Day	Exercise	subjects	T skin	T underwear	RH skin	RH underwear	HR max	HR average
1	1	2	36.7	34.3	77.9	62.0	156.0	134.5
1	2	2	33.9	31.0	85.4	74.0	126.5	106.5
1	3	4	33.3	28.7	80.3	74.8	151.7	122.4
1	4	2	33.3	30.8	90.5	93.1	123.0	91.3
1	5	2	34.0	30.4	92.2	85.8	165.0	133.4
2	6	3	33.9	28.0	88.3	75.2	150.0	107.1
2	7	4	33.1	30.1	80.5	88.2	156.7	97.7
2	8	1	31.9	25.3	58.5	62.1	121.0	92.7
2	9	2	34.0	27.4	79.3	71.0	168.5	113.1
3	10	4	33.6	30.7	79.8	65.6	164.0	139.3
3	11	4	32.3	29.2	85.1	75.5	166.7	137.5
3	12	4	32.0	28.7	87.2	80.7	163.3	123.7
3	13	4	38.4	39.2	94.8	92.7	168.3	129.6
3	14	4	41.1	46.4	96.5	95.5	-	-
4	15	4	37.1	36.5	81.1	75.0	-	-
4	16	3	39.7	49.1	89.7	94.4	-	-
4	17	2	33.5	30.5	95.7	92.2	-	-

Marked cells of the table show critical values, which means mean skin temperatures above 40°C, mean underwear temperatures above 50°C,RH above 90% a HRmax above 160bpm and an average HR above 130bpm

The highest individual temperature measured on the skin was 43.7°C on the upper arm of subject 2 and on the underwear even 57ºC on the upper arm of subject 3. Humidity on skin and underwear reached values of above 90% within 5 minutes after starting the rescue exercises.

In figure 2 the results are shown of a typical example of one fire fighter being into the burning building for about 20 minutes during which the mean skin temperatures reached 42°C. In figure 3 it is shown that the relative humidity can suddenly increase during an exercise from 50% till 95% within 5 minutes.

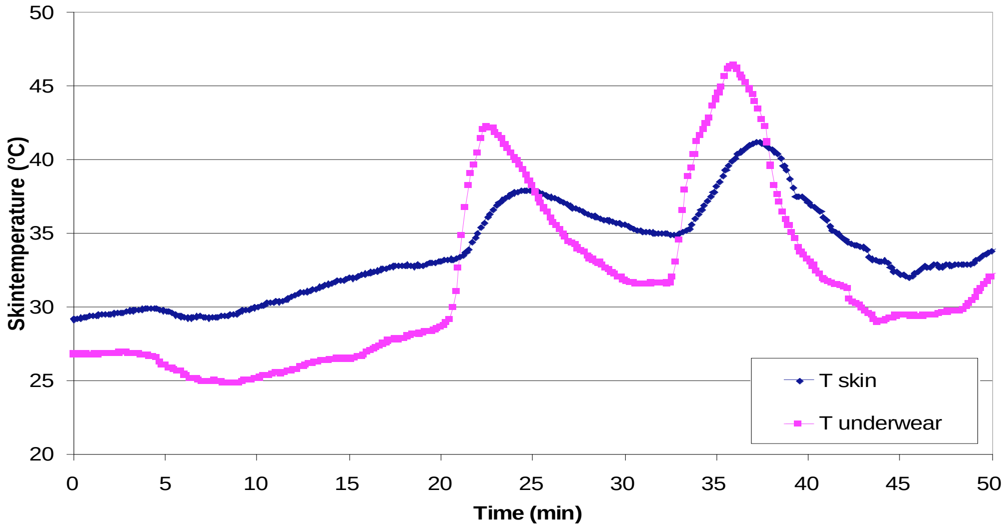

Figure 2. Typical example of mean skin and underwear temperatures (°C) during a training session of

one of the fire fighters.

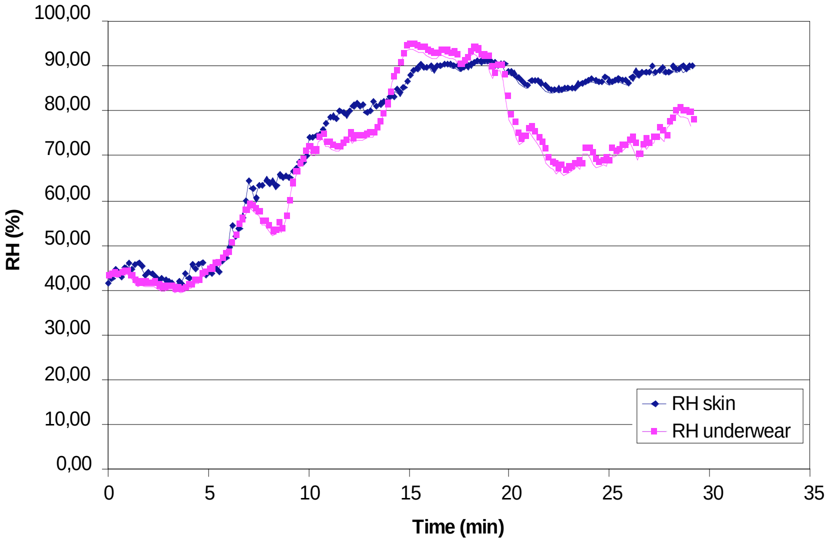

Figure 3. Typical example of increase in relative humidity (%) during a training session of one of the

fire fighters

Subjective findings and reports of the subjects

On the third day of the training week a subject attacking an incident and who was inside the building for 20 minutes complained about steam underneath her clothing. The same day during a second large attack she went in again and after 45 minutes inside the building she went out with red spots on her skin. During the latter incident one of her colleagues came out of the building before finishing the job because of steam underneath his outerwear.

Also, on the last two days of the training week more fire fighters complained about the high temperatures and one of the fire fighters got hurt because of steam coming from outside (from the water extinguishing the fire) through the openings of his trousers. During the very last exercise, one of the fire fighters was fully exhausted and was almost unable to report his findings to the researchers. It took more then 20 minutes in a cold environment (about 5°C) to get him on his feet again. Unfortunately all these individuals were mot instrumented when they reported these extreme thermal stress conditions. In some cases cold packs were used to relieve the pain from the "steam" burns.

Discussion

Thermal and physical load vary largely between the exercises. Because of the importance of the training for the fire fighters we were not allowed to enter the buildings and collect data of the typical environments. These information however is very important to get more insight in the problem of skin burns of fire fighters related to the thermal load. During comparable trails in the UK environmental temperatures varied between 27 and 53°C, with peaks up to 103°C (5), but in that study mean skin temperatures were lower than in this study.

The average physical intensity is not too high. This is reflected by the mean heart rates of the subject, but sometimes very high peaks in the workload were registered. The side effect of repeated expositions to heat must not be underestimated.

During the week fire fighters reported an increased feeling of exhaustion, but we could not relate this phenomenon to the rest heart rates, because every day another group of subjects was followed. Our main reason to follow different groups of fire fighters that we wanted as many as possible fire fighters entering the fires, as the focus our study was on skin temperatures and not on work load.

Although some fire fighters reported steam burns, the potential risk (1) was not widely present during the training week. However, this is in line with the actual daily work situation in which only 5% of the fire fighters' working time contains fire fighting and even less concerns indoor fire fighting attacks. Rossi et.al. (4) reported that with the tendency of making the clothing more breathable and thinner and by use of improved vapour barriers, the risk on steam burns will increase in future.

We also noticed an increased RH on skin and underwear after the first exercise. The main cause for these higher values was not changing the underwear after an exercise and certainly not the outerwear. So to decrease a potential risk of steam burns we advised to change underwear immediately after an exercise and if possible, also the outerwear.

Conclusions

Physical and thermal stress vary a lot between different sessions. From the data we concluded that short peaks of high physical stress are noticed during indoor fire attacks.

Thermal stress with risks of skin burns were seen during fires in complex buildings. Peak values of the skin temperature around 44ºC and of underwear temperature of 57ºC were measured. Together with the over 90% RH under the clothing the capacity of the evaporation to the environment of the moisture is limited and give a potential risk of steam burns.

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GET ME OUT: AN EXPLORATION OF HAPTIC OUTPUT AND POINT-TO-POINT NAVIGATION FOR FIREFIGHTERS

Thomas Visser[1]*, *Ronald Heus*[2]

[1] Eindhoven University of Technology. Department of Industrial Design
[2] TNO, Department of Science and Industry
* corresponding author T.Visser@student.tue.nl

Introduction

The haptic modality is relatively unexplored in the domain of mobile human computer interaction. Existing work often focuses on people with a severe visual impairment, e.g., the wearable navigation system by Ertan et al. (1) or focuses on people without any disabilities, e.g. the GentleGuide system (2) This paper presents an application of haptic output to provide guidance to firefighters that work in a situation without any visibility to find their way out of a building after they got disoriented. Among these complex buildings are schools, hospitals and office buildings.

A range of design options that must be addressed for designing the GMO-system output are discussed in section 2, in the context of the iterative development of GMO. We then describe the implementation of the prototype, its experimental assessment and conclude with some preliminary conclusions from this research.

The design of GMO

The original concept for the GMO-system was of a collection of tokens that would be put down on the way into a complex building at every 8 meters and at every corner. Wearing a haptic device, the user would then be directed to the last token he had put down. If the user had reached that target-token, the user would be guided to the next token in line.

For the haptic device it was decided to use vibration pulses. Mild pressure tends to be ignored after the initial stimulus (e.g. wearing clothes). Concerning the physical and mental stress firefighters have to deal with in real firefighting practice it was decided to use vibration pulses of 0.5 seconds at intervals of 0.5 seconds as long as the user pointed in the direction of the target-token. Vibration output was eventually selected, not least because it easy to produce, as tiny vibration alarms are commercially available or easily created. With these design decisions the users had only to react on one signal: vibration = direction of the target-token.

Also the users had to use a specific procedure in looking for the tokens. Because of eventual training and thus money issues, it was decided that the procedures should integrate very well in the current firefighting procedures. The user would first gently move around with a stretched arm and the hands at breast height. If he/she would get a signal, he/she would walk in the direction of the signal. If the signal stopped, this could mean 2 things: the token was very close by and therefore the user had to point more downwards or the user had wandered off from the straight path while walking around blindfolded. If the user had lost the signal, he/she would first point and wave at the floor about 1-2m in front of his/her feet. If this would not give a signal the user would try to find a signal at breast height in a different direction. If the user had discovered that the token was within the 1-2m in front of his/her position, it would be obvious that within 1 or 2 steps the user would be directed to the next target-token.

The final GMO-system prototype is shown in fig. 1. The remote control generates the navigation signals. The wrist device contains a receiver, a decoder used to identify the signal and a battery fed vibration alarm. If the received pulse train is coded for the wrist device, the vibration alarm will be switched on as long as the pulse train is received. This is as long as the experimenter presses the button on the remote control. The remote control device is housed in a plastic box. The vibration alarm is integrated in a flexible and elastic wristband with the antenna on the outside. The prototypes are typically technical prototypes: focus was on functionality.

Evaluation of GMO

An experiment was conducted to assess the potential of GMO for supporting '*terugtocht*' by disoriented firefighters. GMO was compared to getting in and out of a building without the system, which is the way '*terugtocht*' is currently executed. The experiment was conducted inside a campus building that has a complexity in layout not uncommon for large buildings.

Participants. 16 subjects without any disabilities took part in this study. All subjects were undergraduate students, who are screened so that they are not familiar with the locations where the experiment took place and will not be involved or familiar in any way with the experiment.

Design of the experiment: A mixed design was followed. The within subjects condition was the use of GMO or non-GMO. The between subjects condition was the specific route concerned. Each subject had to walk 2 different routes, 1 with GMO and 1 without in mixed order. 8 subjects using the GMO and 8 different subjects using just hands and feet to get back attempted each of our 2 routes. In pilot testing, the approximate time for a route using GMO was 3:25 minutes.

Picture 1. GMO prototype

Picture 2. Experimenter with subject

Procedure. All way-finding tasks involved returning from a destination to the starting point in an office building, without walking out of the building or going up or down a floor. In all cases the subjects were walked inside a building and asked to observe. They were brought to their starting point, blindfolded and twisted around in order to lose orientation. In the GMO condition, the subjects were instructed to walk back like professional firefighters do; they were introduced to GMO by a brief written explanation and a 5 min. practice session. The experimenters would walk 1-2m behind of the subjects issuing guidance instructions from the remote control console. If subjects would take a wrong turn or walk in the wrong direction, a timer started to count their recovery time. This timer would be stopped at the moment the subject gets back on the track. Subjects were instructed to follow directions, until they would be given a signal that they have arrived.

In the non-GMO condition, the subjects were allowed to find their way back along the exact route that got them into the building. They were also instructed to walk at a firefighter-pace. In both cases, if after 5 minutes the subject had still not arrived at the destination, a time-out of 5 minutes was recorded and the experiment was stopped.

Independent Variables. The use of GMO or not

Dependent Variables. By counting how many of the tasks are completed successfully the effectiveness of GMO was assessed.

The efficiency of GMO compared to a non-GMO situation is measured by the difference in run-times. These are compared in a statistical test.

The number of errors was be counted. An error is simply defined as a subject not making the right decision at a junction point (a point where they have to turn). In order to distinguish from a momentary hesitation/confusion, a margin distance of 2 meters at the wrong direction is allowed. No new errors were counted until the subject got back on the right track.

When an error was made, the time to recover from that error was also measured. This measure shows the limits of the system.

Results. All GMO users got to their destination on all occasions. Five subjects got completely lost when relying on touch only. A Cochran-Q-Test showed this difference to be significant ($Q = 5$; $df = 1$; $0.02 < p < 0.05$).

The average time per route for the GMO was 3:14. The average time per route without GMO was 2:41. In this calculation, missing data (due to a Timed Out return) is replaced by the average of the remaining data. A two tailed *t*-Test showed this difference not to be significant ($t = 0.559$, $p = 0.584$, $df = 15$). In other words, the time it takes to return is not different between both conditions.

In no occasion did a subject make an error following the GMO while 12 errors were made following the signage. Only in 2 cases when errors were made, the subjects achieved to get back on the right track. In the 5 other cases one or more errors were made which finally resulted in getting completely lost.
Other observations. When using GMO, only in 4 of the 16 runs the subjects knew where they were exactly when they were told to stop at their final destination. 12 subjects did not know that they had reached what was considered the entrance of their complex building.
When not using the GMO system, if the subjects recognized the way back they started to walk a little faster, unless the fact that they were told not to do that at the start of the experiment: they were told to walk step-by-step. This incidental acceleration did not happen in the GMO experiments because subjects had to search and find a new token every time. They were instructed to follow the tokens.

Conclusions

Vibration pulses delivered by one wrist-mounted device that reacts to its own direction relative to a point in its environment are a practical way to deliver point-to-point guidance information for people in a firefighter situation. This approach is more effective than relying on a mental map of the situation. It is not slower or faster than the current ways of orientation and navigation.

We plan to extend this study by involving professional firefighters as subject in this study. We expect to have more positive results in that type of experiment because firefighters are more aware of the professional procedures and protocols e.g. walk step-by-step on every occasion, even if they exactly recognize their route. In those situations it would take more time when finding a way back. Also we would like to include even more complex routes, e.g., include multiple floors and automatic doors.

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THERMAL PERCEPTIONS IN INDOOR ENVIRONMENTS : A SENSORY ANALYSIS APPROACH

Cécile Petit[1], Jean-Marc Sieffermann[2], Marc Danzart[2], Edouard Siekierski[1], Victor Candas[3]*

[1] EDF, Recherche et Développement, Moret-sur-Loing, France
[2] ENSIA, Perception Sensorielle et Sensométrie, Massy, France
[3] CNRS, Centre d'Etudes de Physiologie Appliquée, Strasbourg, France
* corresponding author : cecile.petit@edf.fr

Introduction

Thermal comfort has a great influence on the perceived quality of an environment, and has been studied for more than seventy years by physicists, physiologists and ergonomists, who try to predict people's reactions to specific climatic conditions. These days, about one third of the world's energy consumption is used to provide comfortable thermal conditions in indoor spaces, by the means of heating, ventilation and air-conditioning (HVAC) systems.

The existing standards for thermal comfort in buildings [1,2] define criteria of "neutral" or "not-uncomfortable" thermal conditions considering ranges of air temperature, humidity, velocity, etc.

In research on human subjects, the concepts of *comfort* and *sensation* are often assimilated. Moreover, the thermal *sensation* is usually expressed through the subjects' thermal body state and reduced to a single feeling of "temperature" (from cold or hot).

Sensory descriptive analysis has been developed in the food and cosmetic industries to get to a better understanding of complex human sensations. The method consists in training a small group of subjects to describe and quantify their sensations independently of any affective judgment. Their evaluations can then be used to accurately characterize a defined set of products [3].

Considering indoor environments generated by different heating systems, the aim of this study was twofold.

To characterize the perceived human thermal sensations using a sensory descriptive method

To investigate the relevance and efficiency of our experimental approach compared to a classic instrumental one.

Methods

Thermal environments

The study was carried out in specially designed laboratory rooms suitable for both sensory and instrumental measurements, which were performed in thermal steady-state conditions [4].

Thermal indoor environments were generated using five different heating systems : an electric convector (CONV), an electric radiant panel (PAN), a hot water heater (WATH), an electrically heating floor (FLO) and an electrically heating ceiling (CEIL).

The operative temperature (centre of the room – 1.1m height) was fixed either at 21± 0.1°C or 23 ± 0.1°C. Considering a sedentary activity (1.2 Met) and estimated "standard" indoor winter clothes (0.75 Clo), these two temperature conditions correspond to PMV=-0.5 et PMV=0 respectively at low level of air velocity (0.05 m/s).

Instrumental study

The instrumental measurements consisted of surface temperatures (floor, ceiling and walls), air temperature, black globe temperature, air velocity, relative humidity – at different locations and heights above floor.

From these measurements, 33 physical parameters were defined as relevant according to the standards [1,2] to describe the thermal differences between the studied environments : 5 for global comfort, 8 for radiant temperature asymmetries, 10 for vertical temperature gradients and 10 for horizontal temperature gradients.

Sensory descriptive study

We followed a Free Choice Profiling methodology [5]. 10 subjects were recruited and participated in 16 individual working sessions. For all sessions, they spent 15min in each thermal environment (3min walking then 12min sitting at the centre of the room).

Each subject was first asked to generate his own terms to describe the thermal differences perceived between the studied environments. All selected *descriptors* were associated with precise definitions and evaluation procedures (vocabulary development phase).

Using his personal list of terms, each subject had then to rate his thermal sensations on an intensity scale for each environment (quantification phase). Several evaluations were performed to control the discrimination ability and the reliability of each subject.

Results and discussion

For both instrumental and sensory data, the results obtained for the five heating systems at 21°C were quite similar to those obtained for the five heating systems at 23°C.

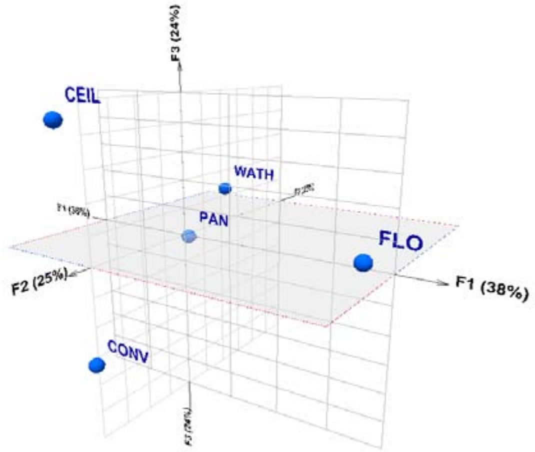

Figure 1. The three dimensional **instrumental map** for 23°C.

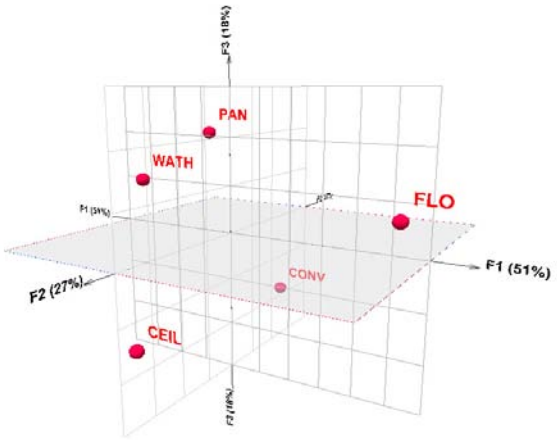

Figure 2. The three dimensional **sensory map** for 23°C.

Instrumental characterization

Considering the great number of physical parameters, multidimensional statistics were needed to analyse our results [6]. A three dimensional map is used to represent the proximities and distances between the thermal environments, as perceived from a physical point of view (Figure 1). The dimensions (or factors F1, F2 and F3) account for a defined percentage of the data variance (respectively 38%, 25% and 24%), and correspond to linear combinations of the initial 33 physical parameters.

There is a clear differentiation of FLO (factor F1), CEIL and CONV (factor F3). PAN and WATH appear to be very close, and opposed to CEIL and CONV on factor F2.

These differences can be described using the most influent physical concepts on the three dimensions (Table 1).

thermal environment	associated physical concepts
FLO	+ radiative part* + floor temperature + air velocity - vertical radiant asymetries - vertical temperature gradients
CEIL	+ radiative part* + vertical radiant asymetries + vertical temperature gradients
CONV	- radiative part* + air velocity + lateral (left-right) radiant asymetries + anterior-posterior radiant asymetries + vertical temperature gradients
PAN and WATH	- horizontal temperature gradients - vertical temperature gradients - radiant asymetries

Table 1. Physical characterization of the thermal environments for 23°C.

* The radiative part is here defined as the difference between the black globe temperature and the air temperature, measured at the centre of the room – 1.1m height.

Sensory characterization

The 10 subjects used between 5 and 8 terms each to describe and quantify their thermal sensations, for a total of 64 descriptors.

A three dimensional map is used to characterize the thermal environments from a sensory point of view (Figure 2). The factors account respectively for 51%, 27% and 18% of the variance. There are strong similarities with the instrumental map : FLO (factor F1), CEIL and CONV (factor F2) are clearly discriminated from the other environments, whereas PAN and WATH appear to be very close – opposed to CEIL and CONV on factor 3.

These differences can be described using the most influent sensory descriptive concepts on the three dimensions (Table 2).

thermal environment	associated sensory concepts
FLO	+ heat felt when entering + air movement + rewarming with time - thermal body homogeneity
CEIL	- heat felt when entering + coolness when moving in the room + air movement + air fluidity - thermal space and body homogeneity - rewarming with time
CONV	- air fluidity - thermal space and body homogeneity - temperature stability - rewarming with time
PAN and WATH	+ thermal space and body homogeneity + temperature stability + rewarming with time

Table 2. Sensory characterization of the thermal environments for 23°C.

Comparison between instrumental and sensory results

According to the standards [1,2], the thermal environments studied were close to the thermo-neutrality and felt in the range of “comfortable” thermal conditions. However, there were noticeable thermal differences depending on the type of heating system, and we were able to characterize them with both physical and sensory descriptive concepts. Although none of the physical characteristics were out of range compared to the ISO 7730 recommendations for comfort, the sensory analysis approach led to the perception of thermal differences – and the results of the instrumental and sensory studies were very similar for both temperature conditions (21°C and 23°C).

In absence of any physiological data (i.e. skin temperatures for instance) it is difficult to conclude firmly on the involved mechanisms but we may assume that the local skin thermal states (as well as the temperatures of the respiratory ways) are at the origin of the perceived sensations. Even if people are unable to clearly define any local body temperature change, they may be able to express their feeling in terms of pleasantness, unpleasantness or any other wording describing their thermal sensations [7].

The relationships between the thermal human sensations (sensory variables) and the main instrumental parameters (physical variables) were investigated using regression techniques. Although they are difficult to analyse, the results reveal some interesting trends. For example, a stronger sensation of “rewarming with time” (for FLO, PAN and WATH) is associated to smaller horizontal and vertical temperature gradients; a stronger sensation of “air fluidity” (for CEIL opposed to CONV) is associated to smaller horizontal temperature gradients and smaller anterior-posterior radiant asymmetries. Further work appears necessary before being able to conclude more precisely on these interactions.

Conclusions

There were sensory differences between the thermal environments generated by the different heating systems, and trained subjects were able to characterize these differences with high reliability and independently of any affective judgment. Our results provide a wide preliminary vocabulary to describe and to quantify human thermal sensations associated to heating systems.

These results may allow us to select a limited number of relevant and efficient physical parameters to describe most of the environmental characteristics related to human thermal perception.

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CUTANEOUS TEMPERATURE SENSITIVITY AND THE THERMAL COMFORT ZONE ACROSS THE MENSTRUAL CYCLE

Nina Kocjan[1]*, Ola Eiken*[2]*, Igor B.Mekjavic*[1]***

[1]Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute,
Jamova 39, SI-1000 Ljubljana, Slovenia;
[2]Swedish Defence Research Agency, Karolinska Institutet,
Berzelius v. 13, S-17177 Stockholm, Sweden.
*corresponding author: igor.mekjavic@ijs.si

Introduction

Apart from modulating basal body temperature, female reproductive hormones have also been demonstrated to affect the perception of experimentally induced noxious stimuli. Riley (1999) reported that, for pain stimuli other than electrical (pressure pain, cold pressor, thermal heat and ischemic pain), higher thresholds were observed in the follicular phase as compared to later phases.

The purpose of this study was to examine the effect of the menstrual cycle on cutaneous temperature sensitivity and on the magnitude of the zone of thermal comfort.

Methods

The protocol of the study was approved by the National Ethics Committee of the Republic of Slovenia. Subjects were acquainted with the protocol and gave their written consent for participating in the study.

Eight healthy, non-smoking, females with regular menstrual cycles, participated in the study. Their average (SD) age, weight, and height were 24 (2) yrs, 59.3 (6.6) kg, and 168.5 (4.4) cm, respectively. They were eumenorrheic, not taking contraception pills, or any other medications on a regular basis. The average length of their menstrual cycle was 30 (1) days. They were requested to refrain from consuming alcohol or caffeine at least 12 hours prior to each test.

Each subject recorded her early morning tympanic temperature with an infrared tympanic thermometer (ThermoScan IRT 3250, Braun, Kronenberg, Germany). A total of three measurements were made immediately upon waking, in the supine position. Ovulation was determined with a one step home ovulation prediction test (OvuSign®, Princeton, U.S.A). Ovulation was also confirmed by determining the plasma concentration of lutenising hormone. Blood samples were analysed for plasma concentrations of progesterone and oestrogen

Assessment of cutaneous thermosensitivity

Cutaneous cold and warm temperature thresholds, and the cutaneous thermal comfort zone were assessed on two occasions: in the menstrual phase (on day 3), and in the mid luteal phase (7 days after ovulation). Cold and warm temperature sensitivity was assessed with a modified Middlesex Thermal Testing System (MTS, Howe Inst. Ltd., Canvery Osland, Essex, UK.). Subjects, dressed in bathing suits, sat semi-supine on a chair, with their left arm resting on an insulated armrest. The 24 cm^2 Peltier stimulating thermode of the thermal testing system was placed on the volar side of the left forearm. Cold and warm stimuli of different intensities were presented to the subjects at regular intervals. Temperature thresholds for cold and warm stimuli were determined as the average of the last three stimuli that were perceived, and the last three that were not. During the tests, ambient temperature was maintained at 26°C.

Assessment of the thermal comfort zone

The thermal comfort zone was determined with a water-perfused suit (cf. Golja et al., 2005). Following a two minute stabilisation period, during which the temperature of the water perfusing the suit was maintained at 28 C° (perceived as slightly thermally unpleasant by all subjects), the temperature of the water increased at a rate of approximately 1°C.min^{-1}, and subjects were instructed to report the moment at which they perceived the temperature of the suit to be thermally pleasant. This was defined as the lower limit of the thermal comfort zone. As the temperature of the water perfusing the suit increased further, subjects were instructed to report when they perceived the temperature to be thermally unpleasant. This was defined as the upper limit of the thermal comfort zone. In this manner, we were able to determine the magnitude of the thermal comfort zone.

During each trial, skin temperature was measured at eight sites (finger, forearm, upper arm, upper chest, abdomen, scapula, thigh and calf) with an Almemo Model 5990-2 data acquisition system (Ahlborn, Holzkirchen, Germany), and core temperature with an infra-red thermometer.

The mean values of cutaneous cold and warm thresholds, the upper and lower limits of the thermal comfort zone, as well as the magnitude of the thermal comfort zone, between the menstrual and mid-luteal phases were compared with a Student's t-test. The 0.05 level was considered statistically significant.

Results

Ambient conditions in the laboratory were similar during the assessment of cutaneous thermosensitivity and the thermal comfort zone. Average (SD) ambient temperature, pressure, and relative humidity was 26.9 (0.7) °C, 988 (7) mbar, and 17.4 (7) % , respectively, for trials conducted during the menstrual phase, and 27.1 (1.1) °C, 985 (11) mbar, and 14.3% (6), for trials conducted in the mid-luteal phase.

Average post-ovulatory core temperature was 0.2 C° higher than pre-ovulatory core temperature. During the menstrual phase, the plasma concentration of estradiol was 25.8 (9) pg.ml^{-1}, and that of progesterone 0.5 (0.1) ng.ml^{-1}. During the mid-luteal phase, the plasma concentration of estradiol increased to 109.1 (48.4) pg.ml^{-1}, and progesterone to 11.3 (6.6) ng.ml^{-1}.

Cutaneous thermosensitivity

There was no statistically significant difference in the observed cutaneous warm and cold temperature thresholds between the values observed in the menstrual phase (warm: 3.1 (1.4)°C; cold: 2.4 (1.2)°C), and those observed in the mid-luteal phase (warm: 3.3 (1.6)°C; cold: 2.0 (1.5)°C).

Thermal comfort zone

The magnitude of the thermal comfort zone was significantly ($p<0.05$) greater in the menstrual phase (4.0 (1.2) °C) than in the mid-luteal phase (2.7 (1.5) °C). The widening of the thermal comfort zone in the menstrual phase was due to a substantial ($p<0.003$) increase in the upper limit of the thermal comfort zone from 32.2 (1.4)°C in the mid-luteal phase to 35.0 (1.4) °C in the menstrual phase. There was also a tendency, albeit not significant ($p= 0.06$), for a decrease in the lower limit of the thermal comfort zone (mid-luteal phase: 30.9 (1.2)°C; menstrual phase: 29.6 (1.2)°C)

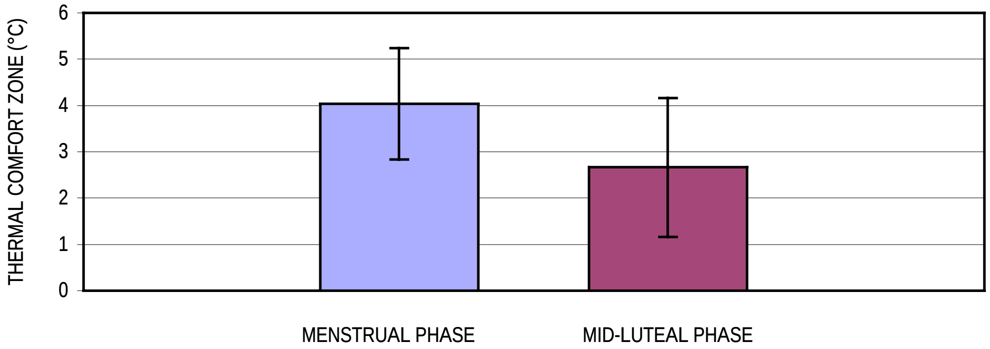

Figure 1: The magnitude of the thermal comfort zone in the menstrual and mid-luteal phases.

Conclusion

The principal finding of the present study is a widening of the thermal comfort zone during the menstrual phase. This is due primarily to the significant elevation in the upper limit of the thermal comfort zone, and may affect behavioural temperature regulation. In contrast to findings regarding the perception of noxious stimuli (Riley et al., 1999), the results of the present study indicate no change in cutaneous thermosensitivity during the menstrual cycle.

Acknowledgements

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EFFECTS OF LOW RELATIVE HUMIDITY ON PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSES – A COMPARISON BETWEEN OLD AND YOUNG PEOPLE

Yujin Sunwoo[1]*, *Chinmei Chou*[1], *Junko Takeshita*[1], *Motoko Murakami*[2], *Yutaka Tochihara*[3]

[1] Department of Ergonomics, Kyushu Institute of Design, Fukuoka, Japan
[2] Kanebo Cosmetics Inc, Odawara, Japan
[3] Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka, Japan
* corresponding author sunwooyujin@yahoo.co.jp

Introduction

In winter, indoor dryness caused by heating causes many problems. Under the low relative humidity environment, the skin dries up and becomes itchy. And when the mucous membranes of the nose and throat become dry, bacteria can easily infect the human body. Moreover as survival rates of viruses increase (6, 7), they become very active in the air causing common colds or other respiratory infections. Therefore, in our indoor lives, it is important to maintain the optimum humidity level as well as maintain the optimum room temperature. Especially, the indoor environment occupies a major role in the everyday life and health of elderly people. Those who are losing the power of resistance to disease are easily affected by low humidity and so research with the elderly as subjects is required.

Methods

Subjects

As the subjects of the experiment, eight non-smoking healthy male students and elderly men were selected. Their mean and slandered variation of age, height, body surface area (BSA) are shown in Table 1. The body surface area was calculated using the formula of Fujimoto et al. (1969).

Table 1 Physical characteristics of subjects

	Age(yrs)	Height(cm)	BSA(m^2)
Elderly (n=8)	71.1±4.1	162.3±4.5	1.64±0.07
Young (n=8)	21.7±0.8	172.1±3.0	1.64±0.08

Procedures

This study was conducted from February to March 2004. The pre-room was controlled with an air temperature (Ta) of 25°C and relative humidity (RH) of 50%. The test-room was adjusted with a Ta of 25 °C and RH of 10%, 30% and 50%, respectively. The subjects wore short pants, a long sleeved sweat shirt and trousers (0.9clo) in the pre-room. After waiting for 50 minutes in a sitting position in the pre-room, the subjects moved to the test-room and sat on a chair for 180 minutes. Figure 1 shows the schedule for experiment.

Measurements

We measured saccharin clearance time (SCT), frequency of Blinking, blood pressure, hydration state of skin, transepidermal water loss (TEWL), recovery sebum level and skin temperature as physiological responses. Also, we asked subjects to judge thermal, dryness and comfort sensations as psychological responses using a rating scale.

Mucociliary transport was measured by SCT. A saccharin tablet (2.5mm×0.5mm) was placed just behind the anterior end of the nasal septum on the level of the anterior end of the middle nasal concha. The subjects were asked to sit quietly with their head forward and not to sniff or sneeze. The time was measured at the first perception of the sweet taste.

We had subjects count the white spots flickering randomly on the center of the monitor for 2minutes (duration of lighting up is 1sec., interval between flickerings is 0.2~1.4sec.). We counted subject’s frequency of blinking for those 2 minutes.

	Pre-room (50min.)	**Test-room (180min.)**						
	-30	**enter**	**30**	**60**	**90**	**120**	**150**	**180**
SCT	●				●			●
Frequency of blinking	●				●			●
Blood pressure	●		●	●	●	●	●	●
Hydration state	●		●	●	●	●	●	●
TEWL	●		●	●	●	●	●	●
Recovery sebum level	●			●		●		●
Judgment	●	●	●	●	●	●	●	●
Skin temperature	------------	------	------	------	------	------	------	-----
Weight	●							●

Blood pressure and heart rate were checked on the right-upper arm using an automatic tonometer 3 times every 30minutes. We used the mean value of each piece of data. Both Hydration state and TEWL were measured in the pre-room and in the test-room on the right side of the cheek and the back of the right hand 3times every 30 minutes. We used the mean value of each piece of data. Recovery sebum level was measured in the pre-room after removal of sebum using an alcohol sponge and in the test-room every 60 minutes on the left side of the cheek and the back of the left hand.

Skin temperatures at 8 local body sites (i.e. forehead, chest, shoulder, forearm, abdomen, hip, thigh, foot) were measured with thermistors every minute. Mean skin temperature was calculated applying the Fukuda's12point i.e.forehead 9.8%, chest and shoulder16.6%, forearm19.6%, abdomen8.1%, hip8.1%, thigh30.6%, foot7.2%.

Body weight loss was obtained by deducting the weight before the experiment from the weight at the end of experiment.

Thermal, dryness and comfort sensations were evaluated once in the pre-room, once on entering the test-room and then every 30 minutes. Head, trunk, legs and the whole-body were evaluated for thermal sensation and nose, throat, eyes, face and hands were evaluated for sensation of dryness. Table 2 shows the scales of psychological judgments.

Table 2 The scales of psychological judgments

	Thermal sensation	**Sensation of dryness**	**Thermal comfort**
3	hot	extremely dry	very comfortable
2	warm	dry	comfortable
1	slightly warm	slightly dry	somewhat comfortable
0	neutral	neutral	neutral
-1	slightly cool	slightly humid	slightly uncomfortable
-2	cool	humid	uncomfortable
-3	cold	wet	extremely uncomfortable

Statistical analysis

Data for comparing the pre-room with the test-room were analyzed by Paired t-test. Result of physiological and subjective data were analyzed by repeated-measure analysis of variance (ANOVA) using Visual State for Windows Release 4.5J Software (Stat Soft, Inc.) The factors were conditions and time. A multiple comparison was performed using Scheffé. The relationship between SCT and hydration state was analyzed using the Pearson's correlation coefficient test. Differences at $p<0.05$ were significant for all statistical analyses.

Results and discussion

SCT (Saccharin Clearance Time)

SCT of the older age group under the thermal conditions with a Ta of 25°C and 10%RH was significantly longer than that of the younger age group.

Frequency of Blinking

Frequency of blinking in both older and younger age groups was significantly increased under the 10%RH and 30%RH, respectively. But there was no significant difference between the older and younger age groups.

Blood Pressure

Diastolic pressure and systolic pressure showed no significant change among the humidity levels.

Hydration state

Hydration state of the face showed significant differences with each humidity level, decreasing from 30minutes after entering the test-room and after 60, 90, 120, 150 and 180minutes it stopped decreasing and was stabilized at 10%RH and 30%RH. But there were no significant differences between groups. Hydration state of the hand showed significant differences between times but no significant differences between humidity levels.

TEWL (Transepidermal water loss)

TEWL of the face increased from 30 minutes after entering the test-room and after 60, 90, 120, 150 and 180minutes TEWL stopped increasing and was stabilized at 10%RH and 30%RH. TEWL of the face was significantly affected by the interaction of humidity and time. TEWL of the hand showed significant differences between times but no significant differences between groups.

Recovery sebum level

Recovery sebum level showed no significant difference between humidity levels and groups.

Mean skin temperature

Concerning mean skin temperature, there was no significant difference not only between humidity levels but also groups.

Body weight loss

Concerning increased body weight loss, there were significant changes between humidity levels showing loss of body weight at 10% RH compared with 50% RH and 30 % RH. But there were no significant difference between groups.

Psychological responses

There was no significant difference between the two groups in thermal comfort. But the younger age group was significantly more sensitive to dryness and thermal sensation than the older age group.

Conclusions

It is known that function of nasal mucociliary clearance decreases as humidity lowers. The more significant increase in SCT in the elderly group than in the younger age group in 10%RH suggests increasing hypofunction of nasal mucociliary activity with age. The hypofunction of nasal mucociliary activity is directly related to a decrease in self defense mechanisms emphasizing the importance of attention to the change of humidity especially in the debilitated elderly.

Blinking acts to supply moisture to the eye. Frequency of blinking reflects the state of dryness of the eye and the sensation of dryness leads to discomfort. Frequency of blinking in both older and younger age groups was significantly increased under the 10%RH and 30%RH, respectively. But there was no significant difference between the older and younger age groups. There seemed little change of ocular mucous membrane with age.

Concerning function of skin physiology, it was revealed that change of humidity affected parameters on moisture of skin like hydration state and TEWL but there was no influence of humidity on sebum secretion.

Concerning thermal sensation and comfort, subjects reacted sensitively immediately after change of environment but got acclimatized gradually. The elderly group seemed to react more sensitively to the change of humidity in the periphery of the body, but in other parts of the body the younger age group seemed to react more sensitively.

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IMPROVED EVALUATION OF THE LOCAL THERMAL ENVIRONMENT WITH CLOTHING INDEPENDENT COMFORT ZONE DIAGRAMS

Håkan O Nilsson

Department of Technology and Built Environment
Laboratory of Ventilation and Air Quality
University of Gävle, Sweden. hnn@hig.se

Introduction

The degree of thermal comfort depends greatly on the local environment. Consequently has the interest in the use of comfort diagrams increased in recent years (1 - 4). Human beings use different clothing and respond differently to heat transfer from different body areas. The development of comfort zone diagrams (1, 5) is a step towards a more general evaluation technique applicable to different manikins and preferably different instruments. It is important to adjust these comfort zones with the change of clothing worn by subjects and manikins. The various types and levels of clothing that manikins use today, make comparative interpretation of results from different manikins/methods very complicated. In order to facilitate comparison of results the comfort zone diagrams should be independent both of the manikin used as well as clothing worn.

In this paper several clothing independent comfort zone diagrams have been constructed based on measurements with two thermal manikins wearing two different sets of clothing. One objective of this work is to use and develop methods to visualise, analyse, and evaluate local thermal climate in order to improve the environmental conditions. The methods are used to find useful climate and ventilation system solutions that provide an improved thermal environment in many different daily life situations, e.g. at homes, working places and different types of vehicles.

Methodology

With the comfort zone diagrams used today (1, 5) evaluations can be made with two clothing combinations, or equivalent ensembles: summer clothing (S) 1.3 clo and winter clothing (W) 1.6 clo, total insulation. For comparison and versatility reasons is it important to be able to use comfort zone diagrams that are not depending on the clothing used. In the same way zones are made to be independent of the thermal manikin, or model, used. The concept of clothing independence assumes that the human being is equally sensitive to different heat losses independent of the insulation of the clothing worn. To show how this method can be used an extrapolation of the results from the summer (S) and winter (W) series are made. The specification of the clothing combinations used (total insulation values) in this paper are:

(S) “Summer clothing” (1.3 clo)
Consisting of shirt with long sleeves and trousers with long legs boxer briefs, shoes and socks.
(LS) “Light summer clothing” (1.1 clo)
Same as S but with shorts and shirt with short sleeves removing 0.2 clo.
(W) “Winter clothing” (1.6 clo)
Same as S but with an additional cardigan.
(EW) “Enhanced winter clothing” combination (1.9 clo)
Same as W but with winter underclothes with long sleeves and legs adding 0.3 clo.
(NC) “No clothing” (0.9 clo)
The total insulation of the air layer around the sitting thermal manikin.

The clothing combinations are slight modifications if the original summer ensemble. The LS has no clothing on arms and legs decreasing the insulation with 0.2 clo and the EW use an additional insulation of 0.3 clo on the upper and lower body.

The equivalent temperature (t_{eq}) can be calculated with (5):

$$t_{eq} = t_s - \frac{q''_T}{h_{teq}} = t_s - R_T \cdot q''_T \qquad \text{(equation 1)}$$

where

t_{eq} equivalent temperature of the environment. [℃]

t_s manikin surface temperature here 34 [℃]

q''_T manikin heat loss [W/m^2]

h_{teq} dry heat transfer coefficient determined during calibration [W/m^{2}K]

R_T total insulation, seated [m^{2}K/W]

By using this equation a “clothing independent” heat loss level can be established for each manikin body part. Making it possible to calculate new comfort zone diagrams by inserting any seated total insulation available between 0.9 and 1.9 clo.

$$t_{eq,zone} = 34 - R_T \cdot q''_{T,zone} \qquad \text{(equation 2)}$$

where

$$q''_{T,zone} = a + b \cdot MTV_{zone} \qquad \text{(equation 3)}$$

With this relationship, between a certain heat loss and the corresponding Mean Thermal Vote from the test panel, the heat loss corresponding to a certain level of comfort, or lack of comfort, in the diagram is consequently the same. However the shape of the zones will change with the clothing used. More insulative clothing should imply that the persons using it would accept a broader interval of t_{eq} and vice versa.

Results

In the table and diagrams below equation 2 and 3 have been used to calculate a mean acceptable heat loss for different body parts. Clothing independence is based on the theory that the human being is equally sensitive to different heat losses independent of the insulation of the clothing worn. This statement is fulfilled with the summer and winter ensemble used for the original diagrams. Linear regression correlations between clothing ensembles was high (r^2 between 0.89 to 0.98 see table 1). In the comfort zone diagrams, figure 2, can it easily be seen that the zones with slightly higher insulation on the upper body (winter clothing) is shifted towards the colder side of the diagram.

Table 1. Results from the regressions and calculated neutral values for the clothing combinations (NC) “No clothing” (0.9 clo), (LS) “Light summer clothing” (1.1 clo) and (EW) “Enhanced winter clothing” (1.9 clo).

Zone	a	b	r^2	R_T (m^{2}K/W) NC	R_T (m^{2}K/W)LS	R_T (m^{2}K/W)EW	t_{eq} (°C) neutral NC	t_{eq} (°C) neutral LS	t_{eq} (°C) neutral EW
Whole body	43.8	-13.3	0.97	0.134	0.160	0.300	28.1	27.0	20.9
Scalp	65.5	-33.9	0.89	0.125	0.199	0.193	25.8	21.0	21.3
Face	65.5	-33.9	0.89	0.125	0.199	0.193	25.8	21.0	21.3
Chest	36.1	-20.5	0.95	0.149	0.229	0.464	28.6	25.7	17.2
Up. back	36.1	-20.5	0.95	0.149	0.229	0.464	28.6	25.7	17.2
L U arm	43.0	-21.1	0.94	0.122	0.215	0.432	28.8	24.7	15.4
R U arm	43.0	-21.1	0.94	0.122	0.215	0.432	28.8	24.7	15.4
L L arm	43.0	-21.1	0.94	0.122	0.122	0.432	28.8	28.8	15.4
R L arm	43.0	-21.1	0.94	0.122	0.122	0.432	28.8	28.8	15.4
L hand	84.9	-57.2	0.98	0.117	0.117	0.146	24.0	24.0	21.6
R hand	84.9	-57.2	0.98	0.117	0.117	0.146	24.0	24.0	21.6
L thigh	46.7	-20.3	0.97	0.128	0.128	0.292	28.0	28.0	20.4
R thigh	46.7	-20.3	0.97	0.128	0.128	0.292	28.0	28.0	20.4
L calf	46.7	-20.3	0.97	0.128	0.128	0.292	28.0	28.0	20.4
R calf	46.7	-20.3	0.97	0.128	0.128	0.292	28.0	28.0	20.4
L foot	46.7	-20.3	0.97	0.128	0.128	0.215	28.0	28.0	24.0
R foot	46.7	-20.3	0.97	0.128	0.128	0.215	28.0	28.0	24.0
Lo. back	39.5	-19.5	0.93	0.145	0.247	0.381	28.3	24.3	18.9
Seat	39.5	-19.5	0.93	0.145	0.247	0.381	28.3	24.3	18.9

Conclusions

By using the concept of “clothing independent” heat loss levels a relationship between equivalent temperature and MTV with different levels of clothing insulation can be formed for each manikin body part. These relationships makes it possible to calculate new comfort zones by inserting any set of seated total insulation values. The heat loss corresponding to a certain level of comfort, or discomfort, in the diagram is consequently the same. The shape of the zones is however changed with the clothing used. Results from calculations shows that more insulative clothing should imply that the persons using it would accept a broader interval of t_{eq} and vice versa. As could be expected, does diagrams with less clothing present an increased sensitivity on most zones, except the normally unclothed head and hands. The opposite, decreased sensitivity for heat loss variations, can be observed for diagrams with increased clothing insulation. The concept of clothing independence assumes that the human being is equally sensitive to different heat losses independent of the insulation of the clothing worn. This might not be completely true, especially at the borders of no clothing or heavy clothing and has to be investigated further.

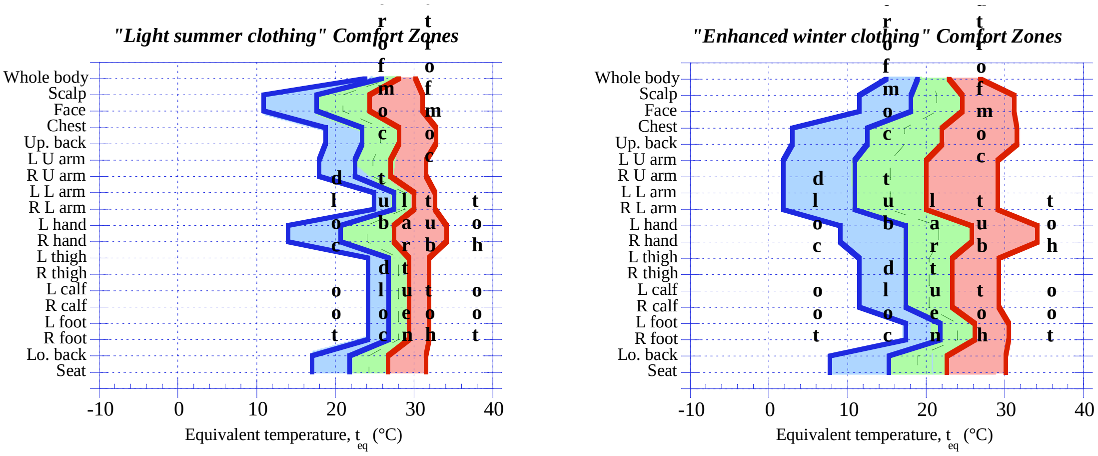

Figure 2a and 2b. Comfort zone diagrams derived for new “light summer” and “enhanced winter” clothing ensembles. Notice that the scales starts at –10ºC!

Observe that the comfort zones of acceptance has become significantly more narrow for the summer clothing, except for the “less sensitive” head and hands. The neutral t_{eq} for the unclothed manikin are for the other zones around 28 °C. This agrees well with the thermo neutral ambient temperature for nude humans, that is around 27 to 29°C (6).

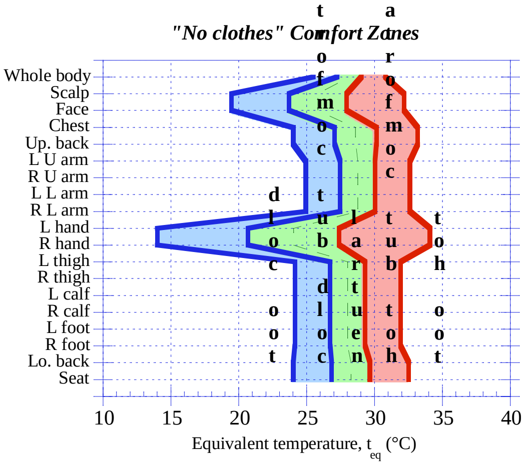

Figure3. Comfort zone diagram derived for the case where no clothing is used.

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VARIABILITY OF CLOTHING ACCORDING TO EXTERNAL TEMPERATURE

Bjarne W. Olesen[2,] *Michele De Carli*[1], *Angelo Zarrella*[1] *and Roberto Zecchin*[1]

[1] DFT – Dipartimento di Fisica Tecnica, Università di Padova, Italy
[2] DTU – Technical University of Denmark, Lyngby, Denmark
corresponding author: bwo@mek.dtu.dk

INTRODUCTION

For predicting or evaluating the indoor thermal environment, clothing is an important factor. In most cases clothing is selected individually by the occupants. In some cases, however, the type of clothing is prescribed by the workplace (e.g. clean room, uniforms and dress codes). Very little information is available, however, on the criteria people use for selecting their clothing. The outdoor temperature will probably have some influence, but if driving from home to work and remaining inside a vehicle, the outdoor temperature may have little influence. The indoor temperature at the workplace may also be a factor. If it is known that the space is conditioned and operated at an almost constant temperature all the year round, clothing will probably be adapted accordingly. If, on the other hand, the building is not conditioned and it has been experienced that the space becomes warm with increasing outdoor temperatures, lighter clothing will be chosen to compensate for the increased indoor temperatures. There may also be gender and social differences in the selection of clothing.

In existing standards and guidelines clothing is specified only for design conditions. In most cases a recommended temperature interval for summer (cooling mode) is based on light summer clothing of 0.5 clo and an interval for winter (heating mode) is based on a clothing insulation of 1.0 clo (1, 2). As whole-year dynamic computer simulations of buildings and the indoor environment become more and more common, there is a need to have some standardized method for simulating people's clothing habits. One possibility is to use a constant clo-value according to season, but it would be more realistic to assume some change of clothing insulation throughout the year.

The present work is based on existing databases and analyses people's clothing behaviour by investigating the parameters (outside temperature, mean weekly outside temperature, space temperature) that motivate people's choices. The data will also be analysed for differences between gender.

METHOD

The analysis of clothing data was based on previous field investigations with databases that could be accessed or provided by the authors. A database with data from 28 cities all over the world, have been analyzed (3, 4).

In this group of data three types of office building were investigated: air-conditioned systems (HVAC), naturally ventilated (NV) and mixed systems (MIX). In the databases, the authors have evaluated clothing resistance factors by observing people. The average clo-value for the occupants at the time of measurement is available. This means that no specific information concerning the clo-value for each person is given in the database, and the standard deviation between persons is not listed. The number of people observed may vary during the day. The way in which the minimum and maximum average clo-values vary will be investigated. This may be useful when simulating a building based on a test reference year (TRY) in order to allow for a certain range in indoor temperature conditions.

For each day and for each group of subjects, average, minimum and maximum clothing resistances have been considered. In group A an admissible minimum clothing resistance of 0.4 clo (for ethical aspects) and an admissible maximum value of 1.6 clo have been included. For group B no restrictions on clothing resistances have been made.

Male and female distinction has been made for group A, while for group B no such distinction has been made. For group A the small number of subjects for mixed mode buildings was not sufficient to reach any significant results.

The basic question is why people choose a certain clothing. Some authors say that it is due to the expected indoor environment in buildings (5). Others suggest that the clothing may be a function also of the external weather (6, 7)

In this work, various external temperatures have been considered:

- temperature at 6 a.m., thus simulating that people base their thermal sensation on the external temperature when they go out in the morning (8);
- mean monthly temperature during the period investigated, thus simulating the variability of clothing according to external mean monthly temperature;

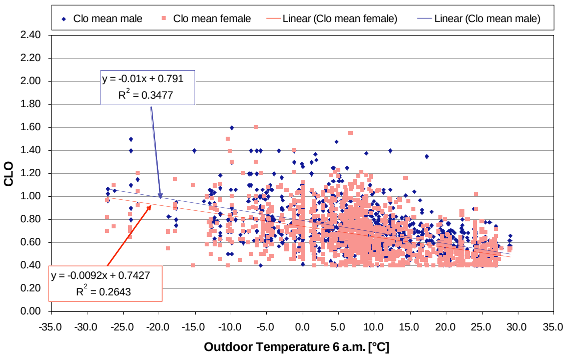
RESULTS

Influence of gender

The influence of gender in HVAC buildings of group A can be seen in Figure 1; differences between males and females is very limited and it has therefore been considered negligible in the study. Also for NV buildings in group A the difference between gender can be disregarded (Figure 2), although in this group of data there is a slight difference between men and women when considering the minimum values of clothing resistance during a day; this is mainly due to cultural aspects, since the majority of data derive from Pakistan.

External temperature

Variation of clo-values in relation to outside air temperature (6 a.m., mean daily, average in the period considered, and weighted weekly value) has been investigated only for group A where data for males and females are combined. In Figures 3 and 4 the relationship between resistance of clothing and minimum outside temperature (outdoor temperature at 6 a.m.) for HVAC and NV buildings respectively can be seen. In Figures 5 and 6 to the mean monthly temperature.



Figue 1 - Daily mean clothing resistance for males and females in relation to outdoor temperature at 6 a.m. in HVAC buildings.

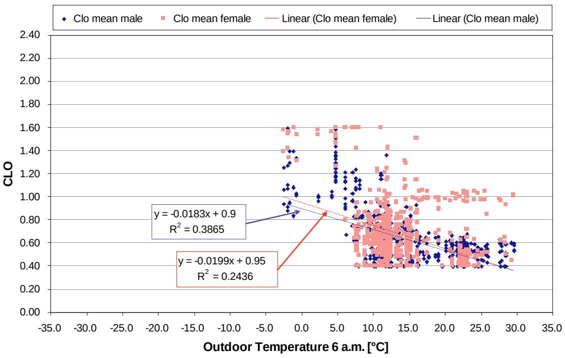


Figure 2 - Daily mean clothing resistance for males and females in relation to outdoor temperature at 6 a.m. in NV buildings.

The correlations are not significant. For HVAC buildings the R^2 value is almost independent of the type of outside temperature used (at 6 a.m. or mean monthly). For NV buildings the highest correlation is obtained using the outdoor temperature at 6 a.m.

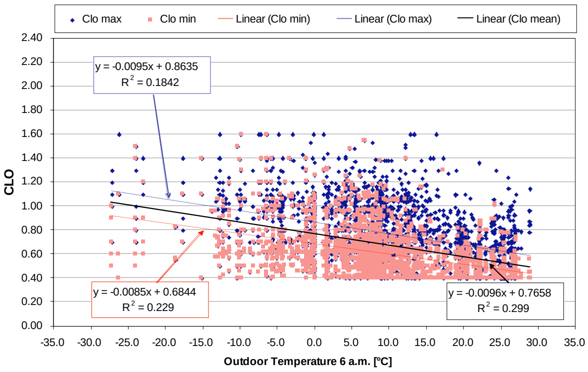


Figure 3 – HVAC clo value vs. temperature at 6 a.m.

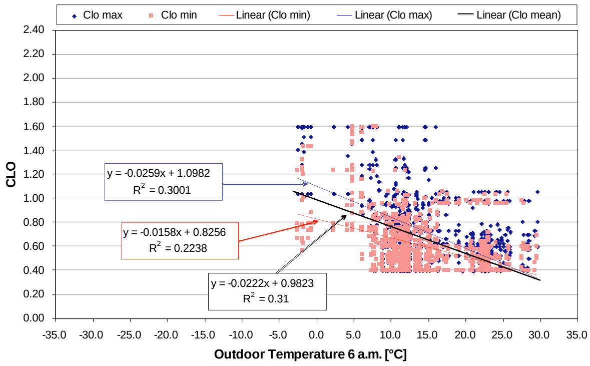
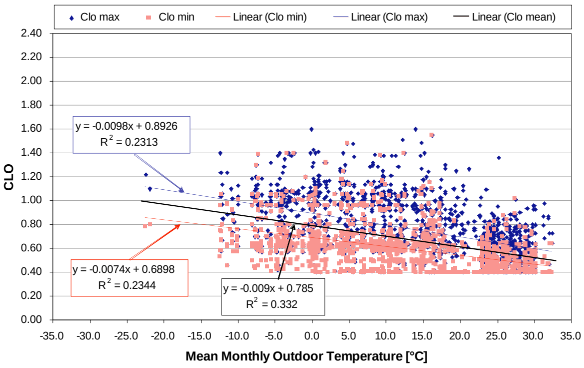


Figure 4 – NV clo value vs. temperature at 6 a.m.



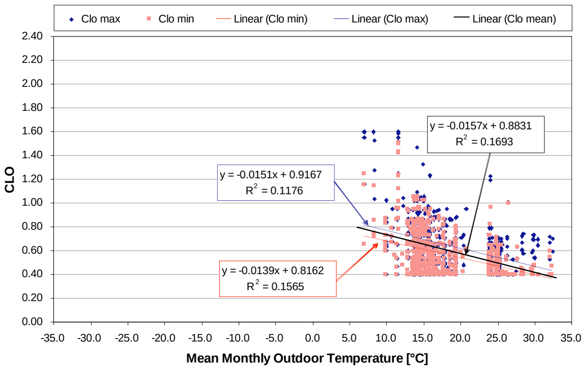
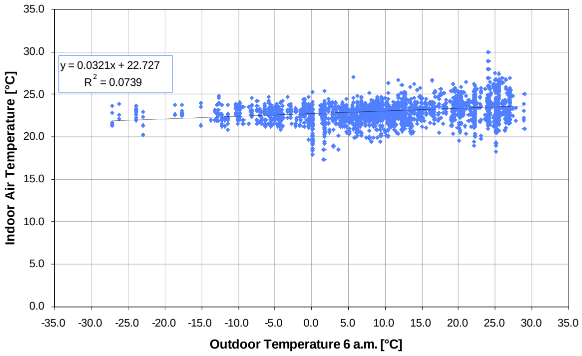


Figure 5 – HVAC clo value vs. mean monthly temperature.

Figure 6 – NV clo value vs. mean monthly temperature.

Influence of indoor air temperature

In Figures 7 and 8 the indoor air temperature, when the maximum clo-value has been recorded, is plotted against outdoor temperature at 6 a.m. As can be observed in HVAC buildings, indoor air temperature does not influence clothing resistance; in NV buildings, on the other hand, indoor air temperature depends on outdoor temperature (R^2=0.72). This means that if indoor air temperature is also considered, the correlation does not increase sufficiently. It is probable that adaptation of clothing during a day depends on indoor air temperature as well, but this needs to be studied further.



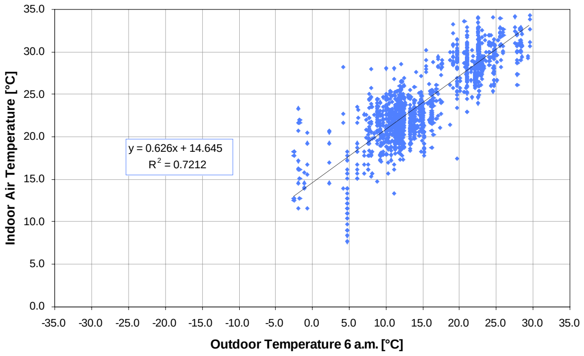


Figure 7 – HVAC: indoor air temperature vs. outdoor temperature at 6 a.m.

Figure 8 – NV: indoor air temperature vs. outdoor temperature at 6 a.m.

DISCUSSION AND CONCLUSIONS

In the present work, the possible correlation between external air temperature and clo-value has been investigated, by considering two existing databases. There is a change in the clo-value during the day (difference max-min, see Figures 4 and 5), both in HVAC and in NV buildings. For HVAC buildings the difference is around 0.2 clo and is independent of outside temperature. This corresponds to the insulation of a jacket or sweater. For NV buildings the difference between max-min varies between 0.2 clo and 0 clo, as it becomes lower at higher outside temperatures (Figure 5). This means that in HVAC buildings an average clothing insulation of between 0.5 clo and 1.0 clo, with a variation of ± 0.1 clo, can be assumed.

The investigation on gender has shown insignificant differences between males and females; therefore it seems that a unique value for the clo-value can be considered for a building.

For HVAC buildings it seems that no appreciable differences appear when considering the minimum daily temperature, the mean daily temperature, the mean monthly temperature or the weighted temperature; for NV buildings the use of the minimum daily temperature gives better correlations.

In the present work the correlation has been carried out considering only the external temperature. It does not seem likely that by including also indoor temperature the results would be better, since the outdoor temperature influences the indoor temperature in NV buildings and does not affect it very much in HVAC systems.

Further studies are needed to consider the clothing items selected individually. The databases indicate large individual differences. To evaluate indoor comfort based on whole-year dynamic simulations of buildings and clothing, the assumed clo-value is very important. There is a need to come to some kind of agreement on “standard” clothing behaviour when analysing comfort and energy use

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IMPROVING HEALTH, COMFORT AND PRODUCTIVITY BY INCREASING INDOOR AIR QUALITY

P. Ole Fanger, Professor, D.Sc., Hon.D.Sc.

International Centre for Indoor Environment and Energy,
Technical University of Denmark, DK-2800 Lyngby, Denmark
Tel.: +45 4525 4041, Fax: +45 4593 2166, e-mail: fanger@mek.dtu.dk

INTRODUCTION

Numerous large field studies among thousands of occupants working in hundreds of commercial buildings in different parts of the world have documented substantial rates of Sick Building Syndrome (SBS) symptoms and dissatisfaction with the indoor air quality in many buildings (Skov et al., 1987; Mendell, 1993; Sundell, 1994; Bluyssen et al., 1996; Lee et al., 1999; Skyberg et al., 2003; Sekhar et al., 2003; Bishof et al., 2003). This occurs even though existing ventilation standards and guidelines are met (CEN, 1998; ASHRAE, 2003) and even though measured individual pollutants are way below any limits or guideline values. One of the main reasons is that the requirements of existing standards and guidelines are quite low. The philosophy of these documents has been to establish an indoor air quality where less than a certain percentage (e.g. 15%, 20% or 30%) of people are dissatisfied with the indoor air quality while the rest may find the IAQ barely acceptable (CEN, 1998; ASHRAE, 2003). The philosophy of the standards behind the design of HVAC systems has in practice led to mediocre air with rather large numbers of dissatisfied persons, as predicted.

Important new information is that a series of independent studies has documented that mediocre indoor air quality also has a negative impact on the productivity of office workers. These studies, which will be reviewed in the present paper, show that it pays to provide high indoor air quality. They form a strong economic incentive to design for high indoor air quality in the future. We need a paradigm shift where we try to satisfy even the most sensitive persons, i.e. to provide healthy indoor air for all occupants in a space. Compared to today's practice, this may require that we improve IAQ by several orders of magnitude. This paper will discuss how such a dramatic improvement can be realized. Four methods are suggested as means to reach this ambitious goal without increasing ventilation. They may even allow for a simultaneous decrement in ventilation and energy consumption. Sensory measurements are of prime importance in this endeavour.

PRODUCTIVITY AND INDOOR AIR QUALITY

A series of recent independent studies document that the quality of indoor air has a significant and positive influence on the productivity of office workers. In one study, a well-controlled normal office (field lab) was used in which two different air qualities were established by including or excluding a commonly used carpet as an extra pollution source, invisible to the occupants (Wargocki et al., 1999). The two cases corresponded to a low-polluting and a non-low-polluting building as specified in the European guidelines for the design of indoor environments (CEN, 1998). The same subjects worked for 4-1/2 hours on simulated office work in each of the two air qualities. The productivity of the subjects was found to be 6.5% higher ($P<0.003$) in good air quality and they also made fewer errors and experienced fewer SBS symptoms. This study performed in Denmark has later been repeated in Sweden with similar results (Wargocki et al., 2002a). A third study was performed in the Danish field lab with the same pollution sources present at three different ventilation rates: 3, 10 and 30 l/s·person (Wargocki, 2000a). The productivity increased significantly with increased ventilation. The three studies involving seven experimental conditions and 90 subjects have been analysed as a whole, relating productivity to perceived air quality (Wargocki et al, 2000b). Results show a significant positive influence of high indoor air quality on productivity in offices.

In another blind study with a similar experimental set-up as the one described above, the air was polluted by 3-month-old personal computers as an extra pollution source (Bakó-Biró et al., 2004. In this blind study the productivity was 9% lower ($P<0.01$) when the extra computers were present and three times as many of the occupants were dissatisfied with the air quality. Each of the PCs polluted the air corresponding to 3 olf. This study was later extended to include the most common brands of PCs with

CRT monitors and TFT (flat) screens (Wargocki et al., 2003b). It showed results very similar to the previous study on sensory pollution and also showed that PCs with flat screens pollute much less.

The positive impact of high indoor air quality on productivity has recently been validated in a blind intervention study in the field in a call centre where the ventilation rate could be increased while particulate filters were either new or used (Wargocki, 2003a). A significant positive effect of increased ventilation on productivity was documented but only when a new filter was used. It should be noted that in the field lab studies mentioned above showing a positive impact of ventilation on productivity, *no* filters were present. Federspiel et al. (2002) made also an intervention study in a call centre where ventilation rates were increased. Old used filters were present all the time in this study and may explain why the authors found only a marginal impact of increased ventilation on productivity. These studies indicate, as shown in several previous investigations, that particulate filters in the HVAC system can be a serious source of pollution (discussed further in the next section).

Providing high indoor air quality, compared with the mediocre air that is present in many existing office buildings worldwide, may increase productivity by an estimated 5-10%. An annual loss of this magnitude caused by mediocre indoor air quality will often be much higher than energy costs, capital costs, and the cost of operating the building. Any life cycle cost analysis of office buildings should therefore include productivity losses caused by mediocre minimum IAQ prescribed by present standards. These losses will often be a dominating factor compared to all other costs related to the construction and operation of a building. It pays to provide high indoor air quality.

WHAT IS INDOOR AIR QUALITY?

When we want to provide indoor air of high quality it is of course essential to discuss what IAQ is and how it can be quantified. One indirect method often applied in standards is to use the outdoor ventilation rate or air change rate as an indicator of IAQ. This is often a poor indicator, however, since it does not take into account the indoor pollution sources. There may be poor IAQ in a space in spite of a high ventilation rate if the sources are strong. On the other hand, good IAQ may be achieved at a moderate ventilation rate if the sources are small. Using ventilation rate as a measure of IAQ is as primitive as it would be to relate human thermal comfort to the supply of cooling power to a space, rather than to the temperature in the space.

Another option is to express IAQ in chemical terms. We know that it is chemicals emitted from people, materials and processes that decrease the IAQ. Can we not just make sure that the concentration of each chemical in the air is below a certain guideline value? Unfortunately this method does not work, the reason being that in nonindustrial buildings there are typically hundreds or even thousands of chemicals in the air, each in very small concentrations, and we have only limited information on their impact on health and comfort. Guideline values are available for only a few dozen chemicals which only apply when they occur alone. How about odour or irritation thresholds that are available for a larger number of chemicals. The thresholds given in the literature vary considerably, however, and provide information only on the concentration where 50% of people can perceive a specific chemical when it occurs alone. The most sensitive people may perceive the chemical at a concentration that is several orders of magnitude lower and may perceive a cocktail of hundreds of chemicals at even lower concentrations. Furthermore, some chemicals are perceived as very unpleasant while others may even be pleasant. A further obstacle is that many chemicals are difficult to measure at the very small concentrations where they still have a negative impact on people.

A third and obvious alternative is to use the human response directly to define IAQ. In general, quality is often defined as the extent to which human requirements are met. Using this definition, high indoor air quality would be air that is perceived as pleasant by all occupants and has no negative effects on health and productivity. To this end, sensory measurements using human panels have been used to evaluate IAQ already by Yaglou in the 1930s (Yaglou et al., 1936) and were later used by Fanger (1988a) to introduce sensory units: the perceived IAQ was expressed in decipol or % dissatisfied while the sensory pollution load was expressed in olf. Sensory measurements have often been shown to be superior to chemical measurements and they have formed for decades the basis for ventilation standards and guidelines (ASHRAE, 2003; CEN, 1998).

The following three recent examples show the superiority of sensory measurements.

The extra pollution source introduced in Wargocki et al.'s productivity study (1999) mentioned above was an old used common type of carpet that had a strong negative impact on perceived air quality, SBS symptoms, and productivity, while the measured chemicals in the air emitted from the carpet occurred in very low and apparently harmless concentrations far below any limits of concern.

The same applied in the above-mentioned study on PCs (Bakó-Biró et al., 2004; Wargocki et al., 2003b). The air pollution from the PCs caused high dissatisfaction among people, SBS symptoms, and a decrement in their productivity while the chemical measurements showed extremely low and apparently harmless concentrations in the air (Nakagawa et al., 2003).

A third example is particle filters in HVAC systems. Fanger et al. (1988b) documented already in the 1980s that the HVAC system could contain serious pollution sources that degraded the air quality even before the air reached the space to be ventilated.. Later it was identified that it was especially the particle accumulation on the filter that had a negative impact on the perceived air quality (Pejtersen et al., 1989; Clausen et al., 2002a,b; Beko et al . 2003). Still it has been extremely difficult to measure and identify individual chemicals being responsible for the poorly perceived air quality.

In the above examples, high percentages of people have been dissatisfied with the air quality due to widely differing pollution sources although traditional chemicals (VOCs) measured by conventional methods seem to be of no concern. In our future aim for much higher indoor air quality that can provide wellbeing even for the most sensitive persons, chemical concentrations in the air will be much lower. Human sensory measurements will, under these circumstances, be even more crucial. It does not mean that we should ignore indoor air chemistry. On the contrary, research in this area should continue and be intensified in parallel with sensory studies, so that we can better understand why indoor air is sometimes perceived as fresh and pleasant and in other cases as stale and stuffy. The chemistry of indoor air is often very complex, influenced by emissions, sorption and reactions, and it comprises often hundreds of chemicals in very low concentrations, including short-lived and stealth chemicals hard to measure (Weschler, 2003). Although difficult, it is essential that we continue our search for the chemicals in the air responsible for the negative impact on perception, SBS symtoms and productivity.

HOW TO PROVIDE HIGH INDOOR AIR QUALITY

The challenge is now to provide indoor air of high quality using sensory measurements. Our aim is to satisfy even very sensitive subjects. Most offices in practice have mediocre air quality with 20-60% dissatisfied.

Let us as an example consider a typical office with 40% dissatisfied. Our aim is to establish a much higher IAQ, where hardly any are dissatisfied, which for practical purposes may translate into 1% dissatisfied (see Table 1). Is such a dramatic improvement at all possible and if it is, how can it be accomplished? In the following sections, different methods that can contribute to this aim will be discussed and rough quantitative estimates will be given on how much each of these different methods can contribute to the ambitious goal of decreasing the dissatisfaction from 40% to 1%. These are the methods to be discussed:

- increased ventilation
- source control
- air cleaning
- personalized ventilation
- cool and dry air.

Table 1. Mediocre and high IAQ (Fanger, 1988a)

	% dissatisfied	dp	Required ventilation rate l/s·olf
Mediocre IAQ	40%	4.1	2.5
High IAQ	1%	0.1	100

Increased ventilation

One method of improving the IAQ is to increase the ventilation. A 40% dissatisfaction corresponds to approximately 4 dp or a ventilation rate of 2.5 l/s·olf (see Table 1). Let us assume a sensory pollution load in this typical office to be as given in Table 2, each office worker contributing one olf; the correspondig building is a non-low-polluting building, which provides 0.2 olf/m^2 floor (CEN, 1998) which with 15 m^2 floor per person contributes 3 olf. A PC less than one year old provides 1 olf. This provides a total sensory load of 5 olf per person. The actual ventilation rate in the building may therefore be 5x2.5 = 12 l/s·person. To reach 1% dissatisfied, which corresponds to 0.1 dp, would require a ventilation rate of 100 l/s·olf or an enormous rate of 500 l/s·person.

This estimation asumes that the sources are constant in the building and its HVAC system, which is not true. We know, for instance, that the emission or pollution from used traditional particle filters increases proportionally with airflow through the filter. With a normal used filter, increased ventilation has therefore only a marginal positive impact on perceived air quality. Even with a clean filter, ventilation would require an enormous rate if this method alone should let us reach our goal. Such a high rate would of course be prohibitive due to cost and energy use.

Table 2. Total sensory pollution load per person in a typical existing and in a new extremely low-polluting building

Pollution source	Existing non-low-polluting building (0.2 olf/m^2) olf	Extremely low-polluting building (0.02 olf/ m^2) olf
1 office worker	1	1
building, 15 m^2 floor per person	3	0.3
1 PC (average during first year)	1	0
Total sensory pollution load	5	1.3

Other methods should therefore first be considered and they may even allow a high IAQ at a decreased ventilation rate to the benefit of cost and energy use.

Source control

An obvious preferred method to improve IAQ is to reduce pollution sources in the building, including the HVAC system. There are three pollution sources that are of special concern: particle filters, building materials (including carpets), and PCs.

Particle filters are particularly serious since the air quality is degraded even before it is supplied to the ventilated space. Furthermore, increased ventilation, i.e. a higher airflow through the filter, increases, as mentioned previously, the emission of pollutants from the particles in the filter so that the air quality downstream of the filter does not improve (Alm et al., 2000; Strøm-Tejsen et al., 2003). This may help explain why increased ventilation in mechanically ventilated spaces in some cases improves IAQ only slightly or not at all. It may also explain why, in some cases, the air quality in mechanically ventilated or even air-conditioned buildings has been found to be worse than in naturally ventilated buildings (during winter). It is therefore recommended that traditional particle filters in HVAC systems should be changed very frequently or better, substituted by alternative equipment that can remove particles from the air to protect the HVAC system without accumulating the polluting dust in the airflow. R&D is obviously required.

The second source of pollution is building materials, including carpets. It is suggested that carpets in general should be avoided unless they have been very carefully tested. It is suggested that requirements for carpets and other materials in the future should be much higher than those specified at present by various recommendations and labelling criteria. Strict sensory requirements should be included in testing of materials.

Following the above recommendations for filters, materials and carpets, it is suggested that a realistic goal for the sensory load for low-polluting buildings that at present is 0.1 olf/m^2 floor in the building (CEN, 1998) be lowered to 0.02 olf/m^2 floor (extremely low-polluting building).

A third important pollution source is common brands of PCs with CRT screens. They pollute 3 olf in the beginning with an average of more than 1 olf during the first year. It is recommended to stop buying the common brands of PCs with CRT screens and instead purchase low-polluting PCs and use TFT (flat screens) that generate only a negligible pollution. Since a PC generation lasts only 3 years and the pollution decreases with a half life of 4 months, the load from the existing stock of PCs would quickly decrease if the above recommendation is followed.

Following the above recommendations for source control, the total sensory pollution load in an office could be reduced as shown in Table 2, from 5 to 1.3 olf/person or by a factor of 4.

Air cleaning

Cleaning of indoor air from gaseous pollutants is a method with a promising potential for improving IAQ and partly substituting ventilation. Different methods including sorption and photocatalysis are applied. The latter method has shown to provide interesting filtering efficiencies documented in relation to individual chemicals in the air (Zhao and Yang , 2003). For the cocktail of chemicals responsible for the perceived air quality in very low concentrations, a cleaning efficiency of above 80% is feasible, i.e. air cleaning may decrease concentrations and improve IAQ by an estimated factor of 5. But further R&D of the technology is obviously needed and studies to demonstrate cleaning efficiencies on perceived IAQ for typical indoor pollution sources are recommended.

Personalized ventilation

In our example, 12 l/s·person of outdoor air is supplied to the office. Of this air, only 0.1 l/s·person, or 1%, is inhaled. The rest, i.e. 99% of the supplied air, is not used. What a huge waste! And the 1% of the ventilation air being inhaled is not even clean. It is polluted by bioeffluents, building materials and PCs in the space.

According to traditional engineering practice, full mixing of clean supply air and pollutants in the room air was often seen as an ideal. What is needed in the future are systems that supply rather small quantities of clean air direct to the breathing zone of each individual. The idea is to serve to each occupant, clean air that is as unpolluted as possible by the pollution sources in the space. In an office, this personalized ventilation may be provided from an individual movable outlet on a desk (Figure 1). Under ideal conditions, each person can inhale clean air from the core of the jet where the air is unmixed with polluted room air and has a low velocity and turbulence which do not cause draught. Such systems are now being developed and studied (Melikov et al., 2002; Kaczmarzyk et al., 2002; Bolashikov et al., 2003). Based on these studies, it seems realistic that a properly developed outlet may reach a ventilation effectiveness as high as 10 or more, i.e. personalized ventilation may increase the quality of the inhaled air by one order of magnitude. An essential feature is that each person has easy control over the position of the outlet, of the flow and its direction, and even of the temperature of the supply air.

Cool and dry air

Comprehensive studies by Fang et al. (1998a,b, 1999) and Toftum et al. (1998) have shown that perceived air quality is also influenced by the humidity and temperature of the air we inhale. People prefer rather dry and cool air. They like a sensation of cooling of the respiratory tract each time air is inhaled. This causes a sensation of freshness which is felt pleasant. A high enthalpy of the air means a low cooling power of the inhaled air and therefore an insufficient convective and evaporative cooling of the respiratory tract, and in particular the nose. This lack of proper cooling is closely related to poorly perceived air quality.

Fang’s studies show that alone a decrement of the air temperature of 2-3 K, e.g. from 23-24℃ to 21℃ will improve the perceived IAQ by a factor of two. Decreased humidity has also a beneficial effect on perceived IAQ down to 20% rh. Below that, dry air may have negative effects on eye blinking rate and productivity (Wyon et al., 2002; Fang et al., 2003).

Figure 1. The principle of personalized ventilation: small amounts of cool, dry, and clean air should be supplied directly and gently to a person's breathing zone and be easily controllable by the individual.

Combined effect of all methods

What happens if we simultaneously use all methods to improve the IAQ? Compared to the typical reference office at 23-24°C with 40% dissatisfied and a ventilation rate of 12 l/s·person, we may by source control, air cleaning and personalized ventilation, decrease the pollutant concentration and the perceived IAQ by a factor of 4x5x10 = 200, without increasing the ventilation rate. These rough estimates assume that the outdoor air is clean.

By decreasing the temperature, we may furthermore improve perceived IAQ by a factor of two, i.e. to a level 400 times better than the reference. This is even ten times better than our ambition of 1% dissatisfied (0.1 dp) and may leave room for simultaneous energy savings by reduced ventilation. Studies of combined effects in the laboratory and in the field would be essential..

CONCLUSIONS AND RECOMMENDATIONS

The indoor air quality in many offices and similar buildings is rather mediocre and gives rise to high percentages of dissatisfied persons as well as SBS symptoms, even though present standards and guidelines are met. Recent studies document that mediocre IAQ also decreases productivity. This will be a strong incentive to search for high IAQ, i.e. truly healthy air, satisfying even the most sensitive persons. To meet this ambitious goal, a paradigm shift is needed. The following methods are recommended.:

- Avoid unnecessary pollution sources.
    - Particle filters in HVAC systems are a serious pollution source. They need to be changed frequently or substituted by new technology.
    - Personal computers with CRT screens are a serious pollution source, at least during the first year of operation. When purchasing new PCs, select TFT (flat) screens.
    - Low-polluting building materials should be selected based on much stricter criteria than hitherto. Avoid carpets.
- Cleaning the indoor air of gaseous pollutants is a promising technology that needs to be further developed as an alternative or supplement to ventilation.
- Small amounts of clean air should be offered where it is consumed, i.e. as personalized ventilation close to the breathing zone of each person and easily controllable by the individual.
- The air should preferably be offered rather cool and dry.

Applying these four methods has the potential of increasing the quality of the air we breathe by several orders of magnitude, i.e. of satisfying all persons while maintaining the same or even a lower ventilation rate and energy consumption.

FUTURE OUTLOOK

The ambition of the first paradigm shift discussed above is to provide indoor air that is perceived as acceptable by all occupants. A second future paradigm shift could be to provide indoor air that is perceived equally fresh and pleasant as outdoor air when it is best in nature, e.g. in the mountains or at sea. Beyond this high ambition, a third paradigm shift is conceivable where indoor air is created that is perceived as better than air pertaining anywhere in nature, i.e. truly air that is “out of this world”. We have learned how to cook and prepare food that is digestible and tastes better than the raw materials found in the wilderness of nature. Similarly, we should not exclude that we can learn how to condition air so that it is perceived as better than that which nature can offer.

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INTERVENTION STUDIES WITH REMOTE MEASUREMENT OF OCCUPANT COMFORT, HEALTH AND PERFORMANCE

J. Toftum, A. Lantner, H. Svanekiær*

International Centre for Indoor Environment and Energy,
Department of Mechanical Engineering Technical University of Denmark
Corresponding author: jt@mek.dtu.dk

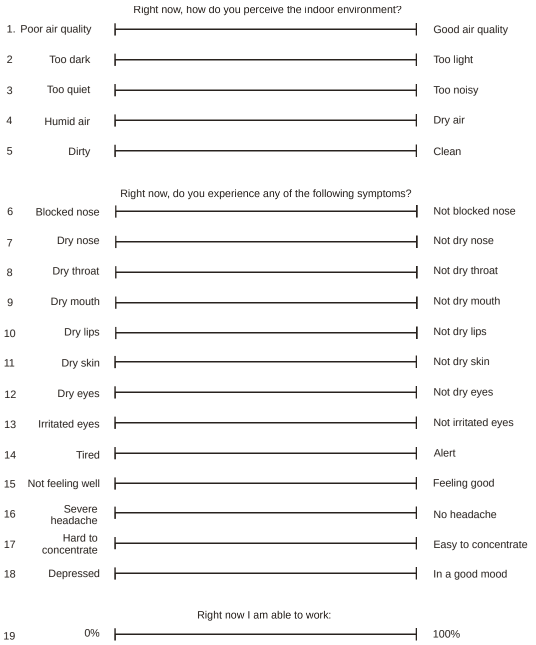
Introduction

Internet-based occupant satisfaction surveys have been used as a valuable tool to benchmark building performance and detect occupants' preferred improvements or modifications of their building (1). Remote Performance Measurement (RPM) has a broader scope and is a research-oriented, internet-based methodology used in intervention studies to assess effects of the indoor environment on occupants' perceptions, symptoms and performance of simulated office tasks. Currently, RPM consists of a questionnaire used to measure instantaneous effects on occupants of the intervention performed, a set of standard office tasks, as well as a general questionnaire, focusing on occupants' overall assessment of the indoor environment and the frequency of occurrence of building related symptoms during the past three to four months. The instantaneous questionnaire uses mostly Visual Analogue Scales (VAS) to measure changes in perceptions and the intensity of symptoms and as such is more useful to evaluate the impact of short-term building interventions (2). The purpose of this study was to analyse perceptions and symptoms measured with VAS and interval scales included in the instantaneous questionnaire during a temperature intervention in three office buildings. Performance results that were obtained in the same study will be reported in Toftum et al. (3).

Methods

The instantaneous questionnaire included VAS to assess perceptions and the intensity of selected specific and general SBS symptoms, a 7-point thermal sensation interval scale, as well as questions that could be answered categorically (e.g. acceptable/unacceptable). Figure 1 shows the VAS that were used to assess perceptions and symptom intensities. As Figure 1 shows, some scales were unipolar and others were bipolar. All scale markings resulted in an integer value in the range 0 (left end-point) to 100 (right end-point). When occupants clicked with the left mouse button on the scale a red marker appeared. The marker could be moved to another location by clicking elsewhere on the scale.

The approach of using questionnaires and performance tasks via the internet was tested in a temperature intervention study conducted in three office buildings located in the greater Copenhagen area. During two consecutive days (Wednesday and Thursday) in two consecutive weeks the temperature in the involved sections of the building was kept either in the range 24 – 26°C or in the range 20 - 22°C. The buildings were studied one at a time. When no intervention was running, a temperature set point of around 23-24°C was used. Two of the buildings allowed cross-over study designs to minimize learning effects when administering the performance tests. Occupants were asked to fill in the questionnaire after being present at their workplace for at least 3-4 hours.



One building was naturally ventilated and two buildings had a mechanical ventilation system (buildings 2 and 3). All buildings had radiators that were controlled individually by thermostats in the offices. In buildings 2 and 3, the temperature was controlled by a combination of the radiators and a

VAV ventilation system (mixing). During the study period, temperature and relative humidity were logged continuously at 18-20 locations in each building and on the intervention days spot measurements of thermal climate parameters and the CO_2-concentration in the offices were made. Table 1 shows the temperatures that represent the exposure of the occupants at the time of completing the questionnaire as well as the number of respondents present during each intervention. Standard deviations indicate between-occupant variation.

Figure 1. Visual Analogue Scales included in the questionnaire.

Table 1. Representative temperatures and the number of respondents in each building.

	Building 1		Building 2		Building 3	
	Temperature (°C)	N	Temperature (°C)	N	Temperature (°C)	N
Cold	21.3 ± 0.7	50	21.4 ± 1.1	42	21.4 ± 0.6	116
Warm	23.9 ± 0.6	45	24.1 ± 0.4	45	25.1 ± 0.6	118

Results and discussion

Figures 2 and 3 show mean thermal sensation and perceived air quality recorded in the three buildings during the cold and warm intervention. With both thermal sensation and IAQ, a majority of the occupants voted near the scale end-points, causing a non-Gaussian distribution of data. This was also supported by the Kolmogorov-Smirnov test, and therefore a non-parametric test (Wilcoxon Rank Sum test) was used to compare perception votes between the cold and warm intervention. As indicated in Figures 2 and 3, both the perceived air quality and the thermal sensation differed significantly between the cold and warm intervention (IAQ: $p < 0.0037$; thermal sensation: $p < 0.0001$). Among the other perception responses (noise, lighting, perceived humidity of the air, cleanliness), only the perception of air humidity differed significantly between interventions in buildings 1 and 3. The air was perceived as more humid in the cold environment. Thus, perception responses related to the temperature intervention changed between interventions as expected and remained unchanged for responses unrelated to the intervention.

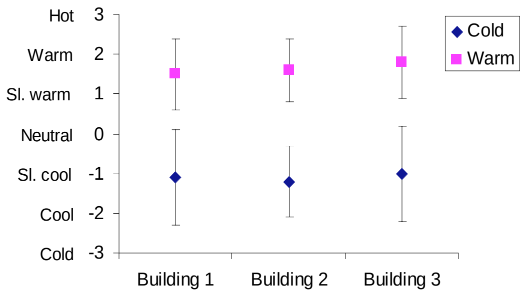


Figure 2. Thermal sensation recorded in the three buildings (mean ± s.d.).

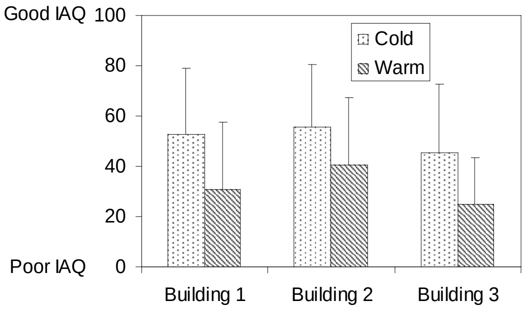


Figure 3. Perceived air quality recorded in the three buildings (mean ± s.d.).

For each building, Table 2 shows the intensity of different SBS symptoms as recorded during the warm and cold interventions. For all symptoms a lower value means a “worse” response, and as seen in Table 2 and indicated by the arrows, almost all symptoms were perceived as being worse under the warm condition.

Symptom responses did not follow a Gaussian distribution and thus the Wilcoxon Rank Sum test (one-sided test, hypothesis: cold intervention response > warm intervention response) was used to test for significant differences between interventions. In buildings 1 and 3 the improvement of most symptoms was significant, whereas in building 2 the symptom intensity changed only little between interventions. Although this does not explain why differences were significant mostly in buildings 1 and 3, it may be worth noting that in these buildings the study was carried out in a cross-over design, for which the configuration of building 2 did not allow. Occupants' self-estimated performance was also significantly higher in the cool than in the warm environment in buildings 1 and 3 (p < 0.004).

Table 2. Symptom intensity (mean ± s.d.) recorded in the three buildings during the cold and warm intervention. Symptom numbers refer to the scales shown in Figure 1.

	Building 1			Building 2			Building 3		
	Cold	Warm	Cold to Warm	Cold	Warm	Cold to warm	Cold	Warm	Cold to warm
6 Blocked nose	71 ± 33	66 ± 32	↓	77 ± 29	74 ± 29	↓	66 ± 32	62 ± 34	↓
7 Dry nose	66 ± 30	42 ± 34	↓ ***	58 ± 33	56 ± 36	↓	53 ± 34	42 ± 32	↓ ***
8 Dry throat	65 ± 33	48 ± 32	↓ ***	64 ± 29	63 ± 31	↓	53 ± 31	46 ± 33	↓ **
9 Dry mouth	67 ± 32	45 ± 32	↓ ***	64 ± 30	63 ± 31	↓	56 ± 33	44 ± 32	↓ ***
10 Dry lips	51 ± 34	36 ± 31	↓ **	55 ± 31	56 ± 36	↑	40 ± 33	31 ± 29	↓ **
11 Dry skin	55 ± 37	43 ± 32	↓ **	53 ± 29	51 ± 34	↓	39 ± 32	34 ± 29	↓
12 Dry eyes	63 ± 34	45 ± 32	↓***	55 ± 31	58 ± 32	↑	46 ± 31	36 ± 27	↓ ***
13 Irritated eyes	59 ± 34	45 ± 32	↓ **	57 ± 29	54 ± 31	↓	49 ± 31	38 ± 28	↓ ***
14 Well-being	64 ± 28	50 ± 28	↓ ***	64 ± 24	61 ± 27	↓	56 ± 26	43 ± 24	↓ ***
15 Alertness	56 ± 29	38 ± 26	↓ ***	57 ± 26	51 ± 24	↓	50 ± 26	39 ± 23	↓ ***
16 Headache	88 ± 20	71 ± 32	↓ **	83 ± 21	79 ± 24	↓	80 ± 25	69 ± 30	↓ ***
17 Concentration	76 ± 25	57 ± 29	↓ ***	72 ± 22	59 ± 29	↓ *	66 ± 28	50 ± 28	↓ ***
18 Mood	84 ± 19	73 ± 23	↓ **	79 ± 18	78 ± 22	↓	73 ± 22	67 ± 24	↓ *

*** p < 0.01; ** 0.01 < p < 0.05; * 0.05 < p < 0.10

In summary, occupants in two of the three buildings surveyed responded significantly to the temperature intervention and felt symptoms to be less intense in the cool environment. Although not significant in the third building, symptom intensity generally changed in the same direction as in the other two buildings and improved in the cool environment. The results emphasize that appropriate control of temperature is important, not only for thermal comfort, because humans may adapt and to some degree accept higher temperatures, but also for the perception of air quality, the intensity of building-related symptoms and for the performance of mentally demaniding office tasks (3).

The applicability of the internet-based questionnaire and the VAS was tested in a temperature intervention study because a temperature change of around 3 - 4°C, as obtained in the current study, was expected to have a measurable effect on occupant responses. Also, temperature effects were expected to appear after a short exposure time (e.g. half a working day) and the exposure could thus be limited to two working days. One disadvantage of using a temperature intervention was that occupants were not blind to the conditions to which they were exposed. Nevertheless, responses changed with temperature as expected and were comparable with previous studies in office buildings in which VAS were used to record the effect on occupants of indoor environment interventions (2).

The use of an internet-based questionnaire simplifies the procedure for carrying out field studies in buildings. Previously, the process of transferring to electronic media responses recorded via paper versions of the questionnaire was rather tedious and could even introduce unwanted variability in data. In the current study, this process was eliminated and occupant responses were saved directly in a database for easy processing and analysis. Also, this allowed us to follow the progress of the survey in real-time and to link precisely logged climate parameters with recorded subjective responses. Occupants took approximately 5-10 min to complete a questionnaire.

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HIGH INDOOR AIR QUALITY IMPROVES OFFICE WORK AND PROVIDES ECONOMIC BENEFITS

Pawel Wargocki

International Centre for Indoor Environment and Energy, Technical University of Denmark, Building 402, DK-2800 Kgs. Lyngby, Denmark, email. pw@mek.dtu.dk, web. www.ie.dtu.dk

Introduction

Recent laboratory and field experiments have shown that improving indoor air quality improves the performance of office work (1). The objective of the present paper is to summarize the results obtained in these experiments and to compare life-cycle costs of upgrading indoor air quality in an office building with the resulting revenues from increased office productivity.

Laboratory experiments

In three independent field intervention experiments, the air quality in normal offices was altered while the health, comfort and productivity of the occupants were measured (2,3,4). Air quality was altered by: decreasing the pollution load (by physically removing a pollution source) always maintaining an outdoor air supply rate of 10 L/s per person with six subjects present, which was the intervention used in offices situated in two different countries (2,3); or by increasing the outdoor air supply rate from 3 to 10 or to 30 L/s per person with six subjects present, thus producing air change rates of 0.6, 2 or 6 per hour in one of these offices, with the same pollution sources always present (4). A major pollution source in all three studies was the same 20-year-old carpet taken from an office building; it was present behind a screen in a quantity corresponding to the floor area of the office in which each exposure took place. Temperature, relative humidity, air velocity and noise level were kept constant, independent of the intervention. Ninety female subjects were exposed to different levels of air quality, 30 in each study. They could not see whether the source was present or perceive changes in noise level or air velocity when the ventilation rate was changed, and they remained thermally neutral by adjusting their clothing. In all three studies, subjects performed simulated typical office work comprising text typing, proof-reading, addition and creative thinking during 4.5-hour exposures to different air quality levels. They also assessed the perceived air quality upon entering the office and the intensity of their Sick Building Syndrome (SBS) symptoms during exposures. The exposures were presented in a repeated-measures design balanced for order of presentation. Removing the pollution sources from the offices or increasing the ventilation rate were observed to significantly improve the perceived air quality and the performance of simulated office work. The quantitative relationship between air quality and the performance of office work was a 1.1% increase in performance for every 10% reduction in the proportion of persons dissatisfied with the air quality, in the range 25-70% dissatisfied (Fig. 1). The effects on performance depicted in Fig. 1 were later verified in two experiments replicating the three studies described above but using other sources of pollution to modify the air quality levels in the office to generalize the results: a mixture of 3-year-old linoleum, a 2-month old sealant and shelves with books and papers from the office ventilated at an outdoor rate of 5 L/s per person (5); and six 3-month-old personal computers with cathode-ray-tube (CRT) monitors from the office ventilated at an outdoor air rate of 10 L/s per person (6).

Field experiments

The field study examined whether the effects on performance observed in laboratory experiments can be repeated in actual office buildings with office employees performing real work. It was done by conducting a 2x2 replicated field intervention experiment in a call-centre with mechanical ventilation system, located in a moderate climate, providing a national public telephone directory service (7). The air quality was modified by adjusting the outdoor air supply rate from 8% to 80% of the total airflow of 430 L/s (3.5 h-1) and by exchanging the supply ventilation filters that had been in use for 6 months with new filters. The 26 operators were blind to conditions. Room temperature and relative humidity averaged 24°C and 27%, and were fairly constant throughout the entire study. Increasing the outdoor air supply rate caused performance to increase as indicated by reduced average talk-time with a new filter and to decrease with a used filter; talk-time was about 10% lower with a new filter than with a used filter at a high outdoor air supply rate (Fig. 2). The effect of increased ventilation rate was later confirmed in a study using a similar experimental protocol carried out in an air-conditioned call-centre with electrostatic filters, located in a tropical climate, and examining the impact of reduced air temperatures, from 24.5oC to 22.5oC, and increased outdoor air supply rate, from 10 to 23 L/s per person on performance of call centre operators. The results showed that at the higher temperature, an increased outdoor air supply rate improved the performance of call centre operators by 8.8 % (8). Both field studies provide field validation of the results obtained in laboratory simulation experiments, the effects of air quality on performance being similar.

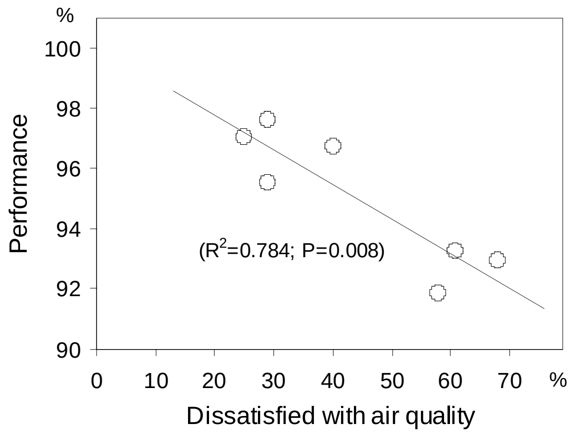

Fig. 1. Performance of office work as a function of the air quality

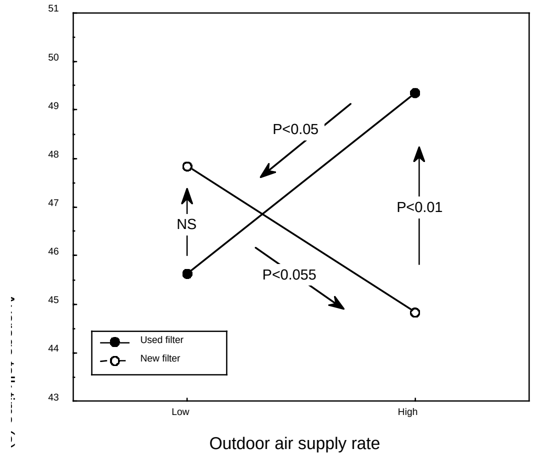

Fig. 2. Average talk time as a function of outdoor air supply rate and filter age

Cost-benefit analysis of improving indoor air quality

To examine whether the positive effects of improved air quality on work performance observed in laboratory and field experiments are economically justified, life-cycle costs of investments for improving air quality in an office building were compared with the resulting revenues from increased office productivity (9). The costs of improving air quality were simulated in a 11581 m2 non-low-polluting office building with 864 employees, ventilated by a constant air volume system with heat recovery, located in a cold, a moderate and a hot climate, and assuming that the air quality in the building caused 50% dissatisfied. The air quality was improved by increasing the outdoor air supply rate from 6 to 60 L/s per person, and by reducing the pollution loads from 0.2 to 0.1 olf/m2 floor to reduce the percentage of dissatisfied to 10% . The change in air quality was assumed to be the only parameter that influenced work performance. Other factors such as noise and thermal conditions were supposed to be constant and not considered in the simulation. The upgrades to indoor air quality involved increased energy and maintenance costs, first costs of a HVAC system and building construction costs. These costs were compared with the increase in office productivity predicted using the experimental relationship showing a 1.1% increase in performance of office work for each 10% decrease in the percentage dissatisfied with the air quality (Fig. 1). This corresponds to an annual economic benefit of $368.75 per person, assuming a salary of $19.4/hour per person. The calculated costs and revenues were used to perform life-cycle cost analysis: the life-time of the building was set at 25 years and the real discount rate at 3.2%.

Table 1. Example of results of LCC analysis for the building located in a moderate climate

Building	*Air quality (% diss.)*	*Discounted increase from the reference condition ($/m^2)*					*Net savings ($/m^2)*	*Simple pay-back time (years)*	*Adjusted internal rate of return (%)*
		Costs				*Benefits*			
		Energy	*Maintenance*	*HVAC first*	*Building*	*Productivity*			
Non-low-polluting	50	*Reference condition*							
	40	-0.2	7.8	9.2	0.0	486.9	470.0	0.3	20.9
	30	2.6	23.8	28.0	0.0	973.7	919.2	0.5	18.8
	20	9.5	56.4	66.2	0.0	1,460.6	1,328.6	0.8	16.6
	15	12.7	86.1	101.1	0.0	1,704.0	1,504.2	1.1	15.3
	10	19.5	130.7	153.5	0.0	1,947.5	1,643.8	1.5	13.9
Low-polluting	40	0	-0.7	-0.8	0.0	486.9	429.9	2.0	12.4
	30	-0.2	8.1	9.5	58.4	973.7	897.9	1.2	14.8
	20	4.2	29.0	34.1	58.4	1,460.6	1,334.9	1.1	15.1
	15	8.8	49.6	58.3	58.4	1,704.0	1,528.9	1.2	14.7
	10	12.7	86.5	101.6	58.4	1,947.5	1,688.2	1.5	13.8

The analysis showed that improving air quality is highly efficient (Table 1) for the following reasons: the benefits from improved air quality can be up to 60 times higher than investments; the investments can generally be recovered in no more than 2 years, similar to other predictions of the pay-back times (10); and the rate of return can be up to 7 times higher than the minimum acceptable interest rate. The estimates do not include benefits resulting from reduced health costs and reduced absenteeism; lower absenteeism from an increased outdoor air supply rate can result in additional annual savings of $400 per employee (11). Similar economic benefits were obtained in all climatic zones, because the benefits from improved productivity become a dominating factor in the life-cycle cost analysis and considerably exceed the increased investment costs. It is expected that the above estimates can be applied in general to most countries of the developed world even though they depend upon a set of assumptions and were obtained by simulation.

Conclusions

- Laboratory and field experiments show that improving indoor air quality improves the performance of office work.
- The benefits of improving indoor air quality by reducing pollution sources or increasing outdoor air supply rates are much higher than the costs involved.
- The present results constitute a powerful argument and strong incentive for providing indoor air of a better quality than the minimum levels required by present standards.

Acknowledgements

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AN ADAPTIVE THERMAL COMFORT METHOD FOR PEOPLE WITH PHYSICAL DISABILITIES

Ken Parsons

Department of Human Sciences , Loughborough University , UK.
k.c.parsons@lboro.ac.uk

Introduction

People with physical disabilities can be handicapped by their environment if the environmental design does not take account of their requirements. There is a responsibility to design environments, as far as is reasonably practicable, to ensure that they are accessible to the widest population. To do this requires a knowledge of requirements and a philosophy of environmental design to accommodate those requirements

Until recently, there was little information concerning whether existing thermal comfort indices, methods and standards are appropriate for determining the thermal comfort requirements for people with physical disabilities and if not, what those requirements are. Knowledge of those requirements will not only enhance understanding of thermal comfort but it will provide guidance for those who wish to design for thermal comfort. Reasons why thermal comfort requirements may differ between people with and without physical disabilities include the effects of the disability on a person’s thermoregulatory perception and response. For example a disability may affect perception of thermal sensation, vaso-control of body skin temperature, ability to cool down through sweating and so on. A physical disability may also require drugs for treatment that may affect thermoregulatory response and the disability may require technical aids such as wheelchairs that will affect thermal comfort. The nature of the disability will clearly determine requirements, as different disabilities will affect thermoregulatory responses in different ways.

The International Standards Organisation (ISO) had identified a need for a standard on thermal comfort requirements for people with disability (also the aged) through their system of international voting. After some years with a Japanese lead and supported by other countries an ISO Technical Specification has been produced (ISO TS 14415(1)). This paper describes a programme of research to determine the thermal comfort conditions for people with physical disabilities. It concludes with a proposed approach to environmental design that will apply to thermal comfort as well as to other aspects of the overall environment. By using an adaptive approach, it is an inclusive method that will apply not only to people with physical disabilities but also to the wider population including people without disabilities as well as taking account of the diversity of cultures across the world.

Methods

Parsons and Webb (2) and Parsons (3) report on a series of laboratory and field studies into the thermal comfort requirements of people with physical disabilities. The subjective responses of 145 subjects with physical disabilities were obtained in a thermal chamber for slightly warm to warm, neutral and slightly cool to cool conditions (i.e. 435 subject sessions). People wore standard clothing (1.0 Clo) and sat in standard office chairs for periods of two hours in a climatic chamber which was set out like a domestic living room and where conditions were closely monitored. The mean and variation in responses and comparison with PMV values (Fanger(4)) were determined for subjects with cerebral palsy, spinal injury, spinal degeneration, spina bifida, hemiplegia, polio, osteo arthritis, rheumatoid arthritis, head injury, and multiple sclerosis.

Results and discussion

It was found that some groups were comfortable in what would be predicted for people without physical disabilities to be ‘slightly warm to warm’, ‘slightly warm’ and ‘neutral’ environments. No group preferred the predicted ‘slightly cool to cool’ environment although there are individual differences. It is particularly important to consider individual factors and characteristics. For the majority of people in each disability group a preferred environment could be identified, they were as follows: 23°C, PMV = 0;

27°C, PMV = +1 slightly warm for; spina bifida, spinal injury, hemiplegia and osteo-arthritis and 29°C, PMV = +1.5, slightly warm to warm for people with rheumatoid arthritis. People with polio were satisfied in the range from 23°C, PMV = 0, neutral to 29°C, PMV = +1.5, slightly warm to warm.

The laboratory results show that ISO 7730 (5) can be used without modification as a first approximation to the average responses of people with and without physical disabilities. The variation in responses is different from those of people without physical disabilities. They also show the importance of considering individual characteristics of people with physical disabilities especially when they vary from those that would produce thermal neutrality.

Physical disabilities and the adaptive model

The most influential and established model of thermal comfort throughout the world is undoubtedly that based upon the work of Fanger (4) which is presented in the International Standard, ISO 7730 (5). Recent developments in thermal comfort research seek to improve on that model by recognizing that true thermal comfort response involves human behaviour. In essence if people are uncomfortable they behave in a way which allows them to become comfortable. It is unlikely therefore that if people are ‘hot’ for example, that they will remain hot if they can take steps to achieve comfort. A prediction of ‘hot’ therefore may be misleading. This change in philosophy would then lead to the establishment of ranges of conditions within which people will be able to adapt to maintain comfort (by changing postures, moving around etc). Of particular importance is the use of the adaptive approach for people with physical disabilities. The present research has led to hypotheses that suggest that thermal comfort requirements for people with physical disabilities should take account of the restricted ability of people to adapt to the thermal environment. An example would be the perceived threat to people with physical disabilities in a hot or cold environment where those without physical disabilities could change posture or move away but those with physical disabilities could not because they have restricted adaptive opportunity.

Equivalent Clothing Index (I_{EQUIV})

In any environment there will be opportunity to adapt to maintain thermal comfort and these adaptive adjustments (behaviours) can take many forms and can occur in combination (e.g. adjust clothing, change activity, open a window, change posture). Each of the actions and their combination will have an effect on human heat exchange. It is therefore possible to represent these effects in terms of the equivalent effect of changing one of the parameters in the heat balance equation. This could be any of the six basic parameters, however a convenient approach would be to relate the total effect of all adaptive behaviour to the equivalent effect of adjusting clothing. An equivalent clothing index (I_{EQUIV}) can be described as follows:

> *The Equivalent Clothing Index (I_{EQUIV}) is the clothing insulation that would give equivalent thermal comfort to people with no adaptation as the thermal comfort of people who adapt to their thermal conditions.*

A group of people initially wearing 1.0 Clo who change clothing, change activity, change posture and open a window to maintain a neutral thermal sensation may have an equivalent clothing index value of 0.2 Clo, where 0.2 Clo would represent the clothing insulation required to maintain a neutral thermal sensation in the original conditions. The total of all adaptive behaviour therefore summates to a reduction of 0.8 Clo. The equivalent clothing index value can then be substituted into the PMV equation, instead of the clothing insulation value, to give a PMV that takes account of adaptive behaviour.

Table 1 and equations (1) and (2) show a possible relationship between adaptive opportunity and $I_{EQUIV.}$

Table.1. I_{ADJ} values for a range of adaptive opportunities

Adaptive opportunity	I_{ADJ}
Minimum	0
Low	0.25
Medium	0.5
High	0.75
Maximum	1.0

$$I_{EQUIV} = I_{start} - \left(I_{ADJ} \times I_{start}\right) \text{ in the heat}$$
$$I_{EQUIV} = I_{start} + \left(I_{ADJ} \times I_{start}\right) \text{ in the cold} \qquad (1) \text{ and } (2)$$

For cases where no adaptation is possible then clothing, posture, activity, physical environment (e.g. windows) cannot be adjusted. Therefore the equivalent clothing is the actual clothing worn at the beginning of the exposure period. ($I_{EQUIV} = I_{START}$). For maximum adaptation, it will be possible to take off all clothing as well as making other adaptive adjustments (open windows, reduce activity). For these conditions it may be useful to adjust parameters separately (e.g. metabolic rate) in the rational index (e.g. PMV) as well as using $I_{EQUIV} = 0$. In these circumstances, thermal comfort is an unusual concept and, in practice, adaptive effects greater than taking off all clothing would be unusual. It may therefore be reasonable to assume $I_{EQUIV} = 0$ is a minimum practical value. A similar argument applies for I_{EQUIV} in cold conditions where doubling of clothing insulation is a realistic maximum with more detailed analysis required for special cases. It should be noted that I_{ADJ} may be different for hot conditions than for cold conditions as different adaptation may be required; for example, if opening windows is the only adaptive opportunity, then I_{ADJ} may be 'medium' in the hot but 'minimum' in the cold etc.

I_{EQUIV} and the comfort temperature range

Although a rational index such as the PMV provides a versatile tool with which to determine thermal comfort conditions in terms of the six basic parameters (variables), there is a requirement to provide temperature ranges within which people can maintain comfort. Suppose people in a building wear 1.0 Clo, perform sedentary activity in conditions with no radiant load ($t_a = t_r$), and vapour pressure of 1.0 kP_a in still air. They can reduce their clothing but cannot increase it, they can move around and open windows. We could assess the adaptive opportunity as high in the heat and low in the cold. A PMV of 0 (neutral) is then obtained at 24 °C for $I_{EQUIV} = I_{START}$ = 1.0 Clo; 28.5 °C for I_{EQUIV} = 0.25 Clo and 22.8 °C from I_{EQUIV} = 1.25 Clo. This provides a comfort temperature range of 22.8 °C to 28.5 °C. If a range between +1 (slightly warm) and -1 (slightly cool) is regarded as acceptable then an acceptable range would be 18.2 °C to 30.5 °C.

The PMV is an example of a rational index and its validity does not affect the principles of the above. This behavioural adjustment method is a practical way forward. It is preferable to 'expectancy' adjustments where statements such as, 'It is what they are used to and do not expect better', border on the unethical and, in any case, are flawed as if people claim comfort at 30 °C, how do we know that they would also not claim comfort at PMV = 0 (e.g. 24 °C).

Comfort temperatures in offices for people with and without physical disabilities

Consider an example where a person in an office has no disability and can remove clothing, change posture and move around the office. Another person has a spinal injury and is in a wheelchair. How can we design for thermal comfort? Suppose people arrive at work in 1.0 Clo of clothing insulation and the work is sedentary office work. With low air movement, no significant radiant effect and 50% relative humidity, both people will be comfortable at around 24 ^{o}C air temperature, although the person with a spinal injury may prefer a slightly higher temperature for comfort (and the wheelchair may also have influence). The person without the disability can be estimated to have high adaptability if conditions become warmer or cooler and (using equations (1) and (2)) should be able to maintain comfort over a range 28.5 ^{o}C to 20.0 ^{o}C. The person with the spinal injury has low adaptive opportunities in heat and cold so should be able to maintain comfort over the range 25.5 ^{o}C to 22.8 ^{o}C . For inclusive design therefore that is the range that must be provided by the building designer to provide comfort.

Conclusions

People with physical disabilities on average, have similar requirements for thermal comfort to those without disabilities however thermal comfort requirements for both populations will be related to the ability of people to behave in a way that provides thermal comfort. A method that accounts for the ability to adapt to conditions will provide an inclusive design method for providing thermal comfort

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VOLUNTARY OR INVOLUNTARY DEHYDRATION – DEHYDRATION AT ALL?

Bernhard Kampmann[1]*, *Friedrich Manz*[2], *Bernhard Kalkowsky*[3]

[1] Division of Applied Physiology, Occupational Medicine & Infectiology, Department of Safety Engineering,
Bergische Universität Wuppertal, Wuppertal, Germany
[2] Research Institute of Child Nutrition, Dortmund, Germany
[3] Center for Occupational Medicine, Deutsche Steinkohle AG, Herne, Germany
* corresponding author kampmann@uni-wuppertal.de

Introduction

Subjects performing physical work in the heat usually drink markedly less fluid compared to sweat loss, even if unlimited drinking fluid is at hand. Adolph's working group termed this observation "voluntary dehydration" (1). – Usually dehydration during work is estimated from the difference of body mass before and after work (12); in some investigations also metabolic weight loss and/or dry mass of food consumption are taken into account.

The adjustment of water excretion by the kidneys by means of ADH is – within the physiological range – independent of the amount of water that is physically bound. When glycogen is spent during work, glycogen bound water will be liberated and may be used to balance water losses of the body. Sodium is deposited in the extracellular compartment together with a fixed amount of water. If sodium is excreted in sweat or urine, the accompaning diminution of extracellular (and total body water) volume does not stimulate renal mechanism to excret or preserve water. A deficit of available water will be shown up by an increased plasma osmolality. The water volume available for water excretion ("functional water volume") therefore corresponds to the loss of body mass minus the water liberated by glycogen consumption, the water disposable by the contraction of extracellular volume, the metabolic mass difference (CO2-O2), and the metabolic water produced in metabolism. Excreted urine (or more precisely: produced urine), no longer available for water balance, has to be added to this value.

The hypothesis of our investigation is that the deficit of "functional water volume" – calculated in this way – will be much smaller than the water deficit described by the "voluntary dehydration".

Material and Methods

We used data from a field study in coal mining, comprising 111 shifts of altogether 38 miners (6). The age of the miners was (mean ± std.-dev.) (34 ± 6) years, body mass showed up to be (85 ± 14) kg at a body height of (177 ± 8) cm. Broca-Index resulted in (111 ± 12) % and BMI-Index was (27 ± 3) kg/m². The climate at the working site showed a Basic Effective Temperature of (26.1 ± 3.8) °C.

Energy expenditure was estimated from heart rates (5)– considering the effect of "thermal pulses" due to the increases of body temperature during work (7). From this values the metabolic mass difference and the amount of metabolic water production were calculated (4), assuming a fraction of 14 % for protein metabolism within total energy expenditure and a respiratory quotient of 0.85 (measured for typical activities in hard coal mining (5)). Food intake had been recorded during the shifts and nutrient intakes were estimated using food tables. From the consumption of carbohydrates during work and the intake of carbohydrates by food the net consumption of glycogen may be estimated. The consumption of 1 g glycogen was associated with the liberation of 3 g water (2, 9).

The loss of sodium within the sweat was calculated from the mass of the excreted sweat, assuming a sodium concentration of 50 mmol/l in the sweat (3, 11, 13). The isotonically contracted extracellular water volume then results as the loss of sodium (mmol) divided by the isotonic sodium concentration of the extracellular volume (140 mmol/l).

Results

The mean loss of body mass (i.e. "voluntary dehydration") for 38 miners during 111 working shifts showed to be (mean values) 1218 g or 1,5 % of body mass. Sweat loss during a working shift was 3337 g, whereas the fluid uptake amounted to 2062 g. The total loss of body water resulted in 1034 g (Table 1).

Table 1. Water loss, sweat loss and change of functional water volume of miners during a shift.

Symbol	Parameter	Mean value	Std.-dev.
	Duration of shift (minutes)	417	18
Calculation of the total loss of body water			
A	Loss of body mass (estimated by weighing before and after the shift) (g)	1218	760
B	Energy expenditure (estimated from heart rate and duration of shift) (kJ)	7474	1812
C	Protein expenditure (assumption: 14 % of energy expenditure due to protein) (g)	59	14
D	Fat expenditure (estimated from energy expenditure and mean RQ) (g)	73	18
E	Carbohydrate (glycogen-)expenditure (estimated from energy expenditure and mean RQ) (g)	206	50
$F = 0,367\cdot C - 0,068\cdot D + 0,425\cdot E$	Metabolic mass loss (g)	104	25
G	Food uptake (g)	271	268
H	Dry substance in food (g)	80	81
$I = A-F-H$	Total loss in body water (g)	1034	770
Calculation of sweat loss			
J	Fluid uptake (g)	2062	704
K	Water in food (g)	191	212
L	Urine excretion (measured; estimated from volume) of miners during the shift (g)	110	144
$M = A-F+H+J+K-L$	Sweat loss (g)	3337	1211
Calculation of the change of functional water volume			
$N = 0,41\cdot C + 1,07\cdot D + 0,55\cdot E$	Metabolic water produced within metabolism (g)	216	52
O	Carbohydrates in food and beverages (g)	49	48
P	Sodium content in food (g)	0,41	0,59
$Q = 3\cdot(E-O)$	Water that is liberated by consumption of glycogen, corrected for glycogen uptake with food “O“ (g)	470	220
$R = M\cdot 50/140 - P\cdot 311$	Contraction of extracellular water pool due to sweat loss, corrected for sodium uptake with food (g)	1065	451
S	Calculated production of urine (estimated from a multilinear analysis for “L“) (g)	258	86
$T = A-Q-R-F-N+S$	Loss of functional water (g)	-379	494

The corrections for metabolic mass loss were 104 g, the produced metabolic water resulted in 216 g; water liberated by means of glycogen consumption resulted in 470 g and the loss of isotonical extracellular water volume corresponded to 1065 g.

After estimating the production of urine during a shift (by means of a multilinear analysis) to be 258 g, the functional water volume shows an excess corresponding to (379 ± 494) g.

Discussion

Our results show that the „voluntary dehydration“ observed during work in the heat seems not to be a deficit within the regulation of water uptake of the body – e.g. due to a lack in the perception of thirst as suspected by Adolph (1) – but rather a physiologically levelled state of the body. Perhaps the miners drank slightly more than necessary to compensate for the loss of functional water volume. More likely however is the assumption that some estimations and/or assumptions within the calculation resulted in this excess of the functional water deficit.

Our calculation assumes a sodium concentration of 50 mmol/l corresponding to (3, 11, 13), as measurements of sodium concentration in the sweat could not be performed in our field investigation. The data within the references (3, 11, 13) are based on measurements with a duration of one hour. At a longer time of exposition (417 minutes within our study) the sodium concentration within the sweat probably could be lower. This would result in a decrease of the excess of the functional water loss. – A further decrease may be caused by continuing urine production after urine excretion; this amount of urine could not be estimated.

Some of the mechanisms taken into account in our analysis have been mentioned and taken into account for sports events by other authors: e.g. Noakes (8) gives quantitative estimations for water stored associated with glycogen and metabolic water production. Rehrer (10) mentions that water is stored with muscle glycogen and that water in the bladder is unavailable for fluid needs of the body; the amount of metabolic mass loss and metabolic water production is referred to from literature.

Our detailed calculation shows that during hard work in the heat the fluid intake by far must not be as high as to compensate the loss in body mass. The miners participating in our study worked underground for (16 ± 5) years and by this may be considered as a “survivor collective” for this kind of working conditions. Different from athletes in other studies (8, 10) – who perform e.g. a marathon run only a few times per year – they have to work every working day: so they should have well adapted to the special problems of fluid balance under hot working conditions in coal mines.

Due to our interpretation of fluid balance the “voluntary dehydration” substantially is caused by the low uptake of food (i.e. carbohydrates) and sodium by the miners during their shifts: mostly fruits and some sandwiches are eaten during the shift at the working site underground. However, until the next working day glycogen storages as well as the extracellular sodium pool – and the water bound within both compartments – have to be refilled.

So our results correspond well with the statement of Adolph and Rahn “…Only when the man has food and rest does he want the water which is missing from his body.” (1, p. 10).

Conclusions

Recommendations for hard work or exercise in the heat with high energy expenditure (and thereby high use of glycogen) and/or high losses of sodium with sweat should take into account our results: the actual loss of body mass must not be compensated immediately by fluid intake.

In order to improve the accuracy of our type of analysis it would be favourable to get better estimations especially of the sodium concentration in sweat – that could not be measured under field conditions in coal mining – and of the volume of urine produced during heat exposure.

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THERMAL STRAIN INDUCED BY ARMOURED VEHICLE ACTIVITIES IN HOT ENVIRONMENTS

Mark J Patterson[1], Warren S Roberts[1], James P Finn[2], David Barton[3]*

[1] Chemical, Biological, Radiological and Nuclear Defence Centre, Defence Science and Technology Organisation, Melbourne, Australia
[2] School of Science and Primary Industries, Charles Darwin University, Darwin, Australia
[3] Land Systems Division, Defence Materiel Organisation, Melbourne, Australia
* corresponding author mark.patterson@dsto.defence.gov.au

Introduction

Environmental heat stress conditions within an armoured vehicle has been reported to exceed a dry bulb temperature of 52°C and wet bulb globe temperature (WBGT) of 34°C in hot-dry conditions (1). These high levels of environmental heat stress are likely to lead to a high level of thermal strain experienced by the operating crew, although this would depend on the work intensity and duration. While environmental conditions have been quantified in an armoured vehicle during field training, the resulting thermal strain exhibited by the crew has not been reported. The aim of this study was to quantify the environmental conditions within the armoured vehicle and assess the thermal strain induced by the work conducted during scheduled training activities in Northern Australia.

Methods

The Australian main battle tank was the vehicle monitored during these field exercises. This vehicle consists of four-man crew, being a crew commander, loader, gunner and driver. Data was collected during two field exercises in the Northern Territory, Australia. These field exercises were conducted in the June-July and September periods and were Squadron and Brigade training activities, respectively. For the Squadron activity three tanks only worked as a team, whereas for the Brigade activity four tank squadrons combined with infantry, artillery and other Army Corps worked together. Tank activities included force-on-force, incident and recovery stands, defensive and offensive operations, road moves, advances to contact, hides and quick attacks. This was a monitoring investigation such that the experimenters had no control over the crews activities.

The first field exercise involved three tanks participating in a 3-day continuous activity during warm-dry environmental heat stress. A total of nine tanks were monitored, although only 27 crewmen volunteered to have their body core temperature monitored. The second field exercise consisted of a 2.5-day monitoring period during a 9-day field exercise during hot-dry conditions. Nine crewmen were monitored across three tanks. The wet bulb globe temperature (WBGT) was monitored in the open environment, external to the vehicle, and within the vehicle at the loader, gunner and driver positions. Crewmen wore the Australian disruptive pattern combat uniform with a clo factor of 0.88.

Body core temperature was recorded at 1 min intervals using a gastrointestinal radio-pill. Heart rate was only recorded in the second field exercise. In the first field exercise it was established that the common Polar heart rate monitor that transmits the heart rate to the wristwatch could not accurately measure the crewman’s heart rate due to gross electrical interference. Subsequently in the second field exercise the Polar Team System was employed since this system records the heart rate data within the chest strap at 5-sec intervals. Hydration status was estimated before and after the field exercises by urine specific gravity (USG) measured using a refractometer.

Results and discussion

During the first field exercise the average maximum external-vehicle dry bulb temperature was 31.6°C (22% RH; WBGT 28.4°C; Table 1). These conditions were similar to the July average maximums for the Darwin area (30.5°C 36% RH). The corresponding vehicle maximum dry bulb temperatures ranged from 38.4°C at the loader position to 33.2°C at the driver position, with subsequent WBGTs of 29.2°C and 25.7°C, respectively. While the dry bulb temperature indicated that it is hotter within the vehicle, the WBGT index implied that the heat stress level in the tank was marginally greater at the loader’s position but lower in the driver’s location when compared to the external environment. It is likely that the heat sources (engine firewall and hydraulic pump block) within the turret of the vehicle contributed to the temperature profile within the vehicle.

The average maximum body core temperatures during the first field exercise was 38.3 ± 0.3°C (range: 38.0-38.9°C) for the 20 crew that had >6 hr of data recorded. On seven occasions the body core temperature data loggers malfunctioned. The average duration of time above a body core temperature of 38°C was 76 ± 70 min (± SD; range: 0-242 min) over the 61 hr monitoring period. There was considerable variation both between crew within a tank and across tanks for the same crew position for the duration above a body core temperature of 38°C (Table 2).

Table 1. Environmental conditions within and outside the armoured vehicle.

Location	**T_{db} (°C)**	**T_{wb} (°C)**	**T_g (°C)**	**WBGT (°C)**	**RH (%)**
External vehicle	31.7 ± 0.9	22.8 ± 1.5	46.4 ± 2.2	28.4 ± 1.5	24.4 ± 2.5
Loader	38.4 ± 1.1	25.1 ± 2.5	39.2 ± 1.1	29.2 ± 1.8	21.3 ± 4.4
Gunner	36.5 ± 0.8	24.0 ± 0.9	35.9 ± 0.8	27.9 ± 1.0	24.1 ± 5.0
Driver	33.2 ± 1.3	22.3 ± 1.7	33.6 ± 1.7	25.7 ± 1.5	29.4 ± 8.2

Mean ± SD; T_{db} = dry bulb temperature, T_{wb} = wet bulb temperature, T_g = globe temperature, WBGT = wet bulb globe temperature, RH = relative humidity.

Table 2. Maximum body core temperatures and duration of body core temperature above 38°C

Crew Location	**Maximum T_c (°C)**		**T_c > 38°C (min)**	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**
Crew Commander (n=2)	38.4 ± 0.1	38.3 - 38.4	168 ± 42	138 - 198
Loader (n=4)	38.2 ± 0.3	37.9 – 38.4	158 ± 194	12 - 270
Gunner (n=5)	38.5 ± 0.3	38.3 – 38.9	113 ± 101	0 - 396
Driver (n=9)	38.3 ± 0.2	38.1 – 38.8	91 ± 99	0 – 294

T_c = body core temperature.

Hydration status before the 3-day activity was not optimal with only 17% exhibiting a USG <1.020, with a considerable proportion (23%) exhibiting a USG >1.025. After completing the activity most crew (96%) exhibited a USG >1.030.

In second field exercise the environmental heat stress conditions were considerably warmer than in first field exercise. The average maximum external-vehicle dry bulb temperatures was 36.6 ± 0.5°C (26 ± 1% RH; WBGT 33.4 ± 0.8°C). Within the vehicle a similar temperature profile was observed such that the loader and gunner positions were hotter than that of the driver. The average maximum dry bulb temperature at the loader position was 40.1 ± 1.8°C (WBGT 32.9 ± 0.8°C).

While the level of environmental heat stress was greater during the second field exercise, the elevation in body core temperature of the crew was less pronounced, with an average maximum of 38.0 ± 0.2°C (range: 37.6-38.4°C). Figure 1 provides an example of a crew member’s body core temperature during the field exercise.

The internal-tank temperatures in both field exercises did not achieve levels similar to those previously report (1). This was not surprising since the current exercises were conducted in winter and early spring whereas the previous data (1) was collected in summer where external-tank dry-bulb temperatures reached 44°C.

Conclusions

While the internal-dry bulb temperature was greater than that observed outside the vehicle, the maximum WBGT within the vehicle was similar to that of the external environment. The elevation in body core temperature and heart rate suggest that the thermal strain of conducting field training in these environmental conditions was not great. In the first field exercise the warm environmental conditions combined with the predicted light to moderate work resulted in moderate elevation in body core temperature, whereas in the second field exercise the higher environmental heat stress conditions combined with the lighter work intensity resulted in mild body core temperature elevations. Further work is required in hotter and more humid conditions with moderate work intensities to ascertain the potential risk of hyperthermia.

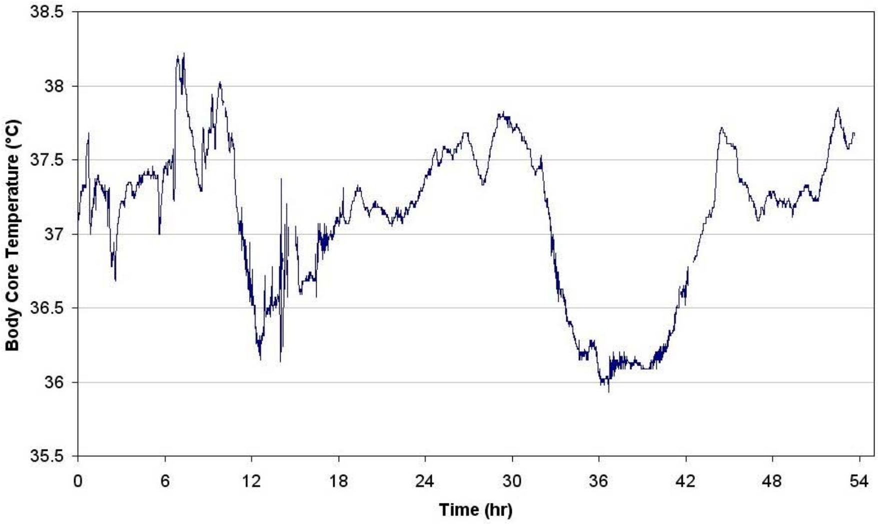

Figure 1. Body core temperature for a single crewman during 54 hr of the field exercise. Data collection commenced at ~12:00.

Heart rate was recorded over an 11-hr period during non-sleeping hours. During most of this monitoring period heart rate was <100 beats/min (9.6 ± 1.8 hr), which would signify that most of the work was performed at light to very light intensities. Very brief periods (3 ± 5 min) involved hard work, as indicated by heart rates >140 beats/min. An example of a crew members heart rate is shown in Figure 2.

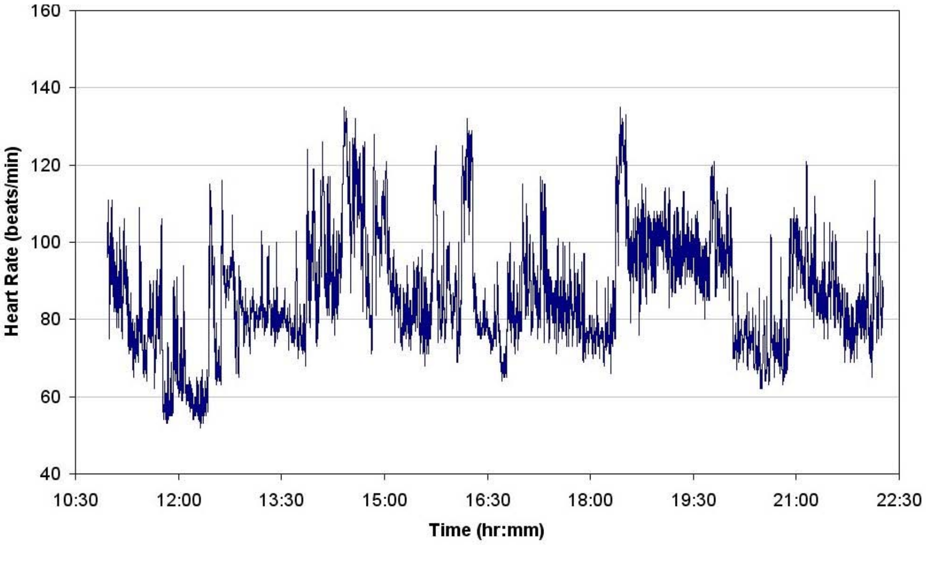

Figure 2. Heart rate response for a single crewman during an 11–hr period of the field exercise.

Only one crewmember exhibited a USG <1.020 prior to the data collection period. The mean USG increased from 1.026 ± 0.006 to 1.031 ± 0.005 at the end of the 2.5-day period. Furthermore, the body mass loss over this monitoring period was 1.2 ± 1.1%.

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PREDICTING HEAT STRESS LEVEL USING PHYSIOLOGICAL MEASURES

Thomas E. Bernard[1]*, *Candi D. Ashley*[1], *Victor Caravello*[2], *Skai W. Schwartz*[1]

[1] University of South Florida, Tampa FL 33612-3805
[2] Currently with United States Air Force
* corresponding author: tbernard@hsc.usf.edu

Introduction

The WBGT-based exposure limits were set such that most workers would be able to tolerate the exposure for an 8-hr day [1]. Implicit in the limits is that most workers working at the occupational exposure limit would be in a region of fully compensable heat stress. Therefore, it is reasonable to believe that many workers can fully compensate for heat stress at a level greater than the occupational exposure limit. The interesting question becomes: Is there a way to identify these workers individually? If the answer is yes, then this provides a means to demonstrate individuals and populations may be adequately protected for prolonged exposures above the occupational exposure limit. The purpose of this paper is a test of principle that simple laboratory measures of physiological state can be used to predict compensable versus uncompensable heat stress.

Methods

A convenience set of data were used to explore the ability of physiological measures to predict compensable versus uncompensable heat stress.

Physiological Measures

Core temperature (T_{re}) was measured from a rectal thermistor placed 10 cm beyond the sphincter muscle. Heart rate (HR) was available from a Polar Heart Rate Monitor. Skin temperature (T_{sk}) was a weighted temperature of four surface thermistors following the pattern and weighting of Ramanathan [5]. Data were recorded at 5-minute intervals.

Physiological Strain Index (PSI) [3] was a computed index of core temperature and heart rate. For this study, the baseline core temperature was taken as 36.5 °C and the resting heart rate was 75 bpm.

Heat Stress Level (Compensable and Uncompensable)

All of the trials in the data set were based on the determination of critical conditions following a progressive exposure method similar to Kenney [2]. When core temperature began to increase about 0.1 °C per 5-minute step for three successive increases, this would mark the end of the trial. The steady increase in core temperature marked a zone of uncompensable heat stress. The critical condition was determined by inspection as was the point five minutes prior to the start of the steady increase.

For each trial, the physiological data associated with the time of the critical condition and 15 minutes prior to the critical condition were associated with compensable heat stress. The physiological data 15 minutes after the critical condition were associated with uncompensable heat stress.

Experimental Conditions

The data used were collected from studies done in three phases. In Phase 1, there were 14 participants who wore five ensembles (work clothes, cotton coveralls, Tyvek 1424 coveralls, NexGen vapor-permeable water-barrier coveralls, and Tychem vapor-barrier coveralls). The coveralls configurations did not include a hood or gloves. In addition, the trials included three levels of relative humidity (20, 50 and 70%). Metabolic rate was about 160 W m^{-2}. A different group of participants repeated these protocols for Tyvek 1427.

In Phase 2, 15 participants wore a similar set of clothing ensembles. The exception was the use of Tyvek 1427 instead of Tyvek 1424. In this phase, the relative humidity was held at 50%. There were three levels of metabolic rate: 115, 180 and 250 W m^{-2}.

In Phase 3, five participants walked at a metabolic rate of 160 W m^{-2}, following the 50% relative humidity protocol. They wore hooded configurations of the Tyvek 1427, NexGen and Tychem coveralls as well as coveralls made from FR cotton and Nomex.

Statistical Analysis

JMP IN v5.1 (SAS) was used for the statistical analysis. A logistical regression based on predicting the probability of a case (uncompensable) from a collection of case and non-case (compensable) data. The principal independent variables were T_{re}, HR and T_{sk} as well as the computed value of PSI. In addition, clothing ensemble, gender and metabolic rate level were treated as potential confounders. Important considerations when predicting the probability of a case as the independent variable increases are the sensitivity (proportion of cases greater than the value of the variable) and the specificity (proportion of non-cases less than the value of the variable). In addition, the receiver operating characteristic (ROC) is a curve the relates the sensitivity to 1.0 - specificity. The area under the ROC curve is a measure of the ability of the independent variable to discriminate between cases and controls.

The analysis path first considered each of the principal independent variables alone. Then the ROC curve was plotted and the area under the curve was computed. Next clothing ensemble, gender, and metabolic rate level were considered individually with the principal independent variable to determine if the confounder was statistically significant. Finally significant confounders were considered together with the principal independent variable. In each case, if there was a statistically significant contribution to the model, the area under the ROC curve was noted. The comparison of ROC is appropriate to serial data collected on one individual in a trial to distinguish when status changes from non-case to case [4].

Results

Logistical regression was used to determine how well T_{re}, HR, T_{sk} and PSI could predict cases and non-cases for a convenience set of data comprised of 1461 observations (487 cases of uncompensable heat stress versus 974 non-cases of compensable heat stress). In addition to each of the principal independent variables, were modelled together. The area under the ROC curve results are provided in the second column of Table 1. The area under the ROC curves ranged from 0.71 to 0.89. The curves for T_{re} and T_{sk} are illustrated in Figure 1, and demonstrate the range of values for the principal effects.

Table 1. Results of statistical analyses by principal independent variables.

		Area under ROC Curve for Significant Confounders		
Principal Independent Variables	**Area under ROC Curve**	**Gender (G)**	**Metabolic Rate Level (MRL)**	**G and MRL**
T_{re}	0.71	ns	0.72	n/a
HR	0.77	0.78	0.78	0.79
T_{sk}	0.88	0.88	0.90	0.90
T_{re}, HR, T_{sk}	0.89	0.90	0.90	0.90
PSI	0.77	0.78	0.79	0.80

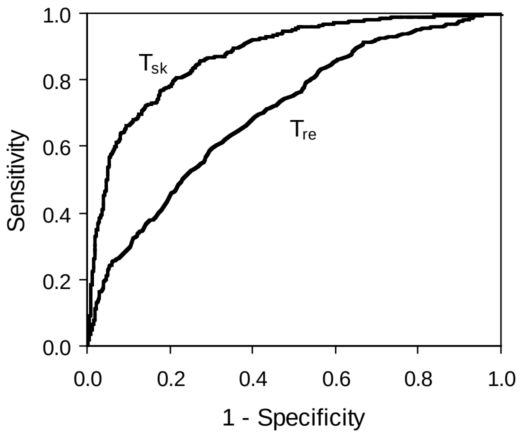

Figure 1. Receiver Operator Characteristic (ROC) curves for T_{re} (lower curve) and T_{sk} (upper curve).

The first thing to note is that clothing ensemble did not significantly contribute to any of the principal independent variables. Gender was significant for all principal variables except T_{re} and metabolic rate level contributed to all. Where both gender and metabolic rate level were significant separately, they were also significant together. The area under the ROC curve for each of these significant confounders is provided in Table 1.

Discussion

logit-p models were used to examine the ability of T_{re}, HR, T_{sk} and PSI to distinguish level of heat stress. It was logical to assume that T_{re} and HR would be good predictors based on their common use and the known relationship to levels of heat stress. PSI was an *a priori* combination of T_{re} and HR with the intent to account for both features of heat strain. While T_{sk} has been suggested as an indicator of excessive strain, there has been some concern about how well it might work. Most of the thought about these measures has been directed toward limiting an uncompensable heat stress exposure. This is fundamentally a different question than what is being asked in this evaluation.

Based on the logit-p models and the resulting ROCs, T_{sk} performed better than the other three principal variables. The area under the curve of the T_{sk} ROC at 0.89 was substantially better than either HR or PSI at 0.77 and T_{re} at 0.71. While the combined model of T_{re}, HR and T_{sk} was slightly higher, this was expected but clearly shows that T_{sk} accounts for virtually all of the performance. Likewise, HR appeared to account for most of the performance of the PSI.

It was surprising that clothing ensemble did not play a significant role in any of the logit-p models. Therefore, compensable (or uncompensable) heat stress can be predicted from physiological variables that do not require an adjustment for clothing.

While gender was expected to affect the logit-p models, the statistical significance was not accompanied by an important difference in performance as measured by the area under the ROC curve. Likewise, the metabolic level was expected to influence the models and where it did it did not have a real effect on the area under the ROC curve. The combinations of gender and metabolic rate level did not improve the ability to distinguish either.

Conclusions

Overall, T_{sk} is a good candidate for further consideration. Based on the present data, the sensitivity and specificity at T_{sk} = 36.55 °C are 0.79 as shown in Figure 2. HR makes a good second choice. Because these were laboratory measures, the ability to move these finding to the field require a consideration of how the field data can be collected (e.g., directly or through surrogates; and changing demands in time).

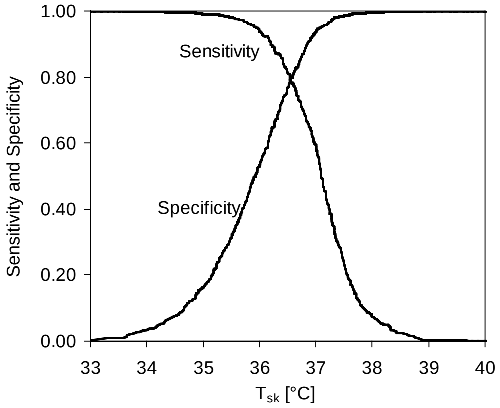

Figure 2. The relationship of sensitivity and specificity to values of T_{sk}.

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Acknowledgments

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DETERMINATION OF THE ACCEPTABLE DEEP-BODY TEMPERATURE FOR EVALUATING THE WBGT LIMITS USED IN MALE BRITISH ARMED FORCES PERSONNEL

A S Weller and W R Withey*

QinetiQ, Centre for Human Sciences, Cody Technology Park, Ively Road, Farnborough, GU14 0LX, UK
* corresponding author asweller@QinetiQ.com

Introduction

Heat illness is a routine and significant risk in military personnel of many nations, including those in the British Armed Forces (1). It is usually not practicable to measure deep-body (core) temperature during occupational activities, and therefore heat illness risk is often predicted by defining environmental heat stress limits, which are dependent on the level of work rate, clothing and state of heat acclimatisation (e.g. 2). In the British Armed Forces, wet-bulb-globe-temperature (WBGT) limits are used as part of the overall heat illness risk management strategy (3). However, the audit trail for these WBGT limits is unclear, and they have not been verified in the user population. Therefore they carry unknown heat illness risk. In order to validate the WBGT limits, first a mean core temperature limit must be chosen to ensure that the probability of any individual reaching an unacceptably high value (often considered to be 39.2 °C (4)) is sufficiently low (e.g. <0.001). This mean core temperature is often taken as 38.0 °C (e.g. 5), but will be dependent on the heat tolerance of the population at risk.

Therefore, our first objective was to establish a suitable population-specific core temperature limit, by quantifying the total (intra- and inter-) individual variability in heat strain in personnel representative of British Armed Forces personnel. The intra-individual component has been quantified in a previous study (6), and therefore the aim of the present study was to establish the inter-individual component. Establishing a population-based core temperature limit will enable the WBGT limits to be validated in subsequent studies.

Methods

Forty-seven, healthy men (35 British Army soldiers and 12 civilians) not acclimatised to heat, participated in this study. Their mean (1 SD) individual characteristics were: age, 27.3 (6.8) years; body surface area, 1.95 (0.14) m^2; nude body mass (BM), 78.8 (10.2) kg; surface area-to-body mass ratio, 2.49 (0.16) $m^2 \cdot kg^{-1} \cdot 10^2$; body fat, 17.0 (4.0) %; and peak oxygen uptake (VO_2peak), 52.8 (4.9) $ml \cdot min^{-1} \cdot kg^{-1}$. The subjects, who were representative of British Armed Forces personnel in these individual characteristics, undertook a standardised work-in-heat test (Heat Test). The Heat Test (Figure 1) consisted of up to 120 minutes of treadmill walking (speed, 5.5 $km \cdot h^{-1}$; incline, 6.5%) in a hot chamber (dry-bulb temperature (T_{db}), 35°C; 50 mm black-globe temperature = T_{db}; relative humidity, 20%; air speed, 1.0 $m \cdot s^{-1}$). The subjects wore lightweight British Army combat clothing (intrinsic thermal insulation, 0.95 clo; Woodcock moisture vapour permeability index, 0.40), and were encouraged to drink at least 12 $ml \cdot kg(BM)^{-1} \cdot h^{-1}$ of water. VO_2peak (Figure 2) was measured during a treadmill running test to volitional exhaustion 7 days before the Heat Test (VO_2peak Test). During the Heat Test, rectal temperature (T_{re}), mean skin temperature (7) (T_{sk}), and heart rate (HR) were recorded every minute. The change in nude body mass, measured immediately before and after the Heat Test, was corrected for water intake, estimations of respiratory and metabolic mass loss, and duration, to calculate gross sweat rate (m_{sw}). Metabolic rate (M) was determined from an expired gas sample taken at 10 minutes into the Heat Test. The Heat Test was terminated before 120 minutes if one of the following withdrawal criteria was reached: a T_{re} of 39.3 °C (T_{re}); a HR of 95% of peak HR measured during the VO_2peak Test (HR); or if the subject wished to stop (SWD). The heat strain variables were confirmed as normally distributed by skewness, kurtosis, Kolmogorov-Smirnov and Shapiro-Wilk's analyses. The probability of T_{re} reaching the critical limit (i.e. 39.2 °C) was evaluated by calculating Z scores (Z = (Critical limit – Mean)/ σ_3). Where σ_3 was the overall variability in T_{re} calculated from the intra- (σ_1) (previously determined (6)) and inter-individual standard deviation (σ_2), according to the equation: $\sigma_3 = \sqrt{\sigma_1^2 + \sigma_2^2}$.

Results

All subjects completed 80 minutes of the Heat Test, although 7 subjects subsequently reached a withdrawal criterion (T_{re}, n=2; HR, n=2; SWD, n=3). T_{re}, T_{sk}, and HR at 60, 80 (n=47) and 120 minutes (n=40), and M and m_{sw} (n=47) are given in Table 1.

Figure 1: Heat Test

Figure 2: VO_2peak Test

Table 1. Heat strain variables

Time	T_{re} (°C)	T_{sk} (°C)	HR ($b \cdot min^{-1}$)	M ($W \cdot m^{-2}$)	m_{sw} ($l \cdot h^{-1}$)
60 minutes	38.26 (0.28)	36.03 (0.56)	142.6 (19.0)	319 (23)	1.0 (0.2)
80 minutes	38.45 (0.34)	36.04 (0.63)	148.8 (20.3)		
120 minutes	38.67 (0.37)	36.05 (0.76)	154.9 (19.1)		

Using data from all 47 subjects, σ_3 was calculated for each minute of the Heat Test. Table 2 details σ_1, σ_2, σ_3, and the probability of a subject reaching a T_{re} of 39.2°C for mean T_{re} values between 38.0 and 38.4°C. It is evident that a mean T_{re} of 38.2°C ensured that the probability of any subject reaching 39.2°C was about 0.001. The relationship between mean T_{re} and σ_3 conformed to a 4th order polynomial (Figure 3).

Table 2. Probability of a subject reaching a rectal temperature of 39.2ºC as a function of mean rectal temperature

Mean rectal temperature (°C)	38.0	38.1	38.2	38.3	38.4
σ_1	0.16	0.16	0.16	0.16	0.16
σ_2	0.23	0.24	0.26	0.29	0.32
σ_3	0.28	0.29	0.31	0.33	0.36
Probability	0.0000	0.0001	0.0007	0.0034	0.0129

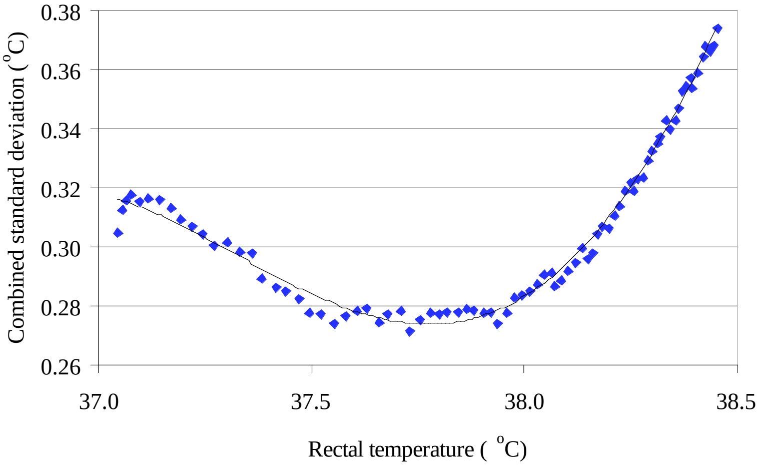

Figure 3. Relationship between rectal temperature and the combined intra- and inter-individual standard deviation (σ_3)

Discussion

In order to establish an appropriate population-based rectal temperature limit, all sources of heat strain variability within the population at risk must be determined. Part of the total variability will be due to the fact that individuals differ on a day-to-day basis. A previous study (6) established that this intra-individual variability is likely to be a relatively large component of the total variability in heat strain. However, the principal source of variability will be due to individual differences in the factors known to influence heat strain (e.g. aerobic power, body size and relative body fat) (8). The present study has quantified this inter-individual variability in rectal temperature in a relatively large sample of male, non-specialist British Army personnel. Therefore, combining these two sources of variability, it has been calculated that the mean rectal temperature limit should be restricted to 38.2°C to ensure that the probability of any individual reaching
a rectal temperature of 39.2°C is less than 0.001. Consequently, subsequent studies that will assess the suitability of the British Armed Forces WBGT limits will be based on this mean rectal temperature limit. This limit is comparable to that reported by Wyndham and Heyns (9), and Kampmann (10), although these researchers did not consider the intra-individual variability component. Furthermore, unlike Wyndham and Heyns (9), but consistent with Kampmann (10), there was no evidence of a positive skew in the rectal temperature distribution. The proposed mean rectal temperature limit assumes that the distribution of rectal temperature about a given mean is independent of environment and physical activity factors, which is not the case. It has been shown that the distribution is narrower for humid heat and exercise relative to VO_2peak (8). However, given that the environment in the present study was dry, and the exercise consisted of treadmill walking at a fixed speed and incline, it is likely that the proposed rectal temperature limit represents the "worst-case scenario", and is therefore unlikely to underestimate the level of heat illness risk in the user population. The proposed rectal temperature limit is applicable only to male British Armed Forces personnel, not acclimatised to heat and wearing one layer of combat clothing. Consequently, further studies are required to establish the influence of sex, state of heat acclimatisation and clothing on the validity of this limit.

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VIGILANCE AND TRACKING PERFORMANCE DURING UNCOMPENSABLE HEAT STRESS

Peter Tikuisis[1], Andrew Shin[1], Allan A. Keefe[1], Martin Taylor[2]*

[1] Simulation, Modelling, Acquisition, Rehearsal, & Training Section
[2] Command Effectiveness & Behaviour Section
Defence Research & Development Canada – Toronto
* Peter.Tikuisis@drdc-rddc.gc.ca

Introduction

An earlier investigation involving the effects of heat stress on target detection and marksmanship (1) indicated no detrimental impact on performance when core temperatures were elevated by 1°C. In preparation for future studies involving higher core temperatures, we developed a method for controlling the rate of rise of core temperature, and tested subjects on vigilance and tracking tasks that were deemed relevant to marksmanship skills.

Methods

Six healthy males (mean ± SD age, height, mass, body fat, and BMI were 28.6 ± 8.8, 175.6 ± 5.8 cm, 78 ± 3.9 kg, 13.58 ± 1.7 %, and 25.3 ± 0.9, respectively) participated in the study, which was approved by the Human Research Ethics Committee for Defence R&D Canada.

Subjects wore a specially designed tube-laced vest and pants (Cool Tube Suit, Med-Eng Systems Inc., Ottawa, Canada) through which hot water (42°C) was circulated. Flow rate was adjusted to regulate the amount of heat applied to the subject to fine-tune the increase in core temperature (Tcore) at a rate of about 0.6°C/h [measured via a rectal thermometer (Pharmaseal 400 Series, Baxter Healthcare Corp., CA)]. Except for the face and hands, subjects were also fully encapsulated in Canadian Forces nuclear, biological, and chemical protective clothing to minimize evaporative heat loss. Heat balance calculations indicated that uncompensable heat stress (2) should occur at a room temperature of 28°C and relative humidity of 70%, which were chosen for the study.

Subjects participated in two trials, hydration (H) and dehydration (D), separated one week apart in counterbalanced order. Water was provided ad libitum in H and none was consumed in D. Subjects remained seated and without passive heating during the first 30 min of each trial to allow baseline measurements of core temperature, psychomotor testing, and subjective sensations. The latter two involved vigilance and tracking tasks, and ratings on thermal sensation [TS; modified 0 - 10 version of the Gagge scale (3)] and perceived exertion [PE; modified 0 - 10 version of the Borg Scale (4)]. Heat was then applied continuously and the subject began a series of half hour sessions that comprised walking for 10 min on a level treadmill at 4.8 km/h, completing the psychomotor tasks and subjective questionnaires, and consuming water (H trial only). The trial continued until one of the following conditions occurred: i) the subject's core temperature reached 39.2°C, ii) 4 hours elapsed since heat was first applied, iii) the subject complained of dizziness, nausea, or requested withdrawal, or iv) upon the discretion of the experimenter.

The vigilance and tracking tasks were presented on a computer. The vigilance (VIG) task lasted 7 min and presented 100 randomly distributed 3-digit numbers per minute of which 8 different numbers were repeated consecutively that required acknowledgement from the subject by a mousepad response. Subjects were scored according to the number of missed, correct, and incorrect responses. The tracking tasks involved three different 1 min tasks of varying difficulty and separated by about 30 s. The first tracking task (TT1) presented a vertical bar that varied in length sinusoidally, but randomly in amplitude and frequency, as shown in Fig. 1. On average, the bar length cycled about 14 times with a coefficient of variation (cv) of about 9-10%. The subject's task was to maintain the length of a horizontal bar equal to the vertical bar through the lateral motion of a mousepad.

TT2 presented two numbers, double and single digit, separated by either a '+' or '-' operation, and the subject was to adjust a third number on the screen to equal the sum or difference of the target numbers through the lateral motion of a mousepad. The magnitude of the target sum or difference cycled 1-3 times with a cv of about 25% (see Fig. 1 for an example). TT3 was similar to TT1 except that a second vertical bar was added that cycled in length and frequency independently of the first. The subject's task was to maintain the length of a horizontal bar equal to the sum of the two vertical bars through the lateral motion of a mousepad. The resultant magnitude of the target vertical bars cycled about 10 times with a cv of about 11-12%. Subjects were scored on all three TT tasks according to the absolute error (displacement between target and response magnitudes), positive bias (frequency of overestimating magnitude of target), and optimal lag (difference in time to obtain closest match to target magnitude using cross-correlation).

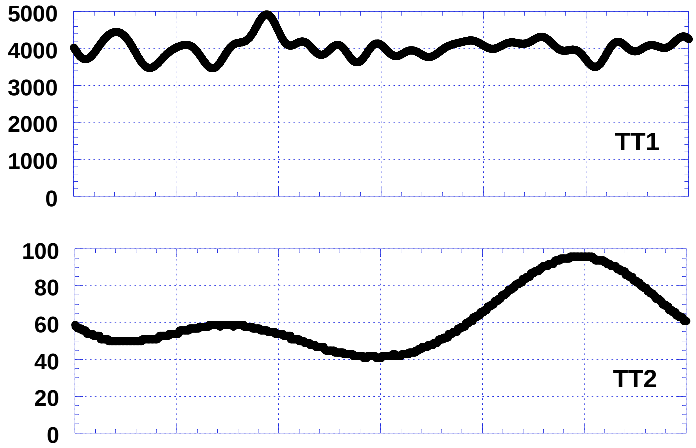

Figure 1. Example fluctuations in amplitude and frequency of the first two tracking tasks, each administered over 1 min.

All measures were analyzed separately as a 2 [trial (H vs. D)] x 7 [time (every 30 min starting at 20 min)] repeated measures analysis of variance (ANOVA) design (Statistica StatSoft Inc, Tulsa, OK). Mean results are reported with ± SD and significance is reported for $p < 0.05$.

Results

All subjects completed 3 h of heated exposure. Their mean Tcore were 36.9 ± 0.2°C at 20 min (during the unheated baseline rest period) for both trials, and 38.7 ± 0.2 and 38.4 ± 0.5°C at 200 min for H and D, respectively (see Fig. 2), which were not different. Tcore began to increase at nearly one hour after the start of the trial at a fairly consistent rate of 0.6 to 0.7°C/h. Net sweat losses amounted to 1.42 ± 1.44 and 2.71 ± 0.80% of body mass for H and D, respectively.

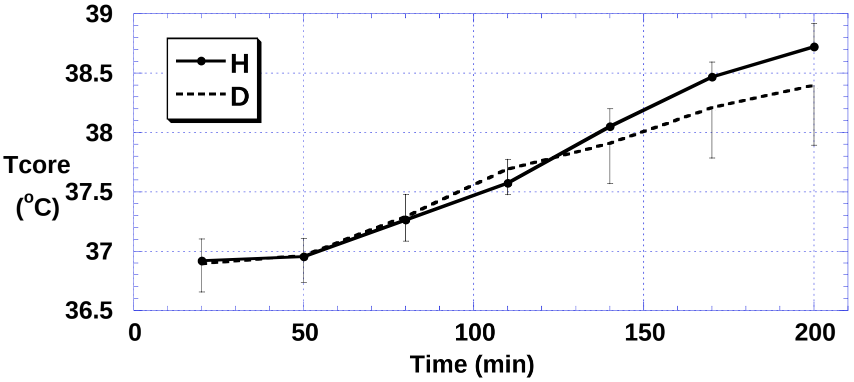

Figure 2. Mean ± SD of core temperature.

TS and PE also did not differ between trials and increased from average baseline levels of 1.8 (warm) and 1.5 (barely tired), respectively, to 6.1 (quite hot) and 4.0 (tired) after 3 h of heating. These ratings correlated highly with core temperature ($r > 0.93$ and 0.96, respectively).

There were no significant effects of time, hydration, or interaction for any of the psychomotor tasks. Overall %missed, %correct, and %incorrect on the VIG task were 68.6 ± 7.1, 10.9 ± 5.7, and 20.5 ± 6.3% for H, and 68.2 ± 12.7, 11.9 ± 7.9, and 19.9 ± 8.8 for D, respectively. Absolute errors for TT1 to 3 averaged approximately 20, 8, and 15%, respectively. Overall positive biases of 95.0, 55.6, and 70.5% for

TT1 to 3 indicated a consistent overestimation of target magnitude. Overall optimal lags were 240, 920, and 793 ms for TT1 (see Fig. 3) to 3.

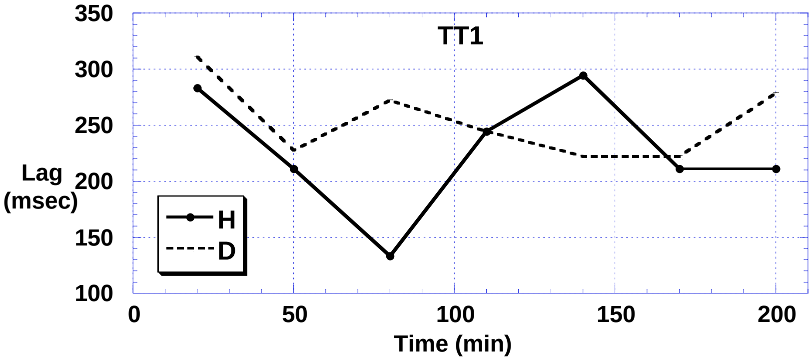

Figure 3. Mean optimal lag for first tracking task.

Discussion

An increase of 1 ℃ in Tcore is considered detrimental to psychomotor performance (5), yet this threshold was exceeded in our study without any obvious negative impact. Our subjects also exceeded the physiological limit of 0.055 ℃/h increase in Tcore declared detrimental for vigilance (5). Respective predicted heat stress limits of performance of 8 and 122 min (5) for vigilance and tracking tasks, assuming a WBGT of 37 ℃ (based on the equivalent ambient condition that would replicate the micro environment that the subjects were exposed to) were also exceeded by our subjects. It is known that feedback and motivation can attenuate or prevent any degradation of psychomotor performance, but the former was not offered and the latter was minor. It is not readily apparent why our findings do not concur with most other observations regarding performance in the heat, except to acknowledge that the effects of heat strain are highly task-specific.

Acknowledgements

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GENDER DIFFERENCES IN RAPID ACCLIMATION TO HEAT

Yoram Epstein[1,2]*, *Daniel S Moran*[1,3], *Yair Shapiro*[1,4]

[1] Heller Institute of Medical Research, Sheba Medical Center, Tel Hashomer, Israel
[2] Sackler Faculty of Medicine, Tel Aviv University, Israel
[3] Institute of Military Physiology, IDF Medical Corps, Israel
[4] School of Health Sciences, the College of Judea and Samaria, Ariel, Israel
[*] Corresponding author: hlrinst@post.tau.ac.il

Introduction

Acclimation to heat is a process of physiological adaptation that results in a higher tolerance to heat. This is manifested both at the physiological level (lower strain) and the subjective rating. The functional mechanism of heat acclimation is elucidated by lowering the thresholds of peripheral vasodilatation and sweating. Overall, the lower physiological strain is associated with an increase in sweat production, lowered skin and body core temperatures, and reduced heart rate. Acclimation is a continuum of processes, and although there is no pointed end to the improvement in the physiological responses, most of the changes are achieved during the first week of exposure, and a new steady state is attained within 9-10 days (5).

Operational requirements to deploy military troops from one climatic condition to another with short notice may impose a thermoregulatory stress when deployment is targeted to locations characterized by warm climate, or if NBC protective gear are enforced. Under such conditions a regular procedure of heat acclimation, or the reliance on natural heat acclimatization, a process that is attained over several weeks, is not practical. This enforces the development of an acclimation procedure, which can be effective in less than 5 days.

In many instances military troops, which are operating under adverse environmental conditions, include men and women soldiers who are required to effectively perform in a like manner. In a preliminary study, the possibility to attain a partial acclimation of male subjects to warm climate within 3-5 days of exposure (120 min per day) to temperate climate, while wearing an impermeable clothing assemble was demonstrated. The present study was undertaken to investigate whether this procedure is equally efficient for females.

Methods

Nine female and 13 male young subjects, whose general characteristics are summarized in Table 1, participated in the study. Following a medical examination that found them eligible to participate in the study, the subjects were informed about the procedure and the potential risk of exercising in impermeable protective clothing. The subjects approved their participation by signing a form of consent. The study and the procedures were approved by the Sheba Medical Center Human Use Committee.

Subjects, dressed in shorts and T-shirt under an impermeable NBC protective clothing (without gloves and rubber boots) exercised on a treadmill at a pace of 1.39 m/sec and 2% elevation. The exercise sessions were conducted under comfort climatic conditions (20^{o}C and 50% relative humidity), for five consecutive days, 2 hrs per day.

During the exposure heart rate (f_c) and rectal temperature (T_{re}) were monitored continuously. Temperature was monitored with a suitable thermistor, which was inserted ≈10 cm beyond the anal sphincter and f_c was monitored by a Polar heart watch. All parameters were automatically recorded and stored using a data logger. Sweat rate was calculated from weight differences corrected for fluid intake and urine output. The physiological strain index (PSI) was calculated from T_{re} and f_c according to Moran et al (4). The mean value of the PSI from the last 5 minutes was used to compare the day by day change in physiological strain.

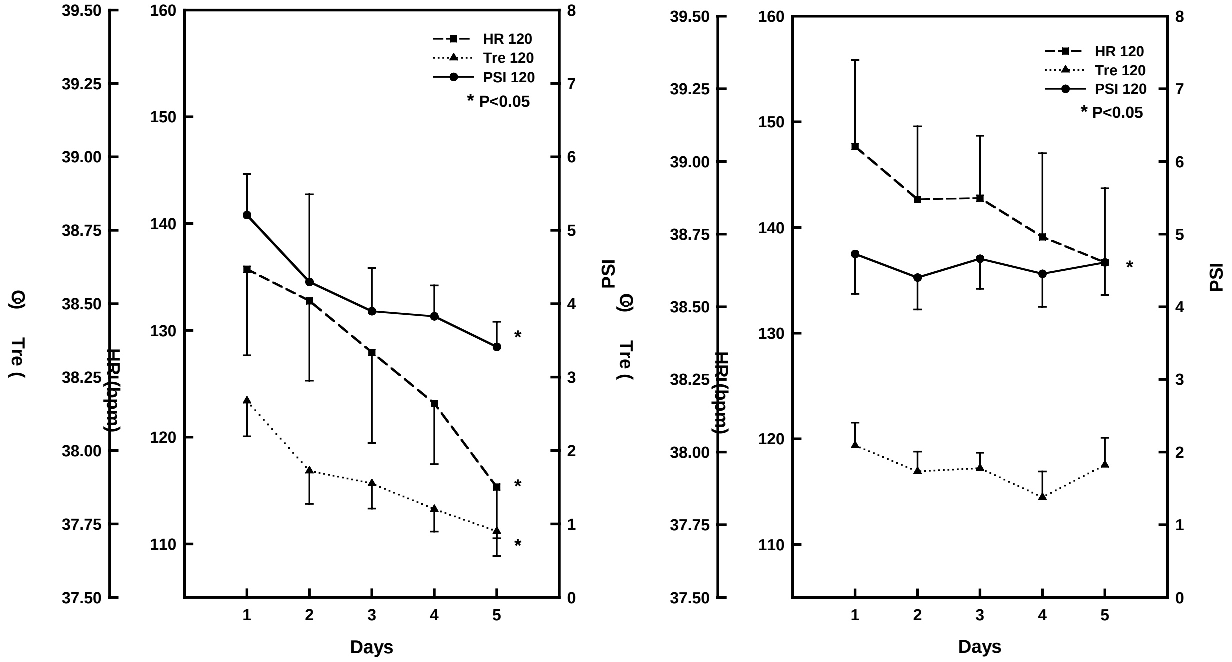
Descriptive statistics was used to look for differences between the two groups. Data are presented as mean±SE, unless otherwise specified.

Table 1. General characteristics of the participants (mean±SD)

	Male	Female
n	13	9
Age (yrs)	22±1	22±1
Weight (kg)	70.0±3.3	58.9±2.6
Height (cm)	175±1	166±2
Surface area (m^2)	1.84±0.04	1.65±0.04

Results

In Fig. 1, the results of the male and female subjects during the five days of exposures are depicted. In the male group a significant decrease ($p<0.05$) in PSI, from 5.2±0.6 units on day 1 to 3.4±0.3 units on day 5 was noted following a significant decrease in f_c and T_{re}. In the female group PSI was 4.7±0.5 units on day 1 and did not change over the entire duration of the procedure, reflecting only changes in T_{re} but not in f_c. Sweat rates of women and men were comparable, being circa 350-400 ml/hr.



Male **Female**

Figure 1. Physiological strain in the male and female groups, exposed wearing impermeable NBC protective clothing to 20°C and 50% relative humidity.

Discussion

Wearing impermeable protective clothing under temperate climatic conditions imposed in the group of males a physiological strain that was comparable to that of an exposure to warm climate while wearing shorts (PSI reduced from 5.2±0.8 units on day 1 to 4.1±0.4 units on day 3) (Fig. 2). Thus, a rapid procedure of acclimation can possibly be based on a 5 day exposure to temperate climate while wearing impermeable clothing. However, the present study failed to show a similar dynamic in women.

In earlier studies it has been shown that women benefit from heat acclimation in a similar manner to men (1-3, 6). Judging from the reduction in heart rate and core temperature the degree of acclimation appears to be similar in the two genders (7). It also has been shown that following acclimation women exhibit a better improvement in tolerance time in the heat than men (3,7). Since sweat rate is usually greater in men than in women, this phenomenon is not explained by a greater evaporative heat loss, but it probably reflects greater circulatory changes in women during heat acclimation (2).

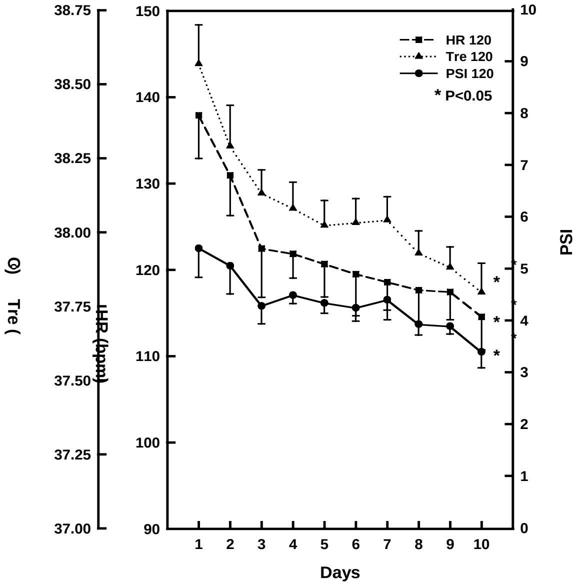


Figure 1. Physiological strain in the male group, exposed while wearing shorts to 40°C and 40%

The two groups of participants were not matched by any of their anthropometrical characteristics, except age, in an attempt to simulate a real life scenario. In fact, the women's group had a lower body mass and thus their metabolic heat production was lower than that for men. This, coupled with the exposure to relatively comfortable environmental conditions, probably did not elicit a substantial physiological strain to induce a process of physiological adaptation. The reliance on sweating as a primary route for heat dissipation was, in the specific set-up of the study, very limited since the subjects were wearing impermeable suits. It follows that circulatory adaptation was significant for dissipating extra heat.

The question of why, in the male subjects, adaptive processes to heat could be exhibited under the underlying experimental conditions, which could not be obtained in the female subjects, can not be answered with the limited information in hand. Physiological variables that were not accounted for in the present study might be crucial. In this respect, parameters such as the effect of aerobic capacity, or the stage of the menstrual cycle should be considered and investigated.

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MATHEMATICAL MODELS IN COLD EXPOSURE RESEARCH: BASIC CONSIDERATIONS, POTENTIAL AND LIMITATIONS

Avraham Shitzer

Department of Mechanical Engineering, Technion, Israel Institute of Technology, Haifa, Israel
mersasa@tx.technion.ac.il

Introduction

Mathematical modeling of complex physiological phenomena, such as the thermal behavior of humans under varying and extreme environmental conditions, has been widely attempted over the years. The principal objectives of modeling can be summarized as follows:

- Facilitate parametric presentation of the modeled phenomena.
- Facilitate management of large databases.
- Develop computational and predictive capabilities.
- Simulate responses to environmental extremes, hot and cold, that are rather costly and may not be readily permissible under experimental conditions.
- Study the validity of physiological control theories and mechanisms.
- Compare the relative effects of various control mechanisms.

Models can be classified into two main categories:

- Regression models based on large databases (curve fitting).
- Heuristic models based on first principles, e.g., the first Law of Thermodynamics.

Theses models can further be sub-classified as:

- Lumped-parameter models (compartmental analysis), and,
- Distributed-parameter models.

These generic types of models are introduced and discussed briefly. Examples will be given to each category with an emphasis on exposure to cold environmental conditions.

1. Regression models

Regression modeling requires the *a priori* availability of large experimental databases. The data are first analyzed for "best fit" options. Next, statistical regression techniques, e.g., least-squares fitting, are employed to obtain the numerical values of the various coefficients and parameters. Typical equation forms, widely found in the literature, include linear, polynomial, exponential, trigonometric and combinations thereof. In most cases regression parameters and levels of confidence of the derived model are also presented.

The main advantage of such models derives from their simplicity. They provide a convenient means for using relatively simple and straightforward equations for presenting large databases in assessing the relationship between measured physiologic variables and environmental parameters. The predictive power of these models is limited, however, in the majority of cases, to the range of values for which the experimental databases were obtained. Thus, extrapolation beyond the original experimental range, although mathematically possible, may yield physiologically invalid values. Additionally, these models are usually "steady-state" ones, lacking time-dependent properties. While this is acceptable in a variety of cases, it may present serious hindrances in other.

One representative example to this type of models, is the one developed by Siple and Passel (9) to assess the effects of cold wind on heat loss from exposed body parts. These pioneers in cold exposure research conducted a series of experiments in the Antarctic in the late 1930's to determine the cooling power of the subfreezing environment. They exposed snow-melted water in a small cylindrical pyrolin (cellulose acetate) container, to combinations of environmental temperatures and winds and calculated the times required for the contents to freeze. Their measured data were presented in term of a wind chill index (WCI), expressing the cooling power of the (subfreezing) environment in complete shade (no insolation) and in the absence of evaporation. The result is given by (9):

$$WCI = (10.45 + 10 * V^{1/2} - V) * (33 - T_a)$$

(1)

where, WCI is the wind chill index, kcal/ m^2 hr, V is wind velocity, m/s, 33 is the assumed average thermo-neutral (exposed) skin surface temperature, ºC, and T_a is air temperature, ºC. The first term in the parentheses of Eq. (1) is essentially the heat transfer coefficient between the exposed skin and the environment and is expressed explicitly in terms of wind speed.

The specific algebraic form which was chosen to regress the data, Eq. (1), is quadratic, as shown in Figure 1 (3). It appears to approximate most of the measured data points up to wind speeds of about 14 m/s. Beyond 25 m/s, the extrapolated WCI would change the trend and will decrease with increased wind speed, contrary to intuition, as demonstrated in Figure 2 (3). Had a different mathematical expression (model) been selected for approximating (modeling) the data, e.g., exponential, this non-physical and non-physiological reversal of trend would have been avoided.

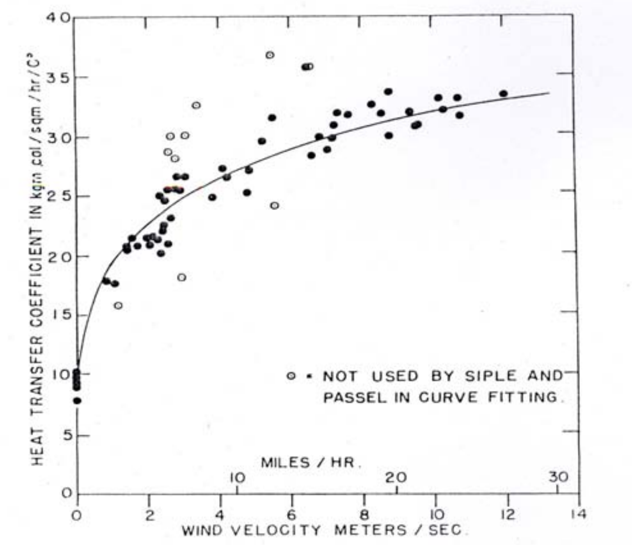

Figure 1. The Siple-Passel data (9) replotted by Molnar (3)

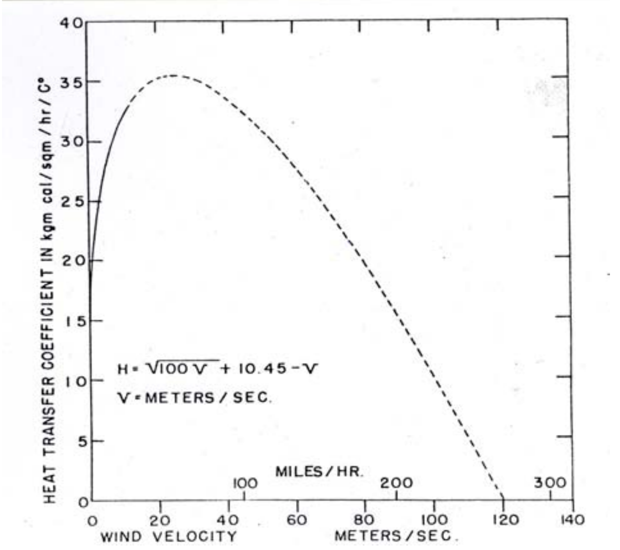

Figure 2. Course of the extrapolation of the Siple-Passel heat transfer coefficient (3)

2. Heuristic models

Heuristic modeling is based on a very different approach than regression models in that it attempts to derive, rather than regress, the relationships between physiologic variables and environmental parameters, from the mathematical expressions of natural laws. The underlying assumption is that natural phenomena are governed by certain laws. While these laws may be complex they are, nevertheless, amenable to relatively simple mathematical representations. For instance, the first Law of Thermodynamics (also referred to as the law of conservation of energy) may be expressed by an equation combining variables such as temperature, tissue physical and geometric properties, metabolic heat production, blood perfusion rate and time. These variables are cast into a differential equation for which boundary and initial conditions are specified. Once a solution to this equation, is obtained by analytical or numerical methods, the predictions of the model need to be verified against experimental data.

This methodology has the potential of providing a powerful tool for describing and studying the responses of the thermoregulatory system under a variety of conditions and as a function of time. There are, in principle, no limitations on the range of parametric values for which the simulation applies but care must be exercised when analyzing the results.

We distinguish between two groups of heuristic models:

(a) **Lumped-parameter models**

Lumped-parameter models are based on first principles, but assume, mainly for simplicity, uniform (lumped) properties rather than distributed. In certain cases, depending mainly on the nature and size of the modeled entity, these models may yield reasonable approximations of the behavior of the natural phenomena. A common example to the applicability of these models are those cases in which a modeled entity may be assumed to be represented by well-mixed compartment(s). Confidence levels and extrapolation capabilities of these models, derive from comparisons to measured data.

Two examples are given below. One is of a single compartment model of a gloved finger-tip exposed to a cold environment. Due to its anatomical structure and relatively small size, the tip of the finger may be depicted as a homogeneous semi-sphere supplied and drained by a single artery and a vein (7), as shown in Figure 3. The modeling equation is the law of conservation of energy (the first law of thermodynamics) assuming a single, uniform value to represent the temperature of the tip of the finger (7):

$$\rho c V \frac{dT}{dt} = hA(T_0 - T) + \rho_{bl} c_{bl} w_{bl} (T_{bl} - T) \tag{2}$$

subject to the initial condition:

$$T = T_1 \quad \text{at } t = 0 \tag{3}$$

where: ρ is mass density, kg/m^3; c is specific heat, kJ/kg ºC; V is finger-tip volume, m^3;T is temperature, ºC; t is time, sec; h is the combined heat transfer coefficient between the finger-tip and the environment, kW/m^2 ºC; A is finger-tip surface area, m^2; and w is blood perfusion rate, m^3/s. Subscripts 0 and bl designate the properties of the environment and of blood, respectively. For an analytical solution of Eq. (2) the reader is referred to (7).

Figure 4 shows one set of typical results for this mdel. As formulated, this model lacks the particulars of an autonomic physiological control mechanism. This control mechanism regulates the flow of blood to the modeled element. Thus, to able to calculate the temperature variations of the finger-tip, one needs to assume the course of change of blood perfusion. The form chosen to represent this mechanism is included as the broken line in Figure 4. This specific form of repeated triangular waves of different intensities for blood perfusion, was chosen based on both intuition and on evidence from plethysmographic (1) and laser-Doppler (8) measurements of blood flow in cold-stressed finger-tips, as shown in Figures 5 and 6. These figures include temperature predictions of the model with the relevant measured blood perfusions as inputs.

The second example is of a multi-compartment, single cylinder, lumped-parameter model of the human body (2). As shown in Figure 7, the body is approximated by 5 inter-connected annular compartments and an interconnecting central blood compartment. Each compartment is represented

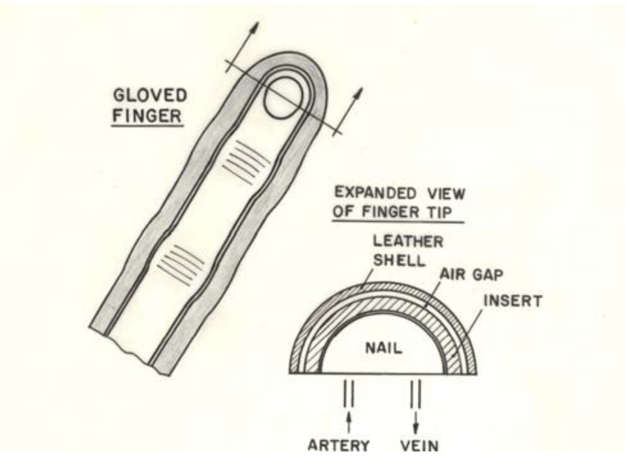

Figure 3. Lumped-parameter model of a gloved finger-tip (7)

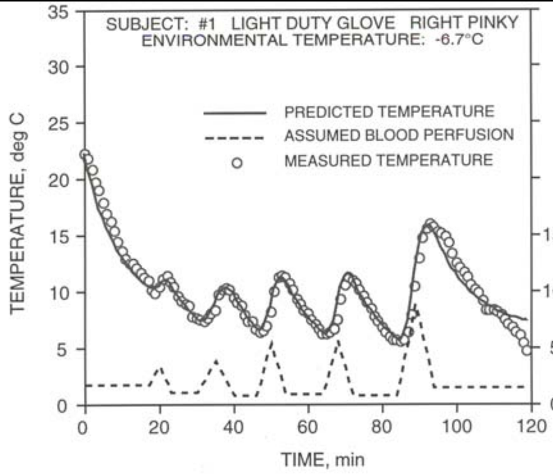

Figure 4. Comparison of measured and predicted gloved finger-tip temperatures (7)

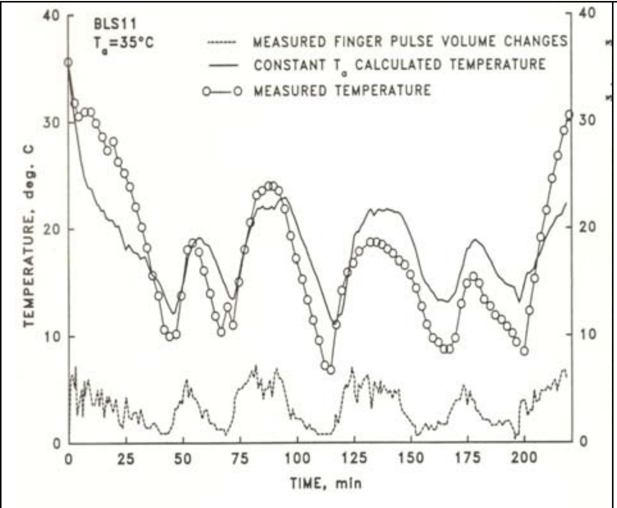

Figure 5. Finger-tip temperature and plethysmographic pulse volume changes (1)

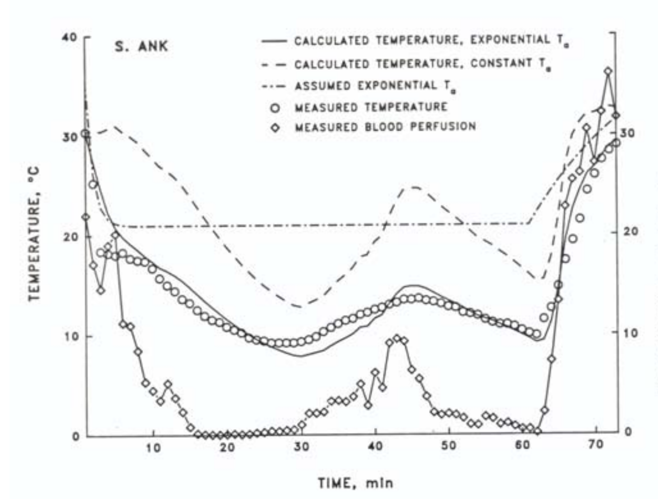

Figure 6. Finger-tip temperature and laser-Doppler blood perfusion variations (8)

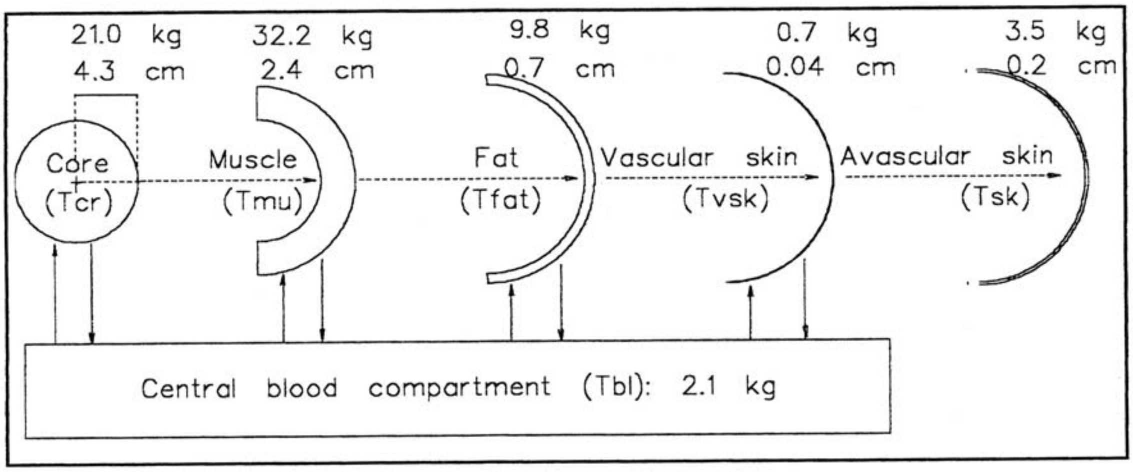

Figure 7: Schematic representation of the five concentric annular tissue, lumped-parameter compartments and the central blood compartment (2).

by a single, time-dependent temperature. Algorithms are specified for each of the control functions and facilitate a first-order study of the temporal variations of body (compartment) temperatures due to exercise and exposure to environmental changes. The model equations were programmed by TurboBasic (called: SCENARIO) for a PC and facilitate a first-order study of body temperature variations for different regimes of heat/cold/exercise exposures (2).

(b) Distributed-parameter models

Distributed-parameter models, unlike the lumped-parameter models, seek to track the variations inside the modeled entity. In general, detailed mapping of all anatomical, physiological, thermal parameters and other parameters is required. These data are used as inputs to the modeling equations which may be solved for a variety of boundary and initial conditions. Since in reality detailed and accurate data are not usually available, simplifying assumptions and compromises need to be made. Two main groups of models may be distinguished: models of single organs and whole body models.

(b.1) Single organs' models

One example of a distributed-parameter model of a single organ is given below, depicting a human head exposed to cold wind (6). The head is approximated by a hollow cylinder with a constant temperature prescribed at its inner surface. A steady-state is assumed and all thermophysical parameters, e.g., thermal conductivity, are assumed constant and uniform. No blood perfusion and metabolic heating effects are included. The outer surface of the cylinder is assumed to be exposed to wind blowing at various speeds and temperatures. The purpose of this model is to obtain an expression for wind chill which is a common measure of the cooling power of the environment due to different wind speeds.

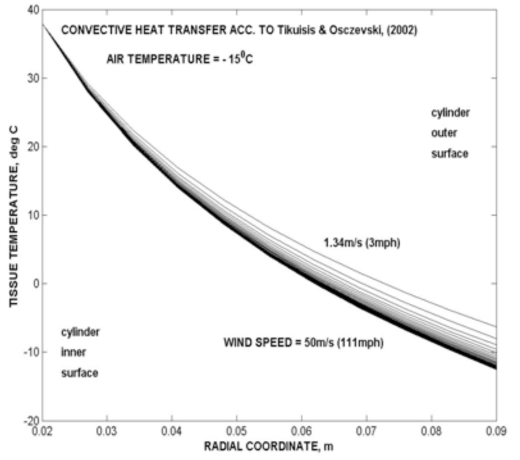	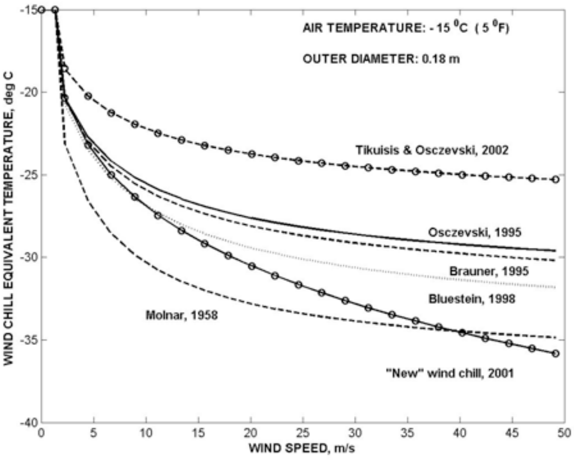
Figure 8. Temperature distributions inside the cylinder model wall (6)	**Figure 9**. Wind chill equivalent temperatures for various heat transfer coefficients (6)

Figure 8 shows how tissue temperatures are distributed from the inner to the outer surfaces of the model as functions of wind speed (6). Under the assumptions made for this simple model, temperatures inside the tissue drop monotoneously and attain lower values for higher wind speeds, as is to be expected. Skin (outer cylinder) surface temperatures facilitate the estimation of the effects of wind speed on wind chill, as shown in Figure 9 (6). The graphs in this figure are plotted for different expressions of the heat transfer coefficient with the environment. A transient analysis of this problem is presented elsewhere (5).

(b.2) Whole body models

Whole body distributed-parameter models are, potentially, the ultimate models for studying the thermal behavior of the human body under a variety of conditions. Attempts to develop such detailed models date back to the 1960's with the pioneering works of Wissler (13,14), Stolwijk and Hardy (10) and Stolwijk (11). Wissler approximated the body by 15 inter-connected cylinders, Figure 10 (4). Each cylinder was subdivided radially into 4 layers representing the core, muscle, fat and skin. He used multi-node models, and incorporated advanced control mechanisms of metabolic heat generation, heat and mass transport in the lungs, blood perfusion control algorithms and sweating. The model was solved numerically and its predictions were validated against measured data under a variety of conditions, e.g., Figure 11.

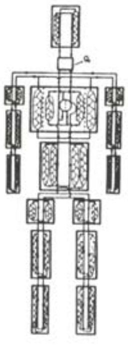	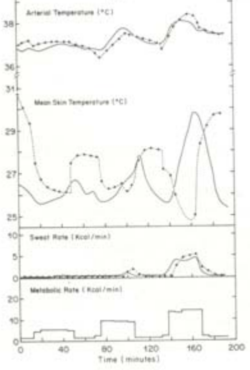	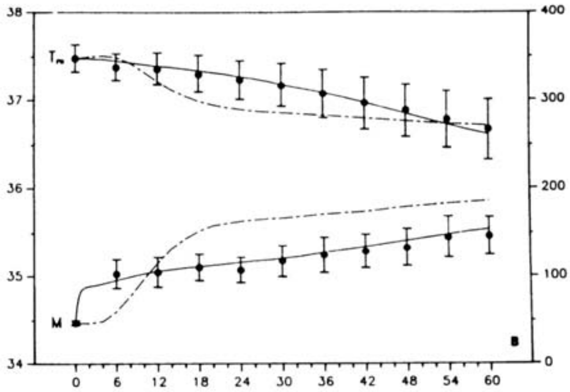
Fig. 10: Wissler's whole body model (14)	**Fig. 11**: Wissler's model validated for a subject exercising at 10ºC (14)	**Figure 12**: Rectal temperature (upper) and metabolic rate variations for a medium body fat subject immersed in 20ºC water (12).

Another example of a whole body distributed-parameter model for cold exposure is due to Tikuisis and co-workers (12) who adapted Wissler's model to study the dynamics of immersion of humans in cold water. They studied the effect of body fat on metabolic rate and rectal temperatures to one-hour immersion in water at different temperatures, Figure 12.

Summary

Modeling of physiological phenomena is important mainly in that it provides an auxiliary tool for quantifying and understanding the natural phenomena. It also facilitates the simulation of the behavior of the modeled biological entity and the testing, under assumed extreme conditions which may not be permitted in practice. Investigators typically divide the body into a passive system and an active system. The passive system contains the anatomical and thermo-physiological details of the body. In this system all heat exchange processes occur and an energy balance is maintained.

The active system embodies the control functions which activate the various control mechanisms. Investigators distinguish between exposures to cold and hot environments. The main differences between these models are embedded in the active system since different control mechanisms are activated in these separate exposures. Thus, the algorithms that are formulated for a passive model of heat exposure, may be adopted for studying cold exposure, and *vice-versa*, provided a suitable adaptation of the active system is performed.

It should be kept in mind that models are just approximations of natural phenomena. In spite of all the intellectual and analytical efforts - models are, and will always be, just as good as the underlying assumptions used in their formulation, the accuracy of the (numerical) solution scheme(s) employed and the data used for their validation.

Table 1: Comparison of the characteristics of model types

Heuristic Models (first principles)		**Regression Models (curve fitting)**
Distributed parameter	**Lumped-parameter**	
Complex/detailed	Complex	Simple/limited
May be extrapolated beyond the domain of experimental data		Interpolation inside the domain of experimental data
Validity depends on modeling equation(s) and experimental data		Validity depends on selected equation and data
May include time dependence		No time dependence (usually)
Validation required		Validated *a-priori* (confidence level)
Require control functions (algorithms)		May form the basis for control functions
Require anatomical, physiological, geometrical and control details		No further details required
1, 2 and 3 dimensional	One-dimensional (usually)	No dimensionality
Differential equations require numerical solutions	Differential equation may be solved analytically (simple cases)	Only curve-fitting required (least square)

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COMPUTER SIMULATOR FOR PREDICTION OF HUMAN THERMAL STATE

.Irena Yermakova[1], *Julia Tadejeva*[1] *and Victor Candas*[2]

1) International Center for Information Technologies and Systems UNESCO, Kiev, Ukraine.
*Corresponding author irena@zeos.net
2) Centre d`Etudes de Physiologie Appliquée (CNRS), Strasbourg, France

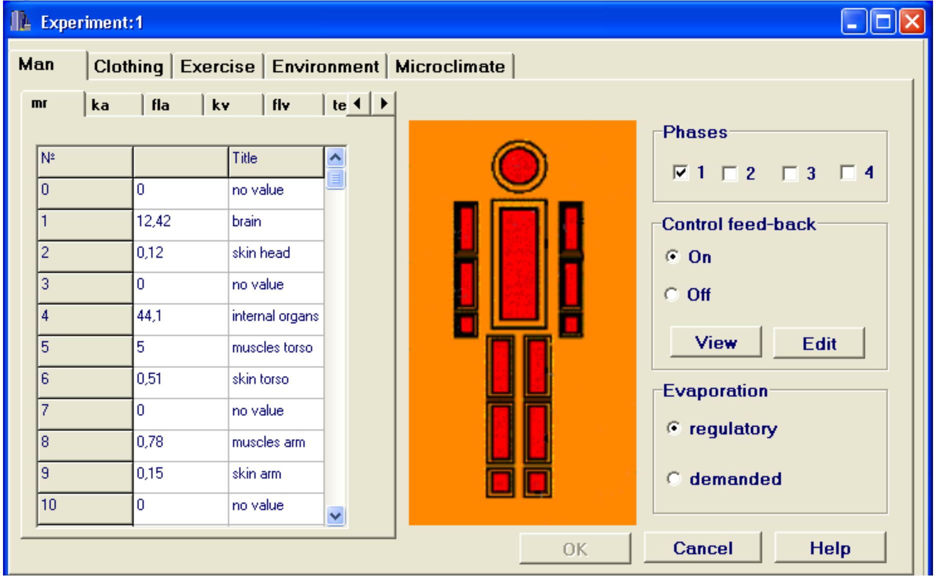
Introduction

Prediction of the human thermal state is important when evaluating the effects of clothing and performance in different environments. It helps to evaluate the thermal comfort or discomfort and additionally to prevent the hazardous impacts on man.

The purpose of this work was to develop an efficient tool which will be useful for modeling the human thermal responses in moderate, hot and cold environments while wearing different kinds of clothing.

Methods

Our Computer Simulator (CS) is derived from the class of multicompartmental thermal models and implemented in an object-oriented approach. It is performed in Borland C++ Builder 6 /1/. The mathematical description involves a detailed presentation of the human thermal processes through body division into compartments taking into consideration heat production in organs and tissues, heat transfer by blood flows, conduction, convection, radiation, and evaporation from the skin and the respiratory system, the afferent and efferent thermoregulatory processes. Our model can simulate the non uniformity of the thermal environment, physical activity and effects of various clothing ensembles. Environment physical effect is simulated by change in environmental temperature, humidity, air velocity, radiant temperature and/or solar radiation. The clothing thermal effect is introduced through additional insulative layers and their textile characteristics. The different kinds of activity are simulated by adjustments in metabolic heat production of the different skeletal muscles involved.



№		Title
0	0	no value
1	12,42	brain
2	0,12	skin head
3	0	no value
4	44,1	internal organs
5	5	muscles torso
6	0,51	skin torso
7	0	no value
8	0,78	muscles arm
9	0,15	skin arm
10	0	no value

Phases
☑ 1 ☐ 2 ☐ 3 ☐ 4

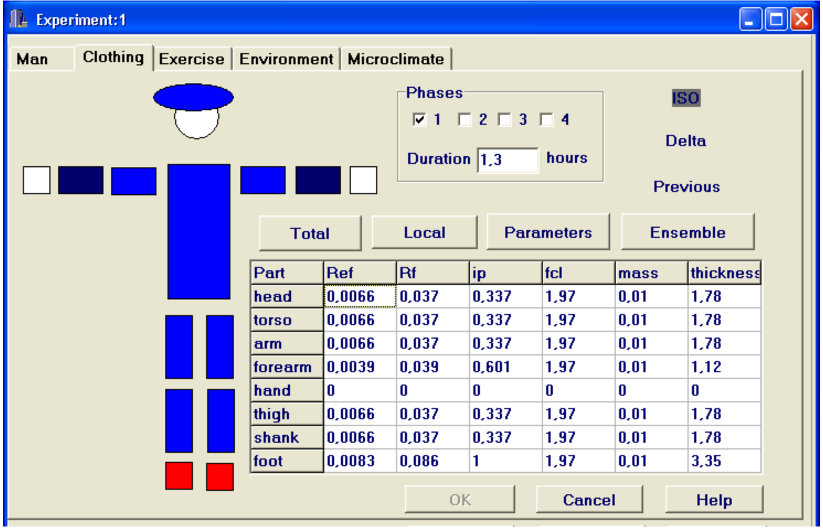
Control feed-back
● On
○ Off

Evaporation
● regulatory
○ demanded

Main menu of CS proposes the following points: MAN, CLOTHING, EXERCISE, ENVIRONMENT and MCS (Microclimate Cooling System)-see companion paper in this conference /2/.

Point 1: MAN gives the choice of the human thermal model .It allows to work with different approximations of the human body from very simple to maximum detailed presentation. There are options for direct access to model parameters and edition of the controlling system of the thermal model. Various phases can be considered and, it is possible to change laws of human thermoregulation, afferent and efferent ways, thresholds of regulatory responses and thermoregulatory center sensitivity /fig.1 a/.

Point 2: CLOTHING allows to build up an ensemble and to choose textiles /3/ It is done by clicking on compartments of human model picture. User chooses a textile from the list in the Data Base of Textiles for every compartment. It can be uniform or not. Textile characteristics are presented through thickness, thermal insulation, evaporative resistance and index of permeability. All actions of clothing inputs are accompanied by color drawing of pictures. For user convenience each textile has its drawing. In the right corner of the screen some Projects are proposed /fig.1b/.



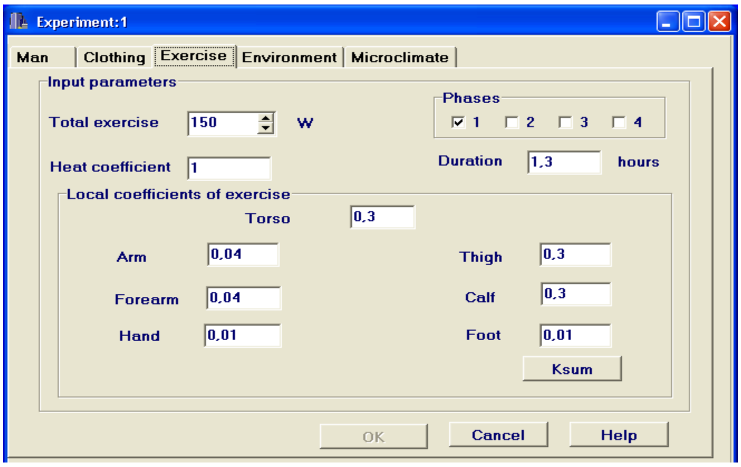
Phases ☑ 1 ☐ 2 ☐ 3 ☐ 4

Duration 1,3 hours

Part	Ref	Rf	ip	fcl	mass	thickness
head	0,0066	0,037	0,337	1,97	0,01	1,78
torso	0,0066	0,037	0,337	1,97	0,01	1,78
arm	0,0066	0,037	0,337	1,97	0,01	1,78
forearm	0,0039	0,039	0,601	1,97	0,01	1,12
hand	0	0	0	0	0	0
thigh	0,0066	0,037	0,337	1,97	0,01	1,78
shank	0,0066	0,037	0,337	1,97	0,01	1,78
foot	0,0083	0,086	1	1,97	0,01	3,35

Figure 1b. CLOTHING /see text/

Point 3: EXERCISE is proposed for input of work power and its distribution through all skeletal muscles of the human body to identify the kind of work or physical exercise /1c/.



Input parameters

Total exercise 150 W

Heat coefficient 1

Phases ☑ 1 ☐ 2 ☐ 3 ☐ 4

Duration 1,3 hours

Local coefficients of exercise

Torso 0,3

Arm 0,04

Forearm 0,04

Hand 0,01

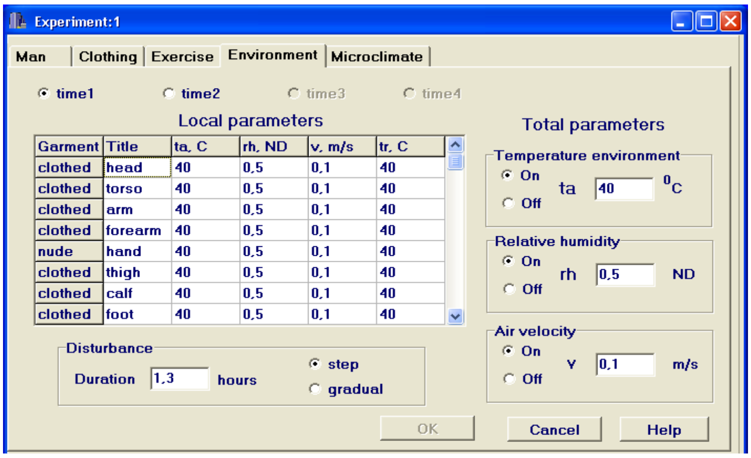
Thigh 0,3

Calf 0,3

Foot 0,01

Figure 1c. EXERCISE

Point 4: ENVIRONMENT makes possible any change via local environmental temperature, humidity, wind velocity, radiant temperature and/or solar radiation /fig.1d/.



● time1 ○ time2 ○ time3 ○ time4

Local parameters

Garment	Title	ta, C	rh, ND	v, m/s	tr, C
clothed	head	40	0,5	0,1	40
clothed	torso	40	0,5	0,1	40
clothed	arm	40	0,5	0,1	40
clothed	forearm	40	0,5	0,1	40
nude	hand	40	0,5	0,1	40
clothed	thigh	40	0,5	0,1	40
clothed	calf	40	0,5	0,1	40
clothed	foot	40	0,5	0,1	40

Disturbance
Duration 1,3 hours ● step ○ gradual

Total parameters

Temperature environment
● On ○ Off ta 40 °C

Relative humidity
● On ○ Off rh 0,5 ND

Air velocity
● On ○ Off v 0,1 m/s

Figure1d. ENVIRONMENT

Results and discussion

The Computer Simulator (CS) predicts transient changes in dry heat losses of human body, heat and mass fluxes, local skin and central temperatures, cardiac output, heart rate, shivering or sweating, dripping sweat, skin wettedness and evaporative sweat efficiency, skin blood flows, and other values that makes possible to get the information for correct conclusion about the human thermal state. Fig.2 shows the results of a computer experiment which corresponds to input data showed in fig1/a-d/. Results of modeling demonstrate that in this case, core temperatures is kept constant close to its initial values during 1.3h /fig.2a/

Active thermoregulation is explained by effective sweat evaporation as the most part of clothing /torso, arms, thighs and shanks man wears in100 % cotton, denim. /number 33 in Table C.5 Fabric Characteristics and Thermal Resistance Values of garments, forearms are in double knit /65% polyester, 35% cotton, number 27 in Table C.5/, foots are in dress socks /number 81 in Table C.5/ /4/. Real sweat evaporation is 105kcal/h (180g/h) under maximal evaporation in this conditions is 170kcal/h /fig.2b/.

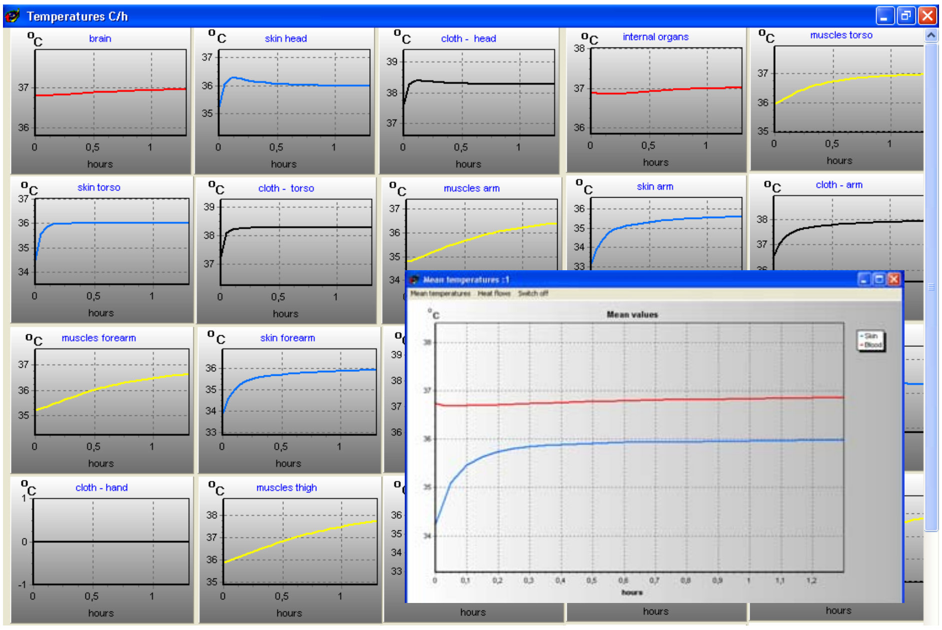


Figure2a. Dynamics of local, blood and mean skin temperatures

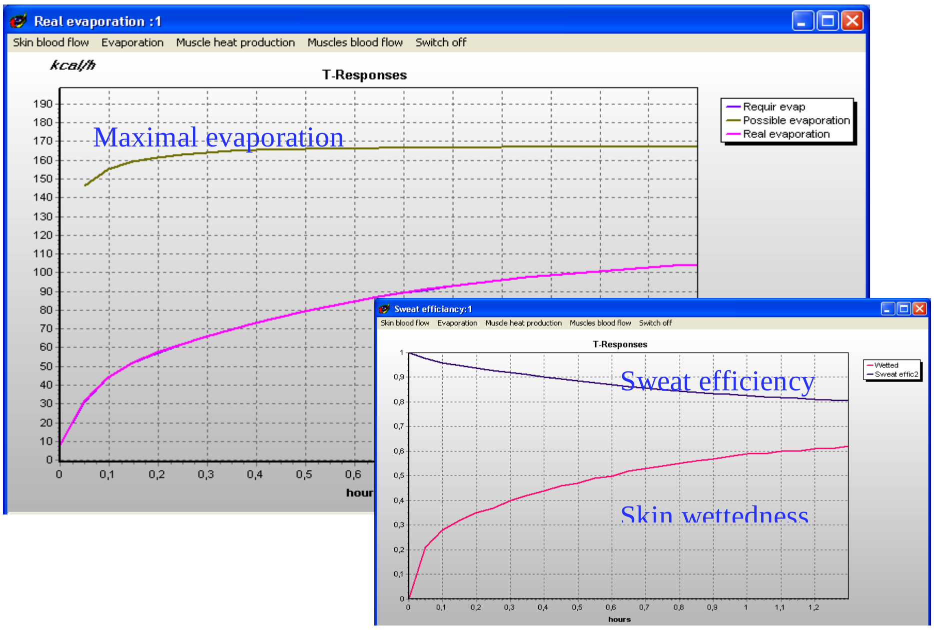


Figure2b. Parameters of thermoregulatory skin evaporation: real, maximal sweat evaporation, skin wettedness and sweat efficiency

Relation of skin wettedness and sweat efficiency shows compensated human state /fig.2b/

Predictions of Computer Simulations were compared with available theoretical and experimental results and showed adequate agreements. It is therefore concluded that it can be used as a good tool for predictions of health risks in case of severe heat exposures.

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Acknowledgements

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NEW INDICES TO ASSESS THERMAL RISKS OUTDOORS

Krzysztof Blazejczyk[1, 2]

[1] Institute of Geography, University of Bydgoszcz, Poland
[2] Institute of Geography and Spatial Organisation, Warsaw, Poland

Introduction

Man outdoors is exposed to various climatic factors that stimulate physiological reactions of an organism. Several bioclimatic indices are in the use to assess health risks (Blazejczyk 2004a, Parsons 2003). The best estimation of health hazard during work and typical daily activity can be obtain when analysing complex human heat balance (Jendritzky et al. 2002).

The aim of the paper is to present new bio-thermal indices (Subjective Temperature, Physiological Strain) that are derived from the Man-ENvironment heat EXchange model MENEX_2002 (Blazejczyk 2004a). The applicability of indices is discussed on an examples of climate-health and climate-work research.

Methods

The general equation of the human heat balance model MENEX_2002 has the following form (for detail formulas used for the calculation of heat fluxes see Table 1):

$$M + Q + C + E + Res = S$$

The general concept of Subjective Temperature (*STI*) bases on thermal physiology in man. Thermal sensations in humans are an effect of signals from cold and/or warm receptors in the skin and in the nervous system. Thermal impacts of environment are expressed by mean radiant temperature (*Mrt*). Actual ambient conditions influence the intensity of heat exchange between human body and the atmosphere and the basic level of net heat storage (*S*). The signals from temperature receptors activate physiological reactions of an organism to keep homeothermy. In the cold skin receptors register actual skin temperature that is influenced by ambient conditions. In the warm intensive sweat evaporation leads to cooling of skin surface and thermal receptors register new, low skin temperature (*Tsk**). Intensive adaptation processes are regulated by thermal receptors in the nervous system. *STI* is calculated as follows::

$$STI = Mrt - \{[|S^*|^{0.75} / (5.386\ 10^{-8}) + 273^4]^{0.25} - 273\} \qquad (\text{if } S^* < 0)$$
$$STI = Mrt + \{[|S^*|^{0.75} / (5.386\ 10^{-8}) + 273^4]^{0.25} - 273\} \qquad (\text{if } S^* >=0)$$

where S^* is the resultant level of net heat storage that is calculated taking into consideration Tsk^* values. The following ranges of *STI* indicate various thermal sensations in man:

< -38.0 – extremely cold, -38.0 - -20.1 – very cold, -20.0 - -0.5 – cold, -0.4 - 22.5 – cool, 22.6 - 31.9 – comfortable, 32.0 - 45.9 – warm, 46.0 - 54.9 – hot, 55.0 - 69.9 - very hot, ≥ 70.0℃ – sweltering.

Physiological strain (*PhS*) is the ratio of heat exchange by convection and heat loss by evaporation. It indicates predominant physiological processes that adapt an organism to cold or to warm environments:

$$PhS = C / E$$

At relative equilibrium of convection and evaporation the adaptation processes have slight intensity. At significant predomination of heat loss by convection ($PhS > 1.5$) the cold physiological strain is manifested by decrease in skin temperature, reduction of peripheral blood flow, increase in blood pressure and in thermal insulation of skin tissue, shivering. Warm physiological strain ($PhS < 0.75$) leads to increase in peripheral blood flow, decrease in blood pressure, increase in heart rate, intensive sweating, dehydration and strong temporal changes in skin temperature. The following scale of physiological strain is applied:

< 0.00 – extreme hot strain, 0.00 - 0.25 – great hot strain, 0.26 - 0.75 – moderate hot strain, 0.76 - 1.50 – thermoneutral, 1.51 - 4.00 – moderate cold strain, 4.01 - 8.00 – great cold strain, > 8.00 – extreme cold strain.

The calculations of bio-thermal indices were made with the use of BioKlima©2.3 software package (www.igipz.pan.pl/geoekoklimat/blaz/bioklima.htm).

Results and discussion

One of the feature of climate change are frequent occurrence of extreme weather conditions: heavy rains, hurricanes, heat waves, strong frosts. They influence human health. Several research refer significant increase in mortality and morbidity in humans in extreme thermal conditions (Gylerup 1998, Kalkshtein 1998, Kuchcik 2001). The new bio-thermal indices were applied to assess health risks in Warsaw (Poland). Total and circulatory mortality (TM, CM, respectively) from the period 1994-1995 were used in this purpose. In the warm season the mortality rates depended on extreme values of the indices studied (Fig. 1). In the cold season the amount of deaths depended mostly on day-to-day changes of bio-thermal conditions. TM and CM rates increased both, after great increase and after great decrease of bio-thermal indices (Fig. 2)

Table 1. Equations used for the calculation of the human heat balance components

Equations	Units' descriptions
Radiation balance in man ($Q=L+R$): $L = (0.5\cdot Lg+0.5\cdot La-Ls)\cdot Irc$ $Lg = 5.5\cdot 10^{-8}\cdot(273+Tg)^4$ $La = 5.5\cdot 10^{-8}\cdot(273+t)^4\cdot(0.82-0.25\cdot 10^{(-0.094\cdot vp)})$ $Ls = 5.39\cdot 10^{-8}\cdot(273+Tsk)^4$ $Tsk = (26.4+0.02138\cdot Mrt+0.2095\cdot t-0.0185\cdot RH-0.009\cdot v)+0.6\cdot(Icl-1)+0.00128\cdot M$ $Irc = hc'/(hc'+hc+21.55\cdot 10^{-8}\cdot T^3)$ $hc = (0.013\cdot ap-0.04\cdot t-0.503)\cdot(v+v')\text{\^{}}0.4$ $hc' = (0.013\cdot ap-0.04\cdot t-0.503)\cdot 0.53/\{Icl\cdot[1-0.27\cdot(v+v')^{0.4}]\}$ $Icl = 1.691-0.0436\cdot t$ (at $t < -30$°C $Icl = 3.0$ clo, at $t > 25$°C $Icl = 0.6$ clo) $Mrt = [1/Irc\cdot R/(5.39\cdot 10^{-8})+(273+t)^4]^{0.25}-273$ R – is calculated according to SolDir, SolGlob, SolAlt or SolMrt models (Blazejczyk 2004 b) Evaporative heat loss (E): $E = he\cdot(vp-vsk)\cdot w\cdot Ie-[0.42\cdot(M-58)-5.04]$ $vsk = e^{(0.058\cdot Tsk+2.003)}$ $w = 1.031/(37.5-Tsk)-0.065$ (at $Tsk > 36.5$°C $w = 1.0$, at $Tsk < 22$°C $w = 0.001$) $he = [t\cdot(0.00006\cdot t-0.00002\cdot ap+0.011)+0.02\cdot ap-0.773)]\cdot 0.53/\{Icl\cdot[1-0.27\cdot(v+v')^{0.4}]\}$ $Ie = hc'/(hc'+hc)$ Convective heat exchange (C): $C = hc\cdot(t-Tsk)\cdot Irc$ Respiratory heat loss (Res): $Res = 0.0014\cdot M\cdot(t-35)+0.0173\cdot M\cdot(0.1\cdot vp-5.624)$ S^* is calculated in the same way as S taking into account resultant value of skin temperature (Tsk^*): - at $E<-50$ W·m^{-2} $Tsk^* = Tsk + 0.066\cdot(E+50)$ - at $E \geq -50$ W·m^{-2} $Tsk^* = Tsk$	*a* –albedo of clothing (%), *hc* – coeff. of turbulent heat transfer (K·W^{-1}·m^{-2}), *hc'* – coeff. of turbulent heat transfer (K·W^{-1}·m^{-2}), *he* – coeff. of evaporative heat transfer (hPa·W^{-1}·m^{-2}), *Icl* – clothing insulation (clo), *Ie* – coeff. of wet heat transfer through clothing (non dim.), *Irc* – coeff. of dry heat transfer through clothing (n.d.), *L* – net long-wave radiation in man (W·m^{-2}), *Ls* – body radiation (W·m^{-2}), *La* – sky radiation (W·m^{-2}), *Lg* – ground radiation (W·m^{-2}), *M* – metabolism (in standard applications *M*=135 W·m^{-2}), *Mrt* – mean radiant temperature (°C), *R* – absorbed solar radiation (W·m^{-2}), *RH* – relative humidity (%), *S* – net heat storage (W·m^{-2}) *S** - resultant value of net heat storage (W·m^{-2}) *t* – air temperature (°C), *T* – air temperature (K), *Tg* – ground temperature (°C), *Tsk* – skin temperature (°C), *v* – wind speed (m·s^{-1}), *v'* – body motion (1.1 m·s^{-1}), *vp* – vapour pressure (hPa), *vsk* – vapour pressure at the skin surface (hPa), *w* – skin wetedness (n.d.)

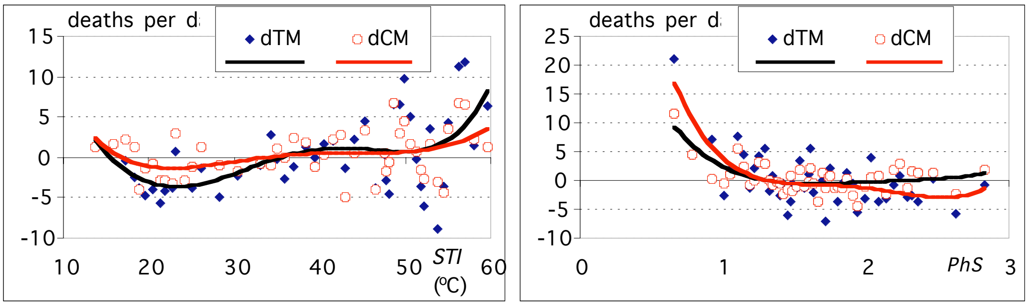

Figure 1. The influence of Subjective Temperature (*STI*) and Physiological Strain (*PhS*) on the increase in total mortality (dTM) and circulatory mortality (dCM) over the average level, warm season (Mai-August), Warsaw 1994-1995.

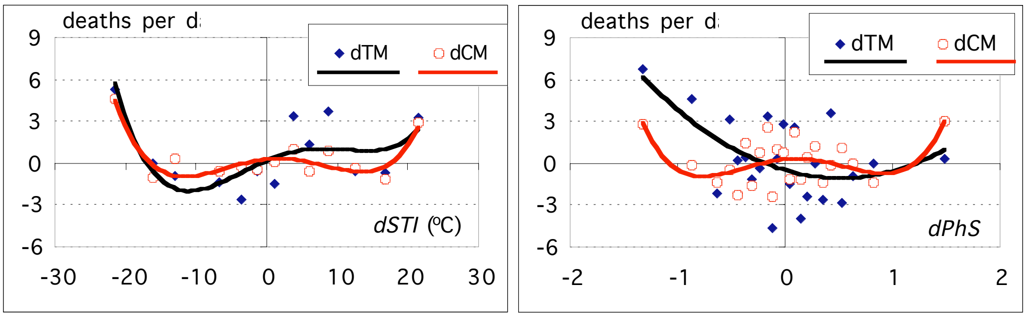

Figure 2. The influence of day-to-day changes of Subjective Temperature (*dSTI*) and Physiological Strain (*dPhS*) on the increase in total mortality (dTM) and circulatory mortality (dCM) over the average level, cold season (November-February), Warsaw 1994-1995.

The applicability of *STI* and *PhS* indices to assess bio-thermal conditions during work was tested at subjects exposed outdoor for 2 hours: first in standing relaxed posture (70 W·m^{-2}) and the second - biking on ergometer (170 W·m^{-2}). The results show significant changes in *STI* and in intensity of physiological reactions to actual ambient conditions (Fig. 3). Thus, *STI* and *PhS* indices were used in simulations of thermal risks during various work load (135 and 300 W·m^{-2}) in different ambient temperature. It is well seen that both, Subjective Temperature and Physiological Strain differ significantly during light and heavy physical work. At low temperature work load minimise intensity of cold physiological strain and thermal sensation of cold. However, at high temperature and heavy work the intensity of hot and very hot sensations increase (Table 2).

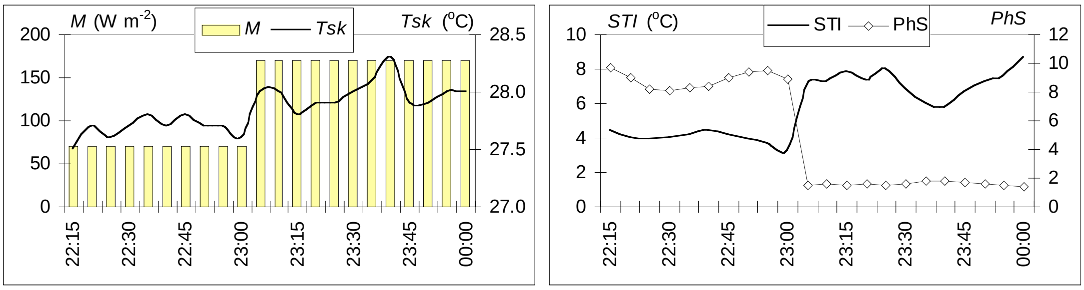

Figure 3. Changes in skin temperature (*Tsk*), metabolism (*M*), Subjective Temperature (*STI*) and Physiological Strain (*PhS*) during outdoor exposure at air temperature of 7-8°C, wind speed 1-3 m·s^{-1}, Bydgoszcz, 17 May 2003.

Table 2. Simulated values of Subjective Temperature (*STI*) and Physiological Strain (*PhS*) at various combinations of air temperature (*t*) and metabolism (*M*).

t	**STI (°C)**	**PhS**

	M_{135}	M_{300}	M_{135}	M_{300}
-40	**-50.2**	**-47.3**	**6.50**	2.04
-20	-26.9	-23.0	**5.39**	1.54
-10	-16.1	-10.5	**4.54**	*1.36*
0	-5.3	2.6	3.51	*1.14*
10	5.6	14.7	2.35	*0.88*
30	34.8	41.9	0.22	0.13
40	50.4	**56.1**	**-0.36**	**-0.20**

Conclusions

Evaluation of thermal state of the human being that bases on the human heat balance considerations is the best way to find physiologically significant relationships between man and his environment (Jendritzky et al. 2002). *STI* and *PhS* indices are the new approach in biometeorological and thermophysiological research. They are applied in several areas of investigations, e.g. evaluation of work conditions, actual weather-human health relationships, climate-recreation/tourism studies, spa climatotherapy, sport and others.

STI and *PhS* illustrate man-environment relationships in realistic way in very wide range of ambient conditions and work load. They can be used both, for actual meteorological and physiological data as well as for simulations of bio-thermal conditions for various purposes

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PREDICTION COMPUTER PROGRAM OF WHOLE BODY TEMPERATURES AND HEAT FLUXES AND ITS APPLICATION TO EDS VALUATE HUMAN THERMAL RESPONSES

Shintaro Yokoyama1, Noriaki Yamamoto1, Hiroyasu Baba1, Dai Shibayama1, Yoichi Atsumi 2, Shinji Kioka2, Takeshi Ishizawa2, Hirokazu Ozaki3, Wataru Ogawa3*

1 Laboratory of Environmental Ergonomics, Hokkaido University, Sapporo, Japan
2 Civil Engineering Research Institute of Hokkaido, Sapporo, Japan
3 Aeromedical Laboratory JASDF, Tachikawa, Japan
* corresponding author yokoyama@eng.hokudai.ac.jp

Introduction

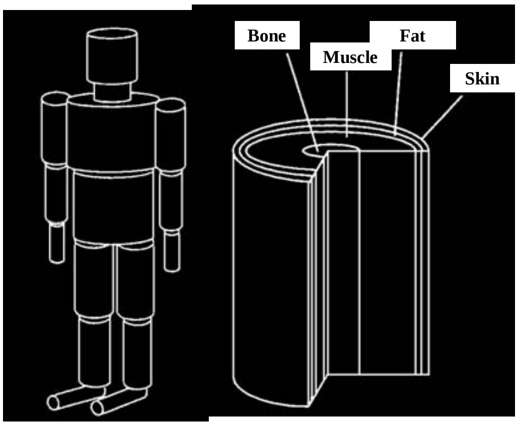
We have been developing a prediction computer program of whole body temperatures expressing local characteristics of each segment in order to apply to making a precise evaluation of human thermal responses (Yokoyama et al., 2002, 2003).

This paper describes the outline of the program and its improvement points. The main improved parts of the program were the calculation procedures of heavy clothing of each segment for evaluating of human adaptability to extreme environment. By using the improved computer program the whole body temperatures and heat fluxes of the subjects during seaside works were simulated. The calculated results were agreed with the measured results both at outside and at a new facilities in the coastal area of Hokkaido in the mid winter season. Finally one of the useful examples of our prediction computer program for long-term calculation was indicated.

Mathematical model

An anatomical model of the human body is divided into 16 segments (see Figure1, left). Each segment is subdivided into five function layers; viscera, bone, muscle, fat and skin layer. The right side in Figure 1 shows a multi-layered model to adopt for the extremities. The assigned parameters of thermal properties of each layer in the present study were determined according to the previous study (Yokoyama. 1993). Inflow and outflow of blood play very important roles for heat transfer phenomena in the body (Yokoyama et al., 2000b). Figure 2 is the schematic diagram showing the circulatory system. In Figure 2 symbols A and V mean the arterial and venous blood pool, respectively. In each segment a pair of large arterial and venous blood pool corresponds to the larger artery and vein. In each layer a pair of arterial and venous blood pools corresponds to the smaller arteries and veins and the capillaries.

Figure 1. Sixteen segments human body model and multi-layer concentric cylindrical model for extremes



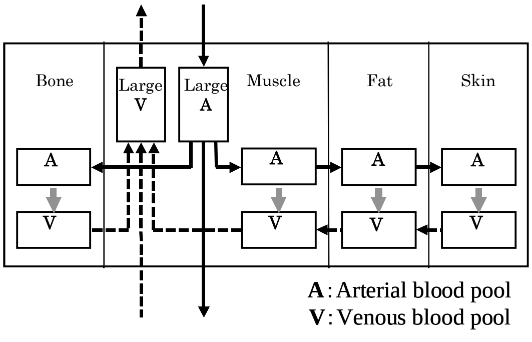
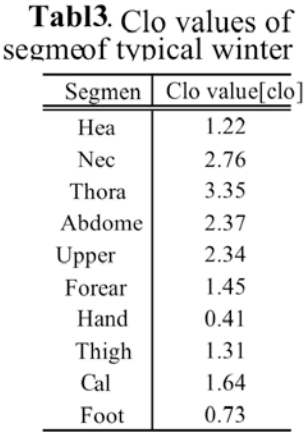


Figure 2 (right). Schematic diagram showing the geometric arrangement of the circular

Table 1. Thermal environmental factors in Non-Shelter and Shelter

	Non-Shelter				Shelter			
Environmental factor	0[min]	10[min]	20[min]	30[min]	0[min]	10[min]	20[min]	30[min]
Air temp.[℃]	-3.48	-3.48	-3.64	-3.98	-3.14	-3.48	-3.81	-3.81
Mean radiant temp.[℃]	-1.82	-2.05	-2.43	-0.89	1.88	4.25	4.83	4.47
Air velocity[m/s]	1.4	1.7	3.7	3.4	0.3	0.9	1.2	1.1
Rerative Humidity[%]	73	76.7	80.3	84	62	62	62	62



Tabl3. Clo values of segmeof typical winter

Segmen	Clo value[clo]
Hea	1.22
Nec	2.76
Thora	3.35
Abdome	2.37
Upper	2.34
Forear	1.45
Hand	0.41
Thigh	1.31
Cal	1.64
Foot	0.73

For the prediction of body temperatures and heat fluxes in the human body a solving procedure of heat transfer equation of each segment in the human body is required. We presented an algorithm for saving computing time of the present multi-layered concentric cylindrical model (Yokoyama et al., 1997).

The present program also included the calculation parts of thermoregulatory responses, i.e. perspiration rate, skin blood flow rate, and shivering heat production rate of each segment. The precise values of the parameters of thermoregulatory response were adopted from in our previous reports (Yokoyama, 1993).

Using both compatibility and equilibrium conditions between their interfaces the final simultaneous equations of the whole subject region should be introduced. At the skin surface outflow heat flux is equal to the sum of heat loss to the environment, convection, radiation and insensible evaporation.

Experimental methods

Subjective experiments were carried out and the thermal physiological data concerning with heavy clothing and under extreme cold environments were collected for the purpose of verifying and improving the accuracy of the present prediction computer program. Measuring experiments were carried out both at outside (Non-Shelter) and at a new facilities (Shelter) in the coastal area of Hokkaido in the mid winter season.

The measuring physiological items were seven-point skin temperatures and the rectal temperature. Total heat production rates were measured with the breath-by-breath method. Measuring thermal environmental factors were air temperature, mean radiant temperature, air velocity and relative humidity. Table1 summarizes the measuring data of thermal environmental factors in Non-Shelter and Shelter.

The subject was the healthy male whose precise anatomical characteristic were shown in Table 2. The subject also wore the typical winter clothing of coastal worker shown in Figure 3. Table 3 shows the measured clo values of each segment with thermal manikin.

After at least one hour spending with resting posture in the comfortable room near the coast the subject engaged the model coastal working both at Non-Shelter and Shelter. The working time of each run was set for thirty minutes.

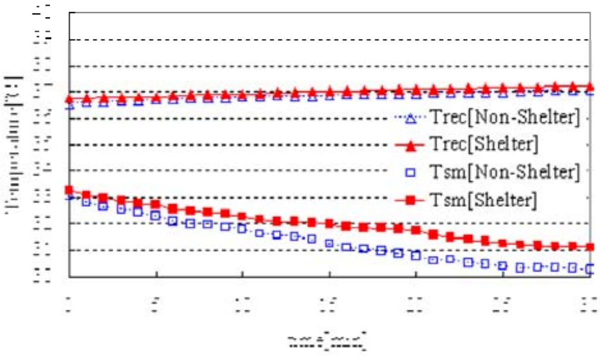


Figure 4. Measured rectal and mean skin temperatures at both points

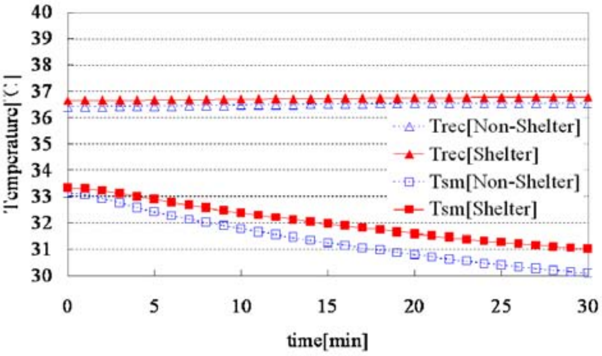


Figure 5. Calculated rectal and mean skin temperature at both points

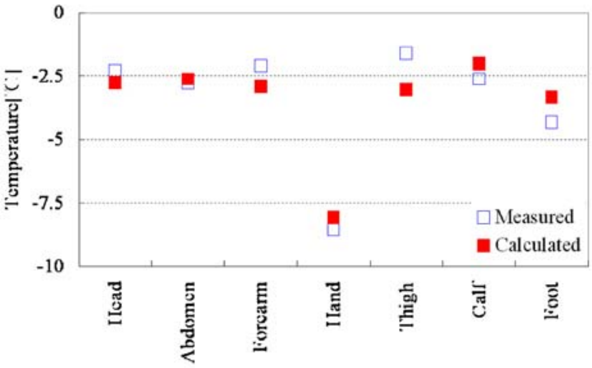


Figure 6. Comparison of calculated and measured segmental skin temperature at

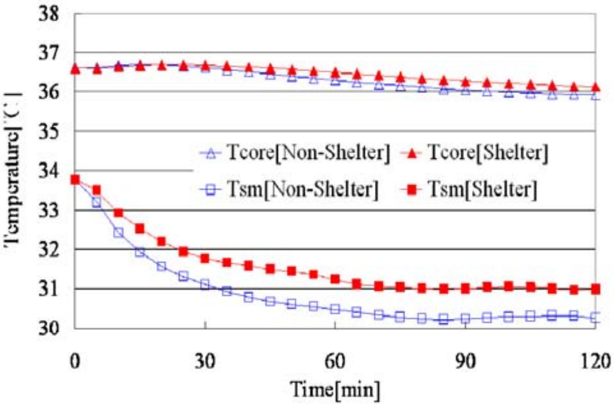


Figure 7. Long-term simulation of core and mean skin temperature with heavy clothing and under extreme cold

Comparison of calculated and measured results

By using the computer program we already reported several calculated results, which well agreed with the measured results (Yokoyama et al., 2002). However in these papers types of human clothing and activity were light clothing and resting level.

We measured physiological responses with heavy clothing under extreme cold working environments. In Figure 4 the measured results of rectal and mean skin temperatures at both Non-Shelter and Shelter in the coastal area of Hokkaido in the mid winter season were summarized. Figure 4 shows that the measured results of mean skin temperature at Non-Shelter were lower than those at Shelter. With the elapse of time the greater difference of mean skin temperature between Non-Shelter and Shelter was observed. On the other hand the measured result of rectal temperature at Non-Shelter was almost same as that at Shelter under thirty minute-cold exposure.

We made several efforts to improve the computer program. One of important points was a new assigning procedure of individual physical differences. We determined the anatomical characteristics of the present subject by using the data shown in Table 2. We also improved our computer program to calculate temperatures and heat fluxes of each segment under heavy clothing conditions.

By using the improved computer program the whole body temperatures and heat fluxes of the subjects under the extreme cold environments were simulated. Figure 5 shows the calculated results of rectal and mean skin temperatures at both Non-Shelter and Shelter in the coastal area according to the thermal environmental data shown in Table 1. The calculated results of Figure 5 were agreed with the measured results shown in Figure 4.

Figure 6 indicates the comparison of calculated and measured local skin temperature at Non-Shelter condition.

The calculated skin temperatures were well agreed with the measured skin temperatures in almost segments. These comparisons between calculated and measured results suggested the validity of the present computer program expressing local characteristic of each segment including a subroutine of calculation of physiological thermoregulatory responses to evaluate human responses with heavy clothing and under extreme cold working environments.

In Figure 7 one of typical examples of our prediction computer program was indicated. We performed long-term calculation of core and mean skin temperature with heavy clothing shown in Table 3. For the simulation thermal environmental factors were assigned according to measured data obtained at Furubira fishing port in Hokkaido. Assigned mean air temperature and relative humidity at Non-Shelter and Shelter were -1.9 ℃ and 65 % respectively. Assigned mean air velocity at Non-Shelter was 2.5 [m/s] and that at Shelter was 0.9 [m/s]. Figure 7 suggested that after two hours the rectal temperature at Non-Shelter was lower than 36 ℃. Mean skin temperature at Non-Shelter was always lower than that at Shelter. The predicted value of skin temperature after two hours was around 30 ℃ level. These results suggested that the present program was a useful tool for evaluating public facilities design.

Conclusions

These calculated results suggested the validity of the present computer program expressing local characteristic of each segment to evaluate human responses with heavy clothing and under extreme cold working environments.

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IMMERSION INCIDENTS: RESEARCH AND REALITY (THE FINAL VOYAGE OF THE RO-RO PASSENGER VESSEL MV ESTONIA)

Mike Tipton

Department of Sport & Exercise Science, Institute of Biomedical and Biomolecular Sciences, University of Portsmouth, UK PO1 2DT

Introduction

A tear appeared in the eye of the young Swedish rescue man as, one year on; he recounted the events of the 28th September 1994 to a hushed gathering of the Swedish Society of Medicine. Events that claimed 852 souls and, either directly or indirectly, touched every person in Sweden and Estonia.

The Estonia-flagged ferry departed from Tallin at 1915h on the 27th September 1994 for a voyage to Sweden. She carried 989 people on board, 803 of whom were passengers. The wind was southerly, 8-10m.s^{-1}, visibility was good, rain showers swept in intermittently. Initially sea conditions were moderate, but deteriorated as the vessel left the sheltered waters of the Estonian coast. As the voyage continued the wind increased gradually and veered to southwest. By midnight it was 18-20m.s^{-1}, significant wave height reached 3-4m and the Estonia achieved 14knots.

Shortly before 0100h, during his scheduled round on the car deck, the seaman of the watch heard a metallic bang from the bow area as the ship hit a heavy wave. Many passengers and some crew reported further observations of unusual noise between 0105h and 0115h. Shortly afterwards the seaman was sent to try and identify the source of the noise; he did not manage to reach the car deck. At about 0115h the bow visor of the Estonia separated from the bow allowing large amounts of water to enter the car deck. The ship quickly took on a heavy starboard list. She was turned to port and slowed.

The speed with which disasters can unfold never ceases to amaze; from the moment the Estonia began to take on a serious list, and it was apparent that she was in trouble, the time for evacuation was about 15 minutes. The first Mayday was transmitted at 0122h and a second shortly afterwards. By 0124h, 14 ship and shore-based radio stations had received Mayday calls. The last contact with the ship was at 0129h, by which time she was lying on her starboard side. The Estonia was submerged by 0130h, she sank stern first, disappearing from radar screens by 0150h.

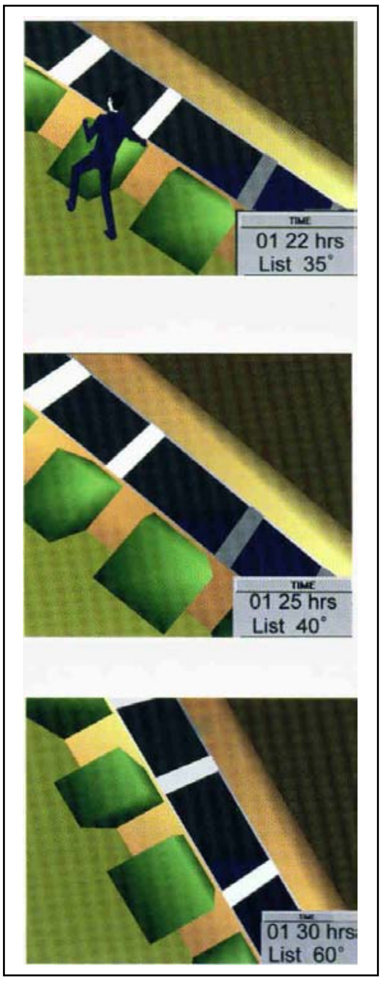
At the time when it became clear that things were going badly wrong, most passengers were sleeping in their cabins. Most were awaken by the noise and motion of the ship. Many left their cabins half dressed. Of those bodies that were autopsied, 25 were naked; 18 had very insufficient clothing; 40 insufficient clothing; and only 10 wore extra clothing.

The description of the final minutes is one of fear, confusion and panic. In the violently moving ship, lying at an acute angle, people struggled to make their way onto the open decks. Stairs and bulkheads were at unhelpful attitudes. Doors, designed to work when vertical, were difficult to open, while unrestrained furniture and gaming machines fell injuring or trapping people. Those that could, rushed up the staircases. For the elderly, infirm and weak this was an overwhelming physical task and many remained trapped in their cabins or in the corridors. It is therefore unsurprising that the majority of those rescued were males, aged 15-44 years. Only 3% of males over 65 survived. No females over 65 survived. Only 5% of the females on board survived compared to 22% males.

"The list increased and people were hanging onto the handrail which came loose. People fell to the floor and there was panic. In the staircase several injured people, drunks and half-dressed people were trying to ascend…the list was so great that it was impossible to walk on the carpets, it was even difficult to crawl” (Final Report).

“The witness who was leading his parents and girlfriend had difficulties reaching the staircase. Once there, he turned to look for the other three who were still on the other side. They could not cross the foyer because of the bodies and the crowd. They shouted and urged him to continue to climb the staircase alone” (Final Report).

The Estonia was equipped with life-saving equipment to the SOLAS 1974 specification. It had 10 motor driven lifeboats, 63 inflatable liferafts, 6 rigid floats, 18 life buoys, 2298 lifejackets for adults and 200 lifejackets for children.



Amazingly, 300 or so people managed to make their way to the open deck, and struggled to maintain their balance long enough to put on the lifejackets which were being distributed from containers. This task was made more difficult by unfamiliarity with the correct method of donning and securing. Several passengers stated that the lifejackets appeared old-fashioned, most did not understand how to put them on, and the fact that they were tied together in threes caused some difficulties. As a consequence, on entering the water, many of the lifejackets either came off or became displaced, rendering them useless. Less than half of those who made it to the upper deck were to survive.

Due to the severe list of the Estonia, the lifeboats could not be launched. Many people tried to launch the inflatable liferafts, but again the list, and their unfamiliarity with the equipment, made this an extremely difficult task. Those that were successfully launched ended up in positions that made subsequent boarding difficult. In the end, with the rapid sinking of the ship, the majority of survivors found themselves in the dark, being tossed about by the waves, surrounded by a mass of unused lifejackets, partially inflated liferafts, and damaged or upturned lifeboats.

The surface water temperature was about 10°C, air temperature between 8-10°C. Many people were shouting for help. Some swam and boarded liferafts only to find that they were inverted and therefore offered little protection from the environment, apart from providing a partially safe refuge from drowning.

“He came under a liferaft with his lifejacket down around his waist. Because his feet and one hand were tangled in ropes, which he believed belonged to the raft’s sea anchor, he was not able to get onto the first raft, which drifted away. Another liferaft drifted towards him upside-down and with the help of a young man he managed to climb on board. On top of this raft there was also a naked elderly man and beneath the raft a Swedish man” (Final Report).

Those who managed to board rafts that were the right way up often found that the canopy support arches had not fully inflated. To make matters worse, waves were washing in and out of the rafts so there was little protection from the cold water. The occupants of the rafts had to hold on to something to prevent themselves from being buffeted about or washed back into the sea. This made it difficult to help other survivors outside the rafts who were holding on to ropes, or lanyards, or endeavouring to clamber aboard. Many were impeded during boarding because their legs or arms had become entangled in the myriad of loose lines in the vicinity of the rafts. For the majority, the physical effort was too much, and after several unsuccessful attempts they became exhausted and gave up.

The occupants of some rafts were able to help a few exhausted cold people to board, only to see them being immediately washed out by the next wave. After a while the cries for help from those in the water diminished, although, remarkably, one German man swam for three hours and successfully managed to attract the attention of rescuers by flashing a torch.

Survival was not guaranteed even for many of those who managed to remain in the rafts or on upturned lifeboats.

Liferaft D

"He swam to a raft that was upside down and a man helped him up. When on board he slid towards the centre of the raft where there was a large pool of water…On the raft there were six persons. The raft turned over in the heavy seas and all on board fell into the water" (Final Report).

Liferaft A

"After a while he found a suit made of aluminium foil. He tried to dress but the suit was too thin and tore, becoming useless" *(Final Report).*

Liferaft B

"A young women from inside held his hand, trying to pull him into the raft, but neither of them had the strength and after a while he lost his grip" (Final Report).

Many worked hard to try and bail the water out of the rafts. Regrettably, through unfamiliarity and cold hands, they could not close the canopy apertures correctly; as a consequence the waves were washing more water into the rafts than they were capable of bailing. In many rafts the survival aid container had been washed out before the occupants managed to board the raft. In those rafts where these containers were still present, some survivors described how they were unable to open them to get at the bailer because of cold hands. The plastic wrappings of the flares proved equally challenging to cold fingers.

Liferaft B

"They were, however, unable to open this bag because their hands were frozen. One of them tried in vain to open it with his mouth but had to give up after losing some teeth" *(Final Report).*

Other survivors were successful in using the flares but some, not sure of how to use them, inadvertently discharged them inside the raft.

Eventually, with the passage of time, and with most inadequately clothed for the conditions and suffering seasickness, many lost consciousness through hypothermia and were washed overboard, or simply slid into the water, swilling around in the bottom of the partially flooded rafts, and drowned.

Liferaft M

"The woman, he reported, was becoming more and more listless and limp. She occasionally slid down into the water in the raft and was pulled up by the others, who tried to massage her and shake her to arouse her. One hour prior to rescue, she died" (Final Report).

Other passenger ferries in the vicinity arrived on the scene fairly quickly – the first in about 45 minutes - but, because of their high freeboard and the prevailing sea state, were unable to launch boats. As a consequence, they could do little about rescuing survivors from the water. One did manage to lower and recover a liferaft manned with some crewmembers to assist survivors. Unfortunately, when another ship attempted a similar manoeuvre, on recovery the floor of the raft ripped just as it reached deck level, spilling the occupants back into the sea where many drowned.

The majority of those who survived were rescued by some of the many helicopters that arrived on scene within a few hours of the sinking; the first about 1½ hours after the ship capsized. Regrettably, even this form of rescue was not without its problems. Initially it was difficult to locate survivors in the dark, this was not helped by the fact that none of the lifejackets had lights. Some helicopters suffered winch malfunctions, and one had an engine problem forcing it to return to base. Most "rescue men" operating at the end of the winch wire became fatigued; they had the arduous job of helping extremely cold, incapacitated, survivors while being buffeted by waves. Some of the rescue men were injured in collisions with the rolling inverted lifeboats while searching for casualties. All survival craft had to be searched. Valuable time was wasted in examining craft that had already been searched by other helicopters. This unnecessary activity added to the crew fatigue. Most of the successful rescues were achieved within four or five hours of the sinking. After 6-7 hours no more survivors were found.

Liferaft M

"The witness…expected to be smoothly lifted by the helicopter…Instead, both he and his rescuer were violently jerked out of the raft by the wire, plunged deep into the water and then violently jerked up again to the helicopter" (Final Report).

During the night of the accident helicopters and ships rescued 138 people, one of whom later died in hospital. Over the two days that followed 92 bodies were recovered. Most of the missing persons went with the vessel to the seabed.

The young rescue man told the Swedish Society of medicine how he had began to rescue a man from a liferaft. He held the man in a single strop and they were winched towards the helicopter. During the lift the winch failed and the man became unconscious. The rescue man held him for as long as he could but he eventually fell back into the water. The rescue man jumped into the water and grasped him but he did not survive.

In the final report of the capsize of the Estonia it is concluded that problems using lifesaving equipment "contributed to the tragic outcome". As with many previous disasters, anyone who reads the final report cannot fail to be moved by the emotion that is aroused when sadness mixes with anger. The lessons hardly need to be reiterated; they constitute a recurrent theme: survival equipment designed, developed and tested in unrealistic conditions; the expectation that frightened, dazed and exhausted people will have the time or ability to adequately protect themselves before enduring adverse conditions; the design and packaging of survival equipment that fails to recognise the decrement in manual dexterity and strength that comes within minutes of immersion in cold water; the lack of knowledge transfer from science to reality.

Sadly, the one enduring lesson that tends to be learned from disasters like that which befell the Estonia, is that those who ignore history are often condemned to re-live it.

Acknowledgments

Dr Frank Golden for many of the words; those who go to search and rescue, for their bravery and humanity.

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MAXIMAL BREATH-HOLD TIME AND CARDIOVASCULAR RESPONSES DURING SUDDEN COLD-WATER FACE IMMERSION

*Ollie Jay and Matthew D. White**

[1]Laboratory for Exercise and Environmental Physiology, School of Kinesiology, Simon Fraser University, Burnaby, British Columbia, CANADA. V5A 1S6.
*corresponding author: matt@sfu.ca

Introduction

Due to the high centre of gravity of helicopters may invert and sink in open water crashes. This requires victims to perform an egress to the water surface and their survival rate appears to be dependent upon their breath-holding ability (1). In the cold waters of the North Pacific or Atlantic, water temperature is often well below 5°C. The Cold Shock Response (CSR) and the Diving Response (DR) are two physiological responses to cold water immersion that are largely involuntary and both have a substantial effect upon breath-hold duration.

A CSR is characterised by a tachycardia, peripheral vasoconstriction, a large inspiratory gasp and a subsequent uncontrolled hyperventilation. The CSR is elicited by a sudden exposure of the torso, arms and/or legs to cold water (2, 5). The DR follows face only immersion and is characterised by a bradycardia, peripheral vasoconstriction, an elevated blood pressure and its effects have been reported to prolong a voluntary apnoea during face-only immersion (3). In some reports a DR has not been observed after face immersion and face-only immersion in 17ºC water has been reported to stimulate ventilation (7, 8). This effect of face immersion on ventilation was supported by reduced breath-holding ability in the similar water temperatures with whole body immersion (4). A study by the White and colleagues (6) with sudden face immersion indicated that shorter maximum breath-hold times at lower water temperatures.

With *sudden* (i.e. no prior hyperventilation) face-only immersion it is not yet evident if the CSR or DR is the predominant physiological response across a range of water temperatures. Breath-hold times are hypothesized to be shorter with a more pronounced Cold Shock Like Response (CSLR) and longer with a more pronounced DR. To address this question breath-hold times and cardiovascular responses characterising both the CSR and DR were assessed during sudden face-only immersion at water temperatures between 0°C to 33°C.

Methods

Participants. Six healthy male participants (aged 29.5 ± 2.2 years (mean ± SE); height: 1.78 ± 0.04 m; weight: 77.8 ± 4.6 kg) volunteered for the study after signing an informed consent. They did not suffer from any vascular diseases.

Instrumentation. A cushioned body length table and a stirred bath (0.50 m x 0.35 m x 0.23 m) connected to a chiller/heater unit (VWR, Mississauga, ON, Canada) were employed for the face immersions. Prior to immersion a 5-litre re-breathing bag (Anesthesia Assoc., Inc., San Marcos, CA, USA) was inflated with a 13.5-litre spirometer (Collins, Baintree, MA, USA) to 50% of each individual's pre-determined inspiratory capacity. The re-breathing bag, a mouthpiece and a 0.45 m length of Collins corrugated respiratory fiber tubing (2 cm diameter) were connected to a 3-way sliding valve (Hans Rudolph Inc., MO, USA); the opposite end of the Collins tubing was suspended beside the face bath. Skin temperature of the forehead, cheek and nose were measured with T-type thermocouples. Acral (foot) cutaneous blood cell velocity (CBV_{FOOT}) in arbitary units (AU) was monitored using a laser-Doppler probe (Moor Instruments Ltd, UK), in the middle of the ventral side of the right foot. Temperature and CBV_{FOOT} data were acquired at a rate of 1 Hz by a data acquisition system (Nat. Instr., Austin, TX, USA) controlled by a Labview (ver. 5.1) program on a personal computer. Heart rate (HR) was recorded using a pulse oximeter finger clip (Masimo SET, Irvine, CA, USA).

Protocol. Maximal breath-hold times (BHT_{max}) were measured under 4 different immersion conditions of 0, 10, 20 and 33ºC. After instrumentation, each participant wearing a nose-clip lay prone and at the end of a regular breath inhaled their pre-determined volume of air and then suddenly immersed their face to a depth of 2 mm anterior of the tragus in the bath. The mean inspired volume was 1570 ± 87 ml (BTPS). Breath-hold time was the time elapsed between the point of contact with water and the breath-hold breaking point. Facial skin temperatures returned to pre-immersion values or in the 33°C condition there was a 10-min rest period prior to the next immersion. Each trial at each water temperature was repeated a minimum of 2 times.

Statistical Analyses. The data was evaluated using a one-way ANOVA. The repeated factor of immersion condition (Levels: 0, 10, 20 and 33ºC) was employed with the dependent variables of maximal breath-hold time (BHT_{max}), time to peak HR elevation (tHR_{peak}), magnitude of the HR elevation after face immersion (ΔHR_{peak}), rate of subsequent decline from HR_{peak} (dHR/dt), and foot cutaneous blood cell velocity (CBV_{FOOT}). For CBV_{FOOT} and minimum HR during face immersion (HR_{min}) a 5th level of AIR was added to the ANOVA model. Paired t-tests were employed for all pairwise comparisons. All analyses were performed using SPSS 11.5 for Windows (SPSS, Chicago, IL, USA). Level of significance was set at an alpha level of 0.05.

Results

A significant main effect of water temperature was found upon BHT_{max} ($p=0.006$) with a significantly shorter BHT_{max} at 0ºC ($p<0.001$) and 10ºC ($p=0.018$) in comparison to 33℃ (Fig. 1A). A main effect of water temperature was found upon HR_{min} ($p=0.001$) with HR_{min} becoming progressively lower ($p<0.01$) in comparison to mean resting HR in AIR prior to breath-holding (Fig. 1B). A sample participant's HR response to face immersion is given as a function of time for face immersiom trials at 0, 10, 20 and 33℃ in Figure 2.

No significant main effect of water temperature was found upon tHR_{peak} ($p=0.77$), with the mean tHR_{peak} reaching a maximal positive value after 10.6 ± 2.4 s of immersion. There was a trend for the main effect of water temperature for ΔHR_{peak} ($p=0.10$) with elevations of 8.6±1.8 beats•min^{-1} at 0ºC, 5.2±1.2 beats•min^{-1} at 10ºC, 4.2±1.6 beats•min^{-1} at 20ºC and 3.6±1.2 beats•min^{-1}at 33ºC, with ΔHR_{peak} significantly greater at 0℃ than at 33℃ ($p=0.004$). There was a main effect of water temperature found upon dHR/dt ($p<0.0001$) that was -58.9±8.3 beats•min^{-2} at 0℃, -33.6±4.6 beats•min^{-2} at 10℃, -24.5±4.7 beats•min^{-2} at 20℃, and -12.4±2.0 beats•min^{-2} at 33ºC, with dHR/dt significantly greater under all water temperatures than at 33℃ ($p<0.05$). The minimun CBV_{FOOT} during breath-holding was significantly decreased ($p<0.05$) from pre-immersion levels in all breath-holding conditions.

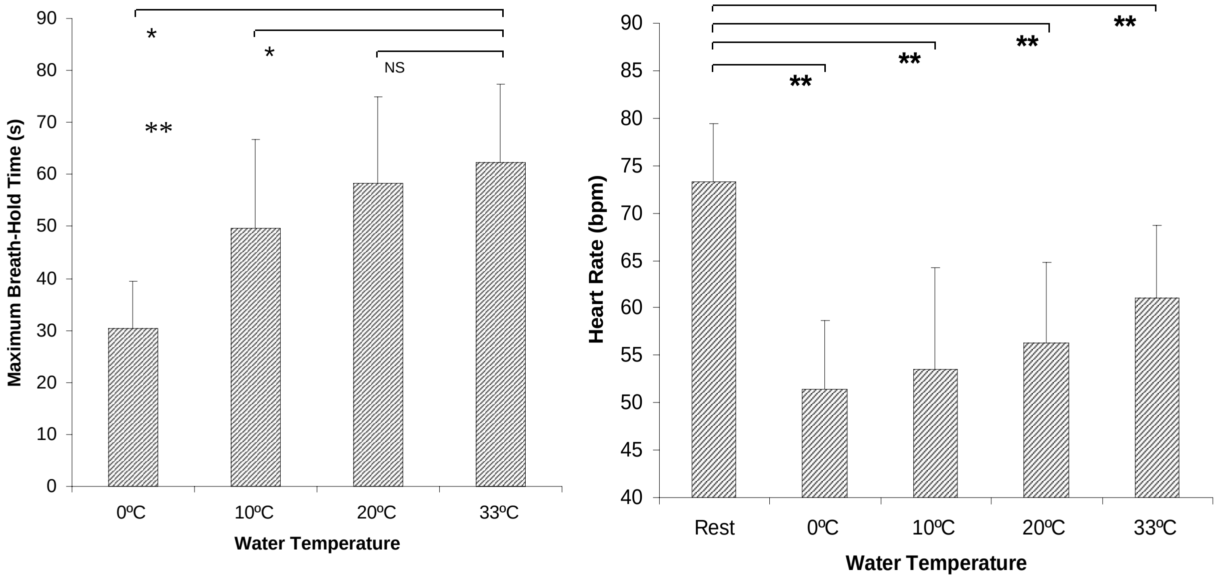

Fig. 1 A: The effect of water temperature upon maximum breath-hold time (BHT_{max}). **B:** A comparison of minimum heart rate reached during immersion (HR_{min}) at each water temperature with resting pre-immersion heart rate. * <0.05, ** <0.01, NS = no significance.

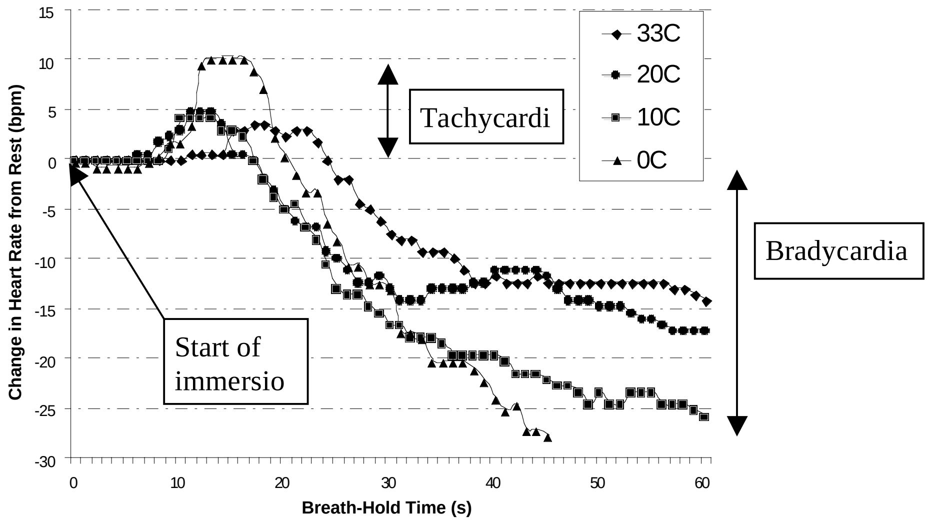

Fig. 2. An example of the heart rate response for one participant during face immersion at 0, 10, 20 and 33ºC

Discussion

The results suggest with *sudden* face immersion and breath holding that a Cold Shock Like Response (CSLR) and followed DR were evident. The initial tachycardia in the first 10 to 20 s of face immersion was one indication of a CSLR. As is evident in Figure 2, the magnitude of this tachycardia appeared to be temperature-dependent since progressively greater HR elevations were evident as the water temperature for face immersion was decreased. This view was supported in the mean data by a significantly greater ΔHR_{peak} at 0°C relative to that at 33°C during breath holding. The results are consistent with a greater CSLR evidenced by lower breath holding times with whole body immersions at 0 relative to 33°C water temperatures (4). The breath holding times were also temperature dependent (Fig. 1A) with the shortest breathing time evident at the 0°C. Following the CSLR phase, a subsequent lowering of HR after face immersion with breath holding suggested that there was a development of a DR. The rate of decline of HR and the degree of bradycardia also both appeared to be temperature-dependent since the bradycardia developed to a greater extent (Fig. 1B) and more quickly at lower water temperatures (Fig 1B). For example the dHR/dt of 58.9±8.3 beats•min^{-2} for the 0 ℃ condition was almost 5 times that of 12.4±2.0 beats•min^{-2} at 33ºC condition.

Common to CSR and DR are a cutaneous vasoconstriction. The current results supported a vasconstriction was evident during breathing holding with face immersion. This was evident by the significantly lower CBV_{min} during face immersion relative to pre-immersion values.

The weakest CSLR as indicated by the longest BHT_{max} (Fig. 1A) and lowest tachycardia (Fig. 2) and least pronounced DR as indicated by the smallest bradycardia (Fig. 1B) and slowest decline of HR (Fig. 2) were evident at 33°C. Relative to these 33°C values, it appears that despite 0 and 10 ℃ producing a more marked and faster decline in HR indicative of a DR, a more pronounced CSLR at these temperatures predominated. It may be that face immersion durations to give a DR-induced apnea prolongation were not reached at 0 and 10°C.

It is suggested that the neural mechanism responsible for the involuntary inspiratory effort associated with a CSR (2) is primarily responsible for the shortest BHT_{max} and heart rate elevation observed at 0ºC in this study. This "gasp response" which is reported to be the result of a non-thermoregulatory neurogenic drive from stimulation of the cutaneous cold receptors, has been found to be elicited by cold water exposure to the torso, legs and arms (2). The present results suggest that such a response may also be evoked during face-only immersion through input from the cutaneous temperature sensitive neurons on the face.

Conclusions

In conclusion, during sudden face immersion and breath-holding, an initial Cold Shock Like Response followed by Diving Response appeared evident for the remaining breath-hold. Overall results support a Cold Shock Like Response had a predominant effect and it is proposed any potential benefits from the

Diving Response on breath-holding abilities were negated by the heightened inspiratory efforts coupled to the Cold Shock Like Response.

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DIRECT EVIDENCE OF A COLD SHOCK RESPONSE WITH SUDDEN FACE ONLY IMMERSION

Julia P.H. Christensen, Ollie Jay and Matthew D. White[*]

Laboratory of Exercise and Environmental Physiology, School of Kinesiology, Simon Fraser University, Burnaby, British Columbia, V5A 1S6 CANADA
*corresponding author matt@sfu.ca

Introduction

Survival suits, that leave only the face exposed, are used for helicopter travel over open water. In this regard studies of face only immersion have been conducted to help better understand the physiological responses to sudden face immersion (2).On immersion in cold-water the Dive Response (DR) can be initiated with face immersion and apnea or the Cold Shock Response (CSR) occurs during sudden whole body immersion in cold water (1). When an individual is left to breathe freely after sudden face only immersion, it is unknown if a CSR or if a response like a DR is evident. If a CSR is initiated this would be expected to increase ventilation needs. Currently, some offshore aviation companies are equipping aircrafts with emergency breathing systems (EBS) for use in an underwater egress. The need arises to determine the magnitude and type of ventilation responses to sudden face only immersion, so adequate EBS can be chosen to allow successful underwater helicopter egress.

Based on the whole body response to cold-water immersion (4), it was hypothesized that the lower water temperatures would produce greater ventilation responses compared face immersion at 33°C. With respect to the DR, it was hypothesized that Heart Rate (HR) would decrease most in the lowest water temperature with face only immersion.

Methods

Participants: Six typical size males (weight 77.6 kg±4.6 kg; height 1.83±0.03 m; BMI 23.1±0.9 kg • m^{-2}) aged 24±2 (mean ± SE) volunteered for this study that was approved by the Office of Research Ethics at Simon Fraser University.

Instrumentation: Participants wore a nose-clip and snorkel and lay prone on a bench. Water flowed to and from a face bath through an adjustable LAVDA K-2/R chiller/heater unit. Ventilation and oxygen consumption were measured breath-by-breath using a Vmax229c metabolic cart (Sensormedics, USA). Skin temperature was measured using T-type thermocouples secured to the skin. Heart rate was continuously monitored with a pulse oximeter. Temperature and HR data were collected by a National Instr. data acquisition system (San Antonio, Tx, USA) controlled by Labview software on a personal computer.

Protocol: Participants rested for 5 min and then immersed their face for 5 min. Water temperatures of 0, 10, 33° and Air were employed with 3 successive trials in condition. Between each trial participants rested until their facial skin temperatures and HR returned pre-immersion values. The order of the conditions was randomized with a Latin Square.

Statistical Analysis: A one-way repeated-measures ANOVA was employed with levels: 0, 10, 33° and Air. Dependent variables were maximal or minimum values of ventilation (V_E), respiratory exchange ratio (RER), end-tidal CO_2 partial pressure ($P_{ET}CO_2$), end-tidal O_2 partial pressure ($P_{ET}O_2$) and heart rate (HR). Individual sums of V_E and VO_2 were compared in a repeated-measures ANOVA with factors of Face Immersion Condition (0, 10, 33° and Air) and Face Condition (resting or face immersed). The level of significance was $p<0.05$.

Results

A typical participant's response to face immersion is given in Figure 1 for V_E, $P_{ET}CO_2$, $P_{ET}O_2$ and RER. In Figure 2 are the respective mean responses for V_E, $P_{ET}CO_2$, $P_{ET}O_2$ and RER, and the main effects for each of the variables were significant ($0.0001 < p < 0.02$). Face immersion in 0°C and 10°C gave a hyperventilation as indicated by significant decreases of $P_{ET}CO_2$ coupled with significant increases in each of V_E, RER, and $P_{ET}O_2$.

For the sum of ventilation there was a significant interaction ($p<0.01$) between face immersion condition and face position. This interaction was explained by the 5 min pre-immersion rest value of 60.5

± 2.2 L being significantly less ($p<0.05$) than the sum of ventilation of 97.2 ± 13.2 L during 5 min face immersion in the 0°C condition. For the sum of oxygen consumption there were no significant differences between the 2 periods.

For the minimum HR response to face immersion, there was a significant main effect face immersion condition ($p <0.01$). This was explained both by the minimum HR of 47 ± 4 bpm ($p<0.01$) at 10°C being significantly lower and the minimum HR of 53 ± 3 bpm tending to be lower ($p=0.07$) than the minimum HR of 63 ± 6 bpm observed for the air face immersion.

Discussion

After sudden face immersion in cold water a CSR was evident with a 2-part hyperventilation. Immediately after face immersion in 0 and 10°C, a transient gasp-like response occurred for ~ 30 s (Fig. 1). This hyperventilation was coupled with transient elevations of RER, and $P_{ET}O_2$ and a depression of $P_{ET}CO_2$, each similar to that for whole body immersions in cold water (1, 4). The second phase of hyperventilation in 0 and 10°C conditions was indicated by further increases in V_E, RER and $P_{ET}O_2$ and further decreases in $P_{ET}CO_2$. Mean responses for 0 and 10°C conditions (Fig. 2) supported a hyperventilation relative to air control condition.

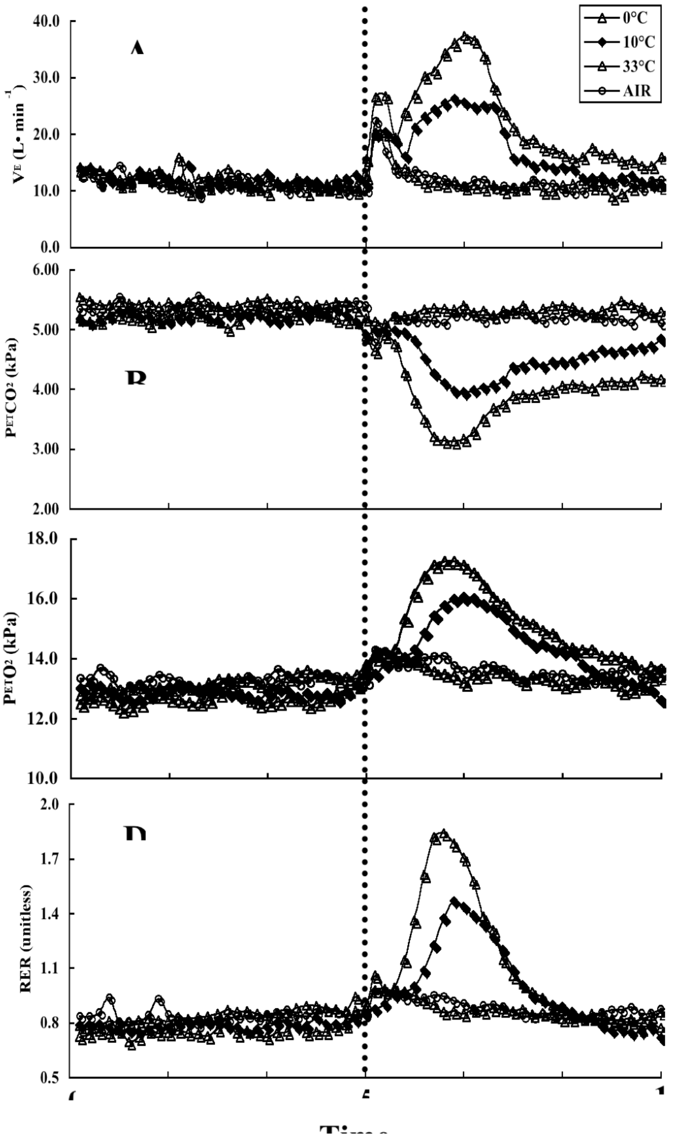

Figure 1. One participant's responses to during prone rest for 5 min followed by 5 min of face immersion in 0°C, 10°C, 33°C or Air. Panel A is ventilation (V_E), Panel B is end-tidal carbon dioxide partial pressure ($P_{ET}CO_2$), Panel C is end-tidal oxygen partial pressure ($P_{ET}O_2$), and Panel D is respiratory exchange ratio (RER). The vertical dashed line indicated the point of face immersion.

The mechanism underlying this response remains to be resolved. Stewart et al (3) reported increased ventilation after face immersion in 17°C water and presently ventilation was more pronounced at lower water temperatures (Figs. 1 and 2). This suggests that facial cutaneous temperature sensitive neurons are involved, potentially stimulating the respiratory control center in the medulla. Burke and Mekjavic (1) suggested for whole body immersion in cold water the gasp response is from a non thermoregulatory drive from these same neurons.

The sum ventilation over the face immersion at 0°C was 97.2 ± 13.2 L and was significantly greater than that of 60.5 ± 2.2 L for pre-immersion rest. This suggests a minimum of ~100 L is needed for this 5 min period in these resting, typical size male participants.

Conclusions

For sudden face immersion a temperature dependent hyperventilation and bradycardia were evident. Greatest ventilation responses and lowest heart rates were evident at the lowest water temperature of 0°C.

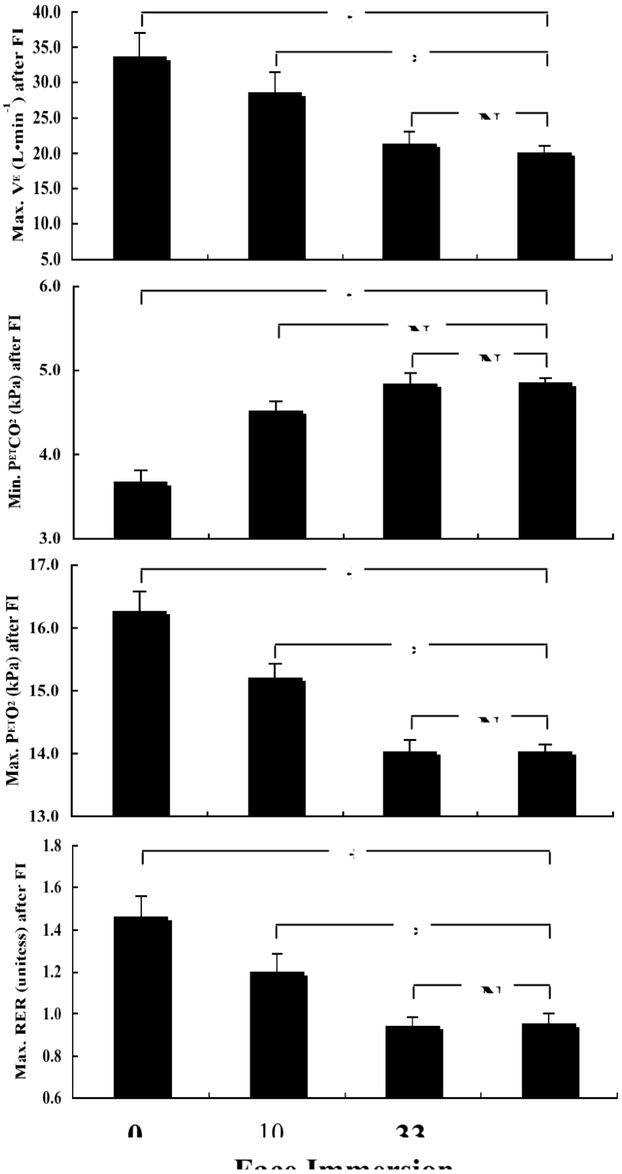

Figure 2. Minimum or maximum mean Face Immersion (FI) responses for 6 participants for each of ventilation (V_E), end-tidal carbon dioxide partial pressure ($P_{ET}CO_2$), end-tidal oxygen partial pressure ($P_{ET}O_2$) and respiratory exchange ratio (RER). Error bars are the SE, NS= Non Significant, *$p<0.05$, † $p<0.01$, ‡ $p<0.001$.

Acknowledgements:

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THE INFLUENCE OF PSYCHOLOGICAL TRAINING ON BREATH-HOLD PERFORMANCE DURING COLD WATER IMMERSION

Martin Barwood[1], Jonathan Dalzell[1], Avijit Datta[1,2], Richard Thelwell[1], Mike Tipton[1]*

[1] The Institute of Biomedical and Biomolecular Sciences, University of Portsmouth, England
corresponding author: martin.barwood@port.ac.uk*
[2] Portsmouth Hospitals N.H.S Trust, Hampshire, England

Introduction

The “will to survive” is a much-used phrase, employed to explain the differing ability of otherwise similar individuals to cope with, and survive in, extreme conditions. The underlying assumption being that, despite the fact that survival should be determined by physical stressors and autonomic physiological responses in such conditions, some aspect of psychological function is able to moderate the responses evoked. Such a proposition is difficult to assess in a non-emergency, laboratory-based experimental model. However, one possible approach is to examine the effect of altering psychological capability on the response to extreme environments, such as immersion into cold water.

The initial responses to immersion into cold water include an “inspiratory gasp,” uncontrollable hyperventilation, tachycardia, peripheral vasoconstriction and hypertension (3, 4). They are collectively known as the ‘Cold Shock’ response (11) and may be a precursor to drowning or cardiovascular problems on initial immersion. The respiratory component of the cold shock response significantly decreases maximum breath hold time, however, the variation in this response between subjects is large (12). Some of this variation may be due to differing individual ability to consciously suppress the strong sympathetic autonomic drives elicited upon contact with cold water. Thus, maximum breath hold time is partly a function of mental “will”, and the ability to tolerate or suppress unpleasant stimuli and their reflex effects; this function may be susceptible to manipulation.

In the sports science literature psychological skills training (PST) is a recognised method for improving performance in stressful sporting environments (e.g. 9,10). In theory, this technique works by focussing attention, improving confidence and modifying arousal (1). The present investigation tested the hypothesis that PST could also attenuate the potentially hazardous autonomic responses to a stressful thermal environment, represented by immersion in cold water.

Methods

The study was approved by the local ethics committee and used 32 healthy male volunteers as participants for the experiment (*mean [s.d];* Age 21 [*3.53*]yrs; height 1.78 [*0.09*]m; mass 76.55 [*10.56*]kg). Written and informed consent was obtained from all participants before experimentation.

Protocol

For a minimum of 2-hours prior to each immersion, participants rested and did not smoke, eat or consume caffeinated drinks. Each participant completed two, seated, 2.5 minute standardised head-out immersions into stirred cold water (11°C). The immersions were separated by a minimum of 7 days; participants wore the same bathing costume on both occasions.

Prior to each immersion participants completed two practice breath-holds in air (BH_{air}) whilst seated in the immersion chair, adjacent to the immersion tank. The breath-hold protocol was standardised as a ‘slightly larger than normal breath’ held until expiration could no longer be resisted. The participant was then winched above the immersion tank for a further 2 minutes. Toward the end of the 2 minute period, a 10-second verbal countdown commenced at the end of which the participant was required to begin breath-holding and were lowered into the water by an electric winch system attached to the chair at a reproducible rate of $8 m.min^{-1}$.

Following immersion 1, participants were grouped into matched pairs on the basis of breath-hold time in water (BH_{water}) and were assigned to either a control group (CG: $n = 16$) or a psychological intervention group (PIG: $n = 16$). Between immersions 1 and 2 the CG continued with normal daily activity, whilst the psychological intervention group (PIG: $n = 16$) completed 5 psychological skills training (PST) sessions aimed at improving BH_{water}; briefly, these comprised:

1 Goal setting: The participant was informed of their initial breath-hold performance time and subsequently they set outcome (desired actual performance) and process (functional task-specific targets) goals to facilitate improved BH_{water} in immersion 2 (7).
2 Arousal regulation: initially sources of arousal and anxiety were identified from immersion 1. Participants then practiced two relaxation strategies (progressive muscular relaxation and centering) in order to reduce arousal prior to, and focus attention during immersion (8).
3 Mental imagery: Participants were required to mentally recreate the positive and negative visual, auditory, sensory and kinaesthetic experiences from the first immersion. They then visualised a successful performance in immersion 2, including the temporal patterning of the environmental stimuli with the addition of the structured PST intervention strategies (5).
4 Positive self-talk: Participants identified negative cognitions and statements associated with the immersion 1. They then developed counteractive positive statements to rebound negativity that may be experienced during the immersion 2 (2).

All participants were strictly instructed not to practice any kind of breath-holding between immersion 1 and 2.

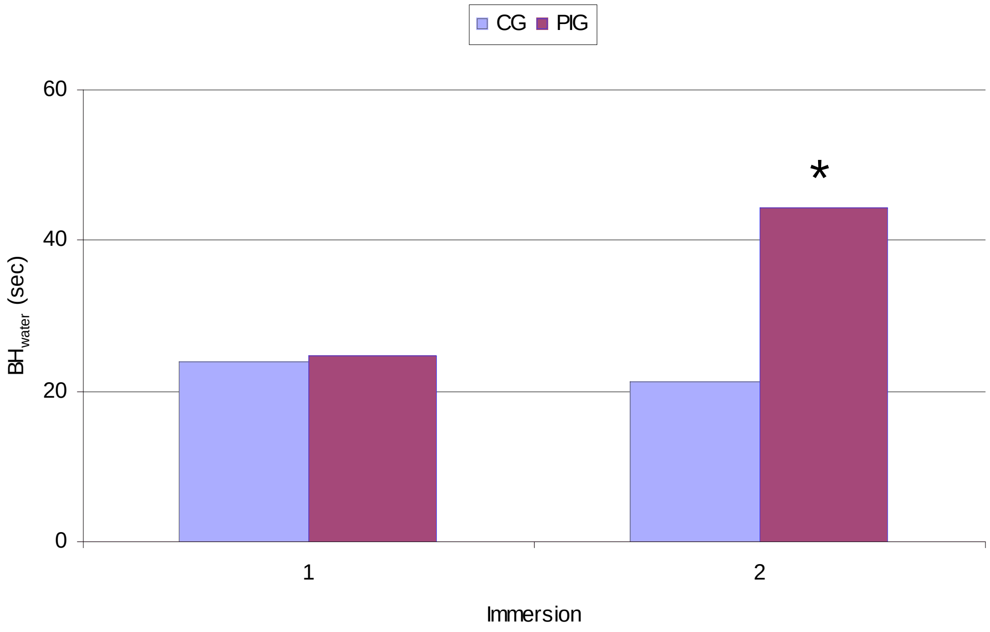
Experimental Measures

Throughout the trials participants wore a nose clip and breathed through a two-way Hans-Rudolph mouthpiece. CO_2 responses were measured at the mouthpiece using a fast responding gas analyser (Fractional expired O_2 - F_{ETO2} & CO_2 - F_{ETCO2}; breath-holding break point - $BPCO_2$, %). Inspired volume (V_I - L) was measured during using a spirometric transducer. A 3-lead ECG (HME Lifepulse, England) linked to a digital data acquisition system recorded cardiac responses prior to and throughout each immersion.

Statistical Analyses

Univariate statistical comparisons were made using a two-way repeated measures MANOVA both within and between group ,(CG & PIG) before and after each immersion Groups were compared for: BH_{water}, BH_{air}, $V_I BPCO_2$ and HR before and during immersion. For all statistical tests the α level was set at 0.05.

Figure 1. Mean BH_{water} 1 and BH_{water} 2 in CG and PIG (n = 32). * Denotes significant difference in PIG (P<0.05) across phase and within group.



Results

PST did not alter BH_{air} in either group. BH_{water} increased significantly between immersion 1 & 2 in the PIG following PST (F,(1,15) 7.187, P = 0.012). No significant difference was observed in the CG (figure 1). The mean difference ([*s.d*]*)* in BH_{water} between immersions 1 and 2 for each group was CG: -2.66

[15.13]; PIG: 19.59s [22.04]. PST did not significantly influence any of the other variables recorded. Mean [*s.d*] values for each of the cardiorespiratory variables recorded are presented in table 1.

Discussion

The significant increase in BH$_{water}$ following PST provides evidence that, with no discernible changes in physiology, psychological alterations can influence the ability of individuals to survive adverse conditions. This gives some insight into mechanisms that may underpin our concept of the "will to survive", and its variability between individuals. Although the magnitude of the response to PST was varied, all individuals in the PIG matched or improved BH$_{water}$, this was not the case in the CG. Moreover, these improvements in the BH$_{water}$ performance appeared to be unrelated to BH$_{air}$.

Table 1. Mean [*s.d*] values of the cardiorespiratory variables recorded.

	CG				PIG			
Variable	Immersion 1		Immersion 2		Immersion 1		Immersion 2	
BH$_{water}$ (sec)	24.01	[*6.72*]	21.34	[*16.31*]	24.66	[*14.60*]	44.25	[*31.63*]
BH$_{air}$ AVG (sec)	46.62	[*17.21*]	45.08	[*12.96*]	64.84	[*22.04*]	61.89	[*21.13*]
BP CO$_{2water}$ (%)	5.52	[*1.04*]	5.35	[*1.29*]	5.62	[*1.00*]	6.11	[*1.32*]
BP CO$_{2air\ AVG}$(%)	6.34	[*0.68*]	6.16	[*0.71*]	6.64	[*0.48*]	6.62	[*0.73*]
Insp Vol$_{water}$ (L.)	2.36	[*0.99*]	2.63	[*1.11*]	2.70	[*0.84*]	2.78	[*0.85*]
HR (b.p.m^{-1})								
Pre Immersion	108.40	[*31.65*]	121.57	[*31.98*]	89.14	[*26.90*]	103.20	[*21.59*]
10s Imm	118.69	[*26.46*]	126.62	[*29.34*]	103.33	[*25.94*]	110.98	[*20.79*]
30s Imm	113.48	[*28.34*]	116.00	[*34.94*]	93.55	[*24.95*]	99.48	[*27.15*]
2 Min Imm	102.19	[*22.51*]	110.31	[*32.26*]	92.42	[*29.35*]	89.96	[*27.22*]

In air, the duration of breath holding is dependent on tolerance to hypercapnia and hypoxia; metabolic rate; carbon dioxide and oxygen storage capacity, chest wall mechanorecpetors activity; and psychological tolerance of the unpleasant sensations of asphyxia (6). In cold water, thermoafferents from the cutaneous cold receptors acting directly on the respiratory centres and alpha motorneurones innervating the intercostals muscles and diaphragm (11), cause an overwhelming drive to breathe that must be resisted if breath holding is to be maintained. Therefore, breath hold time on immersion in cold water represents the balance between autonomic drives to breathe and the conscious ability to suppress that drive. In most individuals, the drive to breathe is overwhelming and breath hold time is significantly reduced on immersion in cold water (11), to the extent that chemical influences do not limit breath hold time. This is seen in the lower initial BPCO$_2$ seen on immersion in cold water compared to air in the present investigation.

The increase in BH$_{water}$ following PST suggests that psychological factors can have a significant influence on breath hold time on immersion in cold water. Presumably, PST works by augmenting the ability to consciously suppress the drive to breathe on immersion in cold water, rather than by diminishing the magnitude of the afferent autonomic drive evoked by such immersion. It follows, that PST should be most effective at altering those responses that are under the greatest degree of conscious control. This suggestion is supported by the finding that in the present experiments PST did not attenuate the heart rate response observed on immersion in cold water. Similarly, PST did not significantly alter the anticipatory heart rate response prior to immersion. If anything the prospect of a second cold immersion caused subjects in both groups to become more tachycardic prior to the event. Therefore, the inhibitory influence enabled by the PST was *specific* to the respiratory response *during* immersion and occurred irrespective of arousal level as estimated both subjectively and from heart rate.

It is concluded that it is possible to extend breath-holding time in cold water by the administration of PST. The abilities developed by PST are specific, and are likely to work by increasing the ability of individuals to consciously suppress the drive to breathe.

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ECG ARRHYTHMIAS FOLLOWING BREATHOLD DURING HEAD-OUT COLD WATER IMMERSION: PUTATIVE NEURAL MECHANISMS AND IMPLICATIONS FOR SUDDEN DEATH ON IMMERSION

DATTA[1], Avijit , BARWOOD Martin & TIPTON, Michael*

Institute of Biomedical and Biomolecular Sciences, University of Portsmouth, UK PO1 2DT and [1]Portsmouth Hospitals NHS Trust
* corresponding author avijit.datta@port.ac.uk

Introduction

The initial responses to immersion into cold water include an “inspiratory gasp,” hyperventilation, tachycardia, peripheral vasoconstriction and hypertension[2,3], collectively known as the ‘Cold Shock’ response[4]. Physiological mechanisms underlying the response have been examined[5,7]. Significantly, ectopic cardiac beats have been noted during the initial stages of head-out, cold water immersions and cardiac arrest is a rare but documented cause of death when water enters the nostrils[1], indicating that the cardiac component of the cold shock response may be a precursor to sudden death on immersion and requires further investigation. Wet and dry suited subjects submersed under cold-water experience supraventricular arrhythmias during and after breath holding[6]. In this study, we investigated two groups of subjects wearing swimming trunks immersed in stirred cold water (a) during and after breatholding (b) during free breathing.

Methods

Subjects

Thirty-two healthy male volunteers were studied during breath holding(mean [s.d]; Age 21 [3.5]yrs; height 1.78 [0.09]m; mass 76.55 [10.6] kg). In a second study four further subjects were studied, each on three occasions (Age 23 [3.4]yrs; height 1.76 [0.07]m; mass 80.6 [19.2] kg). All subjects were informed of potential risks associated with the experimental protocol before giving written consent to participate, approval from the University of Portsmouth ethics committee having been obtained. Subjects had no significant prior exposure to cold water and had normal 12 lead resting electrocardiograms.

Breath holding Protocol

2 hours prior to testing, subjects rested, refrained from smoking, eating and consuming caffeinated drinks. Seated subjects completed two breath-holds in air (T_a 23.5 [0.23]°C) wearing a nose clip and breathing through a mouthpiece connected to a low deadspace respiratory valve (Hans Rudolph, Kansas City, Missouri, USA); inspiratory frequency (fR) and volume (VI ; turbine KL engineering, Sylmar, Calif, USA), mouthpiece endtidal PO_2 and PCO_2 were recorded (Servomex, Series 1400, Crowborough, UK). 3-lead electrocardiogram (HME life pulse L15, South Mimms, UK) recorded lead II. All data were logged digitally (Powerlab, AD Instruments, Mountain View CA, USA). Subjects took ‘a slightly larger than normal breath’, and then breath held for as long as possible. They then recovered for about 2 minutes. Subjects were then raised above the immersion tank for 2 minutes by an electric winch (CPM, F1-8; 2-8; 5-4, Yale, Shropshire, U.K); they then again breath-held, and over 28secs were lowered into water (Tw 11[1.0] °C) at 8m.min^{-1} to clavicular level (total immersion duration 2.5 minutes).

Following the first immersion, subjects were grouped into matched pairs on the basis of their breath hold duration during immersion (BH_{water}),defined as the time between the onset of the last breath prior to breath holding, and the onset of expiration . They were then assigned to either a control group (CG: n = 16) or a psychological intervention group (PIG: n = 16). In the 7 days between immersions 1 and 2 the CG continued with their normal daily activity, whilst the psychological intervention group (PIG: n = 16) completed 5 psychological skills training (PST) sessions aimed at improving BH_{water} (see Barwood et al, this meeting, for details)

Prior to each immersion, the subjects in both groups completed a 10 point tension questionnaire (1 – Relaxed to 10 - Tense) asking ‘How tense do you feel prior to this immersion?’

Free Breathing Protocol
Subjects were able to breathe freely throughout and were not asked to perform breath holds in air or during immersion. This was repeated on three successive days.

Results

Breath holding in air
Breath-hold duration (BH_{air}) averaged 45.8 [15] secs. Arrhythmias were not seen during or following BH_{air}.

Breath holding during cold water immersion
BHwater averaged 22.7 [12.3]sec, significantly shorter than BH_{air} ($P<0.001$; paired t-test, df=31). During BH_{water}, minor bradycardia only was seen.

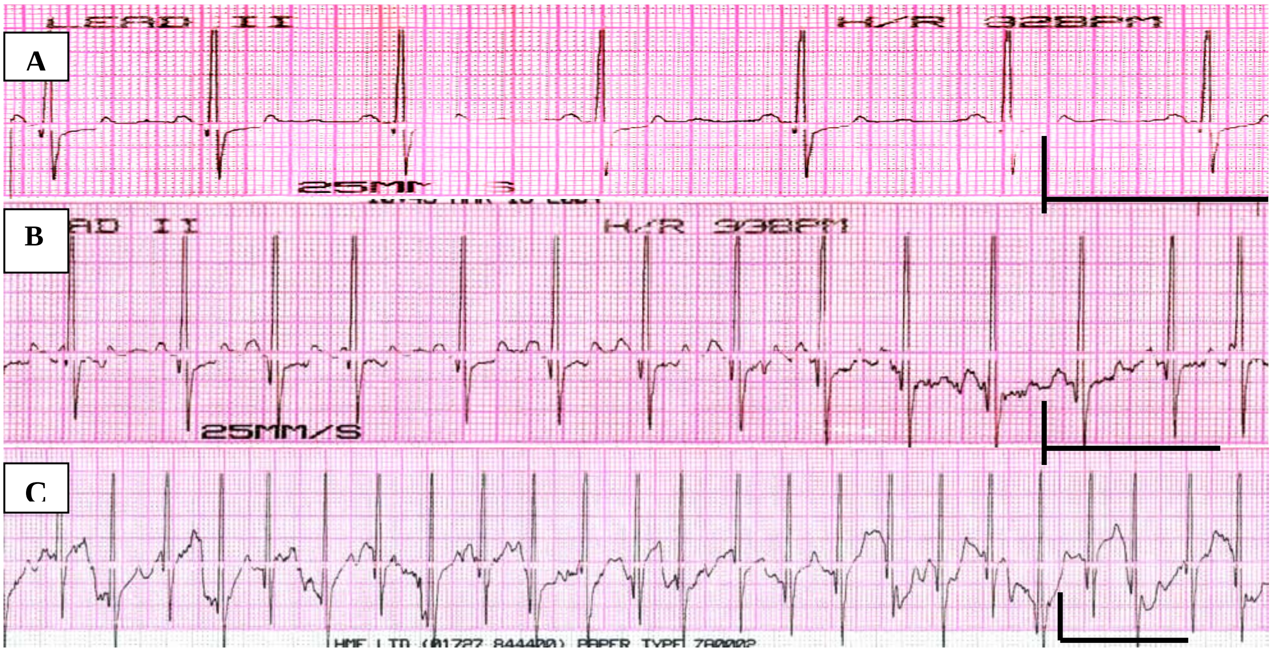

Figure 1. ECG traces - single subject : **A** sinus rhythm during rest, **B** sinus tachycardia prior to breath hold , **C** sinus tachycardia and supraventricular tachycardia following break of breath hold, whilst immersed. Horizontal and vertical lines indicate 1 second and 1mV, respectively.

Following BH_{water} , hyperventilation (fR 41.7 [8.3] breaths.min-1, nadir PCO_2 20.04 [6.3] mmHg) and relative tachycardia occurred in all subjects (HR 115 [3].min^{-1}; resting HR 77[13.6] min^{-1}); supraventricular, junctional (**Figs.1,2**) and ventricular arrhythmias occurred in 20/32 (63%) and 4/32 (13%) subjects respectively, lasting a few seconds and usually in the first 20 seconds after breathing recommenced. On occasion, ectopic beats appeared to be locked to respiration. Two subjects had both supraventricular and ventricular arrhythmias transiently. Sinus tachycardia lasting about 30secs was seen in 8/32 subjects, uninterpretable traces contaminated by shivering-related EMG and movement artefact occurred in 2 subjects. No differences were seen between the CG and PIG groups.

Mean tension rating ranged between 3 and 4 at all times i.e. a “relaxed” rating and did not differ between the CG and PIG group.

Free breathing protocol
Significant tachycardia was seen in all four subjects on each of three trials as soon as they were winched above the tank and well before the subjects were immersed. Following immersion, heart rate rose still further, in one subject reaching 191 beats.min^{-1} , indicative of a powerful sympathetic drive. Tachypnoea and hyperventilation occurred on immersion (**Table1**). In contrast to the breath holding group, notwithstanding significant sympathetic drive, arrhythmias were seen in only one subject on one occasion (coupled supraventricular ectopic beats).

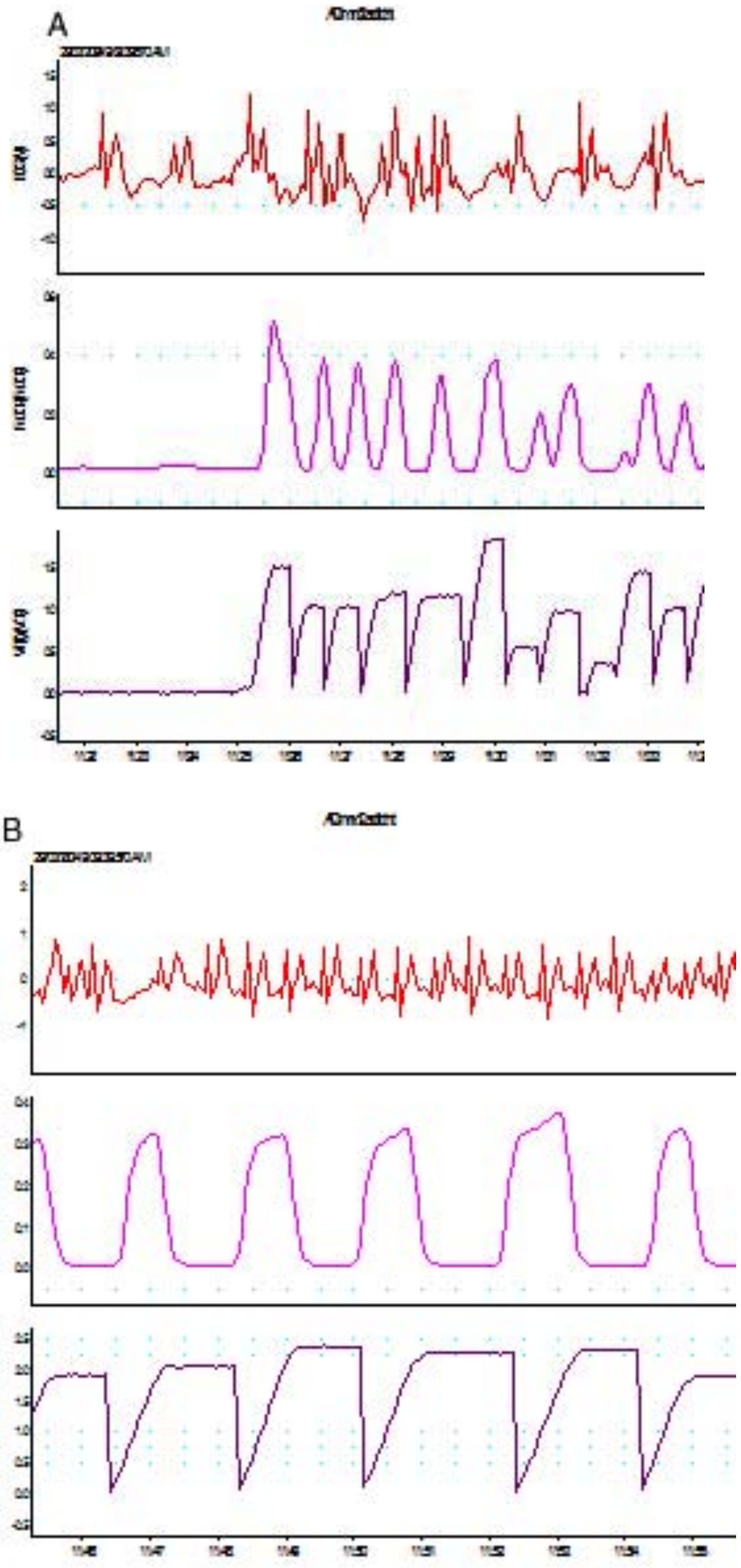

Figure 2. ECG, $P_{ET}CO_2$ and inspired volume at A, break of breath hold and B, 20 seconds later. Vertical markers indicate 1mV, 4% CO_2, and 100ml respectively. 5sec horizontal time marker.

Table 1. Mean, standard deviation (SD) minute ventilation (VI) and heart rate (HR) of four subjects, each on three successive days during free breathing at rest and during immersion (imm).

	VI rest $Lmin^{-1}$	**VI 1st min imm $Lmin^{-1}$**	**HR rest min^{-1}**	**HR above tank min^{-1}**	**HR 1st min imm min^{-1}**
Range	8.8-17.3	17.7-59.8	60-141	77-156	94-191
Mean	11.9	37.5	80.5	112.3	124.0
SD	2.3	12.8	24.8	28.6	30.1

Discussion

This study shows that in the first 20 seconds following breath holding during head-out cold water immersion, healthy subjects are at risk of significant cardiac arrhythmias; thereafter they have a relative (sinus) tachycardia. The results are consistent with those of Tipton and colleagues[6] who found an 82% incidence of arrhythmias, predominantly of supraventricular origin. The interpretation of that study was constrained because the authors studied wet and dry suited subjects who undertook head-under submersion. Under those conditions a significant diving reflex may be expected from trigeminal stimulation and a vagally derived bradycardia consequent to facial stimulation by (cold) water. This is evidenced by the bradycardia (55.8 [17.5]min^{-1} ; lowest heart rate 37 min^{-1})during breath holding that those authors reported, which was not seen in this study.

Comparison of the results obtained in this study between the subjects who breath held and those who breathed freely throughout indicate that both groups experience tachycardia during cold water immersion. The speed of this response, as with the respiratory response, is consistent with cutaneous cold afferents producing sympathetic stimulation via a reflex thought to be mediated through the tegmentum of the midbrain and the hypothalamus. However, unlike those who breathed freely, the group who breath-held were at significant risk of cardiac arrhythmias immediately after breath holding; since both groups are subject to the same hydrostatic and cutaneous cold stimulation during immersion , neither of these proposed mechanisms on their own are the origin of the observed arrythmias. We suggest that the origin of these arrhythmias is due to the release of the breath hold and the consequent vagal stimulation, in a cold milieu. Supportive evidence for this comes from the observation in this study and by Tipton and colleagues[6] that respiratory phase-linking of ECG abnormalities was a frequent finding. Under natural conditions, the nature, timing and sequence of cardiac abnormalities on cold-water immersion are therefore dependent on which of the three factors pertain:

Facial stimulation, producing a bradycardia
Cold, producing a tachycardia
Release of breath holding in cold water, producing supraventricular arrhythmias

Conclusions

Significant cardiac arrhythmias and hypocapnia follow cold-water immersion, even in healthy subjects wearing normal swimming attire.

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EFFECT OF COLD WATER IMMERSION DEPTH AND EXERCISE INTENSITY ON FINGER TEMPERATURE

John W. Castellani, Ingrid V. Sils, Myra Reese, and Catherine O'Brien*

Thermal & Mountain Medicine Division, US Army Research Institute of Environmental Medicine
Natick, MA, 01760 USA
corresponding author: john.castellani@us.army.mil

Introduction

Physiological responses have been shown to exhibit thermosensitivity to regional skin cooling. For example, ventilatory responses are greater when only the torso is cooled compared to leg-only cooling (1,2). Finger temperatures decline via reflex vasoconstriction when skin is cooled, but it is not known if this response exhibits regional thermosensitivity or even if cooling a larger skin surface area lowers finger temperatures to a greater extent.

Previous findings demonstrate that increasing the exercise intensity can attenuate the decline in finger temperature in cold air (3). These studies were conducted on clothed subjects and skin cooling on the lower extremities and torso was relatively minimal. In contrast, cold water immersion, which produces a greater magnitude of heat loss than cold air, could potentially negate the exercise intensity-dependent rise in finger temperature.

The purpose of this study was to determine if different immersion depths or exercise intensity would affect finger temperatures during treadmill walking in cold water. We hypothesized that cooling less of a surface area and exercising at higher intensity would attenuate the reflex fall in finger temperature.

Methods

Subjects. Six males participated in this study, which was approved by the appropriate Review Boards of the US Army. Subject characteristics were: age, 19 ± 1 years; weight, 73 ± 8 kg; % body fat (Lunar DPX densitometer), 16 ± 2 % fat; and VO_{2peak} (cycle ergometer test), 47 ± 3 $ml\cdot kg^{-1}\cdot min^{-1}$.

Experimental conditions. Subjects completed three different trials in 15°C water: in chest (C) and waist (W) deep water while walking at 0.88 $m\cdot s^{-1}$ (FAST) and in W while walking at 0.44 $m\cdot s^{-1}$ (SLOW). Subjects wore an Army battle dress uniform (BDU, ~ 0.85 clo) and neoprene water shoes during immersion. Each subject's trial began at approximately the same time each day and no caffeine was consumed 12 h before each test day.

Baseline temperatures were obtained while the subject was sitting and performing a computerized cognitive assessment battery. Following this, the subject's oxygen consumption was measured for 5 minutes. After 5 more minutes, subjects entered the water and walked to the front of the treadmill. They stood there for ~ 1 minute while electrical leads were connected to the data acquisition system. Following this the volunteer began walking at the prescribed speed. The time elapsed from the end of the baseline measure to the start of their walk was 10-12 minutes.

Measurements and calculations. Rectal temperature (T_{re}) was measured using a rectal probe (YSI, Yellow Springs, OH) inserted 10 cm beyond the anal sphincter. Skin temperature (°C) and heat flow ($W\cdot m^{-2}$) were measured by heat flow sensors with an integrated thermistor (Concept Engineering, Old Saybrook, CT) attached on the skin surface at 8 sites (on the right side): dorsal aspect of the middle finger between the proximal and distal interphalangeal joint, anterior aspect of forearm, subscapula, triceps, pectoralis major, abdomen, anterior thigh, and calf. Temperature data were collected every 15 seconds during treadmill walking (PX 1006, National Instruments). Mean skin temperature was calculated as $T_{sk} = .06(T_{forearm}) +. 09(T_{tricep}) + .095(T_{pectoral}) + .185(T_{subscapular}) +.18(T_{abdomen})+.2(T_{thigh})+.19(T_{calf})$. Oxygen uptake ($VO_2$) was determined using an online metabolic analysis system before exercise and at minute 20. Metabolic heat production was calculated from $((0.23*RER)+(0.77)) * (5.873*VO_2)*(60/BSA)$, where RER is respiratory exchange ratio, VO_2 is in $liters\cdot min^{-1}$ and BSA is body surface area in m^2.

Data analyses. Changes in finger temperature (ΔT_{fing}) from baseline through the first 23 minutes of immersion were analyzed. Repeated measures analysis of variance (trial X time) was used to evaluate the independent effects of water depth (C-FAST vs. W-FAST, n=5) and exercise intensity (W-SLOW vs. W-FAST, n=4) for all physiological variables. When significant F-ratios were calculated ($P < 0.05$), paired comparisons were made post hoc using Newman-Keuls tests. Paired t-tests were used to compare differences in the slope and intercept of the whole body heat loss-ΔT_{fing} relationship. Data are presented as mean ± S.D.

Results

Immersion Depth. Baseline finger temperatures were 32.05 ± 0.93°C and 31.92 ± 0.36°C for C-FAST and W-FAST, respectively ($P > 0.05$). The ΔT_{fing} was greater ($p < 0.02$, Figure 1) during C-FAST (-8.4 ± 1.0°C) compared to W-FAST (-7.3 ± 1.0°C). Mean weighted skin temperature was lower ($P < 0.01$) in C-FAST (20.2 ± 0.5°C) vs W-FAST (24.1 ± 1.1°C) but the change in rectal temperature (ΔT_{re}, +0.8°C) for the first 23 minutes and metabolic rate (170 $W \cdot m^{-2}$) at minute 20 was the same between trials. Figure 2 presents the ΔT_{fing} as a function of the cumulative heat loss across time. These data demonstrate a greater initial ΔT_{fing} from baseline ($P < 0.03$) in chest-deep immersion (y-intercept = -4.86 ± 0.74°C) versus waist immersion (y-intercept = -3.72 ± 0.72). The slope of the heat loss- ΔT_{fing} relationship was greater ($P < 0.02$) in W-FAST (.010 ± .002°C·KJ^{-1}) compared to C-FAST (.007 ± .002°C·KJ^{-1}), indicating that once the finger began to cool, it cooled slightly faster during waist immersion.

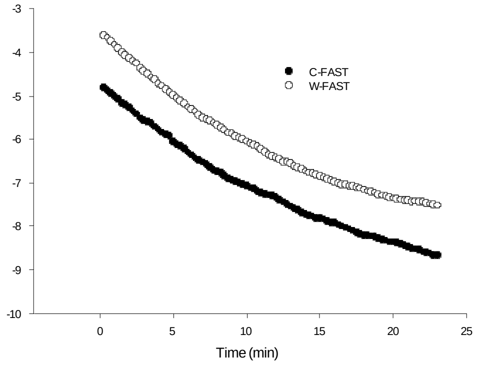

Figure 1. Change in finger temperature vs. time (n =5 during treadmill exercise (0.88 $m \cdot s^{-1}$) with immersion to the chest (C-FAST) and waist (W-FAST).

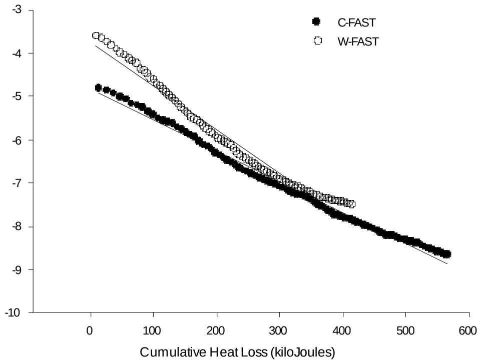

Figure 2. Change in finger temperature vs. heat loss (n = 5) during treadmill exercise (0.88 $m \cdot s^{-1}$) with immersion to the chest (C-FAST) and waist (W-FAST).

Exercise Intensity. The metabolic rate at min 20 of immersion was 42% higher in W-FAST (173 ± 15 $W \cdot m^{-2}$) compared to W-SLOW (122 ± 10 $W \cdot m^{-2}$) and this was associated with a lower ($P < 0.01$) mean weighted skin temperature in W-FAST (23.99 ± 1.15°C) vs. W-SLOW (24.23 ± 1.44°C) and a ΔT_{re} that was 0.15°C higher ($P < 0.05$) in W-FAST compared to W-SLOW. Baseline finger temperatures were 33.15 ± 0.65°C and 32.42 ± 1.48 for W-SLOW and W-FAST, respectively ($P = 0.22$). Despite the differences in metabolism, skin, and core temperature, exercise intensity had no effect on ΔT_{fing} as the ΔT_{fing} was the same (Figure 3) between W-SLOW (-7.5 ± 1.4°C) and W-FAST (-7.3 ± 1.0°C).

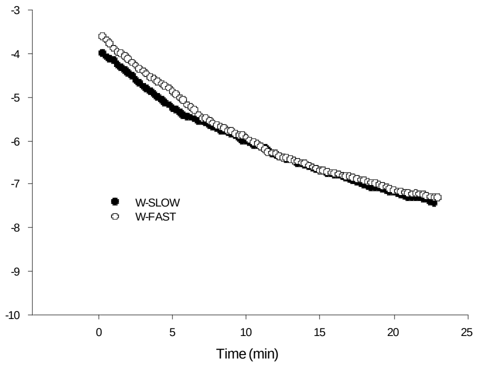

Figure 3. Change in finger temperature vs. time (n = 4) during slow treadmill walking (W-SLOW, 0.44 $m{\cdot}s^{-1}$) and fast treadmill walking (W-FAST, 0.88 $m{\cdot}s^{-1}$) when immersed to the waist.

Discussion

The primary findings of this study are: a) cooling a larger percentage of the body surface area causes a greater decline in finger temperature, b) the fall in finger temperature is related to the total convective heat loss and is not dependent on immersion depth and c) increasing exercise metabolism by 42% does not impact the fall in finger temperature during cold water immersion.

The larger initial fall in finger temperature during chest-deep immersion is likely caused by an increased neural drive subsequent to either greater cutaneous thermal receptor activation or to skin cooling of the upper torso which exhibits greater cold sensitivity (1,2). However, we did not directly measure the fall in finger temperature from baseline immediately upon immersion and this limits our interpretation of a greater initial fall in finger temperature with chest immersion. Following the baseline measures, subjects stood for an oxygen consumption measurement and then stood for an additional 5 minutes as other measures were completed and different wiring connections were completed. Finger temperature could not be measured during this transition period. Once cooling began, finger temperature decreased at essentially the same rate at both immersion depths and was linearly related to overall heat loss.

The lack of an effect on finger temperature with a 50% increase in exercise intensity was likely due to the low skin temperatures (~ 16°C) on the legs during exercise overriding the effect of an increase in exercise metabolism. Perhaps if the metabolic rate was raised to a higher level, the decrease in finger temperature would have been attenuated even at the low skin temperatures observed in this study. In a previous study in -10°C air, Mäkinen et al. (3) observed that a 57% increase in exercise intensity raised finger temperature 10-15°C, but skin temperatures on the legs and torso ranged from 27-32°C and this provided no stimulus for reflex vasoconstriction when working at a metabolic rate of 195 $W{\cdot}m^{-2}$. In one study in cold air (0°C) where mean skin temperatures were close to those observed during immersion (4), increasing the workload on a cycle ergometer from 50 to 100 Watts was enough to elicit vasodilation and an increase in finger temperature. This suggests that local skin temperatures and heat loss are important stimuli for reflex finger vasoconstriction. There is likely an interaction between peripheral skin temperature, heat flow, and metabolic rate on finger blood flow and temperature, but the relationships among these variables is currently unknown as is the critical exercise level that attenuates reflex finger vasoconstriction.

Conclusions

Chest-deep immersion causes a greater initial decline in finger temperature compared to waist-deep immersion. Increasing the exercise intensity by 42% does not change the fall in finger temperature during 15°C cold-water immersion.

Disclaimer

The views, opinions and/or findings contained in this publication are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation. The investigators have adhered to the policies for the protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted with the provisions of 45 CFR Part 46.

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THERMAL COMFORT DURING EXERCISE AND REST WEARING THREE DIFFERENT TYPES OF UNDERWEAR IN A COOL CLIMATE

John W.M. Willems [1], Emiel A. den Hartog [2],*

[1] Dept. of Product Ergonomics, TNO Science and Industry, Eindhoven, The Netherlands
[2]Dept. Of Human performance, Business Unit Human Factors, TNO Defense, Security and Safety, Soesterberg, The Netherlands
* corresponding author john.willems@tno.nl

Introduction

Normally standard cotton underwear is provided to soldiers of the Royal Netherlands Army to wear under combat suits in cool climate conditions. However, in practice more and more soldiers use synthetic underwear because this underwear is considered more comfortable, especially during passive cool down periods after intense exercise in outdoor conditions (‘after chill’). In an earlier study Daanen et al. (1) showed a tendency that thermal comfort was related to the moisture absorption capacity of the underwear material. It can be hypothesized that, wearing underwear with different characteristics regarding moisture absorption and moisture transport, compared with standard cotton underwear, will effect thermal comfort. The goal of this study was to evaluate the effect of three types of commercially available underwear on thermal comfort when used in combination with a standard combat suit for activities in a cool climate.

Method

Twelve male subjects participated voluntarily in this study. We selected the materials cotton (C), polyester (P) and a mixture of wool and polyester (W) (Table 1.). The exercise protocol was carried out on a cycle ergometer. Subjects wore a back pack during exercise to simulate practical use conditions, and to create similar discomfort. The protocol started with a warm up period of 10 minutes cycling 1.5 W/kg followed by a 30 minutes interval cycling 2 W/kg. After the exercise protocol subjects passively cooled down for 30 minutes without backpack in turbulent wind conditions (figure 1). The protocol was performed three times with three different types of underwear (t-shirt and boxer-short). The trials were randomly assigned.

Table 1: Specifications of underwear.

Code	Material	Weight * (g/m^2)	Structure	Thickness** (mm)
C	Cotton (95%) Elastomer (5%)	215	Single jersey	1,30 ±0,05
P	Polyester 100%	174	Jersey tuck stitch	1,10 ± 0,02
W	Wool (52%) Polyester (48%)	200	Double jersey	1,14 ± 0.03

(* information manufacturer; ** = measured with 100 Pa)

The experiments were carried out in a climate chamber (temperature 10ºC and relative humidity 60%). Measured were skin temperatures (at eight sites: four thermistors and four I-buttons), rectal temperature, temperatures of underwear and outer wear, sweat production and sweat absorption by weighing subjects and garments separately and subjective sensations (temperature, wettedness, and thermal comfort (ISO 10551)).
An ANOVA repeated measures with a post hoc Tuckey test was used for statistical analysis. Significance was reached if $p<0.05$.

Figure 1. Experimental set up during forced after chill.

Results

Temperature measurements

No significant differences in rectal temperatures or average skin temperature, nor in underwear and outer wear temperatures were found (figure 2).

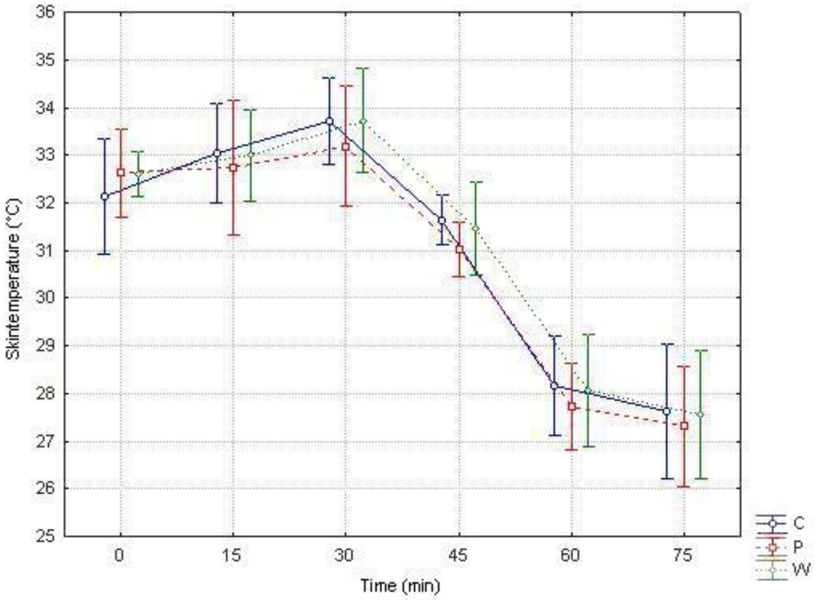

Figure 2. Average skintemperature (°C) of four thermistors in three conditions.

Moisture measurement

As expected, less water was absorbed in polyester underwear during exercise than in cotton underwear (Table 2). Correspondingly, a lower amount of moisture was left in the polyester shirt after the cool down period than in cotton and wool/polyester

Table 2. Amount of sweat absorbed in shirt and jacket after exercise, total sweat produced, and remaining moisture in shirt and after cool down period.

Absorption	C	P	W
in shirt (g) *	51.8 (± 24.1)	42.4 ±(23.5)	47.3 ±(22.1)
in jacket (g)	45.1 (±32.2)	51.2 ±(31.2)	45.7 ±(31.4)
sweat produced (g)	515.5 (±201.7)	492.5 ±(208.1)	486.0 ±(161.3)
remaining in shirt (g)**	19.6 (±14.1)	10.7 ±(8.9)	13.5 ±(8.7)
remaining in jacket (g)	23.4 (±19.9)	29.8 ±(24.5)	27.3 ±(20.6)

(* sign. difference P vs C, ** sign. difference P vs W and C)

Subjective sensations

The perceived wettedness wearing polyester underwear was lower than cotton and wool/polyester. No differences were found in perceived temperature and comfort. However, if cotton was tested versus polyester and wool/polyester together than a strong trend is present (p=0.06) that cotton was perceived less comfortable than the other materials in the cool down period.

Discussion

In this study there is an effect of type of underwear on moisture absorption and perceived wettedness: more moisture is present in the cotton and wool/polyester after the cool down period in comparison with the polyester underwear. This may shorten the after chill period. However, these differences in moisture management of underwear do not lead to significant differences in skin and or rectal temperatures or thermal comfort. No effect of types of underwear on thermal comfort is in accordance with most studies on this subject (2-5). One study did find an effect but this was explained by differences in insulation between the clothing ensembles (6).

The lack of differences in temperatures and thermal comfort observed in this study may be due to the following reasons:

Firstly, the body surface area covered by the underwear is limited (approx. 50%). This means the influence of underwear on total heat exchange of the body is limited. Moreover, underwear is just a part of the two layer clothing ensemble. Possible thermal effects of the different characteristics of underwear will decrease due to the combination with the second outer layer of the ensemble. Hence, the outer layer together with air layers, will have a major influence on the total insulation of the clothing ensemble. This makes it more difficult to demonstrate significant effects due to differences in underwear. It was outside the scope of this project to vary the outer layer material also.

High inter individual differences with respect to sweat production are a second factor which explains the lack of significant differences between clothing conditions.

Rissanen (4) postulated that only subjects whose sweat production is relatively high will notice the difference between materials of underwear. The behaviour of the two different materials in their study is demonstrable in case of high sweat production.

Also Bakkevig & Nielsen (7) report differences in skin temperature and comfort sensation when sweat production is high. Especially in this situation there are substantial differences in absorption and time required for drying the material. It is likely that the wettedness of the material is related to thermal comfort. Expected differences are small in case of limited sweat production.

Furthermore, there are some disturbing factors. Besides moisture absorption, the appropriateness of clothing for certain activities and climates is influenced by a lot of factors: fit, confection, knitting method, thickness, etc. The influence of thickness (7), knitting method (8), and fit (9) is supposed to be of major importance on skin temperature, wettedness on the skin and thermal comfort in relation to the material of the garments. We were not able to use underwear which was exactly the same on these aspects so differences in these aspects will have influenced the results. .

In this study there is an effect of type of underwear on moisture absorption and perceived wettedness. Less moisture is present in the polyester after the cool down period in comparison with the cotton and wool/polyester underwear which may shorten the uncomfortable after chill period. It can be speculated that in colder conditions when more heat loss is present this advantage will be greater.

Conclusion

In general there is not much evidence that polyester or wool/polyester underwear is more comfortable than cotton underwear. It has to be taken into account that thermal comfort is influenced by level of sweat production and many other parameters/factors. Moreover, structure, fit and insulation are of major importance in relation to thermal comfort.

However, this study provided evidence that moisture management of polyester is beneficial for after chill discomfort. Therefore, although effect of differences in moisture management on thermal comfort is not significant in used conditions, we advise to use polyester underwear instead of cotton or wool/polyester underwear when it is used in combination with a standard combat suit in cool conditions and a strong variation in intensity of exercise.

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THERMAL RESPONSES DURING SLEEPING IN UNHEATED TENT IN WINTER

Hannu Rintamäki[1,2], Sirkka Rissanen[1], Ari Peitso[3], Martti Rautanen[4], Juha Junttila[4]*

[1] Oulu Regional Institute of Occupational Health, Oulu, Finland
[2] Department of Physiology, University of Oulu, Oulu, Finland
[3] Eastern Command Headquarters, Mikkeli, Finland
[4] Jaeger Brigade, Sodankylä, Finland
* corresponding author hannu.rintamaki@ttl.fi

Introduction

Sleep is essential for maintaining physical and mental performance (1). The quantity and quality of sleep are affected by many factors like lack of sleep (sleep pressure), noise, light, sleeping ground, nutritional status etc. Sleep is also very sensitive to environmental thermal conditions and, consequently, to body heat balance. Optimal microclimate temperature for sleep is 29 - 34 °C (2). Below or above those limits, the amount of deep sleep stages (REM sleep and levels 3 and 4 of slow wave sleep) decreases and the amount of wakefulness increases. Falling asleep is associated with a decrease in body core temperature and increase in skin temperatures, especially in legs (3).

In military activities the warming of tents is not safe due to infrared detection. Therefore sleeping bags and other garments should provide enough insulation for sleeping in unheated tents. However, the sleeping bags are usually used in heated tents, and the foot part of the bags are sometimes overheated or even damaged by the stove heating. In this study we wanted to find out if used sleeping bags provide enough insulation for good sleep in unheated tents in winter.

Methods

The test subjects were participants of a winter training course. They were officers responsible for field training in their units. Therefore they were well adapted to winter conditions. They were informed of the nature, purpose and possible inconvenience caused by the measurements, and they gave their consent to participate in the study.

Before going to sleeping bags, the subjects participated in field training for ca. 8 hours, mainly by making observations and using new instruments. The work level and heat production was therefore low. The subjects spent overnight in tents designed for 8 men. In the unheated tent there were 7 men: age 29.7 ± 6.2 (22 - 39) years (mean ± SD (min - max)), height 1.78 ± 0.03 (1.74 - 1.82) cm, weight 85.6 ± 10.8 (76.9 - 108.5) kg and body mass index 27.0 ± 2.8 (24.3 - 32.8). Skin (cheek, chest, lower arm, index finger, thigh, foot) and rectal temperatures were measured (YSI 400 series thermistors or NTC DC95, Digi-key -thermistors, Smartreader Plus8 data logger, ACR Systems, Canada) continuously from the subjects sleeping in the unheated tent and, moreover, from 3 subjects in the heated tent. Mean skin temperature (T_{sk}) was calculated as an area weighted average. Temperatures inside the sleeping bag on chest and calf level, tent temperatures (on the waist level of sleeper, ca. 25 cm above the ground) and ambient temperature (ca. 2 m from the tent, ca. 30 cm above the snow surface) were also measured (NTC DC95 and iButton, USA). Average sleeping bag temperature was calculated from the two measured bag temperatures.

All subjects both in unheated and heated tents (n = 17) gave in the morning their records on sleep length, sleep quality (linear scale between 0 and 10), thermal sensation (4) and reasons for poor sleep or waking up too early, if that happened.

The used sleeping bag (Tena Profess 80, with heat protected foot part) is aimed to be sufficient at -25 °C. The bags had been used in a normal military training before this study, and they were dry and clean when starting the measurements. The subjects used in the bag long underwear and woollen socks, and they were allowed to change clothing during the night according to their thermal sensations. Some subjects added the middle layer of the military clothing and felt liners from boots.

Results

The subjects went to sleeping bag at 20:30 - 21:00, they fell asleep at 21:00 - 22:30 (one subject at 1:00) and woke up at 5:30 - 6:45. During the period spent in sleeping bags, ambient temperature varied between

-11.5 - -16.5 °C, temperature in the unheated tent between -5.2 - -9.7 °C, and temperature in the heated tent between 1.0 - 8.7 °C (Figure 1).

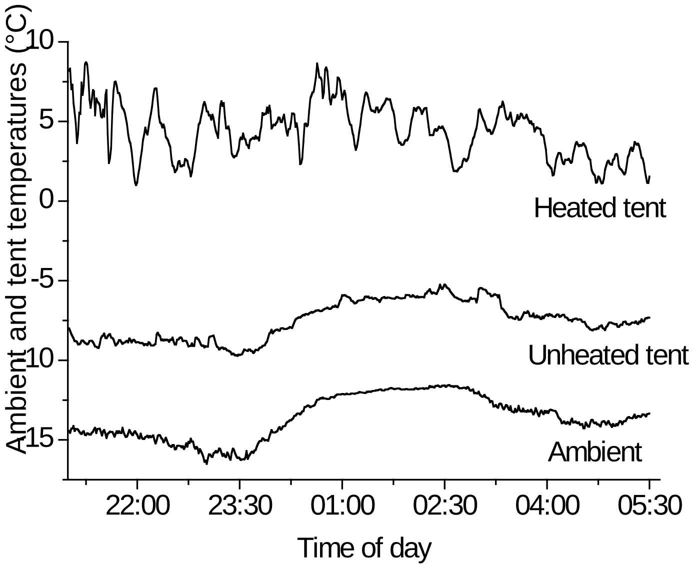

Fig. 1. Tent temperatures and ambient temperature.

Sleep quality was estimated as 5.3 ± 2.4 (2.1 - 8.8) and 5.4 ± 2.6 (1.1 - 8.8) in unheated and heated tents, respectively. Except cold, factors causing poor sleep quality or waking were bad sleeping ground, heat, noise, light, individual sleeping rhythm, cough and need for urination. In the unheated tent the general thermal sensation was in the morning warm (1 subject), slightly warm (2), neutral (3) and slightly cool (1). Feet were felt to be the coldest body part in 6 subjects and face in one subject. Thermal sensation of foot was in the morning cool (4 subjects) or cold (2).

After going to sleeping bag in the unheated tent, T_{sk} and foot temperature rose rapidly to ca. 34 and 32 °C, respectively, and rectal temperature started to decrease to ca. 36 °C. During the night the average foot temperature slowly decreased to ca. 30 °C (Figure 2). However, in 5 out of 7 subjects foot temperature remained quite stable (32.5 - 34.8 °C) through the night, while in two subjects it decreased to low level (ca. 24 - 26 °C), which prevented falling asleep and caused waking up. In the heated tent both T_{sk} and foot temperatures remained high and stable. The association between T_{sk}, foot temperature and sleeping bag temperatures during sleeping in the unheated tent are shown in Figures 3, 4 and 5.

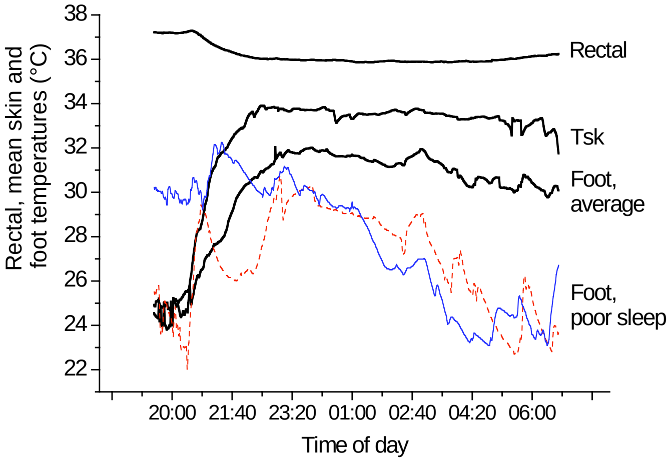

Fig. 2. Rectal, mean skin (T_{sk}) and foot temperatures.

Discussion and conclusions

The present results show that sleep quality was almost the same both in the unheated and heated tents. The results also show that in the unheated tent whole body heat balance was on a comfortable level during sleep, as judged from T_{sk} during the sleep and general thermal sensation in morning. Low rectal temperature also suggests that sleep was deep. In the study of Kreider and Iampietro (5) the lowest T_{sk} of sleeping men was 30.5 °C, which is clearly lower than measured in this study. The present results also demonstrate that falling asleep was associated with a decrease in rectal temperature and a marked increase in skin temperatures, as shown in laboratory studies (3).

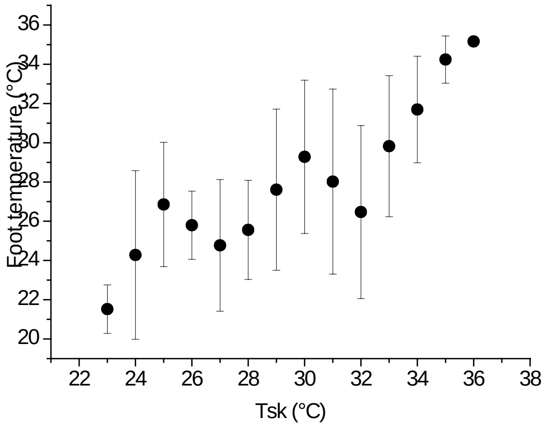

Fig. 3. Association between T_{sk} and foot temperature in the unheated tent (mean ± SD).

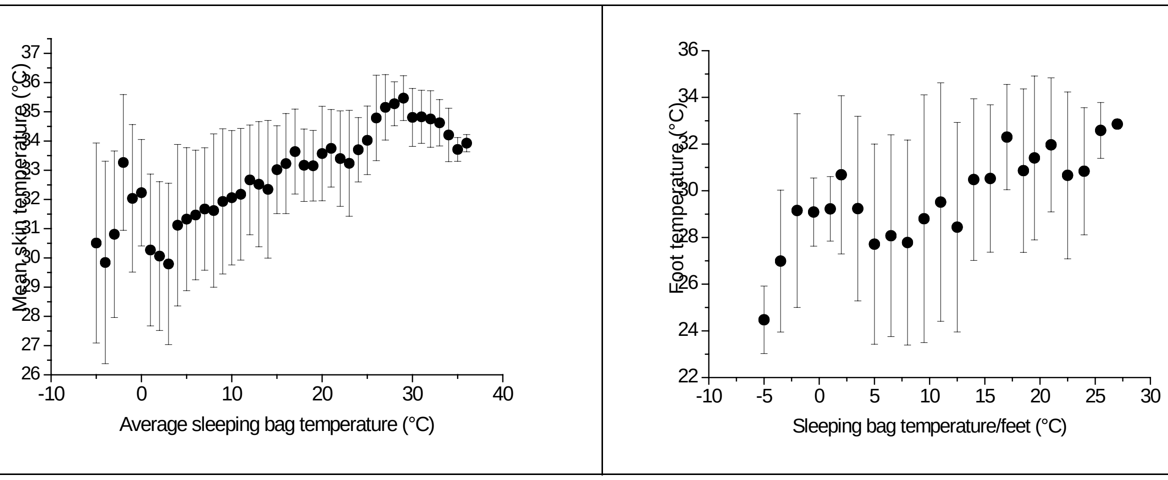

Fig. 4. Association between average sleeping bag temperature and T_{sk}, and sleeping bag temperature/foot part and foot temperature in unheated tent (mean ± SD).

In spite of good whole body heat balance, all subjects in the unheated tent had in the morning cool or cold thermal sensations in their feet. In two subjects out of 7 in the unheated tent the feet were really cold, but in the other cases foot temperature was fairly high (33.0 - 33.5 °C). During daytime military activities in winter such foot temperatures should cause warm thermal sensation (+2 in ISO 100551-scale) (6). During the sleep the feet seem to be very cold sensitive and obviously the association between foot temperature and thermal sensation of feet is different during the sleep than during daytime activities.

In conclusion, the present results show that in studied conditions it is possible to maintain good whole body thermal balance also in an unheated tent, but for ensuring good sleep quality the thermal insulation for feet should be further developed, especially when using used sleeping bags.

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FOOT TEMPERATURES AND TOE BLOOD FLOW DURING A 12 KM WINTER HIKE AND GUARD DUTY

Igor B. Mekjavic[1], Nina Kocjan[1], Miro Vrhovec[1], Petra Golja[2], Carol House[3], Ola Eiken[4]*

[1] Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute,
Jamova 39, SI-1000, Ljubljana, Slovenia
[2] Nova Gorica Polytechnic, Kostanjeviska cesta 16, Pristava, SI-5000 Nova Gorica, Slovenia
[3] Environmental Medicine Unit, Institute of Naval Medicine, Alverstoke, Hants. PO12 2DL, UK;
[4] Swedish Defence Research Agency, Karolinska Institutet, Berzelius v. 13, SE-17177 Stockholm, Sweden.
*corresponding author: igor.mekjavic@ijs.si

Introduction

Toe and finger temperatures are dependent primarily on perfusion, since metabolically generated heat in the digits is minimal. Small changes in blood flow will induce substantial variations in the toe and finger tissue temperature. The vasoconstriction-induced decrements in digit temperature are exacerbated by a cold and wet microenvironment. Depending on the tissue temperature-time profile, such exposures may ultimately lead to freezing and non-freezing cold injury. The aim of the present study was to evaluate the risk of such injuries during regular winter hikes and guard duty.

Methods

Twenty subjects (10 males and 10 females) participated in the study. They were all members of the Slovene Armed Forces. Subjects were familiarized with the experimental protocol and were aware that they could terminate their participation in the experiment at any time. The experimental protocol was approved by the National Ethics Review Committee (Republic of Slovenia).

Each subject participated in two trials. In one, they were requested to conduct a 12 km hike, while carrying a 20 kg load in their backpack. The hike was conducted on the trails surrounding the Alpine military training facility in Pokljuka (altitude 1360 m). The trails were covered with snow. In parts, the trail was well trodden, in others it was covered with fresh snow. The maximum change in elevation during the hike was approximately 100 m. The hike required between 3 to 4 hours, depending on the snow conditions. In the second trial, subjects were requested to conduct a 3 hour guard duty. During both trials they wore standard issue winter clothing ensembles.

During the trials, skin temperature was measured with thermistors embedded in heat flux sensors (Wuntronic Mess-, Steuer- und Regelgerate GmbH, Munchen, Germany) at five sites (arm, chest, thigh, calf and back). In addition, toe temperature was measured with a copper-constantan thermocouples. Temperature data was stored by a 40-channel portable Almemo Data Logger (Ahlborn Mess- und Regelungstechnik GmbH, Holzkirchen, Germany) situated in the backpack. Breath-by-breath oxygen uptake was monitored by a Cosmed model K4 b^2 (Pavona di Albano, Italy) portable oxygen uptake system, which also stored the R-R interval data from a chest heart rate monitor, and the ambient temperature, relative humidity and pressure. Core temperature was monitored with a gastrointestinal (Tgastric) radio pill (VitalSense Integrated Physiological Monitoring System, Minimitter Co., Inc., Bend, OR, USA).

The subjects conducted the trials in pairs. Thus, on any given experimental day, 2 subjects performed the 12 km hike, while 2 subjects were on guard duty.

Following the completion of the trials, data was downloaded from the data acquisition system, oxygen uptake system and the core temperature recorder onto a PC for later analysis.

Results

During the 3 week study, average (SD) ambient temperature at the onset of the trials was 2.0 (3.8) °C, and ranged from -6 to 8.2 °C. Relative humidity was 68 (21)% and barometric pressure 871 (5) mbar.

During the 12 km hike, oxygen uptake was maintained between 1.0 and 1.5 L.min^{-1} with average (SD) midway in the hike being 1.35 (0.75) L.min^{-1}. Oxygen uptake midway during guard duty was 0.2 (0.12) L.min^{-1}.

As can be seen in Table 1, guard duty posed the greatest risk for cold injury of the feet. Toe temperature decreased from 27.2 (3.6) to 14.4 (2.3) °C. The reduction in toe perfusion is reflected in the increase in ΔTcalf-toe (°C) from -0.83 (0.59) to 14.7 (15.9) °C by the end of the 3 hour trial. Gastric temperature remained unchanged during guard duty.

In contrast to the guard duty trial, core temperature increased during the Hike, concomitant with a fairly stable skin temperature, maintained at approximately 32°C. As a consequence of the vasodilatation in the toe (ΔTcalf-toe=-0.8 (3.7)°C at the onset of the hike, and -1.7 (3.4) after 3 hours), toe temperature increased from 27.4 (3.5) to 31.2 (5.4) °C after a 3 hour period during the hike.

Table 1: Core (Tgastric), average skin temperature (Tskin) and toe temperature (Ttoe) at the beginning and end of a 3 hour guard duty and 12 km hike.

	Start	***End***
Guard duty		
Tgastric (°C)	37.25 (0.33)	37.18 (0.35)
Tsk (°C)	33.8 (0.5)	29.0 (1.3)
Ttoe (°C)	27.7 (3.6)	15.4 (2.3)
ΔTcalf-toe (°C)	-0.83 (0.59)	14.7 (15.9)
12 km hike		
Tgastric (°C)	37.20 (0.23)	38.18 (0.42)
Tsk (°C)	32.5 (0.7)	32.0 (2.1)
Ttoe (°C)	27.4 (3.5)	31.2 (5.4)
ΔTcalf-toe (°C)	-0.8 (3.7)	-1.7 (3.4)

Conclusions

Peripheral vasodilatation, presumably as a result of the elevated core temperature, maintained average skin temperature constant during the 12 km hike, and increased toe temperature. In contrast, the low activity during the guard duty resulted in a stable core temperature, and peripheral vasoconstriction. The reduction in toe perfusion resulted in substantial decreases in toe temperature. Should this toe temperature prevail for a longer period, the risk of non-freezing cold injury would be imminent.

In addition to determining appropriate biophysical properties of footwear for cold ambients, evaluation of footwear should also assess the consequence of the combined effect of cold and vasoconstriction on digit temperature.

Acknowledgements

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MOTION SICKNESS PREDISPOSES INDIVIDUALS TO ACCIDENTAL HYPOTHERMIA

Gerard Nobel[1]*, *Ola Eiken*[2], *Arne Tribukait*[2], *Roger Kölegård*[2], *Igor B. Mekjavic*[3].

[1] Royal Netherlands Navy
[2] Swedish Defence Research Agency, Karolinska Institutet, Berzelius v. 13, SE-17177 Stockholm, Sweden.
[3] Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute, Jamova 39, SI-1000, Ljubljana, Slovenia.
* corresponding author: nobel_gerard@hotmail.com

Introduction

In a previous investigation it was found that motion sickness potentiated core cooling during immersion in luke-warm water (28°C), an effect which was ascribed to attenuation of the cold-induced peripheral vasoconstriction[1]. We reasoned that such motion sickness induced attenuation of peripheral vasoconstriction might be overridden by a more profound cold stimulus.

Accordingly, the present study was performed to investigate the effect of motion sickness on core cooling rate and thermoregulatory responses during immersion in 15°C water.

Methods.

After giving their informed consent, eleven healthy male subjects participated in the study, which was approved by the Human Ethics Committee at the Karolinska Institute. The subjects mean (range) age, mass and height of were 25 (22-39) yrs, 78 (63-102) kg and 1.79 (1.72-1.90) m, respectively.

Each subject underwent two separate head-out immersions in 15°C water, the immersions being preceded by baseline measurements performed with the subject resting supine in a 28°C air environment. In the control condition (CN), the subject was immersed immediately after the baseline measurements, whereas in the motion sickness (MS) condition he was rendered motion sick between baseline measurements and immersion. Motion sickness was induced by use of a rotating chair in combination with a regime of standardized head movements. During immersion in the MS condition subjects were exposed to an optokinetic stimulus (rotating drum). For each subject, the CN and MS experiments were conducted during the same time of the day, with a $\geq$ 72-hr period between experiments. The order of the experiments was alternated amongst subjects. Immersion was terminated after 90 min or once the subjects rectal temperature had decreased by 2.0 °C. Throughout the experiments mean skin temperature, rectal temperature, the difference in temperature between the forearm and 3rd finger of the right hand ($\Delta T_{\text{forearm-finger}}$) which is recognized as a measure of peripheral vasomotor tone [2], oxygen uptake and heart rate were recorded. At 5 minutes interval, subjects reported subjective rating of their temperature perception, thermal comfort and motion sickness.

Results

Upon termination of the MS provocation in the rotating chair the median (range) level of MS was 3=very nauseous, almost vomiting (range; 3= very nauseous to 4= vomiting). During the course of immersion, MS gradually subsided to attain ratings of 0=no discomfort (0-1) at the end of immersion. In the MS condition rectal temperature decreased at a substantially faster rate (33%, $p<0.05$) than in the CN condition. During immersion, at any given rectal temperature, $\Delta T_{(\text{forearm-finger})}$ was lower in the MS condition than in CN condition ($p<0.05$). Likewise, at a given rectal temperature, oxygen uptake, was lower in the MS than CN condition ($p<0.05$).

Discussion and Conclusions

The present results showed that core temperature decreased at a faster rate during immersion in the MS than the CN condition. This contradicts the notion that any MS-induced predisposition for developing hypothermia might be overridden under conditions of pronounced cold stimulus. The blunted $\Delta T_{(\text{forearm-finger})}$ and oxygen uptake responses in the MS condition suggest that motion sickness may attenuate cold-induced peripheral vasoconstriction as well as shivering thermogenesis.

It thus appears that motion sickness may predispose individuals to hypothermia by enhancing heat loss and attenuating heat production. This might have significant implications for survival in maritime accidents.

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MOTION SICKNESS ALTERS CORE TEMPERATURE RESPONSE DURING COLD WIND EXPOSURE

Dana Sweeney[1], *Michel B. Ducharme*[2, 1*], *Bob Cheung*[2]

[1]University of Toronto, Toronto, Canada
[2]Defence R&D Canada - Toronto, Toronto, Canada
*corresponding author michel.ducharme@drdc-rddc.gc.ca

Introduction

Survivors in inflatable life rafts may be exposed to cold, windy, and wet conditions as well as severe sea states. Since 75-88% of totally enclosed lifeboat survivors experience nausea and/or frank motion sickness during rough seas (1), life raft survivors may develop hypothermia while simultaneously experiencing symptoms of motion sickness.

Only a few authors have suggested that motion sickness may facilitate body cooling and the onset of hypothermia (2-4). Of these authors, only Mekjavic et al. (2) have generated experimental results to support their hypothesis. In the study by Mekjavic et al. (3), subjects were immersed in 28°C water following a provocative human centrifuge exposure, which resulted in a 29% greater decrease in rectal temperature (T_{re}), as compared to the control condition. However, the experimental design used by Mekjavic et al. (2) had limitations that should be addressed: 1) a human centrifuge was used to induce motion sickness; 2) motion sickness did not occur simultaneously with the cold stress; and 3) control trials in the centrifuge did not use the same acceleration profile as the experimental trials.

To address these limitations and investigate the hypothesis that simultaneous exposure to motion sickness and cold stress would decrease the effectiveness of thermoregulatory defense mechanisms, the current study employed a staircase vestibular Coriolis cross-coupling profile to gradually provoke and maintain symptoms of motion sickness for up to 90 minutes *during* exposure to cold wind.

Methods

Fourteen healthy subjects (12 males, 2 females; age (mean ± SD) 26.7 ± 6.5 years; height 177.6 ± 8.4 cm; mass 81.8 ± 12.7 kg; body fat 15.2 ± 6.8 %) volunteered for this study. Approval for this experimental protocol was obtained from the University of Toronto and the Defence R&D– Canada Toronto Human Research Ethics Committees.

Experimental trials were conducted in three, 90-minute sessions: a cold control trial (CC; 5 ºC; 30% RH; 7.2km/h wind), a combined cold and motion sickness trial (CM; 5ºC; 30% RH; 7.2 km/h wind), and a thermoneutral motion sickness control trial (TM; 26.5ºC, 30% RH, 0 km/hr wind). During all trials, subjects wore neoprene diving boots, quilted mittens, and shorts (females also wore a sport-bra type top). During CM and TM, signs and symptoms of motion sickness were induced using vestibular Coriolis cross-coupled stimulation in a modified "staircase" profile (5). Clockwise rotation of the chair (as viewed from above) was initiated with an immediate acceleration to 5 rotations per minute (RPM). During rotation, the subject was told to pitch their head forward and downward to approximately 90º of neck flexion. The head was held in the head down position for 12 seconds, and then subjects were instructed to return their head to the upright position.

Rotational velocity was increased by 5 RPM (to a maximum of 30RPM) if a rating of 5 or 6 (5-mild to moderate nausea, 6-moderate nausea) on the Golding and Kerguelen scale (6) was not reported after 15 head movements (3 minutes). When subjects reported a motion sickness symptom rating of 5 or 6, they were instructed to maintain their head position until their symptoms subsided to a rating of 4 (mild nausea), at this point, head movements resumed. Trials were continued until 90 minutes had elapsed, unless the subject requested to stop the trial, reached the motion sickness endpoint (rating of 7-moderate nausea, want to stop), retched, or vomited.

A complete range of physiological and psychophysical measurements were recorded during this study. Core temperature (T_{re}) was measured by a a thermistor probe inserted 15 cm beyond the anal sphincter. Mean skin temperature ($\overline{T}_{sk}$) and mean heat flow ($\overline{HF}$) were collected using an 18-point modified version of the Hardy & Dubois skin site weighting formula (7). Expired metabolic gas was collected by open circuit spirometry at baseline, 30, and 90 minutes. Mean heart rate ($\overline{HR}$)was measured using a Polar heart rate monitor. Thermal comfort ratings were also recorded every 10 minutes.

During each trial, two subjective ratings of motion sickness symptoms were recorded: 1) the Graybiel's diagnostic criteria for grading the severity of motion sickness (8) was completed at the beginning of the baseline period and immediately after the trial, and 2) a rating of symptom severity from Golding and Kerguelen's scale after each head movement.

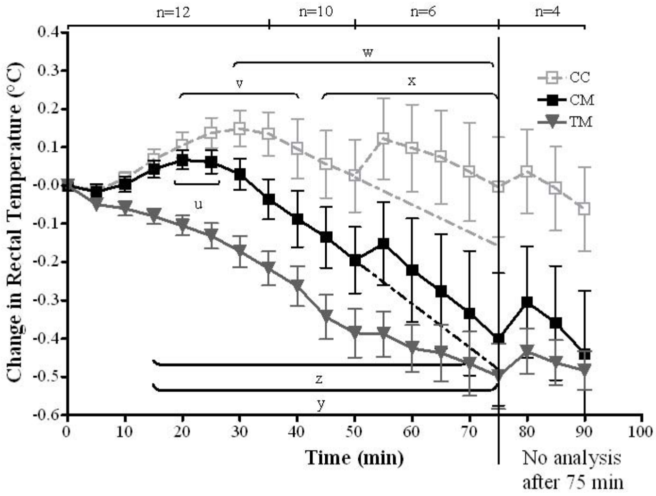

Figure 1. Change in rectal temperature (ΔT_{re} in °C) during CC, CM, and TM (mean ± SE).

Statistical analyses were completed using Statistica (Version 6.1, Statsoft, Inc.). Two-way analysis of variance (ANOVA) for repeated measures [condition (CC, CM, and TM) by time] and Neumann-Keuls post-hoc analysis were used to determine statistical significance of the dependent variables listed above. Significance was deemed to exist when $p<0.05$.

Results

A characteristic that was common to all subjects during exposure to the cold conditions (CC and CM) was a significant but transient increase in T_{re} ($p<0.01$, n=12). This transient increase has been defined as the T_{re} deflection period. The descriptive parameters of the T_{re} deflection period have been considered to be the duration, magnitude, and the zenith.

The magnitude of the T_{re} deflection period was significantly larger for CC than CM with increases of 0.15 ± 0.04°C and 0.07 ± 0.03°C, respectively ($p<0.05$, n=12). The time to reach the zenith of the T_{re} deflection period was significantly longer for CC (30 ± 4 min; $p<0.01$, n=12) than for CM (20 ± 3 min). Thus, T_{re} began to decrease significantly earlier during CM than during CC. From the zenith of the T_{re} deflection period, the decrease in T_{re} was linear (coefficient of determination (r^2) 0.98, n=6) for CC and CM. Core cooling was linear, for both CC and CM, but the rate of core cooling was not significantly different between these conditions with values of 0.45 ± 0.08 and 0.67 ± 0.14ºC for CC and CM (n=6), respectively. T_{re} responses for CC, CM, and TM are displayed in Figure 1.

No significant differences were observed for $\overline{T}_{sk}$, $\overline{HF}$, $\overline{HR}$, or oxygen uptake between CC and CM.

The Graybiel ratings of motion sickness severity were analyzed for 12 subjects during CC, CM, and TM. As expected, no significant differences were observed between the pre- and post-trial motion sickness ratings for CC. During the trials where vestibular Coriolis cross-coupled stimulation occurred (CM and TM), the post trial ratings of motion sickness symptoms were significantly higher than baseline ratings ($p<0.01$, n=12). The mean rating of motion sickness severity was also significantly higher during TM than CM ($p<0.01$, n=12).

Discussion

The results showed that simultaneous exposure to cold wind and motion sickness caused a greater decrease in T_{re} than cold exposure alone. The lack of a significant difference in the core-cooling rate between CC and CM suggests that the difference in core cooling observed between these two trials was due to differences in the T_{re} deflection period. The T_{re} deflection period is frequently observed during cold air exposures (9, 10), but is often ignored, since core cooling rate is typically calculated between the zenith of the T_{re} deflection period and the end of the cold exposure. In the current study, it appears that the T_{re} deflection period is critical in explaining the differences in body cooling that were observed between CM and CC.

The T_{re} deflection period was shorter in duration, and had a significantly earlier and lower zenith point during CM than during CC. Due to these differences in the T_{re} deflection period, T_{re} began to decrease earlier and a greater decrease in T_{re} occurred during CM than during CC. The explanation for the differences in the T_{re} deflection period between CM and CC have not been fully elucidated, however the lack of differences in oxygen uptake and $\overline{HR}$ suggest that peripheral mechanisms, not changes in the central metabolic response to cold are involved. Therefore, the differences in T_{re} observed due to motion sickness could be the result of changes in the vasomotor response to cold and increases in evaporative heat loss, even though the results of this study did not offer support for this assumption. In the current study, there were no significant differences in $\Delta\overline{HF}$ or $\overline{T}_{sk}$ between CC and CM. Therefore, it is suggested that evaporative heat loss (which was not measured) contributed to the greater decrease in T_{re} during CM

Conclusions

This is now the second study to demonstrate that motion sickness causes a greater decrease in T_{re} during cold stress, however the mechanisms responsible for the increase in core cooling due to motion sickness have not yet been determined. It has been speculated here that during cold wind exposure, motion sickness alters the T_{re} deflection period and causes an increase in evaporative heat loss and that this is responsible for the differences observed in T_{re}. This hypothesis has yet to be investigated.

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PHYSIOLOGICAL RESPONSES AND PERFORMANCE DURING EXPOSURE TO SEVERE COLD

Tae-Gyou Kim, Mizuho Fujita, Nobuko Hashiguchi, Yutaka Tochihara*

Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka, Japan
* corresponding author ktg413@korea.com

Introduction

Cold storage workers go in and out of -20 to -50℃ storage dozens of times a day. They load and unload goods, carry them from place to place, arrange them, and check them. Because of this, and the difference in temperature in and out of cold storage (1-2), workers develop circulatory system disorders and also complain of muscle ache because of the heavy frozen products they carry, which usually weigh more than 10kg (3).

This study researched how loading and unloading work can affect the response of regulation of body temperature, physiological processes and performance. The purpose of this research is to suggest preventive measures to offset the negative effects of work in cold storage, and to provide basic information for maintaining the health of workers.

Methods

Eight adult males volunteered as subjects. The subjects were 23.1 ± 2.3 years in age (means ± SE), 167.7 ± 5.4 cm in height, 59.2 ± 4.8kg in weight and 1.7 ± 0.1m^2 in surface area.

The clothing that they wore consisted of underwear (86g), pants (563g), shirt (305g), cotton gloves (118g), socks (60g), cold-protective jacket (1227g), cold-protective pants (888g), cold-protective cap (195g), and cold-protective boots. The total weight was 3491g with 3.4 Clo (excluding boots).

The subjects were kept in a sitting position on a chair for 20 min in an air temperature of 20°C and relative humidity of 50%, then they moved to an environmental chamber maintained at temperature of -25°C. They stayed in the environmental chamber for 30 min, while sitting for 10 min, then performing loading work for 10 min (Condition C: control without work, Condition R1: 9kg loading, Condition R2: 18kg loading), and then sitting for 10 min again. They were exposed to a transition from 20°C to -25°C three times, and then had 20 min recovery time at 20°C as the final procedure. Thus the total time for the experiment was 170 min.

The work in this study simulated conveyance of goods from shelf to lift in cold storage. The work factors were as follows:

- Weight of goods loaded (None, 9kg or 18kg)
- Size of goods loaded (530×366×320 mm)
- Distance goods were lifted (770 mm, from floor to hand level)
- Distance goods were carried (1000 mm diagonal path, measured from center point to center point, with starting position and ending position at right angles to one another)
- Frequency of loading (10 reciprocating motions/min, Operating for 10 min)

Measurements were taken of the following physiological responses: rectal temperature, 11 skin temperatures (forehead, chest, abdomen, back, forearm, second finger, thigh, leg, hand, cheek, and second toe), temperature and humidity inside clothes, heart rate, blood pressure, and weight change. In addition, exhaled air and blood samples were taken, and a 15 second counting task was performed with the subjects seated.

Measurements were taken of the following subjective sensations as psychological responses: thermal sensation, humidity sensation, ratings of perceived exertion (RPE), pain sensation, local thermal sensation, and local pain sensation.

Blood samples were analyzed before and after the experiment.

Each measurement was repeatedly analyzed as a dual distribution placed under the factors of working conditions (three conditions) and time. When the main effect of interaction in the distribution analysis was significant, the Turkey HSD test was performed over the comparisons between conditions. The caution level was set at less than 5% of the risk.

Results and discussion

Rectal and skin temperatures

As soon as the experiment began, the average rectal temperature of 8 subjects started decreasing and kept falling until the experiment was completed ($p<0.01$, Fig.1). When the experiment started, the rectal temperature was 37.2~37.3°C. The final rectal temperature was 1.1°C lower under condition C, 0.8°C under condition R1, and 0.6°C under condition R2.

After entering the experimental environment, the mean skin temperature continued to decrease, and the difference between conditions was significant ($p<0.01$, Fig.2). When the experiment began, the mean skin temperature was 32.0~32.5°C. The mean skin temperature rose under all 3 conditions until the first cold environment, but after that, while going in and out of the cold environment, the temperature repeatedly showed a sudden change of an average of 3°C.

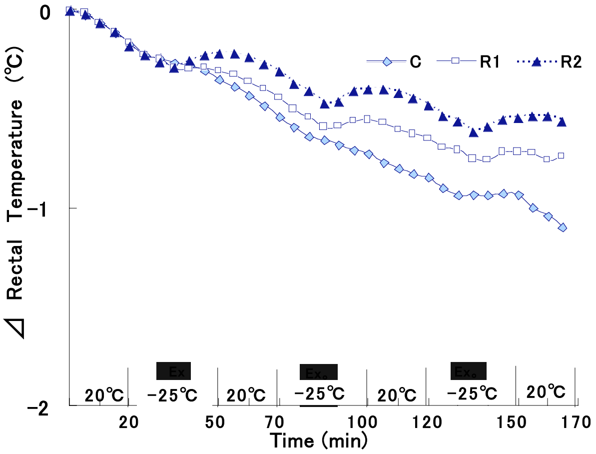

Figure 1. Changes in rectal temperature during repeated cold exposures.

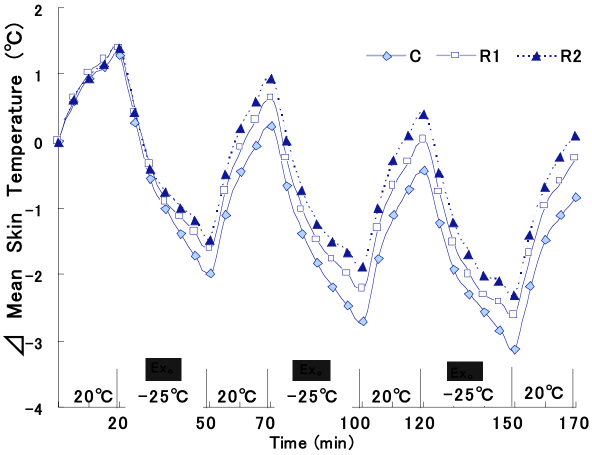

Figure 2. Changes in mean skin temperature during repeated cold exposures.

When the subjects left the last cold environment (after 150 minutes of the experiment), their mean skin temperature was 29.5~30.0°C. Significant differences in the mean skin temperature between conditions occurred in the following cases: after 45 minutes of the experiment, between condition C and condition R2 ($p<0.001$); and after 90 minutes of the experiment, between condition C and condition R1 ($p<0.001$). However, there was no significant difference between conditions R1 and R2.

Among the local skin temperatures, the abdomen and chest temperatures were higher under condition C than under any other conditions ($p<0.05$). In addition, after subjects entered the cold environment, the leg temperature decreased rapidly. There were slight differences along the extremities (the second finger and second toe) but these were not significant.

The above prove results that the thermal production of workers increased as the amount of work in a cold environment increased, but there was no difference in the peripheral skin temperature among conditions. We consider that this because the body gives off heat faster than it produces it in a cold environment by means of heat loss such as conduction, convection, radiation, and evaporation(4).

Blood pressure

Systolic blood pressure was about 115~119 mmHg when the experiment started. It began to rise after subjects entered the cold environment, and the degree by which it rose increased according to the number of times subjects went in and out of the cold environment ($p<0.01$). Although the difference between conditions was not significant, condition C showed the highest blood pressure.

Diastolic blood pressure was about 73~75 mmHg when the experiment started. It began to rise when subjects went out of the cold environment; condition C was 87 mmHg, condition R1 was 85 mmHg, and condition R2 was 80 mmHg. As the intensity of work increased, diastolic blood pressure dropped, and the difference between conditions was significant ($p<0.05$).

Noradrenalin

After the experiment, noradrenalin increased ($p<0.01$). For example, the amount of increase was 0.42±0.13 (ng/mL) during condition C, 0.31±0.06 (ng/mL) during condition R1, and 0.29±0.09 (ng/mL) during condition R2, and the difference between conditions was significant ($p<0.05$, Fig. 4).

It has been reported that noradrenalin in the constituent part of blood does increase in a cold environment because of the stress of coldness (5), and this research confirmed this result. Since the stress of coldness declined due to the increase of heat production during work, the density of noradrenalin in plasma was seen to decrease according to the increase in work.

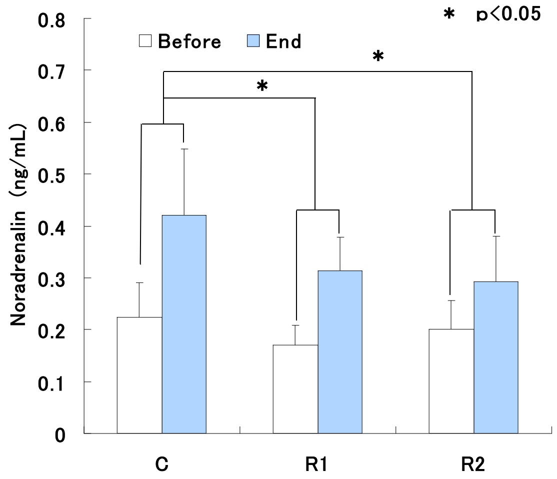

Figure 3. Plasma concentration of noradrenalin before experiment and at the end of experiment.

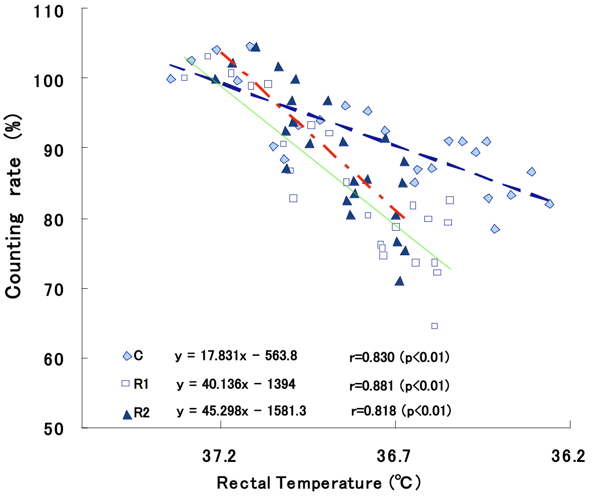

Figure 4. Relationships between rectal temperature and counting rates measured the second time for each group.

Counting task

There was a slight difference in the change of time ($p<0.05$) in the 15-second counting test, although the difference between conditions was not significant. The counting rate declined rapidly as a function of the change in rectal temperature (Fig. 4). When the rectal temperature was 37.2°C, the counting rate was the highest in condition R2, and lower during R1 and C. On the other hand, when the rectal temperature was 36.7°C, the counting rate was the highest under condition C, and decreased during R1 and R2. This demonstrates that finger performance impairment increases with the load weight. These results suggest that the level of hand work possible in a cold environment depends on the amount of work more than body temperature.

Conclusions

We found that core temperature rose and diastolic blood pressure dropped according to the increase in work in a cold environment. However, finger dexterity possible in a cold environment decreased according to the load weight. Handling heavy goods presents more danger in a cold environment, even though it may be the same work over the same range of time as that performed under normal conditions. This leads to a loss of efficiency and dropping of goods. To counteract this, it is necessary to shorten working hours and to take appropriate safety measures for work in a cold environment.

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INCREASING THE REPRODUCIBILITY OF A COLD SENSITIVITY TEST FOR NON-FREEZING COLD INJURY

Clare Eglin, Frank Golden, Michael Tipton*

Department of Sport and Exercise Science, Institute of Biomolecular Sciences, University of Portsmouth,
Portsmouth, PO1 2DT UK
*corresponding author: clare.eglin@port.ac.uk

Introduction

Non-freezing cold injury (NFCI) is a debilitating condition that can result in lifelong cold sensitivity, pain and sweating in the injured part, usually the feet. It is the most common form of non-combative related injury to afflict military forces and is common, at least in a mild form, in those participating in outdoor pursuits. A cold sensitivity test (CST) is one of the assessments used to classify non-freezing cold injury (NFCI)1, 3. This involves resting fully clothed in air at 30°C for at least 30 min, the injured area is then placed in a plastic bag and immersed in stirred water at 15°C for 2 min. Following removal from the water, the bag is removed and the patient rests for a further 5 min. Skin temperature (Tsk) is measured from infra-red thermal images of the injured area taken prior to immersion, immediately after, and 5 min after immersion. The degree of NFCI is determined from the temperature of the injured area immediately before immersion, and the amount of rewarming that occurs following removal from the water (Table 1). The assumption being that the higher the starting Tsk and the greater the amount of rewarming of Tsk following cooling, the less severe the cold sensitization/injury. It is further assumed that the increase in Tsk following cooling is indicative of a greater return of peripheral blood flow.

Table 1. Criteria used to classify the level of NFCI of the feet, based on the Tsk of the coldest toe pad.

Tsk at start	**Tsk 5 min after immersion**	**Injury grading**
> 32°C	> 32°C	Normal
> 32°C	30-32°C	Borderline
> 32°C	28-30°C	Mild
> 32°C	<28°C	Mild/moderate
< 32°C	28-32°C	Moderate
< 32°C	25-28°C	Moderate/severe
< 32°C	<25°C	Severe

Studies of the “normal” population have shown that there is wide variation in response to the CST, with a considerable proportion being classified as having a moderate/severe NFCI 2, 3. The CST was also found to have a poor reproducibility 2. Furthermore, the average response appears very similar to that of a non-perfused physical model, suggesting the changes in Tsk do not reflect blood flow 2. One possible explanation for the poor reproducibility of the CST is that the resting period prior to immersion does not ensure all the subjects are fully vasodilated before testing. The hypothesis of this study was that increasing deep body temperature prior to the CST would improve its reproducibility.

Methods

The experimental protocol was approved by the University of Portsmouth ethics committee. Six healthy male volunteers (mean (SD) age 35.5 (8.1) y; height 181.2 (4.1) cm; body mass 86.7 (12.3) kg), with no previous history of cold injury, peripheral vascular disease or diabetes participated in the study over the summer after giving informed written consent. All were non-smokers at the time of the trial and abstained from caffeine for 3 hours prior to testing.

Tsk was measured on the left great toe pad using a skin thermistor attached with a small piece of adhesive tape. Tsk was recorded prior to immersion, immediately after removal from the water and 5 and 10 min after immersion. Deep body temperature was measured using an aural thermistor (Tau) placed in the external auditory canal and insulated with neoprene. Temperatures were recorded every minute using a data logger (1200 series, Grants Instruments, Cambridge). Blood flow in the left great toe was measured using a photoplethysmograph (PPG 13, Medasonics, California) placed adjacent to the skin thermistor and recorded on a chart recorder (Model R12B, Medasonics, California) throughout the CST. The blood flow recorded prior to the CST was used as a baseline and measurements taken during the CST and the 10 min period afterwards were expressed as a percentage of this value. The position of the feet was kept constant except during the immersion phase of the CST when the left knee was bent and the foot lowered into water.

The subjects entered a climatic chamber at 30°C (mean temperatures (SD) at 0.95m were: wet bulb 22.80 (0.50)°C; globe 31.04 (0.21)°C; dry bulb 31.09 (0.14)°C; at 0.05 m dry bulb 30.11 (0.13°C)), removed their socks and shoes and sat resting for 15 min while their aural temperature (Tau) equilibrated. Prior to the CST they either lay down resting for a further 15 min (control); lay resting covered with blankets for 20 min (blanket), or exercised at a comfortable, self-paced work rate until Tau increased by 0.3°C by stepping (22cm step, average rate 15 steps.min-1), cycling (average 50W) or arm cranking (average 15W). The subjects then rested in a recumbent position whilst baseline readings were taken. During the CST, their left foot was placed in a plastic bag and immersed to the level of the mid-malleoli for 2 min in stirred water at 14.95 (0.02)°C. The foot was then removed from the water, the bag removed and the subject remained resting in a recumbent position for a further 10 min. During the CST the subjects were allowed to read but auditory stimuli were kept to a minimum. All subjects undertook each condition twice; the conditions were undertaken in a random order and separated by at least 4 hours.

Data are given as the arithmetic mean (SD). Data were analysed using a Wilcoxon Signed Ranks Test. The relationship between Tsk and blood flow was examined using Pearson's correlation. Statistical significance was taken as $P<0.05$.

Results

The average exercise duration undertaken to increase Tau by 0.3°C was 9.5 (2) min for stepping, 10.6 (2.6) min for cycling and 12.7 (3.0) min for arm cranking. Tau during the CST was similar in the control and blanket conditions (37.04 [0.18]°C, n=24) and significantly higher in the exercise conditions (37.26 [0.18]°C, n=36). Within conditions, there was no difference in Tau between the first and second tests.

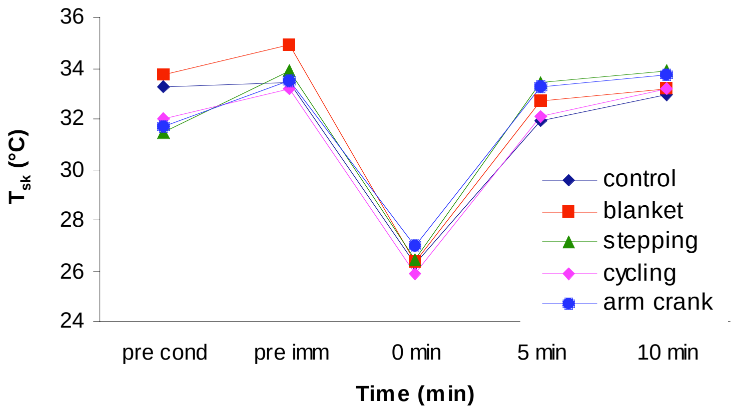

Figure 1. Mean great toe Tsk during CST in the different conditions. Each data point represents the mean of 12 observations (6 subjects, 2 tests).

Tsk during the CST was similar prior to immersion and after 5 min in each condition (Figure 1). These Tsk were used to classify the level of NFCI based on the criteria shown in Table 1, the resultant classifications ranged from normal to moderate/severe. Between the different experimental conditions, 2 subjects had the same classification as a result of their CSTs. One subject varied by one classification, one by three classifications and the remaining 2 subjects varied by four classifications. The most consistent categorisation was seen with stepping. This condition also provided the greatest number of "normal" responses.

The variability in Tsk between the test-retest for each condition is shown in Figure 2. No significant differences were identified, with the exception of the finding that that the variability in the stepping condition was less ($P<0.05$) than that seen in the control and blanket conditions pre-immersion.
The blood flow and Tsk in the 10 min after immersion were not linearly correlated.

Discussion

In this study, supposedly uninjured "normal" subjects were found to have a NFCI classification that ranged from "normal" to "moderate-severe". It is therefore concluded that mild to moderate NFCI is a fairly common condition2. As a consequence, a proportion of those individuals who enter the armed forces are likely to have an undetected, but classifiable, NFCI. The prevalence of mild to moderate NFCI raises the argument as to whether this mild form should be regarded as a normal rather than injured state.

To be a useful measure of injury and recovery, the CST should be as reproducible as possible with regard to the NFCI classification and discriminate between those that are injured and those that are not. Both the variability in the Tsk response immediately before the CST (pre-immersion), and the level of injury categorisation, were reduced by raising Tau by 0.3°C prior to testing, 10 minutes of stepping is a reasonable way of achieving this. Presumably, increasing deep body temperature a little completely removes any central vasoconstrictor input to peripheral blood flow and thereby negates this potential source of variability, leaving local factors (including degree of injury) to determine peripheral blood flow and temperatures. These findings need to be confirmed in patients with NFCI. As can be seen from Table 1, pre-immersion Tsk is important, as a temperature of less than 32°C at this time results in a categorisation of, at best, "moderate" NFCI. The lack of an effect of prior exercise on the variation in the test results observed 5 min post-immersion, suggests that the permissive influence of deep body temperature has been lost by this time as deep body temperature returned towards normal.

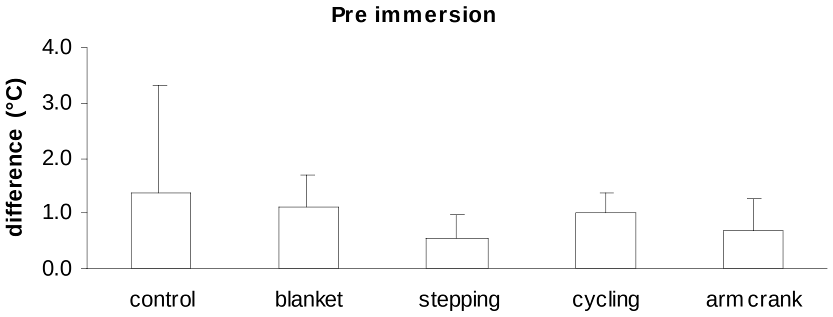

Figure 2. Mean (SD) difference between the two CST in Tsk prior to immersion and 5 min after immersion in each condition (n=6).

The lack of a linear relationship between Tsk and blood flow suggests that the changes in Tsk during the CST may be independent of skin blood flow as measured by photoplethysmography. The photoplethysmographic technique tends to be sensitive to changes in venous capacitance as well as blood flow. Thus, changes in venous capacitance following exercise and immersion may have been confounding the blood flow measures in this study. Additionally, a number of factors associated with the distribution of blood flow and heat loss to the environment mean that blood flow and Tsk would not necessarily be linearly correlated in the dynamic situation of a CST. Alternatively, the increase in Tsk observed after immersion may result from passive warming by the environment. This conclusion is supported by the results of the earlier study in which a non-vascular model was found to respond in a very similar manner to a "normal" toe2. More detail vascular studies using additional blood flow assessments and larger subject numbers are required to settle these issues.

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PHYSIOLOGICAL RESPONSES OF HUMANS TO LOCAL COLD STRESS

Ladislav Janský [1]*, *Vojtěch Vávra* [1], *Stanislav Vybíral* [2]

[1]Faculty of Biology, University of South Bohemia, Budweis, Czech Rep.
[2]Faculty of Science, Charles University, Prague, Czech Rep.
*corresponding author janskyl@seznam.cz

Introduction

Compared to physiological responses to whole body cooling, physiological responses to local peripheral cooling attract less attention, in spite of the fact that the whole body surface of humans is being rarely exposed to cold during the normal life. Furthermore, surprisingly very little effort has been made to explain the physiological background of the generally recognized positive effect of repeated cold water bathings on human health. Therefore, experiments were performed to study effect of local peripheral cooling of legs on human cardiovascular functions and on body temperature control.

Methods

Six male subjects (21 years, 67 kg, 182 cm) wearing trunks were used for experiments, performed in morning hours during the month of October. Control subjects were considered as warm acclimated, because during the summer season they were not exposed to cold. Prior to cooling they rested lying at thermoneutral conditions under a blanket. Then, after 15 min of acclimation to the erect position, standing subjects were immersed up to the knees into 12 oC water for 45 min (cold foot test - CFT). Air temperature during the experiment was 26,9 o C (relative humidity 46,8 %, air velocity 0,078 m.s-1). During the time course of the experiment changes in skin temperatures (finger, palm, forarm, thigh, chest, forehead), heart rate and systolic blood pressure were measured. Skin temperatures were monitored in second intervals by thermosensors (Analog Devices, U.S.A.), using a computerized data acquisition system. Thermosensors were attached to the skin by a tape. Heart rate and blood pressure were measured by the oscillometric blood pressure instrument Omron R3 (Germany). Metabolic rate was measured using a computerized paramagnetic oxygen analyzer (Dvorak, Czech Rep.) in 1 min intervals. Venous blood samples were taken prior to, 20 min and 40 min after the start of cooling and plasma catecholamine concentrations were measured using radioenzymatic kits (Catechola) by the RIA method (Immunotech – UVVR Prague, Czech Rep.).

Data obtained by the above mentioned methods served as control data and were compared to those obtained after local cold acclimation. Local acclimation to cold was induced by immersing subjects of the same group up to the knees into 12o C water for 30 min, 5 days a week, during a period of 4 weeks. Thus, 20 cold immersions were used to induce cold acclimation. At the end of the acclimation procedure similar parameters were measured during CFT as in control subjects prior to local cold acclimation.

In order to induce a greater stimulation of thermoregulatory responses, in a separate experiment, controls and locally cold acclimated subjects were immersed up to the armpit into 14o C water for 45 min.and rectal temperature and metabolic rate were monitored .

Data are presented as means ± SD. Statistical significance of data was assessed by Student’s paired t-test and set at the $p < 0.05$ level. Experiments were approved by the Ethics Committee at the Priesnitz Spa, Jeseník (Gräfenberg), Czech Rep.

Results and discussion

Local peripheral cooling of legs (water, 12oC for 45 min) induces immediate, but temporal decrease in skin temperatures. This effect appears not only in cooled, but also in uncooled areas of the body. The response is more evident in distal areas (thigh, finger, palm) than in central areas of the body. (Fig.1) Paradoxically, during the later phase of cooling, skin temperatures in some areas of the body (finger, forarm) tend to increase (1). Skin temperatures in all areas of the body fluctuate.

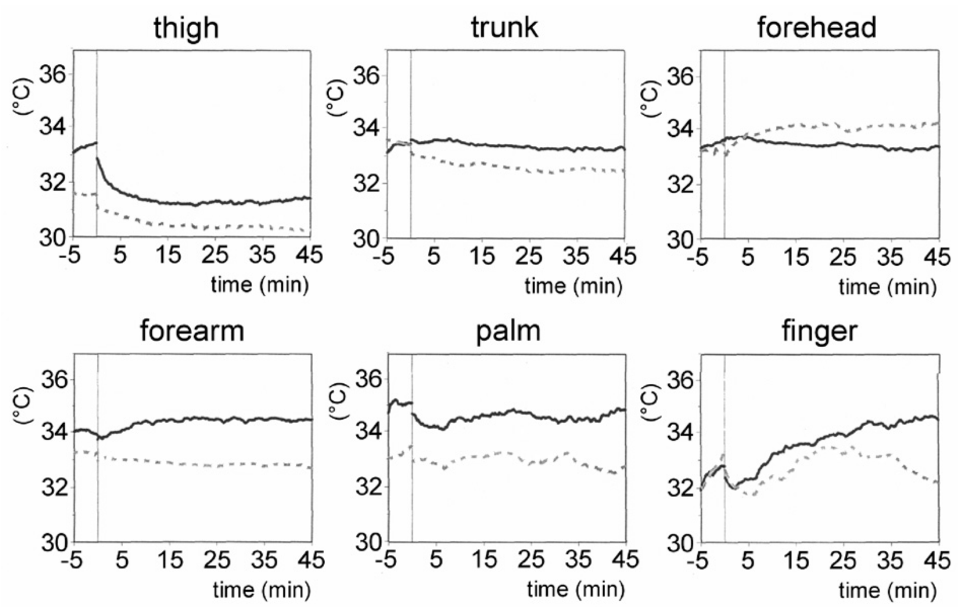


Fig.1. Changes in average skin temperatures in various areas of the body during local cooling (n=6). Dotted lines denote changes after locally induced cold acclimation.

Initial vasoconstriction and increase in heart rate induce a temporal increase in systolic blood pressure (Fig.2). After the first five minutes of cooling, when vasoconstriction starts to disappear (see Fig.1), blood pressure decreases, in spite of the fact that heart rate remains elevated during the whole period of cooling.

The following conclusions can be made on the basis of these observations:

1.Since the central body temperature does not change during the initial period of the local cooling (and even increases during the further time course of cooling - Fig.3), while the skin temperatures decrease, responses of the cardiovascular system are set into action by changes in the peripheral thermal input, solely.

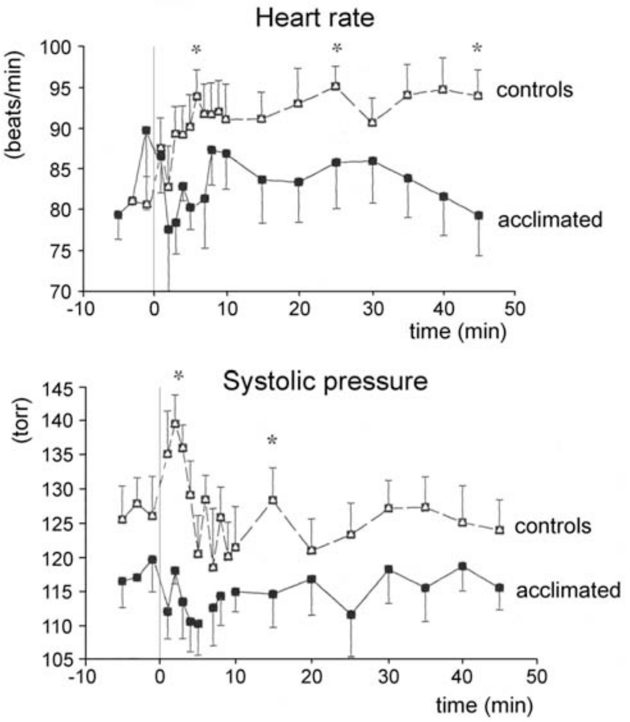


Fig.2 (above). Heart rate and systolic blood pressure beforeand during local cooling of controls and locally cold acclimated subjects

2. Since brain temperature increases and the increase in blood pressure attenuates, while heart rate remains elevated, redistribution of the cardiac output must occur during the later phase of cooling.

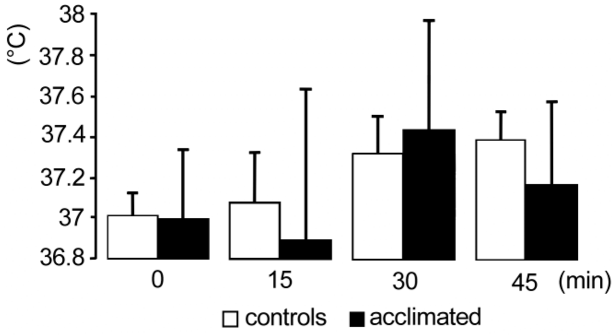
3. Although no changes in blood levels of catecholamines were observed 20 and 40 min after the start of local cooling (Fig.4), sustained vasoconstriction and tachycardia indicate permanent activation of the sympathetic nervous system (SNS). This discrepancy may be explained by unadequacy of the method used, which may not be sensitive enough to trace the minute activation of the SNS.

4. Since skin temperatures decrease also in uncooled areas of the body, it can be concluded that a generalized vasoconstriction occurs after local cooling.

5. Greater initial vasoconstriction in distal parts of the body surface and smaller vasoconstriction in central parts of the body surface indicate that the SNS is activated to different extent in different areas of the body during local cooling.

6. Fluctuations of skin temperatures indicate a mosaic of permanent changes of local heat loss from the body surface.

Fig.3 (below). Tympanic temperatures during local cooling in controls and locally cold acclimated subjects



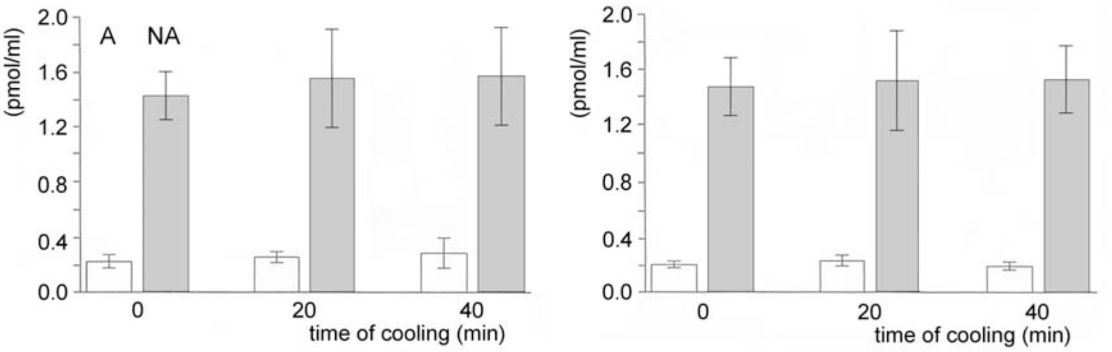


Fig.4. Blood levels of catecholamines (A, NA) during local cooling in controls (left) and locally cold acclimated (right) subjects

After **local cold acclimation** (for acclimational procedure see Methods) the average skin temperatures were found to be generally lower than that in controls (except for temperatures on the forehead) (Fig 1). Also heart rate and blood pressure values appeared to be lower and the initial increase in heart rate and blood pressure was abolished (Fig.2). Blood levels of catecholamines (Fig. 4) were not influenced by local cold acclimation, however, similarly as after the whole body cold acclimation (3,4).

Locally cold acclimated subjects, when exposed to **head out cold water immersion** showed nonsignificantly lowered rectal temperatures and no change in heat production (Fig. 5), compared to controls. When plotting data on metabolic rate against rectal temperature, no changes in threshold temperature for induction of cold thermogenesis and in the thermosensitivity of the body temperature controller were observed (Fig. 6). Thus no hypothermic type of acclimation was induced by the acclimational procedure used.

All these findings can be interpreted as follows:

1. Local cold acclimation attenuates the initial alarm reaction, which indicates a lowered reactivity of the SNS. Lowered skin temperatures may indicate an insulative type of acclimation, similar to that observed after the whole body cold acclimation (2).
2. Lowered skin temperatures indicate increased vasomotor tone on the body periphery. Since production of catecholamines is not increased this may be due to an increased sensitivity of adrenergic receptors. The low sensitivity of the method used makes this conclusion dubious, however.
3. Since repeated whole body coolings (total cold acclimation) induce 1. downward shift of the thermoregulatory threshold (2, 3), 2. increased capacity of heat production due to potentiation of nonshivering thermogenesis (4), 3. increased efficiency of vasoconstriction (4), it can be concluded that cold adaptation due to local cooling induces less extensive changes than the whole body cold adaptation. Whether the more intensive or longer lasting cold stimuli would induce similar acclimational changes as the whole body cold acclimation remains to be seen.

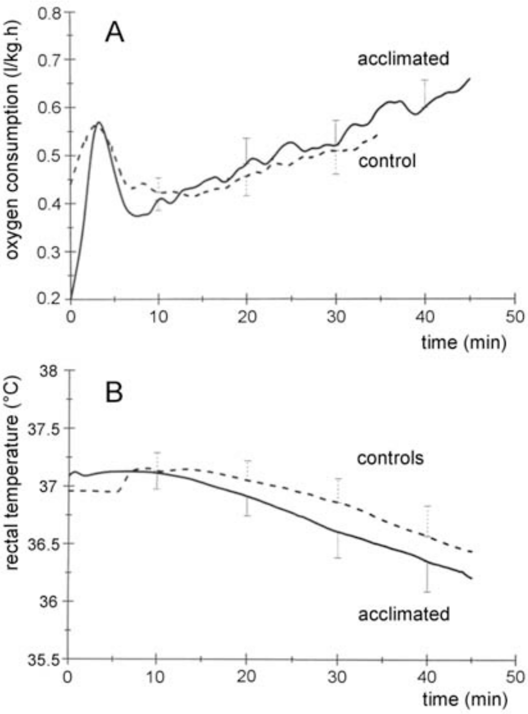
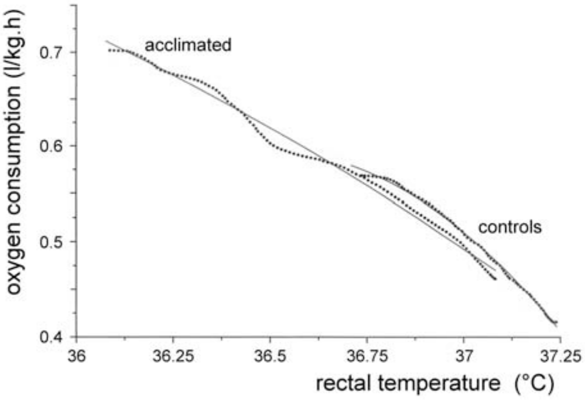


Fig.6 (left). Changes in oxygen consumption and rectal temperature during whole body cooling in controls and locally cold acclimated subjects

Fig.7 (below). Relationship between rectal temperature and oxygen consumtion during whole body cooling in controls and locally cold acclimated subjects



Conclusions

Our previous findings indicate that metabolic, hypothermic and insulative types of adaptation may occur in cold acclimated humans. While the whole body cold acclimation increases chances for survival under extreme cold stress, the biological value of the local cold acclimation is still obscure. It is suggested, however, that a lowered reactivity of the sympathetic nervous system could the reason for the positive curing effect of Priessnitz’s and Kneipp‘s procedures in patients suffering from hypertension or neurasthenia.

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HOW DOES EXPOSED SKIN TEMPERATURE VARY IN THE FACE OF COLD WIND – REFLECTIONS ON THE ASSESSMENT OF WIND CHILL EQUIVALENT TEMPERATURES.

Avraham Shitzer

Department of Mechanical Engineering, Technion, Israel Institute of Technology, Haifa, Israel
mersasa@tx.technion.ac.il

Introduction

Assessment of the effects of wind in cold environments on exposed skin areas has long been of great interest. Hill (2) introduced the kata-thermometer for measuring the cooling rate of the atmosphere by exposing to wind a shaded thermometer, initially heated to a temperature slightly above that of normal human blood. The time required for it to cool from 0.55ºC (1ºF) above, to 0.55ºC below the initial temperature was related to the cooling capacity of the environment. Winslow, Herrington and Gagge (10) have adopted a different approach by using human subjects in their partitional calorimeter. Heat loss from the body to the environment was expressed by an overall heat transfer coefficient. Siple and Passel (9) conducted experiments in the Antarctic in the 1940's to determine the cooling power of the subfreezing environment. They exposed snow-melted water in a cylindrical pyrolin (cellulose acetate) container, to combinations of environmental temperatures and winds and calculated the times required for the contents to freeze. A wind chill index was calculated, expressing the cooling power of the wind in a subfreezing atmosphere in complete shade and without any evaporation.

Up until recently, wind chill factors were estimated by the method due to Siple and Passel (9). This method, which had been criticized over the years, cf. e.g., (3,4), has recently been replaced by the weather services in the USA (5) and Canada (1) by a “new” wind chill temperature. Values assessed by this new method are considerably higher than those predicted by the old one. They are derived numerically, based on a number of assumptions, among which are: thermal steady state, angular-dependent convective heat exchange coefficient, radiation effects, “calm” wind conditions corresponding to walking at 1.34m/s (3 mph), etc. These assumptions, excluding radiation effects, are incorporated in the present study to calculate one-dimensional, transient heat conduction in a hollow cylinder, representing the exposed human head and face. Skin surface temperature variations are calculated along with wind chill-equivalent temperatures. The same convective heat transfer coefficient that is used in deriving the "new" wind chill temperatures (6), is employed in the analysis.

The principal purpose of this study is to emphasize the transient, rather than steady-state, nature of this problem.

Analysis

Exposure of humans to cold and windy environments has been analyzed as a steady-state problem e.g., cf. (6). This, however, is far from adequate since the process is clearly best described as a transient one. It initiates with the individual’s engagement with the outdoor environment upon exiting from a comfortable and protected indoor environment. In anticipation, humans don suitable clothes which leave only certain areas of the body exposed. Typically, these are the face and the ears and sometimes the hands as well.

In this study preliminary results are presented of a transient heat conduction model of the human head/face that is exchanging heat with a cold and windy environment. For simplicity, a homogenous, hollow cylinder is chosen to depict this body element. The following assumptions are made, many in accordance with those underlying the “new” wind chill index adopted recently by the weather services in the USA (5) and Canada (1): (i) the cylinder is in a transient thermal state, (ii) heat flow in the cylinder is by conduction alone in the radial direction, (iii) the cylinder is made of a homogenous material having thermal properties close to those of biological tissues, (iv) currently, no blood flow and/or metabolic heat effects are included, (v) a constant “core body” temperature, $T_{in,}$ is maintained at the inner surface of the cylinder (6), (vi) at the outer surface heat is exchanged by convection with an environment at a constant temperature, $T_{0,}$ and effective wind speed, U, at face level, taken as 2/3 of the value measured at normal meteorological observatory height of 10m, to account for the boundary layer (6), (vii) at this stage, radiation and evaporation effects are excluded from the analysis, (viii) “calm” wind conditions are assumed for wind speeds less than, and equal to 1.34 m/s (3 mph, Ref. 6).

An analytical solution to the problem, presented elsewhere (8), was obtained by the method of integral transforms. Data used in the calculation of the presented results are listed in Table 1.

Results and Discussion

Figure 1 shows the temporal variations of tissue temperatures for 10 hours from the initiation of the exposure to -15°C, at 30 min intervals. A thermal steady-state is seen to have been established in the tissue in about 7 hours, for the case presented here. As is to be expected, most of the changes in tissue temperatures occur during the first 2-3 hours. Afterwards, the heat exchange process slows down, due to decreased temperature differences between tissue skin surface temperature and that of the environment. Subfreezing tissue temperatures, below -1.5°C, are observed to have been established in sections of the tissue after a while, the first appearing on the surface of the skin after about 1:15 hour. Lower temperatures take longer to appear.

Table 1. Data used in the computation of result

Outer surface initial temperature (°C)	Inner surface temperature (constant) (°C)	Ratio of inner to outer diameters	Outer cylinder diameter (m)	Thermal diffusivity (m^2/s)	Thermal conductivity (W/m °C)
32	38	0.2	0.18	0.00047	0.535
Environmental temperature (°C)	"Calm" wind heat transfer coefficient (W/m^2 °C)	"Calm" wind speed (m/s)	Actual (at 2/3 wind speed) heat transfer coefficient (W/m^2 °C)	Measured wind speed (at10m height) (m/s)	Initial tissue temperature profile (arbitrary)
-15 (5°F)	15.5247	1.34	31.888	6.7 (15mph)	logarithmic

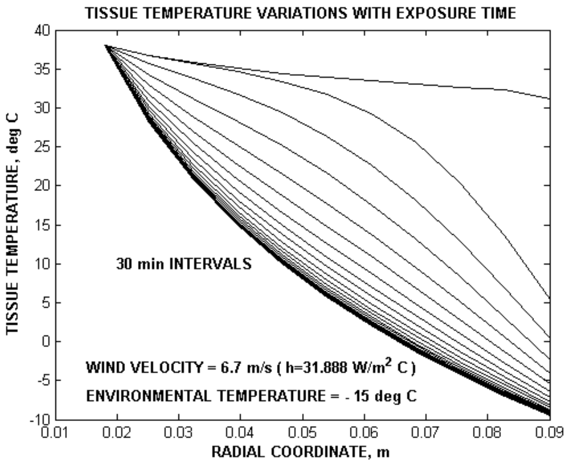

Figure 1. Tissue temperature variations with exposure time

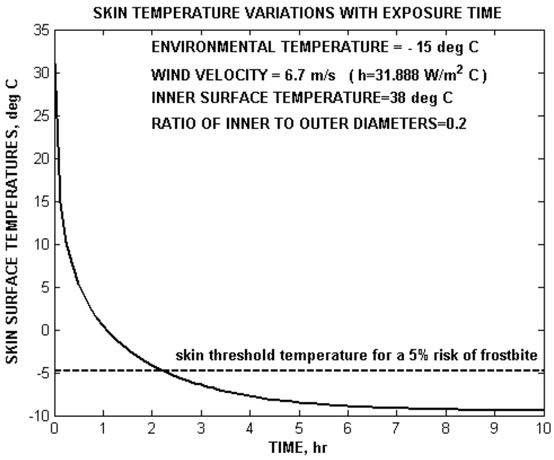

Figure 2. Skin temperature variations with exposure time

As far as wind chill effects are concerned, skin surface temperature is the most important variable since this is the site were the thermal communication with the environments takes place and where possible frost damages may occur. Figure 2 demonstrates how this variable changes in time. Also plotted is the skin threshold temperature for a 5% risk of frostbite, taken at -4.8°C (6). It is seen that, for the conditions of this study, this risk level may be reached after about 2:15 hours from the initiation of the exposure. The "new" Wind Chill Chart (1,5) does not indicate any imminent frostbite risk for these conditions.

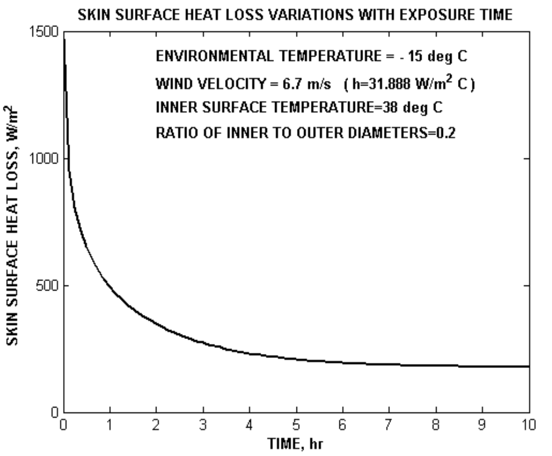

Figure 3. Skin surface heat loss variations with exposure time

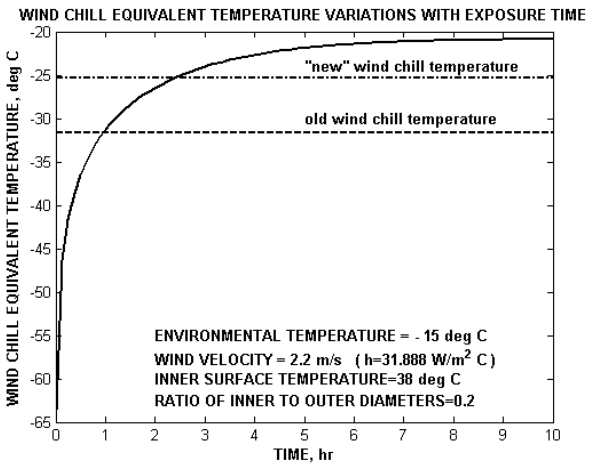

Figure 4. Wind chill equivalent temperature variations with exposure time

These values facilitate the estimation of skin surface heat losses, Fig. 3, and the assessment of wind chill equivalent temperatures (WCET), Fig. 4. WCET is defined as the air temperature of an equivalent environment that, under "calm" wind conditions, would entail the same skin surface heat loss to the environment, as in the "actual", windy environment, (6):

$$\mathbf{WCET = T_s - \frac{h_{actual}}{h_{calm}} * (T_s - T_0)} \qquad (1)$$

where T_s is skin surface temperatures, ºC, and h_{actual} and h_{calm} are the convective heat transfer coefficients, listed in Table 1, for actual and "calm" wind conditions, respectively.

The inherent transient nature of the effects of wind in a cold environment, is clearly demonstrated in Fig. 4. During the first few minutes of the exposure, WCET may attain extremely low values, i.e., -63°C. As the exposure continues, and less power (heat per unit time) is lost to the environment, Fig. 3, WCET increases gradually until, after about 7 hours, it practically reaches a steady-state value of about -21°C. The wind chill values predicted by both the old and the "new" wind chill charts are included in Fig. 4 for comparison purposes. It is seen that neither these indices predict a steady-state condition despite what is stated in their underling assumptions.

The "new" wind chill chart (1,5), and indeed the old one, contain "Frostbite Times". Highlighted areas in the chart differentiate four groups of 5, 10, 30 min and unlimited (no risk) exposure durations for a 5% risk of imminent frostbite. This risk is assumed to occur when the skin temperature has reached -4.8°C (6). Assuming a 6.7 m/s (15mph) wind speed, as above, and environmental temperatures of -23.3°C (-10°F), -31.7°C (-25°F) and -40°C (-40°F), wind chill temperatures according to the "new" wind chill chart (1,5), are -35.6°C, -46.1°C and -57.2°C, respectively. The frostbite times for these respective conditions are 30, 10 and 5 min. The present model predicts WCETs at -30°C, -40.1°C and -48.6°C, which are considerably higher. Times estimated by this transient analysis for 5% risks of frostbite, are also considerably higher at about 1 hour, 30 min and 20 min, respectively.

It should be noted, however, that all three methods of assessing the effects of windy and cold environments on humans that are included in Fig. 4, differ not only in the nature of the heat transfer process (transient versus steady-state) but in many other aspects. Among these are the different values of the heat transfer coefficients that were used to compute them. Thus, a full comparison of actual results for a given set of environmental conditions, is not attempted at this stage.

Conclusion

This study is intended to demonstrate the transient, rather than steady-state, nature of the effects of exposing the human head/face to cold and windy environments. Many additional factors are involved in this complex process, e.g., convection heat transfer coefficients (7), radiation effects, blood perfusion (and to a lesser extent also metabolic heat effects), direction of the wind relative to the exposed body part, core body temperature following a prolonged exposure, etc. These factors are not being considered here.

This study is not meant to address all these other factors, but, rather, to emphasize the non-steady nature of the problem, and point out directions in which further research should progress.

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THE ”DOUBLE SENSOR” - A NEW NON-INVASIVE DEVICE TO MEASURE CONTINUOUSLY CORE TEMPERATURE IN HUMANS

Gunga HC[*]*, Sandsund M,*[2] *Reinertsen RE,*[2] *Sattler F,*[3] *Koch J*[3]

[1] Charite University Medicine Berlin, Department of Physiology, Berlin, Germany
[2] SINTEF Health Research, Trondheim, Norway
[3] Draegerwerk AG, Luebeck, Germany
* corresponding author: hanns-christian.gunga@charite.de

Introduction

Fundamental to the study of human temperatures regulation is the accurate measurement of deep body core temperature. The relatives advantages and disadvantages of these and other measurement sites for body core temperature including the time response of the sensors have been the focus of much discussion since the benchmark investigations by Claude Bernard in 1876 nearly 150 years ago.[1-4,6-10]. Standard body core temperature sites (rectum, oesophagus, nasopharnyx or tympanum/auditory meatus) exhibit limited applicability in occupational health and safety environments.[5,7] Here, the ideal non-invasive measurement of core temperature has to meet several requirements such as i) the measurement site should be convenient, ii) the measurement should not be biased by environmental conditions, and iii) the changes should be quantitatively reflect small changes in the core temperature. The Draegerwerk AG has recently developed a non-invasive body core temperature sensor (“Double Sensor”) aiming to meet the measurement requirements described above. It was the aim of the present study to evaluate the applicability of this Double Sensor in fire fighters under different physical and environmental conditions and when placed on the cranium of the subject under a fire fighter helmet.

Methods

The study was performed in the work physiology laboratory of SINTEF in Trondheim (Norway). 20 male subjects (39.5 ± 10.2 years, height 1.80 ± 0.06 m, 83.8 ± 11.0 kg) participated in the study. Thermal (rectal, nasopharnyx, skin temperatures, Double Sensor temperatures) and cardiovascular data were collected continuously before, during and after the different experimental set-ups from 25-55% maximal intensity work load at 10, 25, and 40°C environmental temperatures. A detailed description of the experimental procedure is given in figure 1.

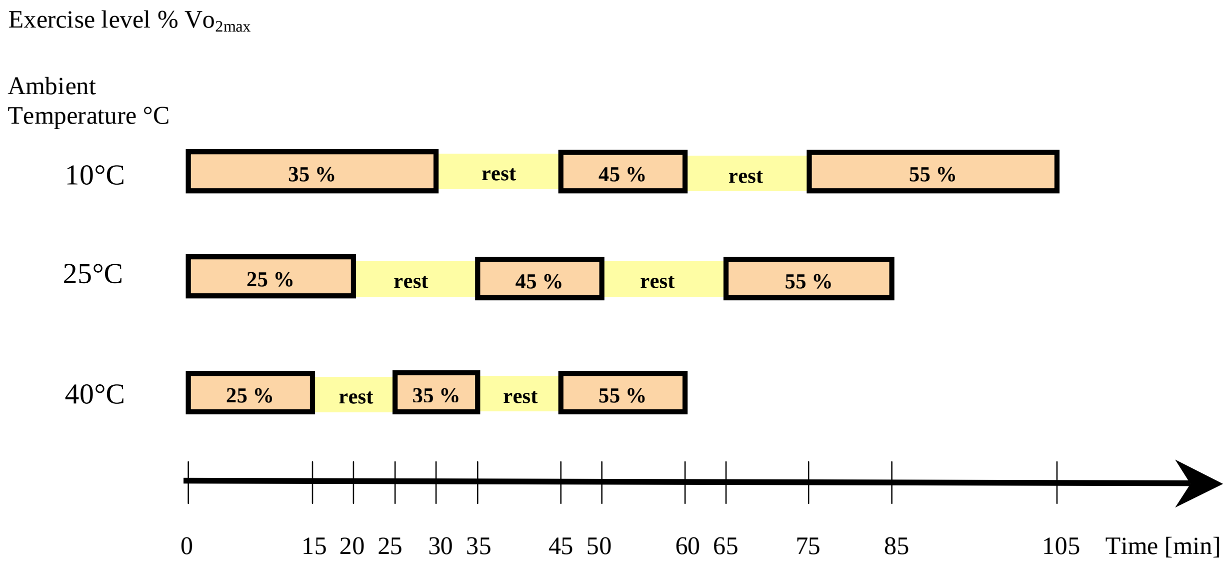
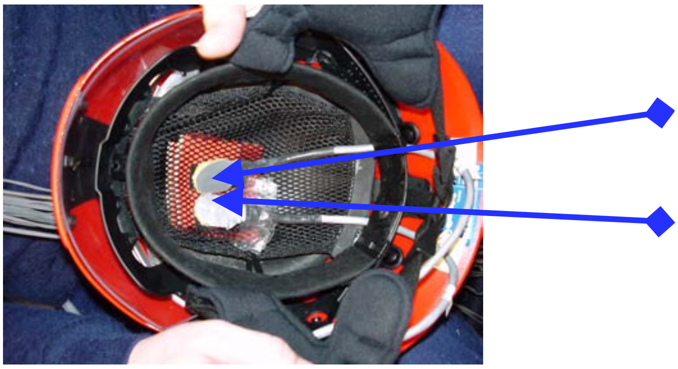


Figure 1 Experimental protocol of the study showing the different exercise levels and changing environmental temperatures in the climate chamber

For this study, two identical Doubles Sensor were placed inside the fire fighter helmet. The position of the two Double Sensors, one at the vertex and another slightly lateral, are shown in figure 2. The Double Sensor itself has been recently patented in 2003 (Patent No. DE 100 38 247, DE 101 39 705). Actually, this Double sensor is a heat flux sensor which contains two temperature probes. Between both temperature probes an insulation disc with its known heat conductivity (Ks) is placed. With the first temperature probe the temperature of the skin (Th1) will be measured, with the second temperature probe (Th2) the heat flux between both sensors will be detected. This second value will also recognize the dependence of the ambient temperature. Under the conditions that the heat flux between the sensors is the same as between the underlying tissue and during the balance of the heat the following equation can be used to calculate the core temperature of the body:

$$Tc = Th1 + (Ks/Kg)*(Th1-Th2)$$

Ks is the heat conductivity of the sensor and Kg is the heat conductivity of the tissue at this position.



Position of the **Double Sensor 1**

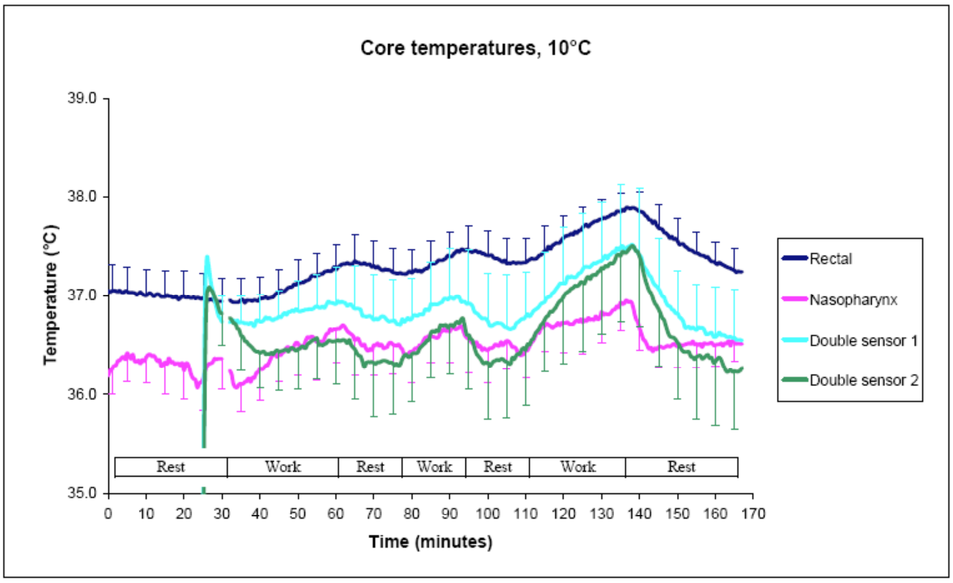
Position of the **Double Sensor 2**

Figure 2 Position of the Double Sensor 1 and Double Sensor 2 in the fire fighter helmet

Statistical Methods: GLM (general linear model) and paired t-Test were applied (SPSS 12.01). $P < 0.05$ was considered for statistical significance. The study was approved by the Regional medical Ethics Committee of the Faculty of Medicine at the Norwegian University of Science and Technology.

Results

The results are summarized in figure 3a-c.



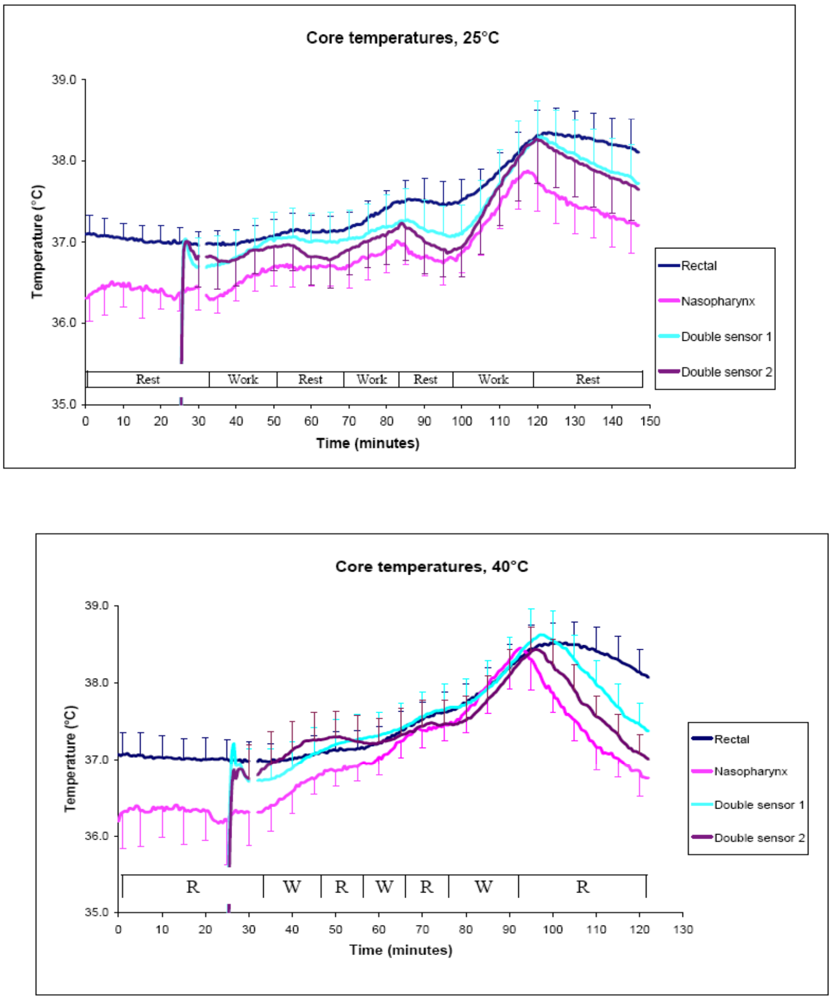


Figure 3a-c Rectal, nasopharyngeal, Double Sensor 1 and Double Sensor 2 temperatures during three working and four resting periods. (N=20, arith. means ± SD).

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STATIC AND DYNAMIC EVALUATION OF THE BIOPHYSICAL PROPERTIES OF FOOTWEAR - THE JOZEF STEFAN INSTITUTE SWEATING THERMAL FOOT MANIKIN SYSTEM

Igor B. Mekjavic[1*], *Borut Lenart*[1], *Miro Vrhovec*[1], *Martin Tomsic*[1], Naoshi Kakitsuba[2], Nigel A.S. Taylor[3] & Howard Oakley[4]

[1]Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute, SI-1000 Ljubljana, Slovenia;
[2]Department of Environmental Science and Technology, Meijo University, Nagoya, Japan;
[3]Department of Biomedical Sciences, University of Wollongong, Wollongong, Australia;
[4]Environmental Medicine Unit, Institute of Naval Medicine, Alverstoke, Gosport, United Kingdom
*corresponding author: igor.mekjavic@ijs.si

Introduction

We have previously reported the development of a thermal foot manikin for determining the static thermal insulation of hiking boots (1). The aim of the present study was to develop a sweating option for the thermal foot manikin, and a device with which to simulate gait, thus enabling the determination of biophysical properties under dynamic conditions.

Methods

The Thermal Foot Manikin System (Fig. 1) comprises a sweating thermal foot manikin, a gait simulator and a control unit.

Figure 1: *The thermal foot manikin system comprises three components: the Gait Simulator (left), the Sweating Thermal Foot Manikin (attached to the flywheel of the gait simulator), and the Control Unit (right).*

1. Sweating thermal foot manikin

The ten segments of the foot manikin are made of a silver-copper alloy. Each segment has a heater rated to 10 W (Minco Products Inc., Minneapolis, USA) mounted on the inner side of the silver-copper segments. Temperature of each segment (Fig. 2) is monitored by an RTD Pt1000 (Minco Products Inc., Minneapolis, USA) temperature sensor, also attached to the inner side of the silver-copper segments.

Water is distributed to 6 sweat glands in each of the ten segments by a peristaltic pump, which can deliver water at a rate ranging from 18 L/segment/hr to 1.8 L/segment/hr. Each segment is covered by three layers: a polypropylene layer to transfer the water away from the silver-copper shell; a cotton layer to evenly distribute the water across the surface; a water impermeable membrane, to allow only the

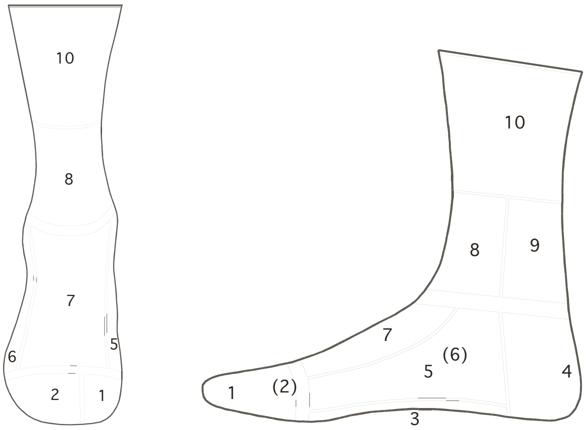

Fig. 2: Diagrammatic representation of the front and side views of the Thermal Foot Manikin. Segments are activated in three possible user-defined combinations: Segments 1 to 7 for testing shoes; segments 1 to 9 for testing hiking boots; segments 1 to 10 for testing boots extending to the mid calf.

transfer of water vapour through the membrane. Sensors attached to the cotton layer provide information regarding the water content of the fabric.

2. Gait simulator

The Gait Simulator simulates a range of walking paces and ground reaction forces. In this manner, the thermal insulation of test footwear may be determined under dynamic (walking) conditions. Simulation of gait is achieved by the combined actions of a large flywheel, powered by a three phase electric motor, and a pneumatically driven platform (Fig. 3). There are several points of attachment (holes) on the flywheel, varying in their distance from the centre of rotation. These different points of attachment allow the simulation of different stride magnitudes (0.2 to 0.4 m). The simulated walking pace is adjustable, and is determined by the rotation of the flywheel (10 - 45 min^{-1}). During operation, the spinning action of the flywheel raises and lowers the attached Thermal Foot Manikin. Though the thermal foot manikin is attached to the flyweel as a pendulum, its movement is limited by stainless steel guiding rods attached to the pneumatically driven platform. As the foot manikin approaches the mid point of the down phase, it makes heel contact with the metal platform connected to a pneumatic piston. During the latter half of the down phase, the thermal foot manikin pushes down against the metal platform, and causes it to be displaced downwards. The air pressure in the pneumatic piston determines the force exerted on the footwear by the platform, and therefore determines the simulated mass (24 to 125 kg) of the wearer. As the flywheel continues to spin around, it causes the heel to be lifted and the pressure to be exerted by the sole and finally by the toes. The combined rotation of the flywheel and constant pressure exerted by the

Figure 3: Simulation of gait is achieved by the combined action of the flywheel and pneumatically driven platform (see text for details).

pneumatically driven platform simulate the heel-to-toe action of walking and also simulate the ground reaction forces during such simulated gait.

The Gait Simulator may also be operated independently of the Thermal Foot Manikin Control Unit. In this mode, the durability and biomechanical properties of footwear may be tested.

3. Control Unit

The control unit maintains the temperature of the segments at the desired levels with National Instruments (Austin, TX, USA) Fieldpoint hardware and LabView software. To maintain the segment temperatures, the individual heaters are activated in discrete time intervals. The power to each segment heater is always identical (10 W) and constant . Within any time interval, power to a segment is determined simply by the cumulative time the heater was activated. The user defines the segment set-temperature and segment surface area.

Segmental insulation of footwear is calculated by dedicated LabView software. Values of insulation are tabulated online, and the programme automatically stops, once measurements of insulation vary by less than 0.01 $°C.m^2.W^{-1}$ between measurements at any given site, for all sites.

Water delivery to each segment is dependent on the water content of the cotton layer. Once the desired level of water content is attained, a microvalve prevents further delivery of water to that specific segment. The range within which water content is regulated is be set by the operator, and regulated by the control unit. The peristaltic pump is situated in a temperature-controlled box, and the tubes delivering water to the foot, insulated. This allows the determination of water vapour resistance in subzero temperatures.

Conclusions

The sweating thermal foot manikin attempts to simulate the principle of the Skin Model (2). By regulating the water supply to the cotton layer and preventing water coming into contact with the test footwear, we are able to measure water vapour resistance of a given shoe or boot.

The innovative aspects of the present Thermal Foot Manikin System, is that it can test three properties of footwear (mechanical, thermal resistance and water vapour resistance) over a wide range of temperatures. In contrast to other manikins (c.f. 3), it is capable of simulating a wide range of ground reaction forces. In addition, different levels of regional sweating may be simulated by removing the water vapour permeable membrane.

Acknowledgements

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HEAT TRANSFER THROUGH BICYCLE HELMETS: MEASUREMENTS USING A THERMAL HEAD MANIKIN

Paul A. Brühwiler[1]*, *Munkhbayar Buyan*[1], *Roman Huber*[1], *Josué Sznitman*[2], *Siegfried F. Graf*[2], *Thomas Rösgen*[2]

[1] Empa, Materials Science and Technology, Lerchenfeldstrasse 5, CH-9014 St. Gallen, Switzerland
[2] Institut für Fluiddynamik, ETH Zürich, Sonneggstrasse 3, CH-8092 Zürich, Switzerland
* corresponding author: Paul.Bruehwiler@empa.ch

Introduction

Bicycle helmets provide effective protection of the head from impacts, which is their primary function. Physiological aspects of bicycle helmets, on the other hand, have been a field of more recent interest (1). While health considerations due to overheating when wearing a helmet were shown to be relatively unimportant (2, 3), comfort is often important, and may influence performance in certain situations. Given the large variation in designs available, it is apparent that there is no general approach to designing bicycle helmets for optimal ventilation (4), although some studies have illustrated aspects of how air can enter a helmet (4, 5). Considering the geometrical complexity of a helmet and the situation in which it is used, unnecessary thermal discomfort for many cyclists is a likely consequence. The cooling of the forehead and scalp, which is what should be most strongly affected by wearing a helmet, is something that can affect comfort (6). More importantly, it is possible that, due to the lack of guiding principles, safety is sacrificed in some cases due to misguided notions of how to increase air flow, e.g., simply by adding holes and thereby reducing the amount of protective foam.

The object of this study was to begin to establish principles of bicycle helmet ventilation via a broad survey of current designs (24 helmets). Aspects of helmet ventilation which could be considered as following "common sense", such as maximizing the number of vents in front (4) (to let air in) or in the rear (letting air out again) were examined explicitly. Targeted modifications were undertaken to extend the observations.

Methods

The heat transfer measurements were carried out using a thermal head manikin in a climate chamber, described in detail elsewhere (7); the manikin is artificially divided into a "skull" (corresponding to the scalp) and a "face" section, in order to separately measure heat transferred in those physiologically-important areas. The climate conditions were 25±0.1° C and 50±0.5% RH. A fabric hood (Venosan®) was placed on the manikin to be able to simulate perspiration, but only the dry heat transfer data are presented here; because of this, the power levels are reduced from those which would be obtained with the nude manikin. Wind was simulated using a wind tunnel with a 0.5x0.5 m^2 cross section (7); two wind speeds were chosen here: 1.6 ms^{-1} ("slow") and 6.1 ms^{-1} ("fast"). Each measurement was obtained under steady state conditions; normally during a 20 min period starting approximately 40 min after setting the helmet and manikin in the appropriate configuration. Two head angles (0° and 30° forward from vertical) were studied, but only the results for 30° are presented here; the angle dependence has been discussed elsewhere (6, 8). The vent cross sections were measured by photographing the helmet from the front, indicating the area by hand in the digital image, and calculating the total indicated area, as described in more detail elsewhere (8). The face section of the manikin extends through the ears to a portion of the back of the neck (7), and is covered by a bicycle helmet in the forehead region and in small regions under the rim, corresponding roughly to what is expected in reality when one discusses the "face". The scalp section is normally completely covered by a helmet.

Results and discussion

Fig. 1 shows the basic results for the heat transfer for all helmets and the nude manikin, differentiating between the scalp and face sections of the manikin (7). The results were ordered based on the results for the scalp section at the slow wind speed. The nude manikin exhibits the largest heat transfer, as would be generally expected. Variations of up to 30% can be seen in the scalp section, whereas the maximum variations are about 10% in the face section; the smaller value in the latter case is intuitively sensible, given the relative importance of the helmet as a source of thermal insulation in the two areas. To understand the variations in the scalp section, we considered several possible sources, two of which we discuss here: a) forward vent cross section and b) number and placement of rearward- and upward-facing vents.

The vent cross sections are compared to the scalp heat transfer in Fig. 2. There is a weak correlation between the two, but the largest variations in cooling power are not directly correlated with similar cross section variations, and vice versa. The large cross section for Helmet 3, in particular, as well as the cooling power changes between Helmets 13 and 17, or 22 and 16, e.g., indicate that other aspects of the helmets are often more important.

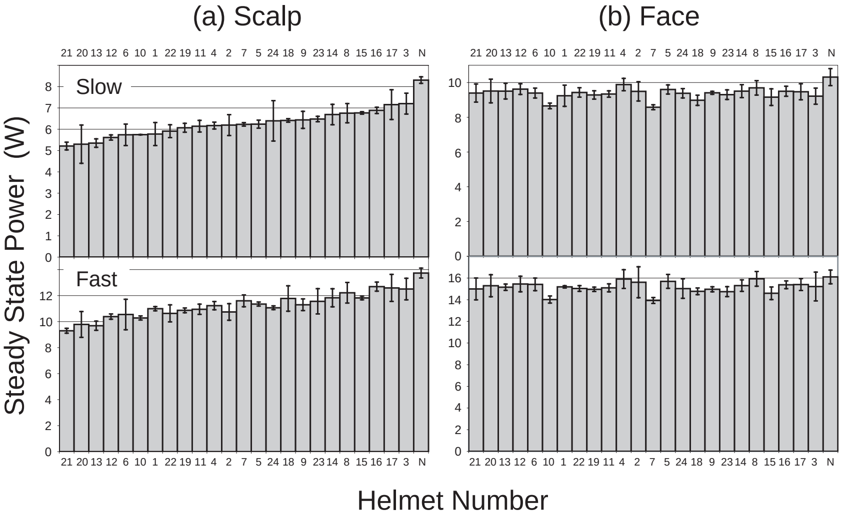

Figure 1. Steady-state heating power of the manikin in the indicated sections, for the given wind speeds, for all helmets tested. The nude manikin is indicated by “N”.

One issue of obvious importance is how air, after entering the space between helmet and scalp, is transported, and where it exits the helmet again; in other words, what kind of channels are formed by the helmet in contact with the scalp. This is a multifaceted issue, which can be divided into the aspects of the channel geometry (number, placement, and form), potential blockage (e.g., hair and/or comfort pads), and subsequent openings (air exit paths). It is difficult, after considering these aspects, to characterize them as simple numbers, which corresponds to condensing a three-dimensional problem into one dimension. We choose here to illustrate the study of the issue of the exit paths via modification of selected helmets.

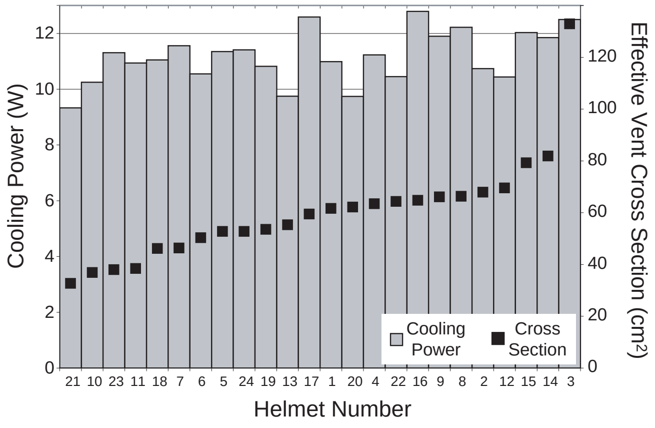

Figure 2. Comparison of the forward vent area to the transmitted wind cooling power in the scalp section, ordered according to increasing values in the former.

Since air pressure from the front drives air through the channels, one can imagine that openings further back along the helmet could reduce the cooling power in at least two ways: (1) By redirecting a large airflow which succeeds in countering the flow introduced by more forward-placed vents, thus reducing the forced convection due to those vents; (2) By effectively increasing the diameter of a given channel, thereby reducing the speed of the air in that channel and directing airflow out of the helmet. We studied this by selectively blocking vents in such a way that the channels underneath were unaffected, as illustrated in Fig. 3(a); we covered all vents into which air could not stream from the forward direction. Fig. 3(b) displays the effects of the modifications for a subset of helmets, including four with superior ventilation (Helmets 3, 8, 16, 17). We found only minor changes in the face section, as expected. The same was true for several helmets in the scalp region. However, for Helmets 2, 3, and 8 there was a noticeable effect. For Helmets 3 and 8, an improvement was obtained. Both have a relatively large air channel volume toward the rear of the helmet, suggesting that airflow is diverted from the optimal path in the normal configuration to reduce the obtainable level of cooling. For Helmet 2, on the other hand, the cooling power decreased. In this case we found that the air channels converged to a single, narrow channel at the rear of the helmet. It is apparent that this would increase the pressure in the closed-vent configuration, reducing the flow of air through the forward channels, whereas in the normal configuration the rear vents serve as flow enhancers. Effects such as these may partially explain the higher sensitivity at the back of a manikin found in an earlier study of six helmets (9). More importantly, they show that even some of the best-ventilated helmets are not fully optimized, and could deliver better forced convection ventilation with fewer vents. This might allow greater use of protective foam in their construction, enhancing the level of protection offered.

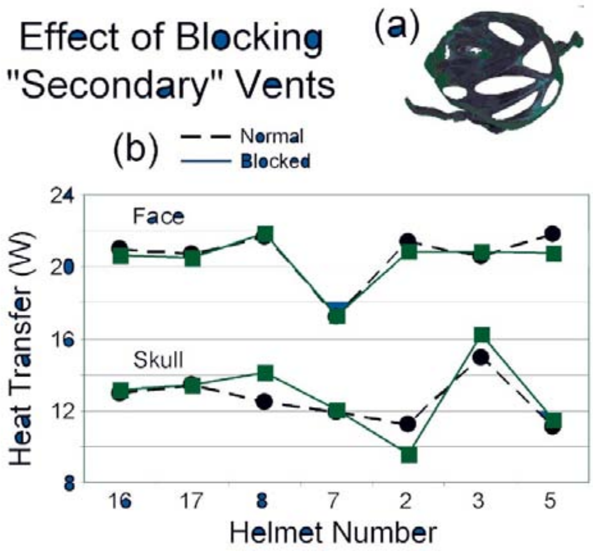

Figure 3. (a) Illustration of the method used to block rearward- and upward-facing vents. (b) Heat transfer before and after modification for the indicated helmets.

Conclusions

The results presented here and elsewhere (6, 8) show that the myriad of helmet designs found for modern bicycle helmets yield a range of scalp ventilation levels, varying up to about 30%. The vent cross section, which should limit the amount of air flow available, is not trivially reflected in the ultimate performance. We ascribe this to the three- dimensional nature of the helmets, causing a complicated interaction of this and other parameters. Nevertheless, variation of a single parameter for a given helmet allows effects of that parameter (vent configuration, here) to be elucidated. The relative degree of scalp cooling for a given helmet can be noticeable to the wearer and correlates well with manikin data under specific conditions (6); it remains to be seen if this is true for interhelmet comparisons, or under levels of activity which induce perspiration (10).

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THE SUCAM PROCEDURE FOR THE USE OF PPE IN AGRICULTURE-A CASE STUDY

*Torsten Hinz**,

[1] Institute of Technology and Biosystems Engineering, Federal Agricultural Research Centre, Braunschweig
* corresponding author torsten.hinz@fal.de

Introduction

Work may be dangerous or may have not wanted impacts on human health and welfare. Several working places and steps of work include a possible risk potential due to load and exposure by:

- mechanicals stress
- thermal stress
- radiation
- vibration
- noise
- harmful agents.

Harmful agents for example chemicals are to consider in different ways. They may be solid, liquid or gaseous. Their uptake by individuals is possible penetrating the skin or the breathing system. The oral path will be mainly neglected.

In all cases possible risks must be excluded by diminishing the load or using protective measures to keep limits given by legislative regulations. These measures my be connected with a kind of machinery but will be at least personal protective equipment (PPE). In the past performance criteria of PPE were reflecting to the efficiency of protection only, without any other considerations like comfort, applicability or purpose and wearing time. For chemical protective clothing accidental or emergency use was the target.

But nowadays the problems of the use of PPE are seen in general much broader.
This leads to the creation of the so called SUCaM procedure:
Selection, Use, Care and Maintenance

Method

At the present time different groups create a SUCaM guidance for particular fields of load for example noise protection (1), respirators (2) and chemical protective clothing (CPC) (3). At least there should be a model which covers all single aspects of load and work. The principle approach is given in figure 1 which defines and explains the single steps of the procedure: What means what and who is the addressee?

The two first parts selection and use are more personal related while care and maintenance target the product, the protection measure. Starting will the procedure with risk assessment for a particular situation of work considering all possible kinds of hazard and exposure. Comparison of actual values with allowable levels gives the need of protection and its required efficiency. Duration of exposure and expected wearing time of a protective measure is part of risk assessment and an important factor of selection of PPE. Cross compliance with other stress or ergonomic factors are to take into account. Other considerations are availability and logistic aspects for example the possibility of PPE rental. Use covers the questions of training and the very important instructions for use. Training is required by the Directive 89/656 section 11 Article 4. Employees shall be made aware of relevant safety procedures and shall be instructed on the function and limitations of their protective measure. This includes limited wearing times and safe donning and doffing from the viewpoint mainly of the wearer. Especially for clothing with a lower degree of protection the question arises to change clothing after work.
In contrast to selection and use care and maintenance are mainly product related as mentioned above. Main factor of care is cleaning of the equipment and decontamination if work has been carried out in an atmosphere which was contaminated by hazardous substances. Maintenance describes the problems of storage repair inspection and at least disposal. Here is an important feed back given to instruction for use, because the supplier of PPE must give answers to all these questions.

Example Agriculture

Food and agricultural non-food production is characterized by a wide variety of work. It has to be distinguished between indoor work e.g. in livestock buildings or greenhouses and outdoor mobile working places, that means on self propelled harvesters or tractors with and without mountings. Particular stress factors result from climate conditions and particular work and require specific means of protection. Table 1 gives an overview to the work fields and the targets for protection.

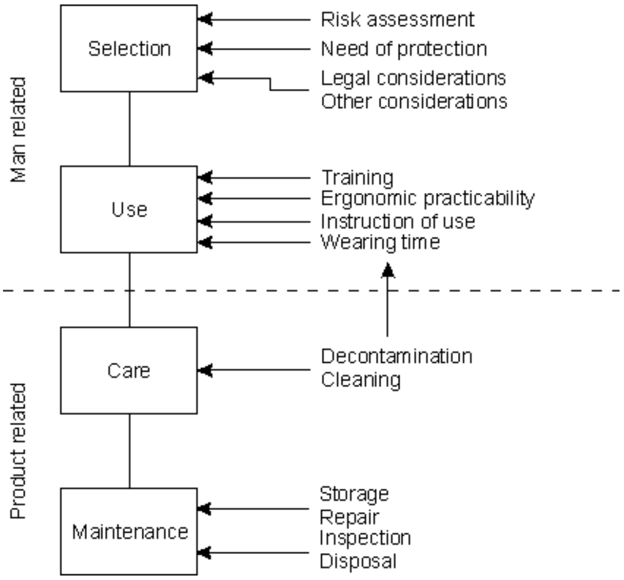

Figure1. Scheme of the SUCaM procedure

Table 1. Application of PPE in agriculture

Work field	Protecting
Use of pesticides, disinfectants, work in dusty atmosphere	Respiration
Handling of lifted goods, work on tress handling agric. mobiles, contact with claw and hoof animals	Head
Handling agric. mobiles, contact with claw and hoof animals	Foot
Work with saws and cutter, handling chemicals	Eye and face
Work on non capsulated mobiles, with motor saw, feeding pigs	Hearing
Work with saws and cutter, handling chemicals	Hand
Work with motor saws, handling chemicals, pesticides applic	Body

Main targets of protection are hearing, respiration and the body, that means the skin, due to the exposure to noise and airborne contaminants. Airborne contaminants in agriculture are gaseous and particulate. Gases occur in animal production during handling manure or silage and applications for conservation or controlling pests. A further source exist by the possible evaporation of liquid particles of sprayed agrochemicals for disinfecting animal houses and for plant protection, that means the use of pesticides. Particulates expose farmers during field operations and in animal houses. They influence mainly respiration with toxic or allergic effects, but they may also affect the skin. That’s the reason of the upcoming discussion of special clothing against allergic hazard in animal production.

In figure 2 a flow chart to select protective clothing against hazardous agents is given. s These agents are mainly chemicals but in future biological materials will be taken into account. For protective clothing the network of CEN standardization with type 1 to 6 is the base.

Starting point is the identification of the agents and their possible hazards depending on their state. If exposure to gases or vapours is given suits type 1 or 2 are to consider. These are severe emergency suits and not applicable in agriculture. Here the discussions for use start with liquids and e.g. the use of type 3 or 4 depending on national limit values and legal demands. Application of pesticides with may probably evaporate in hot climate regions or in greenhouses are targets. As a minimum requirement of protection type 6 is available to protect against the sprayed highly diluted pesticides. Same intentions are valid for the use of disinfectants in animal production. To protect against particulates (PM) type 5 is to use.

Looking to figure one additional considerations are demanded. For agricultural production especially for work on the fields or in fruit gardens the colour and the design are important criteria. Price and availability are no secondary questions. Of course it must be decided for one way ore re usable suits. Most important information farmers will get from the instructions for use of the pesticides in which normally safety advices are included. Looking to use it must be clear that the suits are for work only and must be changed after this. For care and maintenance the farmer must consider correct storage in good ventilated rooms, cleaning or washing separately. For disposal different national instructions may exist. It must paid attention to interaction with the environment. For a further use it must be ensured that there are no leaks in the suit.

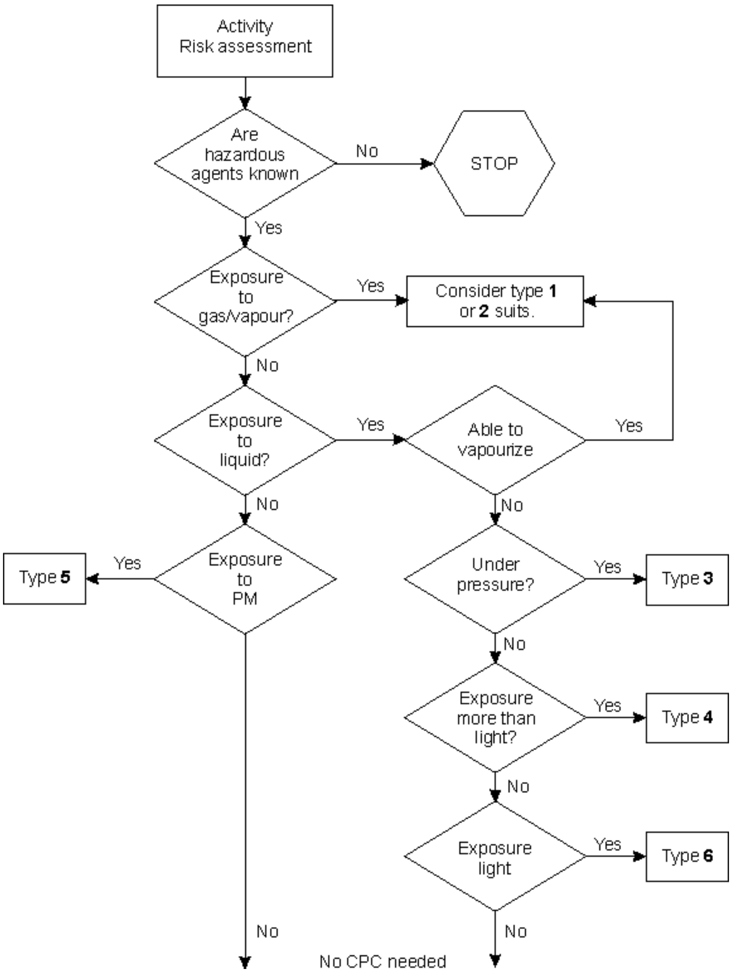

Figure 2. Selection chart for hazardous agents protective clothing

Conclusion

Actually discussed procedures for selection, use, care and maintenance of different kinds of PPE can be a good assistance applicable for different regions of work including agricultural production.

Literature

1. EN 458 (2004) Hearing protectors-Recommendations for selection, use, care and maintenance Guidance document
2. prEN 529 (2005) Respiratory protective devices-Recommendations for selection, use, care and maintenance-Guidance document
3. CEN TC 162 WG3 doc N 507 Protective clothing- Guidelines for selection, use, care and maintenance of chemical protective clothing

A SET-UP FOR FIELD STUDIES OF RESPIRATORY DEPOSITION IN HUMANS

Joakim Pagels1, Jakob Löndahl2, Jingchuan Zhou2, Mats Bohgard1 and Erik Swietlicki2

1 Div. of Ergonomics and Aerosol Technology, Lund University, P.O. Box 118, SE-22100, Lund, Sweden
2 Div. of Nuclear Physics, Lund University, P.O. Box 118, SE-22100, Lund, Sweden

Introduction

It has been estimated that airborne particles in ambient air (e.g. PM10 and PM2.5) leads to a loss of 6.4 million years of healthy life annually in the world (WHO 2003). The corresponding estimate for Europe is 750,000 years (WHO 2002; Ezzati et al. 2002) and for Sweden 2,500 years (Forsberg et al. 2005). It has been suggested that fine and ultrafine particles, especially from combustion sources, have a stronger association with adverse health effects than larger particles (Donaldson et al. 2001). The biological mechanisms by which particles affect health at moderate levels in the industrialised world are not fully understood. Susceptible sub-groups such as people with pre-existing respiratory or cardiovascular diseases, elderly and children have been identified.

In 1881, Tyndall made the first observation of aerosol particle deposition in the respiratory system. The probability of an inhaled particle to be deposited in the human airways depends on its size, shape and chemical composition as well as on the breathing pattern and airway geometry of the inhaling person. The term “respiratory deposition” refers to the mean probability for an inhaled particle to be deposited in the respiratory system. Most knowledge of respiratory deposition comes from measurements of particle concentration in inhaled and exhaled air using monodisperse hydrophobic particles in healthy young test-persons. There are surprisingly few experimental data available for ambient particles and ultrafine particles in general. In addition there are only few experimental data for ultrafine particle deposition in susceptible sub-groups (Chalupa et al. 2004). To fill this gap there is a need for experimental methods with which large groups can be studied in various environments e.g. at the low concentrations often encountered for ambient particles. An important parameter rarely taken into account is the hygroscopic growth into solution droplets that occurs in the respiratory tract for soluble species

The aim of this work was to develop and characterise a fast respiratory deposition method suitable for field measurements in humans. The method should have well-documented accuracy and allow fast measurements (less than 15 min).

Respiratory Deposition Method

The system can be divided into three main parts: aerosol generation, breathing system and measurement system. The two latter parts are shown in figure 1.

Aerosol Generation

Two different sources of aerosol were used, hygroscopic sodium chloride and hydrpophobic di-ethyl-hexyl-sebacate (DEHS). Polydisperse aerosol was generated with a nebuliser (Model 3076, TSI Inc., US), sodium chloride from a distilled water solution with 1% salt and DEHS from an ethanol solution with 0.1% DEHS, which resulted in a dried aerosol with a number geometric mean diameter (GMD) of 50-80 nm. In experiments involving human test persons the wet aerosol from the nebuliser passed a single nozzle impactor with a cut-off diameter of 0.7 µm. This reduced the mass concentration by a factor of 5-10. The ethanol was subsequently adsorbed in two active charcoal denuders. The aerosols were diluted with particle free air in a 1 m3 box in order to decrease the RH below 30% and achieve the desired number concentrations (50,000-430,000 cm-3). Typically a particle concentration of 90,000 cm-3 was chosen. The arrangement of the system is shown in Figure 1. It basically consists of a mouthpiece, two tanks made of stainless steel connected by a T-shaped brass piece with two one-way valves, an automatic two-way valve, a drier and a particle spectrometer. When a human test-person inhales, air is drawn actively from the larger tank for “inhaled” air. Inhaled and exhaled air is separated by two one-way valves (Lip membrane, Laerdal medical, Norway), of the “duck-bill” type, which opens with minimal flow obstruction. The valves are made of silicon rubber, but were covered with a 50 nm thick layer of gold applied with vacuum deposition (Auto 306, Edwards, UK) to decrease losses by electrostatic deposition. The exhaled aerosol enters a smaller tank that is heated to 38-40 °C to prevent condensation. Both the inhalation tank and the exhalation tank are thus open to the surrounding atmosphere and operate at pressures near ambient. The breathing continues until a sufficient number of particles are counted to calculate the deposition, normally between 10 and 20 minutes depending on the aerosol concentration. A pressure transducer (PasCal 100, Hoffrichter, Germany) connected to a pneumotachograph (Type 1, Dr. Fenyves und Gut, Germany) is used to register the exhaled flow-rate and breathing frequency. Temperature and RH are measured in the aerosol sampling lines just after exit from the two tanks using capacitive sensors (Hygroclip S, Rotronic, Switzerland).

Measurement System

In both systems the aerosol concentration is measured in the reservoirs for inhaled and exhaled air. The sampling location is chosen with a computer controlled two-way valve (Solenoid Valve, type 330, Bürkert, Germany). The aerosol is dried with a 48" Nafion single tube drier (MD-070, Perma Pure, NJ, USA), which reduces the RH to below 25%. Measurement of the particle size distribution was made with a scanning mobility particle sizer consisting of a differential mobility analyser (DMA, Model 3071, TSI Inc., US) and a condensation particle counter (CPC, Model 3010, TSI Inc., US). The DMA is operated in a closed loop set-up with a diffusion drier (Model 3062, TSI Inc., US) in the sheath flow to reduce the RH in the DMA to below 5%. Temperature and RH is measured after the nafion drier and in the DMA sheath flow loop.

A computer program (written in LabVIEW 7.1) was constructed in order to control the particle spectrometer, record the breathing pattern, control valves and sensors and continuously calculate the respiratory deposition.

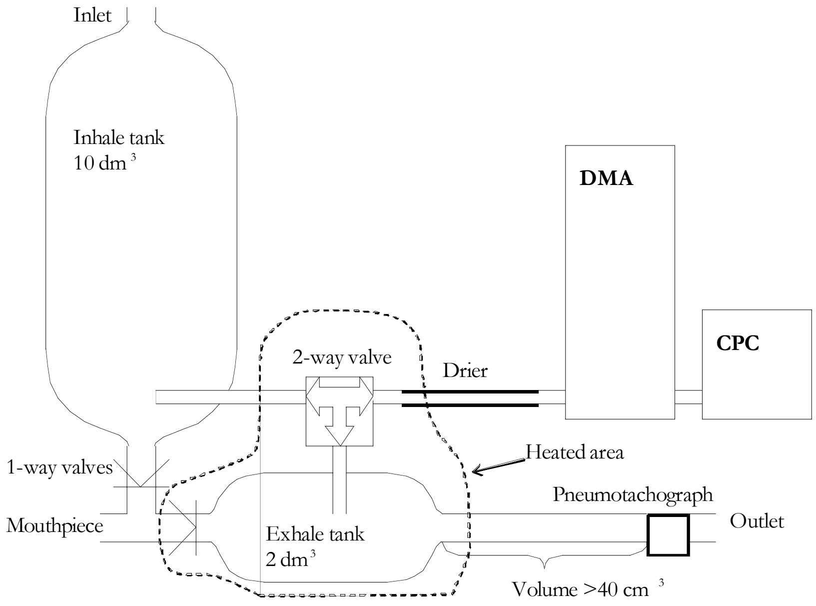

Figure 1. Schematic figure of the flow-through system

Method Characterisation

The flow-through method was characterised with reference to losses in the breathing system using a sinus wave piston-type breath simultor. When determining respiratory deposition, corrections must be made for particle losses in the equipment, DFequip.

$$DF_{human}\left(d_{p,i}\right)=1-\frac{C_{ex}\left(d_{p,i}\right)}{C_{in}\left(d_{p,i}\right)\cdot\left(1-DF_{equip}\left(d_{p,i}\right)\right)} \quad (1)$$

Where dp,i is the particle diameter in size-channel i and Cin and Cex denote the particle concentration in the inhaled and exhaled samples.

Experiments with human test-persons

The main part of the validation experiments were performed in one healthy male test-person (26 years old) to minimise physiological variations. The test-person followed suggested (square wave) breathing patterns on a computer screen.

To estimate the precision of the method, NaCl aerosol was inhaled in three “identical” experiments (on the same day) with breathing frequency 10 ± 0.1 min-1, minute volume 10 ± 0.1 L/min. The measurement time was 15 minutes for each of these sessions.

To validate the sensitivity of the method, deposition of NaCl was compared for three different breathing patterns, 6 ± 0.5 min-1, 10 ± 1 min-1 and 15 ± 1 min-1. Hydrophobic DEHS particles were inhaled at 10 ± 1 min-1 and 10 ± 1 L/min.

The experiments were performed at a concentration of 100,000 cm-3. The inhaled mass concentration in experiments with human test-persons was below 100 µg/m3 as determined with combined measurements with an APS 3321 and the SMPS.

Modelling respiratory deposition

Respiratory deposition predicted with the ICRP 66 model (ICRP, 1994) was calculated for a healthy male, breathing through the mouth at 10 L/min with frequencies 6, 10 and 15 min-1. Hygroscopic growth was incorporated in the model by assuming RH=99.5% throughout the respiratory tract and immediate growth to the equilibrium size.

Results

After covering the one way valves with gold, the deposited number fraction in the system decreased with up to a factor of two and is below 6% for 20 nm particles and approximately 1% for 100-300 nm.

The respiratory deposition determined with the system was found highly repeatable in identical experiments with a single test-person (Figure 2). The method is clearly sensitive enough to distinguish between the three different breathing patterns in single experiments (Figure 3). The variations are in relatively good agreement with the ICRP model. Figure 4 illustrates the difference in deposition between hygroscopic NaCl particles and hydrophobic DEHS particles. The agreement with the ICRP-model is relatively good, indicating that the RH is close to 99.5% in regions of the respiratory tract where particles were deposited.

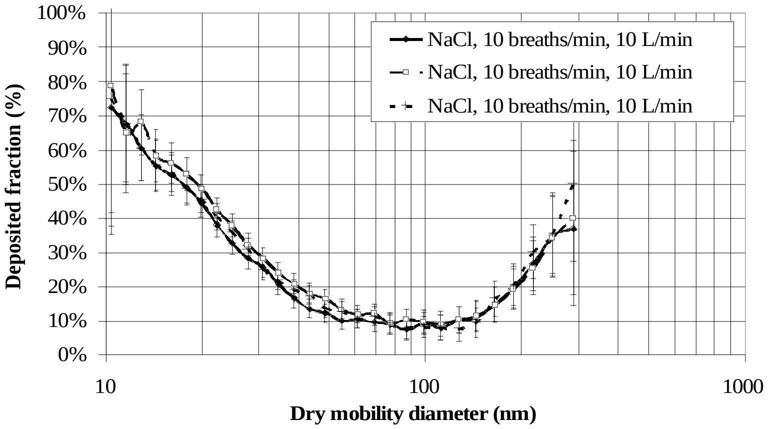

Figure 2. Respiratory deposition of NaCl for a single test-person in three identical experiments. Breathing frequency, 10 min-1, minute volume 10 L/min Error bars show a 95% confidence interval due to counting statistics.

Discussion and Conclusions

The flow-through system performed favourable in experiments with hygroscopic aerosols in human test-persons. The precision of the method investigated with “identical” experiments with semi-controlled breathing patterns resulted in variations below 5% (DF = x ± 5%) for the main part of the size interval. The method is sensitive enough to quantify differences between breathing patterns and

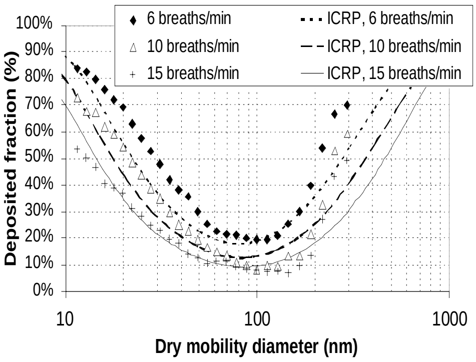

Figure 3. Respiratory deposition of NaCl in a single test-person. Single measurements with breathing frequencies of 6, 10 and 15 min-1 and an average flow-rate of 10 L/min.

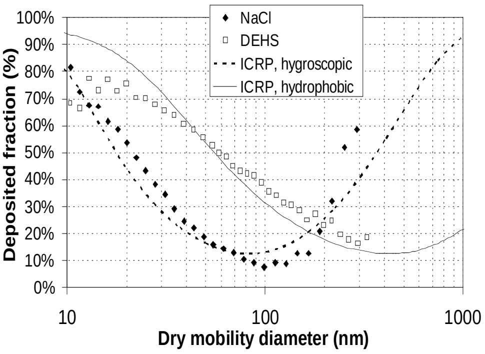

Figure 4. Respiratory deposition of hygroscopic NaCl particles and hydrophobic DEHS particles in a single test-person. Breathing frequency 10 min-1, minute volume 10 L/min.

differences between hygroscopic and hydrophobic aerosols. Respiratory deposition increased for all particle sizes for decreasing breathing frequency since the deposition efficiency of both diffusion and sedimentation increases with residence time. Our results with NaCl and DEHS and comparisons with the ICRP model shows that the hygroscopic particles deposit as if grown to their equilibrium sizes at RH=99.0-99.5.

In conclusion, the method offers a fast and relatively simple way to determine respiratory deposition in human test persons. The method performed well in precision and sensitivity tests. We plan to use the described method on larger groups of test-persons with varying respiratory status in various environments, including street canyon, fresh wood smoke and indoor aerosols.

Acknowledgements

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THE EFFECT OF MOVING NATURAL IMAGES ON PHYSIOLOSICAL RESPONSES

Ryuichi Uchikawa 1, Jeong-Mi Lee1, Yeon-kyu Kim1, Minoru Koriyama1, Sachiko Nagayoshi1, Yvonne Chang2, Shigeki Watanuki1*

1 Ergonomics Laboratory, Department of Human Living System Design, Kyushu University,
Fukuoka, Japan
2 Solution Produce Group, Sony PLC Inc., Tokyo, Japan
* corresponding author r-uchi@rms.design.kyushu-u.ac.jp

Introduction

People struggle with many stress in their daily lives. Routine hassles may have significant negative effects on a person’s mental and physical health. Stress may influence the onset and course of various type of disease or illness (5). It is known that the natural images make reduce stress and make relax a person. However, effects of moving natural images without sounds on physiological responses are not clear. In this study, the effects of moving natural images without sounds on young adult’s physiological and psychological responses were investigated using indices of autonomic nervous system (ANS).

Methods

Participants

Participants were 30 healthy undergraduates and graduates (male, 15;female, 15; mean age, 22.14±1.40). Females participated in this experiment in the follicular phase of menstrual cycle All participants provided written informed consent after the explanation of the experimental purpose and procedures, and were paid reward for their participation.

Procedures

Participants wore T-shirt and short-pants during experiment. Experiment was performed in an electrically shielded, sound-attenuated chamber. Room temperature and relative humidity were set at 28℃ and 50%, respectively. The 48 inches plasma TV (SONY) was used for display of images and was located 1.5 m in front of the participants.

Repeated measurement that one participant receives all 6 times repetition of 3 conditions— rest, stress, and natural images conditions was performed. All stimuli were presented for 3 minutes respectively, and grey screen was displayed during rest condition. A presentation order of stress and natural images stimuli for each participant were counterbalanced by combination of presentation orders according to rotation method.

For the selection of stress stimuli, 154 pictures were collected from the web and transformed the stress-related pictures. To compose six stress stimuli sets of similar stress intensity, those images were evaluated their stress intensity by 14 undergraduates and graduates (8 males and 6 females) with 5-point Likert scale. 54 among 154 pictures were selected in order of high average of stress intensity, and 9 images were evenly distributed to each set so that six sets have the similar stress intensity.

As the stimuli of natural image condition, 5 videos without audio that had photographed in the different locations respectively were used. Figure 1 show the examples of natural images. Grey screen was adopted as a control stimulus. Subjective evaluation was also executed for the moving natural images. Preference- and relaxation-related adjectives was evaluated on the 7-point of semantic differential scales.

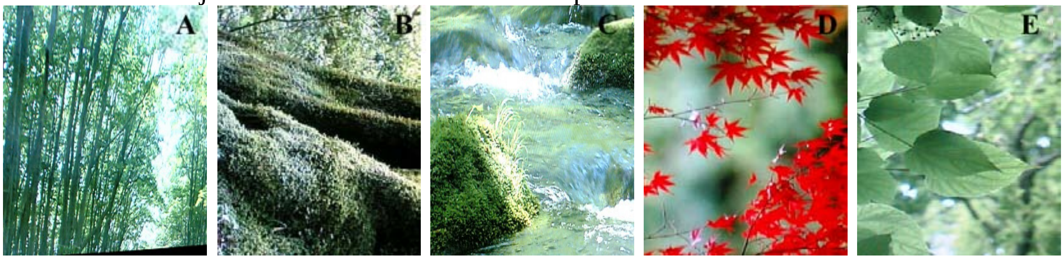

Figure 1. The contents of five moving natural images stimuli; A- road through a forest, B-old trees, C-stream in the forest, D-autumnal tints, E-Japanese cedar forest

Physiological recordings
Electrocardiogram, blood pressure, and impedance cardiogram were continuously measured during 3 conditions. Parameters of heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), cardiac output (CO), stroke volume(SV), pre-ejection period (PEP), left ventricle ejection period (LVEP), and total peripheral resistance(TPR) was analyzed.

Results

Subjective evaluation

Semantic differential evaluation to adjectives of nervous-calm, bad-good, dislike-like, and strained-relaxed showed a consistent response pattern in order of C=B=D>E=A>Control (> means statistically significant differences).

Response changes during the stress condition

ANS parameters showed significant response changes with a consistent directivity. HR, LVEP, SBP, DBP, MBP and TPR decreased, and SV and PEP increased compared with rest condition (Table 1).

Table 1. Response of ANS on stress stimuli compared with rest condition
(A·B·C·D·E·Control(Ctrl) means stimuli used in natural images condition and these are just referred to distinct each repetition of rest-stress-natural images sequence)

(*p<.05 †p<.01 ‡p<.001)

	LF/HF df=23	LF df=23	HF df=23	HR df=25	CO df=24	SV df=24	PEP df=24	LVEP df=24	SBP Df=25	DBP df=25	MBP df=25	TPR df=24
A	-2.423 *	-0.663	3.035 †	-4.386 ‡	1.141	4.583 ‡	2.622 *	-2.528 *	-2.211 *	-4.213 ‡	-3.263 ‡	-2.980 †
B	-0.573	0.293	0.869	-2.859 †	1.802	3.218 ‡	2.062	-2.371 *	0.767	-0.867	-0.057	-0.869
C	-0.891	-1.708	0.462	-3.865 ‡	2.499 *	4.555 ‡	3.710 ‡	-4.410 ‡	-2.134 *	-3.133 ‡	-2.760 *	-3.279 ‡
D	-1.139	-0.255	0.162	-3.448 ‡	1.466	4.386 ‡	2.819 †	-4.141 ‡	-2.674 *	-2.872 †	-2.862 †	-2.477 *
E	-1.270	0.969	1.193	-2.659 *	2.163 *	2.299 *	1.025	-4.312 ‡	0.522	-0.622	-0.153	-2.020
Ctrl	-1.021	-0.393	0.192	-3.913 ‡	1.923	6.638 ‡	2.728 *	-4.287 ‡	-2.207 *	-4.432 ‡	-3.684 ‡	-3.116 †

Response changes during the natural images condition

Responses of each moving natural images showed significant changes in different parameters, but changed with a consistent directivity to each parameter. B, E, and Control induced a significant HR increase compared with stress condition. A, C, and D showed increase of SBP, and A also showed increase of DBP, MBP, and TPR. B and Control showed a significant decrease in SV and PEP (Table 2).

Table 2. Response of ANS on natural images compared with stress stimuli.

(*p<.05 † p<.01 ‡ p<.001)

	LF/HF df=23	LF df=23	HF df=23	HR df=25	CO df=24	SV df=24	PEP df=24	LVEP df=24	SBP df=25	DBP df=25	MBP df=25	TPR df=24
A	1.264	−0.207	−0.996	1.378	1.683	0.233	0.171	−1.222	4.029 ‡	3.080 †	3.515 †	2.341 *
B	1.011	0.065	−1.038	2.759 *	−0.204	−2.598 *	−2.398 *	0.420	−1.393	−1.922	−1.762	−1.143
C	1.017	0.202	−1.279	0.546	−0.858	−0.725	−0.065	0.260	2.348 *	1.378	1.813	2.187 *
D	1.924	0.304	−1.515	0.067	2.969 †	1.157	0.045	−0.944	2.381 *	1.022	1.649	−0.612
E	1.270	0.588	−2.290 *	2.133 *	1.645	−0.405	−0.359	−0.088	0.508	0.388	0.466	−0.517
Ctrl	1.030	1.766	−0.764	3.499 †	0.373	−3.342 †	−3.393 †	1.686	1.314	2.582 *	2.047	0.577

Comparison of response changes by the moving natural images

Figure 2 shows physiological changes in the natural images condition. C and D differentiated from Control by HR changes, and were also differentiated from Control by PEP and SV changes respectively. A and B were distinguished each other by SBP, DBP, MBP and TPR changes, and B was also differentiated from C and F by SBP and DBP changes respectively.

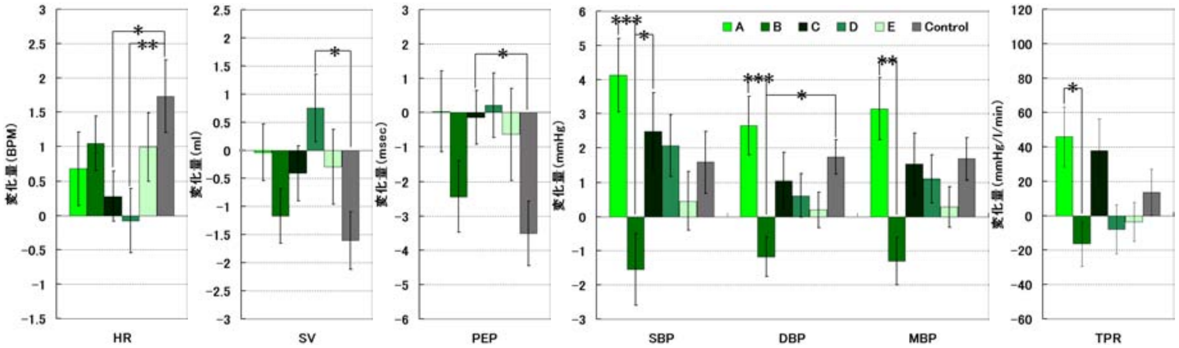

Figure 2. Comparison of response changes by moving natural images (*p<.05, **p<.01, ***p<.001)

Discussion and conclusions

Visual stimuli such as pictures and films induce cardiac deceleration (or HR deceleration). Such a cardiac deceleration appears regardless of the stimulus's valence and arousal, and that is so large that the visual stimulus gives more displeasure and arousal (2, 3).

According to precedent study (4), HR deceleration is an index of visual attention or perceptual-attentional requirements and is larger in moving images than in still images because image motion sustained person's attention throughout the viewing period.

In this study, all natural images showed negative correlation between HR change and subjective evaluation, and HR deceleration appeared during rest and stress conditions. But HR didn't go on with its deceleration to natural images condition (Figure 3). Although B and E, relatively static moving images showed significant HR increase compared with stress stimuli and A, C, and D also showed a tendency of increase, HR response while viewing A, C, and D didn't recover to HR level in rest condition. Evaluations that B is the most silent moving images and E is the most monotonous moving images with A were received in subjective evaluation.

These results suggest that natural images might suppress HR deceleration by the image property of moving images, and recover from stress-induced HR decrease.

In addition to, these responses tendencies also appeared in SV and PEP. SV and PEP showed positive correlation with subjective evaluation and recovery responses from stress-induced response. And also all natural images showed negative correlation between MBP･DBP changes and subjective evaluation but MBP and DBP didn't show a consistent response tendency.

The above results imply that natural images prompt the recovery from stress-induced ANS response, and vascular responses well reflect the contents effects of moving natural images.

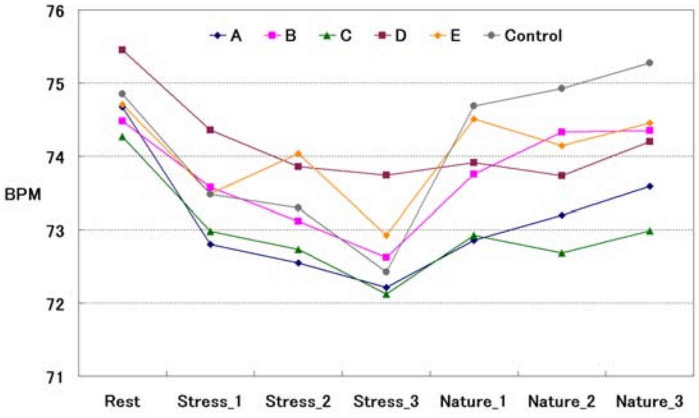

Figure 3. HR response changes of every 1-min duration in stress and natural images conditions.

Acknowledgements

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THE RELAXATION RESPONSES OF CNS BY THE MOVING NATURAL IMAGES WITHOUT SOUNDS

Jeong-Mi Lee[1]*, *Ryuichi Uchikawa*[1], *Yeon-kyu Kim*[1], *Minoru Koriyama*[1], *Sachiko Nagayoshi*[1], *Yvonne Chang*[2], *Shigeki Watanuki*[1]

[1] Ergonomics Laboratory, Department of Human Living System Design, Kyushu University, Fukuoka, Japan
[2] Solution Produce Group, Sony PLC Inc., Tokyo, Japan
* corresponding author jmlee@gsd.design.kyushu-u.ac.jp

Introduction

People reports that the natural landscape provides emotion like being healed, getting rest, feeling released from all kinds of obligation, getting rid of stress, etc (1).

Although various natural images for relaxation and stress reduction are commercialized, the physiological effect which they actually exert on human is not clear. Natural image or picture has often been used as a control stimulus in the emotion research (2), but the research which used natural image itself as an experimental stimulus and examined its physiological relaxation responses hasn't been almost performed.

This study aims at investigating the relaxation response of the central nervous system by the natural images after giving stress stimuli and investigating whether the contents of natural images can be distinguished by the CNS responses.

Methods

Participants

Healthy 30 undergraduates and graduates (15 males and 15 females), aged 19~25 years (22.14±1.40) participated in this experiment. Females in the follicular phase of menstrual cycle participated in. All participants provided written informed consent after listening to the explanation of the experimental purpose and procedures in advance, and were paid reward for their participation.

Procedures

Participants changed their cloth into short T-shirt and pants and listened to experimental details. Experiment was performed in an electrically shielded, sound-attenuated, and temperature-controlled chamber (28℃ and 50% RH).

Repeated measurement that one participant receives all 6 times repetition of 3 conditions— rest, stress, and natural images conditions was performed. All stimuli were presented during 3 minutes respectively, and grey screen on rest condition, displeasure-evoking pictures on stress condition, and moving images made by specialist on natural images condition were shown with the 48 inches plasma TV positioned 1.5 m in front of the participants. A presentation order of stress and natural images stimuli for each participant was counterbalanced by combination of presentation orders according to rotation method.

Stress stimuli used were collected and transformed the stress-related picture images on the internet. To compose six stress stimuli sets of similar stress intensity, those images were evaluated their stress intensity with 5-point Likert scale from 14 undergraduates and graduates (8 males and 6 females). 54 images were selected from what has high average stress intensity, and 9 images were evenly distributed to each set so that six sets give the stress of similar intensity.

As The stimuli of natural image condition, five-min of videotapes without audio that had photographed in the fixed locations respectively was used. Grey screen was adopted as a control stimulus. Subjective evaluation was also executed for the moving natural images. Preference- and relaxation-related adjectives was evaluated on the 7-point of semantic differential scale.

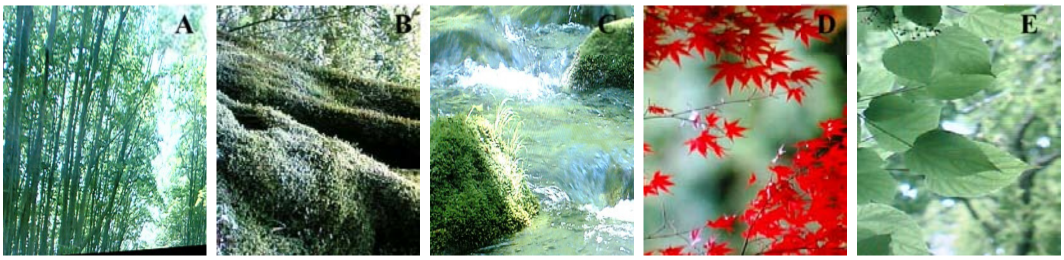


Figure 1. The contents of five moving natural images stimuli; A- road through a forest, B-old trees, C-stream in the forest, D-autumnal tints, E-Japanese cedar forest

Data acquisition and analysis

Electroencephalogram (EEG) data were recorded and displayed by Digital EEG SYNAFIT EE5000 (NEC, Japan) using Electro-Cap and Electro-Gel (Electro-cap International, Inc., USA).

EEG signals were recorded on 19 scalp locations (Fp1/2, F3/4, F7/8, C3/4, P3/4, O1/2, T3/4, T5/6, Fz, Cz and Pz) using reference recording with both earlobes. The signals were filtered by 0.05-Hz LFF, 30-Hz HFF, and 60-Hz Notch filter, and then digitized by a sampling rate of 500 Hz. To control for the eye movement artifacts, Electrooculogram (EOG) was recorded from above and below the outer canthus of each eye with two Ag–AgCl disc electrodes. All electrode impedances were less than 10 kΩ.

BIMUTAS®II (Kissei Comtec Co., Ltd.) was used as a data analysis software. Fast Fourier Transform power spectral analysis through a Hamming window executed for all artifact-free epochs over 1-sec of 3-minute EEG data for every condition. The relative power of delta (2~4 Hz), theta (4~8 Hz), alpha1 (8~10 Hz), alpha2 (10~13 Hz), beta1 (13–20 Hz), and beta2 (20–30 Hz) bands to the total power were calculated.

24 participants' data (50% females) among 30 were used for statistical analysis because of the reason that the noise went into the EEG signals or some participants fell asleep in the middle of the experiment. To examine response changes in stress conditions and natural images conditions, paired t-tests were performed to the rest-stress responses pair and stress-natural images responses pair. Moreover, in order to separate presentation order effects of stimuli and carry-over effects of stress stimulus from error and confirm whether there is any significant response difference among the moving natural images, Univariate analysis of variance using the Latin square design was carried out. As a software for statistical analysis, SPSS 11.5.1J was employed.

Results

Response changes during the stress condition

Stress stimuli elicited consistently increase of relative δ, θ, and β power and decrease of relative α power in the general brain regions compared with rest condition, although the significance levels were different. Right-hemisphere dominance for displeasure was also shown.

Response changes during the natural images condition

Each moving natural images induced response changes in the different frontal regions and frequency bands. A showed decrease of relative α2 power in F8 without changes of frontal δ, θ, and β powers compared with stress picture stimuli, and B, C, and D showed mainly increase of relative β power or decrease of relative δ, and θ power in the frontal regions (C also showed decrease of relative α2 power in Fp2). On the other hand E and Control brought about increase of relative α1 power in frontal regions without changes of β power compared with stress stimuli pictures. E showed decrease of δ and θ power in Fp1 and increase of α1 power in F4 and F8, and Control stimulus showed decrease of δ power and increase of α1 power in the general regions.

Response comparisons among stimuli of natural images condition

1) Subjective responses

Semantic differential evaluation to adjectives of nervous-calm, bad-good, dislike-like, and strained-relaxed showed consistent response pattern in order of C=B=D>E=A>Control (> means statistically significant differences).

2) EEG responses

Significant activation differences were observed between moving natural images and grey screen as a control stimulus, and not among moving natural images. Relative α1 power for control stimulus was significantly higher than moving natural images in all regions except for parietal and temporal 3/4 regions. Control stimulus induced also higher relative α2 power than natural images in Fp1 and O1/2, but induced lower relative β2, δ, and θ power in Fp2, F8 and O1/2, C3, Cz, P3/4, Pz, O1/2, and T5/6, and O1/2 respectively.

Response pattern in each condition

Figure 2 shows the response patterns of relative EEG power at all measured locations by rest, stress and natural images conditions. In figure 2, EEG response patterns in all regions are very similar between stress and natural conditions as well as between left and right hemispheres. And also relative θ and β power responses to the stress and natural images conditions is prominent in all regions, and the response patterns of control stimulus are similar to that of rest condition.

Discussion and conclusions

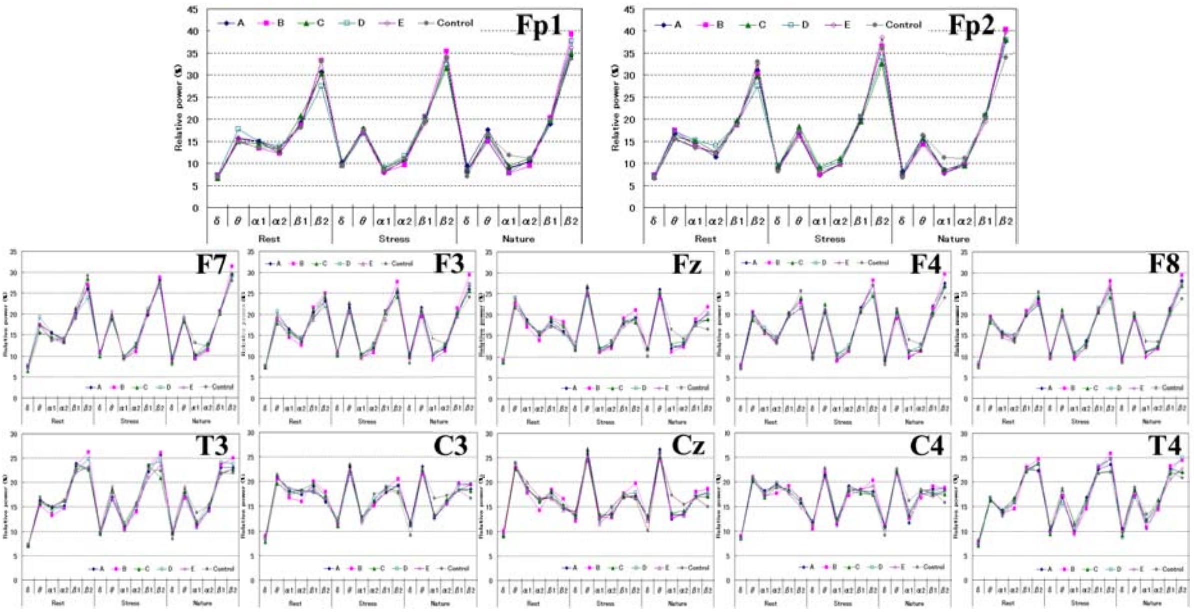
Figure 2 is showing the response consistencies between image stimuli and among brain regions. This result suggests that relative EEG powers to image stimuli might induce visual stimulus-dependent response pattern regardless of its emotional valence.

θ power and β power associated with perceptual and emotional information processing (3, 4). The results of present study also showed the prominence of relative θ and β powers in all regions to the stress and natural images stimuli, and implied that relatively large occupancy of θ and β powers can be associated with relative deduction of α power (or cortical activation).

α power reduces during the viewing of moving images compared with still images independent of stimulus valence, which means that attenuation in α power indicate greater attention (5) and α power is inversely correlated with the frequency of scene change (6). According to study by Simons et al. (5), moreover, subjective reports of emotional arousal were directly related to cortical activation, and that was associated with both positive and negative images relative to neutral images.

The present study also appeared significant correlations between subjective responses and EEG responses. As subjective preference and relaxation intensities were lower, relative α powers were lower and relative β powers were higher in frontal regions. Besides natural images E showed increase of relative α1 power not only in F4 and F8 but also in C4, P4, and T4/6, and control stimulus of a mere grey screen showed increase of relative α power appeared in the whole brain. E received the lowest subjective estimate with A, but A have a different image property from E and the others because of its sustained image motion. These results reflect that relaxation responses of CNS by moving natural images were affected by both stimulus properties of visual stimulus and moving images.

Although this study did not confirm the contents effect of moving natural images, the present results suggest that the reduction of physiological arousal level don’t mean a bigger relaxation effect in moving natural images and that the natural images might suppress the reduction of α power caused by image motion.



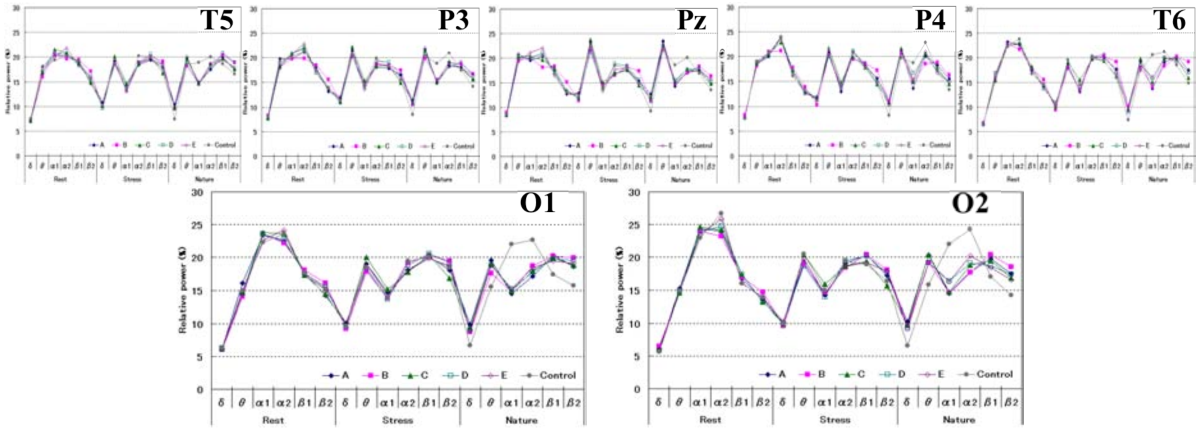


Figure 2. Response patterns of relative EEG power by frequency band during the each condition (rest, stress, and natural images)

Acknowledgements

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THE EFFECTS OF JAPANESE CEDAR (CRYPTOMERIA JAPONICA D. DON) ON PHYSIOLOGICAL RESPONSES

Yeon-kyu Kim, Jeong-Mi Lee, Minoru KORIYAMA, Ryuichi UCHIKAWA,* Sachiko *NAGAYOSHI, and Shigeki WATANUKI*

Kyushu University, Fukuoka, Japan
* corresponding author: yk-kim@rms.kyushu-id.ac.jp

Introduction

Japanese cedar (Cryptomeria japonica D. Don; Sugi) is the most common species for forestry in Japan. Because of the fragrance, light, and fine grained of the timber of Japanese cedar, it is used as a decorative pillar in the *tokonoma* (alcove) in traditional Japanese rooms and for items such as sake barrels, boxes for Japanese-style cakes and confectionary and small, decorative fixtures. However, the effects of Japanese cedar on physiological responses are not clear in laboratory and practical studies. This study investigated that the effects of Japanese cedar on children' physiological and psychological responses during 4 months.

Methodology

Participants

Participants were 98 first-year students of 3 classes (mean age: 12 .6±0.5 years, 43 girls, 55 boys) of a middle school in Oguni, Kumamoto. Participants' parents or protector gave written informed consent.

Conditions

There were 3 conditions; Children of **Class A** (38 students) used new desk and chair made by Japanese cedar (in Oguni, Kumamoto), Children of **Class B** (33 students) used new desk and chair made by steel and plywood and Children of **Class C** (27 students)used old desk and chair made by steel and plywood as usual. This study was conducted during 4 months (from October, 2004 to January, 2005). In October, 3 classes all used old desk and chair made by steel and plywood as usual, and from November to January, they used different types of desk and chair.

Physiological parameters

Secretory immunoglobulin A (s-IgA) in saliva and salivary cortisol, blood pressure, pulse rate, and tympanic temperature were measured during 4months.

Saliva collection

Participants were instructed to hold the cotton swab of the Salivette® (Cat. No. 51.1534; Sarstedt, Nümbrecht, Germany) in the mouse and not to swallow for 3minutes. Subsequently, saliva is allowed to accumulate in the floor of the mouth. After collection, saliva was clarified by centrifugation (3,500rpm×15min.) to eliminate buccal cells and oral microorganisms. Before and after saliva collection, plastic tubes were weighted on an analytical balance. Saliva volume in gram was converted to milliliters assuming that the specific gravity of saliva is 1, and express salivary flow in ml/min.

Salivary immunoglobulin A measurement

The concentration (μg/ml) of salivary IgA was determined by ELISA (Enzyme-linked immunosorbent assay) at a sample dilution of 1:1000. The secretion rate of s-IgA (μg/3min) was calculated as concentration (μg/ml)× volume(ml/3min; 3min sample time).

Salivary cortisol measurement

The concentration (ng/ml) of salivary cortisol was determined by ELISA (Enzyme Immunoassay for Cortisol®, Product No. EA65, Oxford Biomedical Research, USA) at a sample dilution of 1:100.

Questionnaires

STAI-trait and their health history wear asked in October. STAI-state and questionnaire of their health were asked during 4 months.

Data reduction and statistical analyses

Inclusion criteria for all physiological data, especially s-IgA, s-cortisol were that the participant was (a) in current good health, i.e., free from current or recent upper-respiratory tract infection, or other immune-related disorders, (b) not using any steroid-based medication. An unpaired t-test was used to calculate in October and from November to January in 3 classes. And one-way ANOVA Scheffe test for unequal n's was employed among 3 classes during 4 months using SPSS statistical package.

Results

Saliva volume was not significantly different for each class during 4 months. The concentration of s-IgA significantly (p<0.05) increased for each class in November to in January than in October. And for the concentration of s-IgA, Class A was significantly (p<0.05) higher than Class C in November to in January, and than Class B late in December and in January (Figure 1). The secretion rates of s-IgA significantly (p<0.05) increased for Class A and Class B in November to in January than in October, and for Class C late in December than in October. And for the secretion rates of s-IgA, Class A was significantly (p<0.05) higher than Class C in November and in January. The concentration of salivary cortisol significantly (p<0.05) increased for each class in November to in January than in October. And for the concentration of salivary cortisol, Class A was significantly (p<0.05) higher than Class B in January (Figure 2). Blood pressure, pulse rate and tympanic temperature were not meaningful differences for each class during 4 months. STAI-trait was not different among 3 classes. And STAI-state did not significantly changed for each class during 4 months.

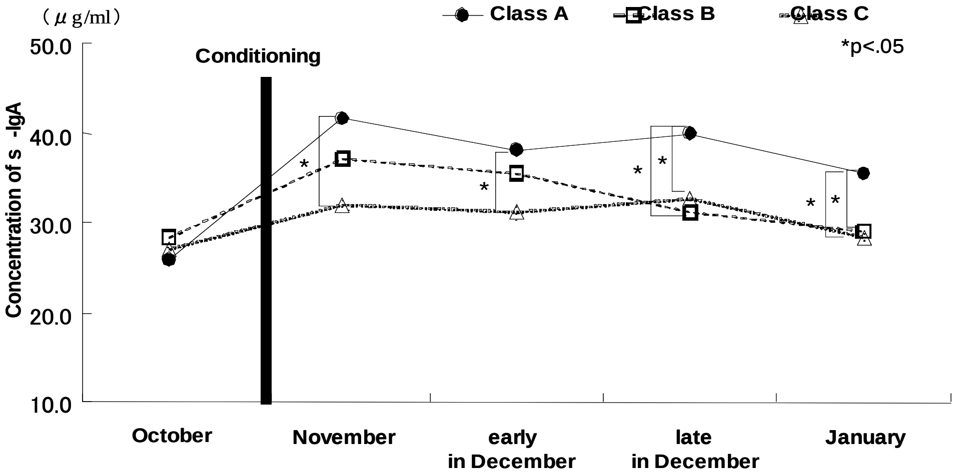

Figure 1. The changes o f s-IgA concentration in 3 classes during 4months.

Discussion

It has been demonstrated that salivary immunoglobulin A (IgA), which appears to defend against viral infections, particularly of the upper respiratory tract, can vary as a function of both personality and situational variables. In the result, s-IgA showed seasonal changes in 3 classes. And, Class A was more increased the concentration of s-IgA than Class B and Class C (Figure 1). That means Class A promotes s-IgA than the other 2 classes as season changes. Li & Tokura (1996) reported s-IgA increase according to seasonal changes from September to November. And they explained s-IgA is related to the activities of sympathetic nervous systems. But, there is no relationship between s-IgA and blood pressure and pulse rate

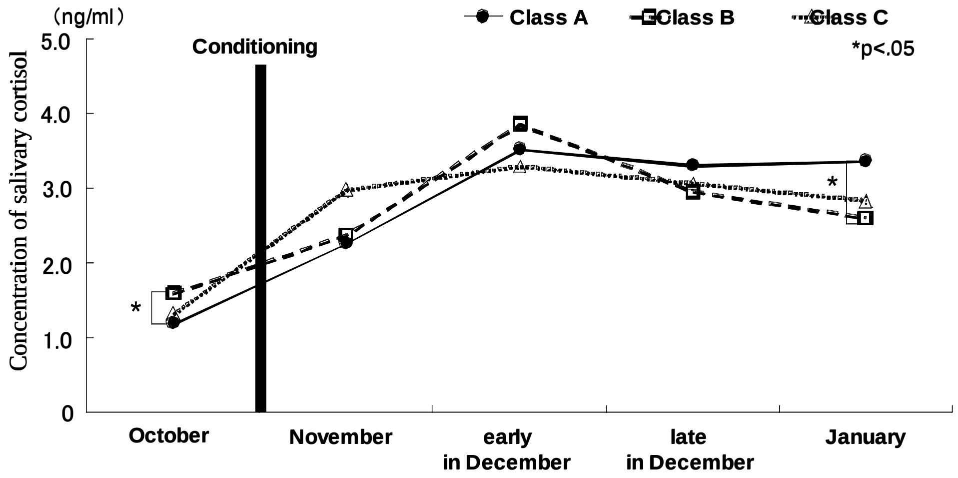

Figure 2. The changes o f salivary cortisol concentration in 3 classes during 4months.

in this study. And, Winzer et al. (1999) revealed that s-IgA is not regulated by beta-adrenergic mechanisms. But, Ring et al. (2000) said that acute decreases, but not increases in s-IgA by the cold pressor are mediated by alpha-adrenergic mechanisms. As like these, it is not clear the mechanism of s-IgA seasonal changes. However, the results of this study and Li & Tokura (1996) suggest that s-IgA has a defence system in cold environment for a long time.

It is well known that psychological stressors such as public speaking, parachute jumping have been shown to induce significant increases in salivary cortisol levels above “at-rest” baseline levels (Deinzer et al., 1996; Kirschbaum et al., 1993). In this study, there was no difference of STAI-state among 3 Classes, but the concentration of salivary cortisol increased according to seasonal changes. And, Class A was more increased the concentration of salivary cortisol than Class B (Figure 2). King et al. (2000) reported that a seasonal variation in cortisol levels with significantly higher levels found in winter and fall, compared with spring and summer. Cortisol has been reported to increase metabolisms in winter than summer to adapt to cold environment. As stated above, the changes of cortisol levels of this study were unaffected by psychological stressors, but occurred to regulated metabolism to adapt to cold environment in winter.

Conclusions

Class A that used new desk and chair made by Japanese cedar activated s-IgA and salivary cortisol to adapt to cold environment more that Class B and Class C.

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EFFECTS OF RESPIRATORY CYCLE ON CARDIOVASCULAR SYSTEM

*Minoru Koriyama, Sachiko Nagoyoshi, Yeon-kyu Kim, Ryuichi Uchikawa,Jeong-Mi Lee, Shigeki Watanuki, *Satsuki Matsumoto*

Department of Human Living System Design, Kyushu University, 9-1 Shiobaru 4, Minami-Ku, Fukuoka 815-8540, Japan
* Sony PCL Inc.

Introduction

Modern society is called Stress-Society, and it is necessary to develop a way to reduce stress. Generally speaking, activating para-sympathetic nervous system leads to physiological comfortable. That is because there is correlation between heart rate variability and death toll attributable to cardiac disease(Musialik-Lydka et al. , 2003). It is necessary to find a way to inhibit sympathetic nervous system or activate para-sympathetic nervous system.

Medullary respiratory area has neural connection with heart, and it is well known that heart rate increases in inspiratory phase and decrease in expiratory phase, which is called respiratory sinus arrhythmia(RSA). The purpose of this study is to investigate the effects of respiratory cycle on cardiovascular system using several indices, and find a respiratory cycles whose cardiac vagal tone is activated.

Methods

Subjects

Table1. Characteristics of Subjects

Number of Subject	Age(year)	Height(cm)	Weight(kg)
1	22	179	64
2	22	176	62
3	23	167	55
4	21	164	55
5	23	176	68
6	22	168	56
7	22	171	69
8	21	175	86
9	22	178	63
10	22	166	52
11	21	169	64

Twelve healthy male students(age 20 - 23 yr) participated in this study. All subjects ware nonsmokers. Table1 shows the characteristics of subjects. Subjects gave their informed consent in writing before participation. They refrained from having foods and drinks before experiment. They wore T-shirts and short-pants during experiment.

Indices

In this study, respiratory flow, electriccardiograph(EEG), successive blood pressure and breast impedance were measured, and following indices were calculated. : Tidal volume(TV), respiratory cycle, R-R interval(RRI), systolic blood pressure(SBP), diastolic blood pressure(DBP), mean blood pressure(DBP), stroke volume(SV), pre-ejection period(PEP), left ventricular ejection time(LVET), total peripheral resistance(TPR), HF/(LF+HF), LF/HF, CVI(Cardiac Vagal Index),CSI(Cardiac Sympathetic Index).

Experimental Conditions

This experiment was conducted in acoustical insulation and radio shield chamber from November to December, 2004. Room lightning was turned off during experiment and black background was displayed when subject was in rest sitting position.

Experimental Procedure

Subjects controlled their respiratory cycle following 4 conditions. : 0.16Hz, 0.25Hz, 0.33Hz, pacing their spontaneous respiratory cycle. They paced visual metronome. When a green circle is getting bigger they did inspiration, meanwhile, a green circle is getting smaller they did expiration.

Figure1 shows experimental time schedule. Subjects kept sitting position during experiment and conducted all conditions at random in a day.

Data Analysis

All data were measured at 1000Hz sampling. All data during respiratory control were averaged.

In calculating LF and HF components, 1024 points of 3-min data were used for FFT(fast fourier transform) after interpolating at 6Hz. Power in two bands were calculated as follows. : LF(0.04-0.15Hz), HF(0.16-0.40).

Statistical Analysis

SPSS 11.5J was used for statistical analysis. To compare each index between respiratory cycles, one way analysis of variance(ANOVA) was used, and Tukey's HSD test was used for multiple comparison. For all analyses, statistical significance was set to $p<0.05$.

Results and discussion

Figure2 shows that all subjects could pace metronome accurately.

Figure3 shows averages of each index during respiratory control. There was significant difference between 0.16Hz and 0.33Hz in TV, however, no difference was found in other indices.

The slower the cycle was the larger the HF/(LF+HF) called as an index of cardiac parasympathetic nervous system, but there was no significant difference between respiratory cycles. However, taking into account that there was no significant difference in RRI, SV, PEP and LVET,

cardiac autonomic nervous activity was the same between 4 cycles. HF/(LF+HF) reflects RSA as well as cardiac parasympathetic nervous activity. Also, the slower the cycle was the larger the TV, which might mean RSA rather than cardiac parasympathetic nervous activity appeared in HF/(LF+HF). In addition, CVI which reflects parasympathetic nervous activity showed a similar tendency as well as HF/(LF+HF) (Motomi Toichi et al. , 1997).

It is known that respiratory changes gradient of venous pressure between intrapleural and extrapleural spaces, and that venous return is increased during inspiration at normal respiration. However, no significant difference in SV means that there is no gradient of venous pressure between intrapleural and extrapleural spaces and venous return is the same between respiratory cycles within normal respiratory cycle. As to blood pressure and TPR, there were no significant differences between respiratory cycles. This means that respiratory cycle does not alter sympathetic nervous activity for blood vessels.

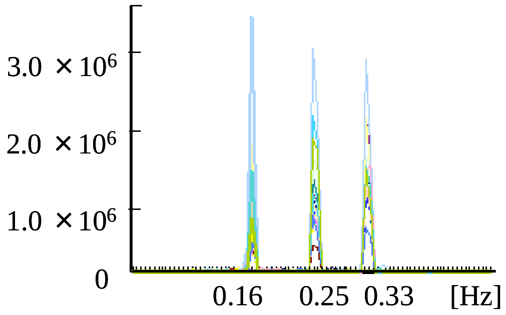

Figure2. Accuracy of Respiratory Control
It was confirmed that all subjects could paced metronome accurately.

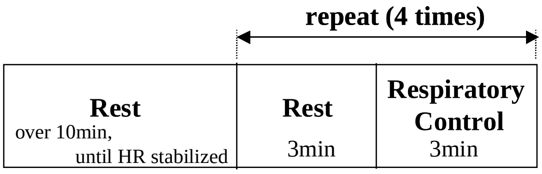

Figure1. Accuracy of Respiratory Control

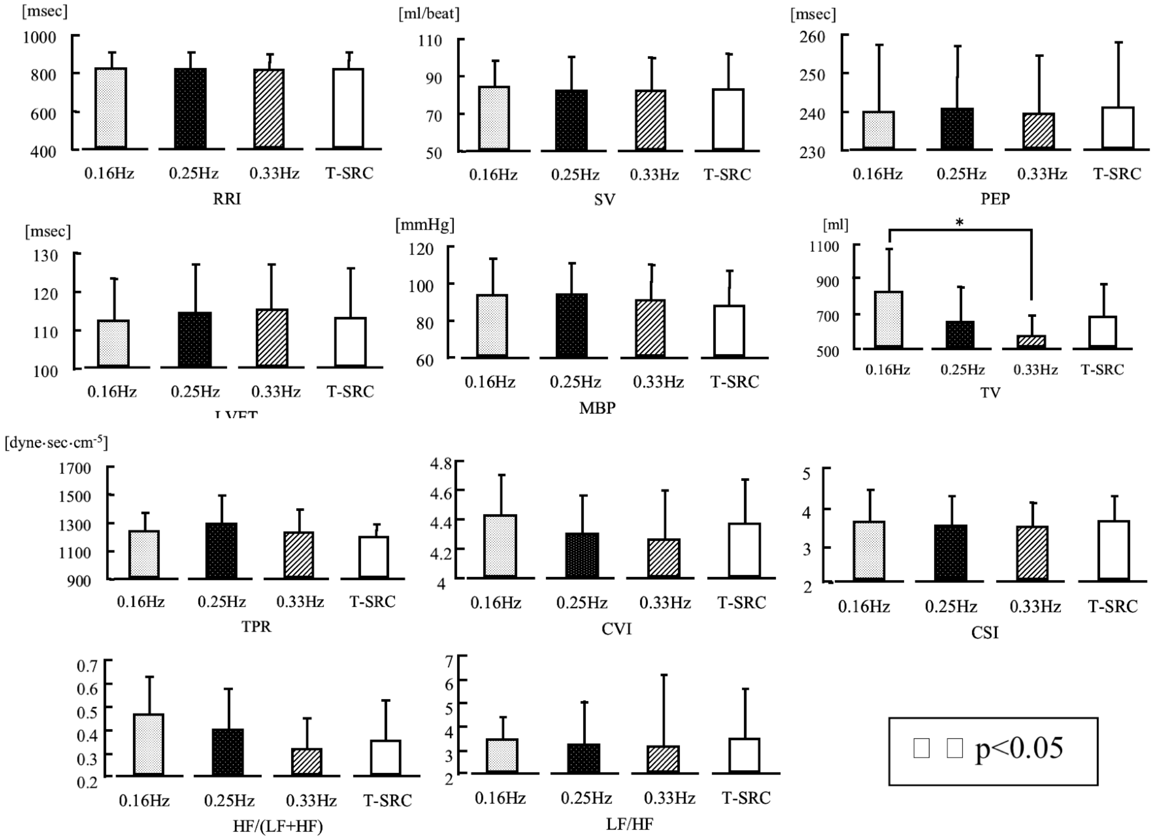

Figure 2. Comparison of each cardiovascular index between 4 conditions.

Figure3 shows the model of central regulations of cardiac vagal out flow composed of two separate systems suggested by Hayano et al. (2003). Cardiac vagal activity is affected by both of phasic and tonic controls. The former is mainly affected by RSA, and the latter is affected by cardiac mean vagal tone. The results of this study suggest that the effect of respiratory cycle on mean vagal tone dose not differ within normal respiratory cycle. And it can be interpreted that HF/(LF+HF) and CVI reflect activities of two separate systems(both of phasic and tonic), and difference of TV between respiratory cycle might have appeared in this study. Our results are consistent with the advanced studies(Brown et al. , 1993 ; Stark et al. , 2000).

Conclusions

We investigated the effects of respiratory cycle on cardiovascular system under the following respiratory cycle. : 0.16Hz, 0.25Hz, 0.33Hz, spontaneous respiratory cycle. There was no significant difference between respiratory cycles except for TV. Respiratory cycle does not alter mean vagal tone. Furthermore, respiratory cycle does not alter sympathetic nervous activity for blood vessels. Pacing respiratory cycle alone may not alter tonic cardiovascular activity and is not good way to reduce stress.

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ERGONOMICS IN USER-ORIENTED DESIGN

Lena Sperling

Industrial Design, Department of Design Sciences, Lund Institute of Technology, Lund University, Lund, Sweden
Lena.sperling@design.lth.se

Introduction

Ergonomics is one of the factors which charge design with power of high importance to individuals, society and the environment, and consequently one of the important cornerstones of design in research and practice. Already about 20 BC the Roman architect Vitruvius formulated in his book “De Architectura” (1) a trinity based on *Functionality, Technical quality* and *Aesthetical organisation* (Figure 1). Functionality relates to the performance of an artefact in relation to humans and consequently includes ergonomics. As aesthetics represents the emotional dimension of products, as experienced by all senses, strong relations exist between aesthetics and functionality.

In design, the focus of ergonomics/human factors is under constant development. Today products are not only material artefacts such as buildings and things, but also immaterial artefacts such as systems and services. From being mainly concentrated on matters of safety and health, ergonomics has moved on into the comfort level of human wellbeing. The computer era has called for usability knowledge and methods for interaction design, of significant importance to all fields of design. In large industrial companies, the demarcations of marketing research and ergonomics seem to be under dissolution. Advances in design research have led to a number of new approaches, which look at the aspects that make products compelling to us, by analyzing human motivation (2). Ergonomics in design is now entering the area of pleasure, considering human body, mind, relations and ideals.

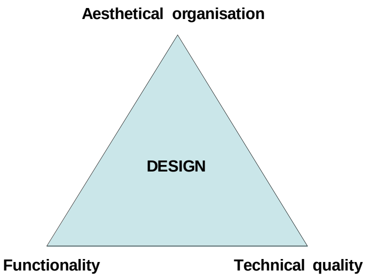

Figure 1 Design illustrated by Vitruvius’ theoretical model of architecture.

The aim of this paper is to present user-oriented design, a growing research area where qualitative methods in ergonomics form an important basis. Examples are given from current research of the department of Design Sciences at Lund University, regarding learning in industrial design education, communication with users in industrial design practice and support of ergonomics in engineering design of automotive industry.

User oriented design

Design is a noun as well as a verb, a result as well as a process to reach a result. The *noun* design comes from the French word *dessin* which means a sketch or a pattern. People in general seem to use the word design for describing the appearance of an object as a design. The *verb* design comes from the Latin word *designare*, which means to define or decide in advance. The element of intention makes design different from purely artistic creation, the latter allowing ad hoc adjustments of major shape as well as details of objects. Design is a process where a designer proceeds from the general to the specific, from outline proposals to details. The design process can also be seen as a negotiation between problem and solution through the three activities analysis, synthesis and evaluation (3). Different actors in industry are referred to as designers. *Industrial designers'* work is of a conceptual and aesthetical character, often of a user-oriented perspective, while *engineering designers'* focus is rather related to manufacturing, technological quality and performance. Both groups of actors, as well as competencies of an integrating character, are key-actors of the design and development process and their close co-operation should be supported in industry as well as in education and research. A Swedish definition of industrial design is to create utility products to meet requirements of humans and the environment, aimed for serial or mass production (4). Users' functional as well as emotional requirements for products are included.

Design work is carried out for, with and by users (5). *Design for users* regards a "would-be user". We learn about human factors so that we can design to enable people to work effectively and safely. *Design by users* is carried out with users as participants in the design process (participatory design), with the ergonomist as a facilitator. Practitioners' mixed strategies seem to be successful. If we are to develop a solid base for professional practice in ergonomics, we need to make explicit what is necessary to *design for users by designing with users* (5), which user-oriented design considers. Users' problems and needs are the starting-point of user-oriented design, aiming at welcome products.

Within the European 6th Framework Programme, the coordinated action ENGAGE, which is the acronym of Engineering Emotional Design (www.engage-design.org), aims to open the European industry towards a knowledge-based economy in the area of satisfying people's subjective and emotional lifestyle needs. The action points out that although functionality has always been - and will remain - an essential precondition for product satisfaction and market success, various developments point at an increasing importance of product experience as a driving force of product acquisition and use. Today the bottleneck in introducing new successful products quickly to the market has moved from factory floor manufacturing to the product specification, design & evaluation process, although of course world-class manufacturing remains essential. Researchers from many disciplines (consumer sciences, psychology, ergonomics, industrial design and engineering) as well as industries participate in the coordinated action ENGAGE.

The widening of ergonomics to all sectors of life means that users of a wide range of ages and individual characteristics need to be considered and approached. Design for dynamic diversity means that users of various capabilities as well as cultures are included in design work. An important factor is the growing proportion of elderly users and their assistants both at home and institutional care. Elderly persons take care of even elder spouses or relatives, and there is a need for ergonomic knowledge about elderly at work. Designing for a global market, differences in anthropometrics as well as interpretation of semiotic messages must be considered. The concept of the user pyramid (6) was created by a Swedish industrial design company as an illustration of universal (inclusive) design (Figure 2). At design of environments, objects and services, needs of a wider range of users will be met by integration of disabled users' functional requirements. There is no reason why disabled users' emotional requirements for products should be different from other persons. A market for assistive products will still exist, and also such objects and services must be designed for optimal function, comfort and pride. The three-year-long intervention "Universal Design Educational Project – Sweden" (7) has hopefully made universal design a natural and precious part of all Swedish educations in architecture, industrial design, interior design and landscape planning.

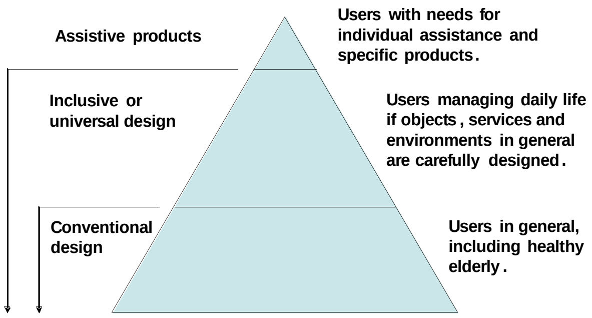

Figure 2 The user pyramid (6).

Users and co-users are persons involved in the use of a product. In sustainable design, requirements of secondary user groups in the product's life cycle need to be addressed. The importance of designing for and with users in products' maintenance and end-of-life will be steadily growing. The very qualified work of disassembly personnel must be supported by work-places meeting both functional and emotional needs, to facilitate recruitment, contribute to health and wellbeing and to pride at work.

Communication with users in design

In large industrial companies with development of products of a pronounced user focus, methods and procedures for handling customer requirements are since long adopted, such as Quality Function Deployment (8) and Kansei Engineering (9, 10). In practice however, due to secrecy and confidentiality of companies, application of such procedures involves real end-users only in the very early phases and at the very end of the development process or by feedback from users when products are already at the market. Procedures for increased participation by real users should be elaborated and implemented also in the synthesising activities design.

A smaller interview study of industrial designers in small design consultancies (11) revealed that the informants relied on their own experiences as users, and they regarded communication with users as time consuming, complicated and restricting their creativity. These findings are in agreement with a larger study of user models in design (12), which also demonstrated that ergonomics tools such as tabular information, templates and manikins were not employed extensively and also highly criticised by the practitioners. On basis of the Swedish interviews of designers (11), four criteria were crystallized for communication with users in industrial design: Provide stimulation and creativity at design work; Provide usability and efficiency at design work; Natural and spontaneous interaction with users; and Support the client's decisions. To fulfil these criteria, quite new and exciting methods need to be elaborated. However, existing methods from market research and ergonomics could also be utilised even in small consultancies. Rating scales are since long used in marketing research, ergonomics and quality processes in industry. Using them as numerical mediating tools at interviews with users about existing products at use, requirements for new products and qualities may be elicited by asking users to comment on their judgments. At the same time a rough quantification of present qualities will be obtained. A respectful attitude at communication with users is necessary, and training in communication with users should be introduced early in undergraduate educations in design, in order to give designers tools for practical use in their future careers.

User Compass Chart (UCC)

In order to successfully implement research methods in industry, it is important to build them on methods and models which are already established in practice. One example of this is the User Compass Chart (UCC) which was elaborated and tried for studies of professional drivers' experiences of qualities of material surfaces of panels in vehicle interiors (13), aiming at attractive eco-materials. Compass charts are since long time used in industrial strategic development in order to guide the direction of efforts, from a less desirable combination of qualities in the South West to a more desirable one in the North East sector. In the applied UCC, vectors were labelled: More professional – More unprofessional and More natural – More synthetic. Labels were also provided with verbal associations. The UCC was about 500 x 500 mm large and was provided with lines in accordance with rating scales in order to enable later quantification. Four truck and four taxi drivers were first interviewed about surface materials of their present vehicle interiors. Thereafter they were asked to characterise samples (about 50 x 50 mm) of traditional and untraditional materials for car interiors, by positioning samples in the four sectors (Figure 3). The characters of the materials were: plastic-like, rubber-like, wood-like, stone-like and future-like, and in total 37 material samples were to be characterised. Further a black marker was to be positioned representing the driver's existing vehicle and a white marker representing the "dream vehicle". After the markers had been positioned, there was also a possibility to finally adjust all positions in relation to each other. Although only few drivers participated as subjects, some material samples proved to be experienced as more professional and natural than other characterised samples. Wood-like samples (oak, ash and oak imitation) were the most frequent samples of the North-East vector, followed by plastic-like and stone-like samples.

Swedish automotive industries have expressed their interest in the UCC method, and a larger study should be carried out were also the subjects' verbal reflections are recorded and analysed, in order to elicit more detailed information about why they perceive materials the way they do. The UCC is possible to use for quite other dimensions of products, in early as well as later design activities, as it makes it possible to mix "new and hot" qualities or features with other samples of less significance of the company's development work.

Figure 3. A truck driver's positioning of material samples and markers for his present vehicle (black) and for his "dream vehicle" (white).

Early awareness of functional and emotional product qualities in universal design

In an attempt to make universal design an integral part of industrial design in general, an experiment was implemented about form and function, during the first year of the industrial design undergraduate programme of Lund University (14). The aim of the experiment was to increase the awareness of the students regarding the fact that products may at the same time be attractive and well-functioning for a wide range of users. Five categories of home products were included in the experiment, objects in each category covering extremely stylish, ordinary and inclusive products as well as assistive products designed especially for disabled persons. Twenty-five students took part in the experiment and were divided into five groups. They were not informed about how products had been selected for the experiment. The students tried the objects in true use situations and were asked to, in a consensus process, evaluate, reflect and comment on three more emotional product qualities (attractive, pleasurable, considerate) and three more functional qualities (handy, comfortable regarding surface, comfortable regarding shape). A visual analogue scale was used for rating. At a summarising seminar, they presented and reflected around their results. After the presentations, all students were asked to, altogether, group all objects in any kind of families. The presentations by the students demonstrated that very lively discussions had taken place about qualities of the different products. The evaluation method, although used group-wise, provided rich information about young persons' experiences of qualities in products of different form and function. For instance, white colour was in general associated with hospital care.

At the final grouping of products, the students decided to present objects as being related to different user characters. One among other interesting findings was that a product family aiming at a very average user included an angled kitchen knife, a product that some years ago was regarded a typical aid for disabled persons (Figure 4). It became obvious to the students that much needs to be done in order to make conventional products more inclusive and assistive products more attractive. A portable toolkit is under development in order to give new generations of students, as well as product developers and purchasers, increased awareness of functional and emotional dimensions in universal design.

Figure 4. Product family representing an average user (14).

Supporting ergonomics in engineering design

Quality systems intend to support development as well as standardised work regarding the quality of the product and increase satisfaction of the company's customers and other stakeholders. Guidelines and instructions of quality management systems do not correspond to some companies' requirements for usability in daily work and as support to interest and engage the personnel in development work (15). Along with the development of new technology and Internet, new possibilities have emerged, but web based documents in a traditional format have few benefits compared to printed documents. However, web technology opens up many presentation possibilities. The aim of a study by Blomé et al (16) aimed at designing a computer aided system of ergonomic guidelines visualised by means of interactive multimedia technology based on cognitive theories and practical examples. The interactive multimedia system was a result of a participatory design process with experts and potential users in collaboration with SAAB Automobile in Sweden. Frequent feedback meetings and discussions were carried out to support set-up designs of prototypes representing different multimedia techniques for visualising the ergonomic guidelines (interactive/ hyperlinked icons, photos, drawings film clips and animations). The prototypes were evaluated by interface and content experts, and the proposed compromises and adjustments were discussed with each of three human factors engineers of the company. A complete system of all existing ergonomic guidelines was then designed. The new system was evaluated at practical tasks in comparison with a traditional report on an intranet, with five groups of in a total 25 subjects. Efficiency (speed and correct answers) in and attitudes towards the two systems were included in the evaluation. The results showed that the new and interactive system was faster and more enjoyable to use, and animations made it easier to understand the use of details and dimensional relations. It was concluded that it is a successful approach to visualise an interactive multimedia system of ergonomic guidelines based on findings in web design and educational media with a participative design process (16).

Concluding remarks

Ergonomics is under constant development and qualitative research methods are getting generally accepted in ergonomic research and practice. User-oriented design is a field of action where design is carried out for and with users and where qualitative methods are of significant importance for eliciting problems and needs leading into relevant user requirements for improved or new products. Ergonomics and aesthetics meet in user-oriented design. Industrial design students need to learn about and get a positive attitude to user-oriented methods early in their education, so that user requirements are handled in a both stimulating and structured way, which will be useful and competitive in their professional careers. However, also the use of more traditional ergonomic guidelines needs to be supported by stimulating processes based on participatory development.

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THE DISTRIBUTION OF SIGNS AND PEDESTRIANS' WALKING BEHAVIORS IN UNDERGROUND SPACE

– A CASE STUDY OF THE UNDERGROUND SHOPPING CENTER IN TENJIN, FUKUOKA –

Ji-Sook Choi[1]*, *Yoshitsugu Morita*[2]

[1] Kyushu University, Faculty of Design, Fukuoka, Japan
[2] Kyushu University, Faculty of Design, Fukuoka, Japan
* corresponding author jisook586@yahoo.co.jp / morita@design.kyushu-u.ac.jp

Introduction

The purpose of signs in public space is to provide information (convenience) for the user. Underground spaces represent a major turning point in the use and increase in the efficiency of public space in general (J. Archit. Plann. Environ. Eng., AIJ, 1996). Regarding the sign system used to direct pedestrian behavior, it cannot be said that much thought is put into the general needs of pedestrians in underground spaces. This is because safety and convenience are provided for and communicated to the pedestrian one-sidedly (Lee , 1996;Yokota , et al. 1997; Murakashi and Shimizu, 1989). There is little research on the use of the information provided by signs to pedestrians in underground spaces, although there is research related to pedestrians' walking paths on roads and in buildings when guided by signs. In this paper, which is one in a series of papers on the use of information by pedestrians in underground spaces, we investigated pedestrian walking behavior and the use of signs in an underground shopping center in Tenjin, Fukuoka.

Methods

The following three problems have became clear from our research to date (Choi and Morita, 2002). First, we have found problems related to the kind and quantity of information provided by signs. Second, we have found problems concerning the placement and distribution of information signs. Often too much or too little information is provided because of the dispersal or concentration of signs. Third, we found that often the number and type of signs are similar in different places, so that the signs cannot be distinguished. Therefore, we investigated what signs pedestrians could notice in underground spaces. In the present research, we wanted to discover the routes pedestrians followed using the pedestrian information sign system in Tenjin, Fukuoka Japan.

The subjects were told to find and look at every public information sign along the route between the start point and the destination. Subjects carried a portable tape recorder and recorded their impressions of each sign they found and observed. The observer followed the subject from a distance of 5 meters and recorded the course the subjects followed as they looked for signs. Recording of subject movement took the from of a pencil line drawn on a floor plan of the shopping center. Data collected included the signs the subjects saw, the line of movement of the subjects between signs, how often a sign was used, the placement of the signs, and the height of the signs. We combined these factors according to the type of path followed by the subjects between signs. We used these results to examine the relationship between sign placement and how effectively pedestrians could use the information provided by signs to find their way in the shopping center. (Hikaru, et al. 1997; Inoue, et al. 1997).

The investigation site is indicated in Fig. 1. It is an underground shopping center in Tenjin, Fukuoka. The site consists of an entrance, a passage, an open space, a crossing, and other spaces. An entrance in the north part of the central passage was used as the starting point, and an experiment was conducted involving the information sign in the parking zone near an entrance along the central passage to the southern (see Fig. 1).

Fifteen subjects participated in the experiment: 8 women and 7 men between 20 and 31years old. The target of the investigation was the subject's ability to find and use signs in the underground shopping center. We also instructed subjects to search for commercial signs, of shops surrounding the investigation object. Therefore all the public signs in the underground shopping center were target signs, because we wanted to find out how well people could use the signs in this underground shopping center. Because the subjects were likely to be familiar with the overall layout of the center, and because the layout of the center was simple, they might not have used the signs to find their way through the center from the start point to the destination. Subjects were asked to find the smoking section, but this was an essentially arbitrary choice of destination. The true object of the investigation was how well the subjects could find and use the signs in the shopping center.

In order to investigate the use of information signs in the underground space, we first told the subjects the name of the starting point and the destination. The experimenter observed the points where subjects stopped to find their way by following the subject at a distance of 5 meters. Subjects were given a voice-recorder and they were asked to verbally describe the signs they used when searching for a particular kind of information, and the difficulties encountered when searching for information.

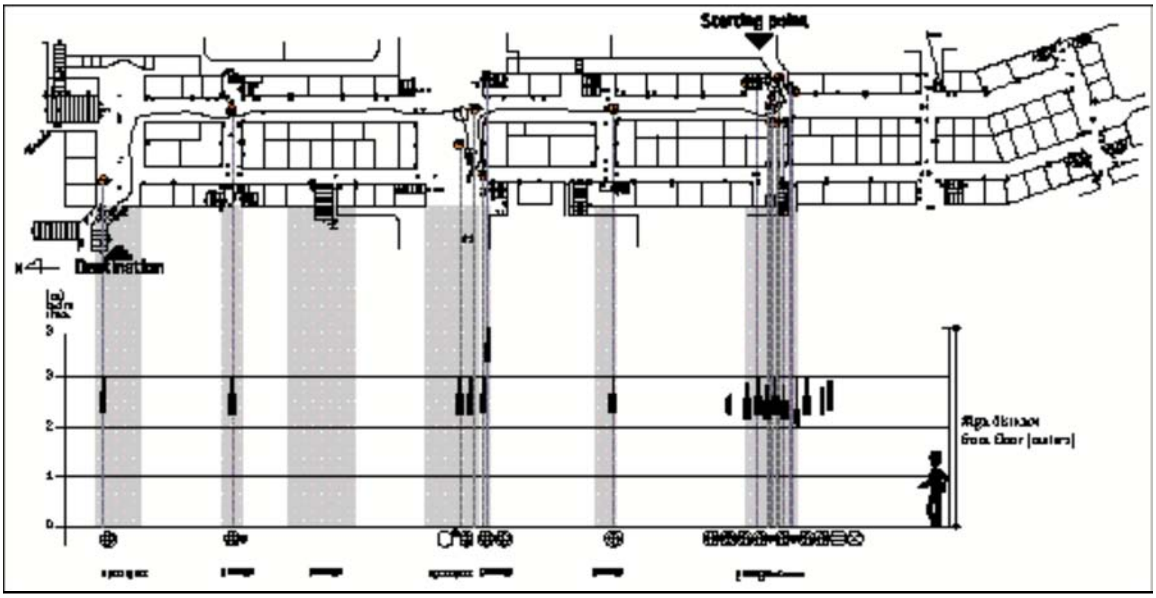

Figure 1. The distribution (subject A) of the subject's walking path and the height of the signs found by the subject. The figure indicates the subject's walking path. The signs consulted by the subject in the underground shopping center are indicated by a dot ( ).

Results

In order to analyze how and where subjects looked for signs, we compared the routes taken by the subjects according to the following four points: first, the relationship between the information signs found and the walking paths between signs; second, the relationship between the placement of a sign and the walking paths between signs; third, the relationship between the sign height and the walking paths between signs; fourth, a classification of pedestrian walking paths according to type. The results are shown in Fig. 1. This figure indicates the walking paths of the subjects. The signs found by the subjects in the underground shopping center are indicated by a dot (●). The height of signs found by the subjects was divided into four groups, as shown in Fig. 1. Heights (from the floor) were between 0-1m, 1m-2m, 2m-3m, and higher than 3m.

In Fig. 1, it is shown from the position of the dots that subject A found signs directing to the open space, crossings, the passage, and exits/entrances. In Fig. 2, it is shown from the walking paths that all subjects often found signs in places where the signs needed to be used.

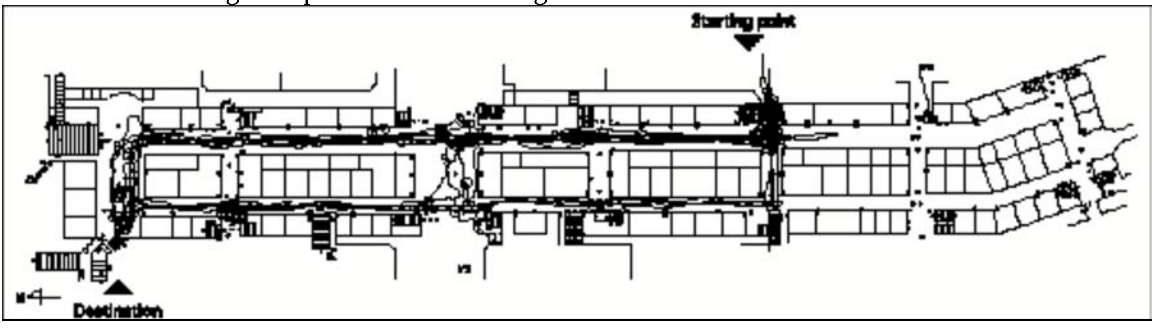

Figure 2. All subjects' walking paths. The directions followed by the walking paths indicate that all subjects found the signs.

Considering the results of all subjects, we can see in Fig. 2 that at the open space there are strong curves in the line of movement. Before reaching the destination, all subjects on average consulted the information signs 14 times in total.

Signs consulted by subjects can be divided into four categories according to where they were placed: signs at crossings, exits/entrances, open spaces, and other spaces. The signs at crossings were consulted by subjects in 93 of 220 cases (42.27 %); signs in exits/entrances, in 67 cases (30.45%); signs at open spaces, in 32 cases (4.55 %); signs in passages, in 22 cases (10 %); and signs in other spaces in 6 cases (2.73 %). Concerning the rate of sign use, although the rate of use was quite high for signs at the crossings and in the exits/entrances, the signs placed at the exits/entrances were not used often, even though the concentration of signs was highest in these places. With respect to the height of the signs (from the floor), 8 cases were found (3.63%) in the 0-1m group, 13 cases (5.90%) in the 1-2m group, 196 cases (89.09%) in the 2-3m group, and 3 cases (1.36%) in the more then 3m group. Most signs subjects found were placed at a height of 2-3m. Regarding the information signs consulted by subjects, in the 0-1m group 3 cases were found at crossings, 5 cases were found at exits/entrance, 1 case was found in passages, and 1 case in the open spaces. The signs in the exits/entrances were most often consulted. In the 1m-2m group, 1 case was at crossings, 7 cases were at exits/entrances, 7 cases were in open spaces and 1 in others. In the 2-3m group, 88 cases were at crossings, 57 at exits/entrances, 27 in open spaces, 23 in passages, and 5 in others. However, in the more then 3m group, only 2 cases were found at exits/entrances: almost no subjects found the signs. In summary, most signs were found at crossings, in the 2-3m height group.

The pedestrian walking path relates to how easy or difficult it was for subjects to find signs. In order to get a clear picture of subject walking paths from place to place, we divided the walking paths into crossings, exits/entrances, open spaces, and passages. The shapes of subject walking paths give rise to various interpretations. When the walking path to a destination was simple, the most efficient number of signs could be found, and the number of signs found was often small. Regarding the placement of signs, there was a difference between the rate of sign use and the number of signs installed. Moreover, in certain places, subject walking paths became complicated (open spaces, others). In other words, the positions where signs were installed may not have been suitable. Most subjects found the guidance signs at a height of 2-3m. Moreover, in places where the walking paths were complicated, such as open spaces, the ratio of the use of signs was lower than that compared with exits/entrances and passages.

Conclusions

From our investigation of the walking paths of sign placement through analysis of pedestrians in an underground shopping center in Tenjin, Fukuoka, we think that the following changes might be necessary to improve sign placement and use. First, more information sould be provided for pedestrians than before in order to guide them to use this underground shopping center easily. Second, many signs were installed in some place, but few were installed on others, and the continuity between places needs to be shown more effectively by the guidance system.

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IMPROVING STORAGE SYSTEM EFFICIENCY TO INCREASE WORKER PERFORMANCE WITHIN THE WORKSPACE

Nermin ELOKLA, Yoshitsugu MORITA And Yasuyuki HIRAI

Department of Industrial Design, Faculty of Design, Kyushu University
Corresponding author **nelokla@hotmail.com**

Introduction

The storage unit is possibly the most important aspect of office furniture [1]. In today's workspace, storage takes on a more varied and dynamic role in work support [2]. At present, most studies on storage systems focus on their design, quality, capacity and history for home usage and others [3-5]. The evaluation of storage system efficiency in the workspace is limited. The author found, according to the results of the survey which was previously conducted within five account division workspaces in Tokyo and Fukuoka, about 62% of workers complained about the personal storage system within the own workstation and 38% of workers complained about the file cabinets (communal use) [6]. As the majority of workers complained about their personal storage, the present study aims to identify storage system problems and recommend solutions for them. Moreover, a test was carried out to validate the effectiveness of these solutions for overcoming the problems.

Methods of the Survey

The survey was carried out as follows: first, five account division workspaces of Japanese companies were visited as a field survey to examine the current workspace and storage systems. Account division was selected for our study, as we noticed that its workspaces are more crowded with paper documents than the other divisions' workspaces, e.g. design and sales. Second, interviews were carried out with 72 persons who work in these workspaces to understand how they managed their documents in their workstations. Third, a questionnaire was distributed among these workers to identify the problems of the personal storage system that affected their comfort and productivity.

Results and Discussion of the Survey

The results of the survey revealed that the main problems of the personal storage system are:
1. Workers do not have enough desktop space to work, as the files are piled up on it.
2. Workers couldn't find the files that they need easily.
3. Workers couldn't sit comfortably, as some of the files were stacked under their desks.

The first and third problems concern the storage capacity and file distribution within the storage space. The second problem concerns file display. As for the first and third problem, we tried to find a solution to increase the personal storage space to be adequate for the large amount of documents. Actually, many workers have huge numbers of documents and each worker is usually provided with only one pedestal in which to keep all his/her documents. Hence, they are forced to distribute the files throughout the workspace as follows: frequently used files are usually placed on the desktop and less frequently used files are placed in the pedestal. The remaining files are placed under the desk**.** As offices become smaller, the personal storage space that is offered each worker is very limited. The office space standard in Japan continues to decrease in response to real estate costs and the tight economy. The average workspace per person has shrunk from 11.21 square meter in 1995 to 10.19 square meter in 2001 [7]. Regarding the second problem, file display, we found that about 49% of workers rely on their memory to remember where information is. They don't use visual cues that might guide them to locate documents quickly. These workers mentioned that they don't have enough time to file each paper. On the other hand, about 27% of the workers use labeling and coding systems and about 24% of workers label only the important documents. We observed, concerning the file display through the personal storage space that the way of arranging the files in the pedestal is not convenient to see the files' tabs easily. Based on the survey, we realized that there are two types of file arrangement within a pedestal: side - to - side and front to back (Fig.1). Front to back is the most common arrangement used in these workspaces. Therefore, we recommend the following tips to overcome the mentioned problems:

1. Personal storage space can be stretched by going vertically rather than relying on the horizontal office space, e.g. by using an overhead bin or shelf.
2. A worker needs to apply a clear filing system when arranging documents that enables them to find a required file quickly. Labeling and coding systems are recommended, as they help a worker to define the folder's location and return into its home easily [8-10]. As for file arrangement, this study recommends side to side layout, as a worker is not required to turn his/her body around or get up tosee the files' tabs [11].

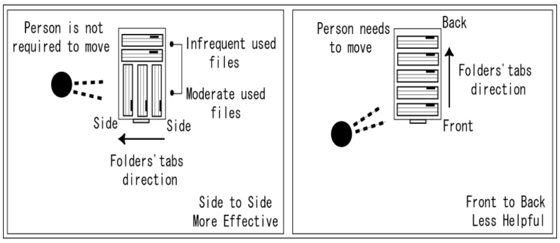


Fig. 1 Filing arrangement types in the pedestal

3. Before distributing the documents within the desk space, a worker needs to consider how often each document is used. Frequently used files should be within hand's reach to be accessed easily [11,12].

By following these recommendations, a worker could overcome the previous problems. To demonstrate that the recommended tips are effective for organizing the files within a desk space, we carried out the following experiment.

Methods of the Experiment

The experiment was conducted with 20 persons (15 men and five women - their ages ranging from 24 to 40 years) in a working area. The participants were asked to access the files from two types of workstations (each workstation consisted of desk and separated pedestal). The size of a desk and a pedestal were: width 1200mm x depth 700mm x height 700mm and width 400mm x depth 600mm x height 610mm respectively. File organization within the first workstation reflected the current situation used by many workers. But the second workstation was arranged in accordance with four recommendations for file organization. In the second workstation, a person was provided with a vertical unit beside a pedestal to stretch the storage capacity. The selection of an added storage unit for the second workstation is determined according to the persons' preference for one of three suggested units: low height, high height shelves or a wagon. The results of the survey that was carried out on 20 workstations in the visited workspaces to determine the average file meter "Fm"(a defined space that is occupied by documents in a workstation, 1Fm = 1000 cubic mm) revealed that the average Fm of one workstation (including the space of desktop, pedestal, and under the desk) is about 1.1Fm as follows: the average Fm on the desktop space is about 0.3Fm, in the pedestal is about 0.5Fm and the space under the desk is about 0.3Fm. One file box (A4 size) is 310mm long x 260mm in height x 100mm wide, corresponding to 0.1Fm. Therefore, eleven file boxes were placed within each tested workstation. The files were classified into two groups based on their subject, e.g. groups A and B.

Results and Discussion of the Experiment

In the beginning, three storage units were evaluated by 20 persons to select the most convenient one to be used within the second workstation. The three units were low height, high height shelves (their height from the desktop were 200mm and 500 mm respectively) and a wagon. While the more convenient height for accessing the document from the shelf is 500mm (from the desktop) [12,13]. The persons' evaluations revealed that the low height shelf on the desktop (its size is depth 260 x height 200 mm) is the most convenient storage unit to access the folders quickly, as its low in height and its location enables a person to see the files' contents easily. Next, the recommended tips were tested in the following stages:

First stage: effectiveness of stretching the storage space on the person's comfort

Eleven file boxes were distributed within each desk space based on the available space. In the first workstation, there are three spaces for placing those boxes, i.e. desktop space, pedestal, and under the desk. The numbers of the file boxes in each space accorded with the mentioned Fm. For example, three boxes were placed on the desktop. As for the pedestal, five boxes from group A and B were placed in its third drawer, as its size is suitable for A4 paper size. The remaining three file boxes of the former groups were placed under the desk. But, two storage spaces were available in the second workstation, e.g. pedestal and low height shelf. The file boxes were distributed in the second workstation space as follows: six boxes of groups A and B were placed on the shelf. The third drawer of the pedestal is devoted to keeping five file boxes from the former groups. Then, each person was asked his/her opinions about the available space on the desktop for working in both of the first and second workstations. In the first workstation, about 40% of persons remarked that the situation was inconvenient while 30% of them found the space was acceptable. About 20% of persons remarked that the situation was between acceptable and inconvenient levels. And about 10% of persons said that it was between convenient and acceptable levels. In the second workstation, about 95% of persons found the situation was convenient for working. The suitability of the available leg space of the two workstations was also evaluated. For the first workstation, about 65% of persons found the leg space acceptable. About 20% said that it was between acceptable and inconvenient. And about 15% said it was inconvenient. In the second workstation, about 80% of persons found the leg space convenient.

Second stage: effectiveness of the filing display on the time for file accessibility

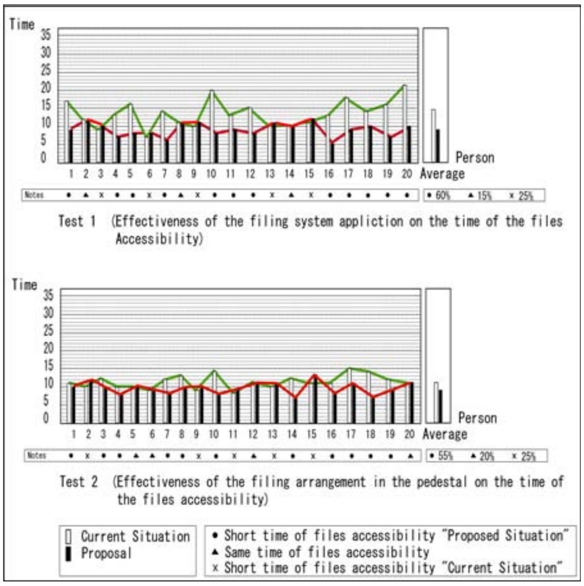
a. Filing system application test

We tested the time for file accessibility (the time that is spent to access the required file) by placing five file boxes within each workstation in the same place, e.g. on the shelf but displayed differently. For example, in the first workstation, a person relied on the folders' tabs to find the required file. In the second workstation, a clear filing system was applied by labeling each file box- including the main title, subtitle of its subject and the folders' names. The font size was 11 point, to provide clear visibility [14,15]. In addition, we used different color tabs to differentiate between two groups (e.g. the tab colors for the folders of groups A and B were orange and blue, respectively). Each person was asked to access a file from the first workstation, then from the second one. The time spent searching for the required file was measured using a stopwatch. The average time to access a file in the current situation was about 14 seconds and in the proposed one was about 9 seconds. The results of this test revealed that labeling and coding systems enable a person to find a file quickly (Fig. 2 – Test 1).

Figure 2 Filing display within the workstation

b. Filing arrangement test

According to the internal depth size of the pedestal (580mm) and the width size of the file box (310mm), three boxes were arranged from front to back in the pedestal of the first workstation. On the other hand, another three boxes were arranged from one side to the other side in the pedestal of the second workstation. The test boxes in both these situations were provided with the same filing system (including labeling and coding systems). Then, each person was asked to access a file from these workstations. Again, we measured the time that was spent searching for the required file. The results of this test showed that the average time of file accessibility in the current situation was about 11 seconds and in the proposed one it was about 9 seconds. According to this test and the persons' opinions, we detected that a person can find the required file easily when the files' tabs are directed toward the worker (Fig. 2– Test 2).



Test 1 (Effectiveness of the filing system appliction on the time of the files Accessibility)

Test 2 (Effectiveness of the filing arrangement in the pedestal on the time of the files accessibility)

Third stage: effectiveness of the files' locations within the workstation on the time for file accessibility

The purpose of this test was to identify whether the location of the files within the workstation space affects the time for the file accessibility. This stage was accomplished as follows: five file boxes were placed within the pedestal of the first workstation. In the second workstation, five boxes were placed on the shelf. File boxes of those workstations had identical labeling and coding systems. Then, each person was asked to access a file in these situations. While each person was searching a required file, we measured the time that was spent to access a file. The result of this test showed that the average time for file accessibility in the current situation was about 12 seconds and in the proposed situation was about 9 seconds. Persons mentioned that the files' location on the shelf enables them to see the contents of each file box more quickly than the current situation in which files are hidden in the pedestal (Fig.3- Test 3). Next, the file boxes' locations within those workstations were shifted as follows: five file boxes were placed under the first desk (on the floor). In the second workstation, five file boxes were placed within a pedestal. Again the boxes in these two conditions had the same filing system (including labeling and coding systems) Again, each person was asked to access a certain file in both of these situations. While each person was searching a required file, we measured the time that was spent to access it. The results of this test revealed that the average time for file accessibility in the first workstation was about 15 seconds and in the proposed situation was about 11 seconds. In the current situation, a lot of effort is required to access a file because a person has to bend forward to search and pick up what he needs (Fig.3- Test 4). According to the results of the previous stage, we recommend that a worker use a shelf upon the desktop for placing frequently used files. The pedestal, best used to place files that are not used continuously.

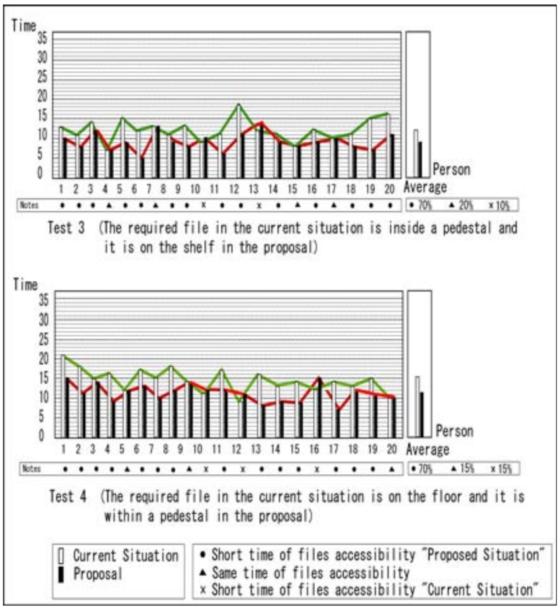


Figure 3 Effectiveness of the files' locations through the workstation on the time of file accessibility

Conclusions

This study concluded that displaying and distributing the files well through the workstation can facilitate a worker performance. High efficiency of personal storage for file accessibility demands two requirements:

1. A worker needs to display the files clearly within the workstation by applying the filing system with each paper. And, we recommend that a worker use side - to - side type of file arrangement within a pedestal to pick up simply what he/she wants.
2. A worker is required to distribute the files within his/her workstation based on frequency of use.

Acknowledgements

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STORAGE SYSTEM PERFORMANCE FOR FILE ACCESSIBILITY WITHIN JAPANESE OFFICE

Yasuyuki Hirai, Yoshitsugu Morita And Nermin Elokla

Department of Industrial Design, Faculty of Design, Kyushu University
Corresponding Author hirai@design.kyushu-u.ac.jp

Introduction

An office storage system is more than just a container. It is a system that has great responsibility in the workplace for helping a worker accomplish his/her job effectively. No doubt, the primary function of a storage unit in the workplace is simply to put away documents and other supplies not only for the next use, but also where each paper has a home, so that an individual gains a sense of control and the workplace seems clean and in a good view for clients [1]. According to a review of academic studies concerning storage systems, we found out that the storage system efficiency in the workplace has not been discussed yet. Many studies focused on the storage furniture capacity, function and design for home usage and other aspects [2-6]. We focused on the storage system efficiency for file accessibility, since the results of a survey within five Japanese companies in Tokyo and Fukuoka detected that the majority of workers complained about it. This study aims mainly to prove that the organization of the documents within the file cabinet of communal use not only affects the workers' comfort but also has a strong effect on the time for file accessibility.

Methods of Survey

This study was done using the following procedures: **first** five Japanese offices were visited as field survey in Tokyo and Fukuoka. Observations and discussions with 72 persons who work in these offices were used so as to understand how the storage system is managed. **Second**, a questionnaire was distributed among those workers in order to identify the main problems of a storage system which effects their comfort and performance. Based on observation and discussion, some answers were included in a questionnaire and the workers asked to select from the answers in accord with the complaints. **Third**, a solution was recommended in order to overcome the storage problems. In addition, we tested the recommended solution at a laboratory in Kyushu University to be sure of its effectiveness.

Results of Survey

The results of the questionnaire revealed the following: about 35% of workers complained that they cannot access the required files quickly, as file organization within the storage unit space is a problem; those workers complained of finding it difficult to get what they needed. About 29% of workers complained that the location of the file cabinets within a workplace is far from their workstations and therefore they cannot simply access needed files. About 28% of workers complained that the storage units are overloaded with the files, and about 8% of workers selected “other”. We focused on the first problem, as it had a high percentage of complaints. According to the survey, this study identified that the workers cannot access the files easily from the storage unit due to two reasons: the first one concerns the files' display inside the cabinet and a second reason relates to the files' location within the cabinet space. In other words, the distribution of files, especially inside a tall cabinet (e.g. 2100mm high) is inadequate for some workers to access a file easily. This study focused on the second reason, as the first one was previously discussed in another study [7]. In the visited offices, we found that two offices had considered frequency of use for distributing the files through the cabinet (e.g. frequently used files are kept on the shelves that are easy to reach). Another two offices don't arrange for distributing the files throughout a cabinet. Concerning the fifth office, the documents are distributed among the shelves of a file cabinet according to their topics; in this office, each shelf is devoted to keeping a certain group of files. Actually, office workers should set up the storage unit space based on frequency of use. The selection of the file's place within a storage unit should be determined according to how often it is used [8,9]. This study next examined this recommendation to prove its effectiveness for saving the workers' time and effort.

Methods of Experiment

The following experiment was conducted with 20 persons (15 men and five women- their ages ranging from 23 to 40 years) at a laboratory in Kyushu University (Table 1). These persons were asked to access the files from two tall file cabinets (Fig. 1). Each cabinet included six shelves and its size was width 800mm x depth 450mm x height 2100mm. About three file boxes (A4 paper size) were kept on each shelf as examples. The file box size was width 310mm x height 260mm x thickness 102mm. In each file box, six folders were put as examples; the folders' contents were divided into three groups based on their subject. The folders of each group had, e.g. two states of usage: folders of group "A" included folders "A-1" (frequently used) and folders "A-2" (infrequently used). Folders of group "B" included folders "B-1" (frequently used) and folders "B-2" (infrequently used). The folders of third group "C", included folders "C-1" (frequently used) and folders "C-2" (infrequently used). As for displaying the documents, each file box was well labeled (including, main title of each box, subtitle and the name of each folder) and the font size was point 11. In addition, color tabs were used to differentiate between these groups. For example, the tab color of folders of group "A", "B" and "C" was red, green and blue respectively. On the other hand, file distribution in the first cabinet accorded with the current situation used in some offices. Folders were distributed within the first cabinet based on their subject. For example, the first and second shelves were devoted to keeping the folders of group A (including A-1 and A-2). The third and fourth shelves were devoted to keeping folders of group B (including B-1 and B-2). The fifth and sixth shelves, were devoted to keeping the folders of group C (including C-1 and C-2). In the second cabinet (proposed situation), the files were distributed among its shelves according to the recommended concept. The selection of a convenient shelf that enables a person to access the frequently used files easily was determined according to the following points: 1. The standard height of shelf within a cabinet that accommodates Japanese human size [10-12] (Fig.2). 2. The persons' selection of the suitable shelves to their height.

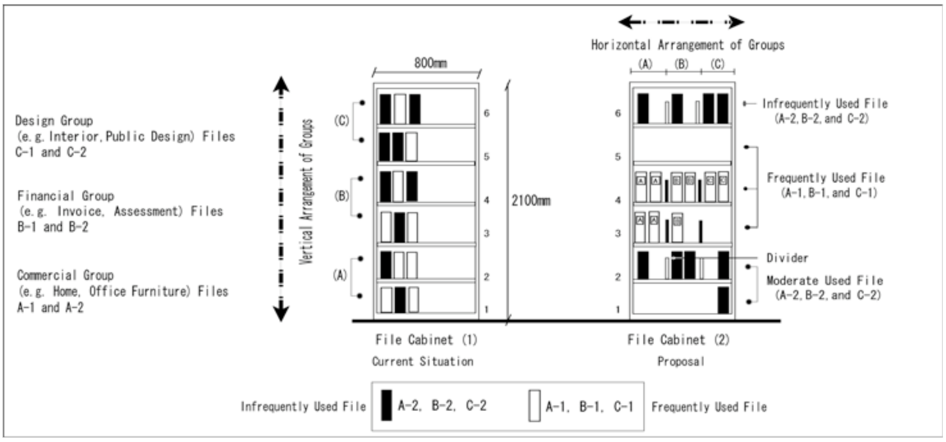


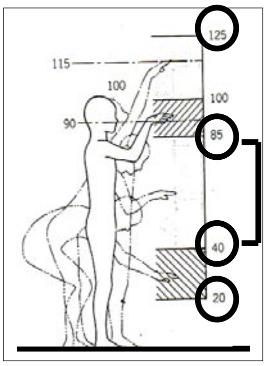
Fig. 1 Current and Suggested Situations of File Distribution in the File Cabinet

Results and Discussion of Experiment

In the beginning, each person was asked about the most convenient shelf to access and retrieve the folders easily. Based on the standard height of storage unit's shelves (Table 1) and the persons' answers, we obtained the following results:

Table 1 The Person's Height in Relation to the Height of the Storage Unit's Shelves

Person no.	Gender	Human Height size	85% ~	40%	Shelf no.	125%	Shelf no.	20%	Shelf no.
1	Male	180	153cm	72cm	5-2	225cm	6, 7	36cm	1
2	Male	177	150cm	71cm	5-2	221cm	6, 7	35cm	1
3	Male	175	149cm	70cm	5-2	219cm	6, 7	35cm	1
4	Male	172	146cm	69cm	4-2	215cm	6, 7	34cm	1
5	Male	171	145cm	68cm	4-2	214cm	6, 7	34cm	1
6	Female	170	145cm	68cm	4-2	213cm	6, 7	34cm	1
7	Male	170	145cm	68cm	4-2	213cm	6, 7	34cm	1
8	Female	169	144cm	68cm	4-2	211cm	6, 7	34cm	1
9	Male	167	142cm	67cm	4-2	209cm	6	33cm	1
10	Male	166	141cm	66cm	4-2	208cm	6	33cm	1
11	Male	166	141cm	66cm	4-2	208cm	6	33cm	1
12	Male	165	140cm	66cm	4-2	206cm	6	33cm	1
13	Male	165	140cm	66cm	4-2	206cm	6	33cm	1
14	Male	165	140cm	66cm	4-2	206cm	6	33cm	1
15	Male	163	139cm	65cm	4-2	204cm	6	33cm	1
16	Male	160	136cm	64cm	4-2	200cm	6	32cm	1
17	Male	160	136cm	64cm	4-2	200cm	6	32cm	1
18	Female	158	134cm	63cm	4-2	198cm	6	32cm	1
19	Female	155	132cm	62cm	4-2	194cm	6	31cm	1
20	Female	155	132cm	62cm	4-2	194cm	6	31cm	1



The Maxim Percentage of Height to Put and to Retrieve Supplies

An Average Percentage of Height to Put and to Retrieve Supplies

The Minim Percentage of Height to Put and to Retrieve Supplies

Fig. 2 Height of the Storage Unit Shelves [10-12]

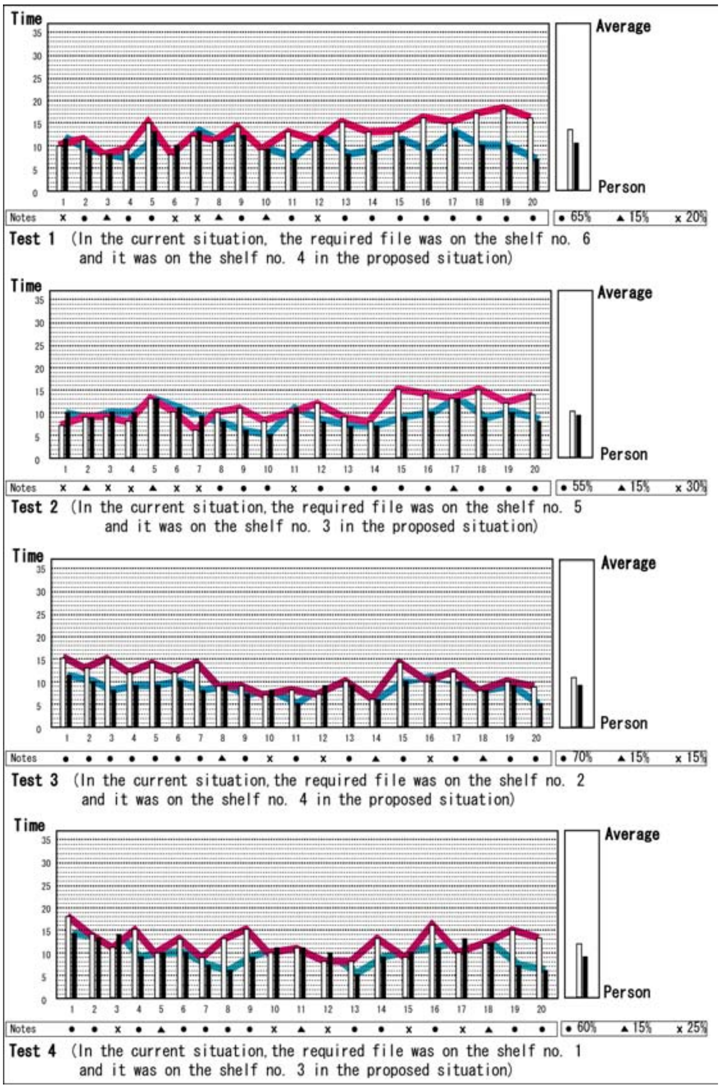
1. Handy reach shelf: About 60% of persons mentioned that the fourth shelf is convenient to get a file easily. About 20% of persons mentioned that the third shelf is convenient to get a file and 20% of persons said that the fifth shelf is convenient to get a file easily.
2. Easy visibility of the files' contents: About 75% of persons said that the fourth shelf is convenient to see simply the folders' tabs. In addition, about 20% of persons agreed that the third shelf is the most suitable shelf to observe the files' tabs easily and 5% of persons said that the fifth shelf is fit to see the files' tabs well (Fig. 3). Based on the evaluations of 20 persons, we detected that the most convenient shelves to keep the frequently used files are numbers four, three and five respectively.

In the light of the former results, fourth and third shelves within the second file cabinet were selected to keep frequently used files (A-1, B-1 and C-1). As for infrequently used files (A-2, B-2 and C-2), they were kept on the first, second, fifth and sixth shelves.

In the next step, each person was asked to access a certain frequently used file only (e.g. A-1, B-1 and C-1) from the first cabinet, then from the second one as well. On the other hand, using a stopwatch, we measured the time that was spent to access the required file from each cabinet. We pressed the button of the stopwatch when a person started to search for the required file and we stopped it when a file was accessed. The following are the results of this experiment (Fig. 3).

Test 1: the required file was placed on the sixth shelf of the first cabinet and it was placed on the fourth shelf of the second cabinet. We found out that the average time of file accessibility in the former situation was about 13 seconds and in the latter one was about 10 seconds. Test 2: the required file was placed on the fifth shelf of the first cabinet and it was placed in the third shelf of the second cabinet. We found out that the average time of file accessibility was about 11 seconds in the former situation and it was about 9 seconds in the latter one. Test 3: the required file was placed on the second shelf of the first cabinet and it was placed on the fourth shelf of the second cabinet. We found out that the average time of file accessibility was about 11 seconds in the former situation and it was about 8 seconds in the latter cabinet. Test 4: the required file was placed on the first shelf of the first cabinet and it was placed on the third shelf of the second cabinet. We found out the average time of file accessibility was about12 seconds in the former situationand it was about 9 seconds in the latter one.Consequently, this experiment demonstrated that the majority of persons spent more time to access the required file from the first cabinet than the second one. Based on those persons' viewpoints, two factors have great influences on the time of file accessibility: the first one is the file's location inside a file cabinet related to the depth of shelf and the weight of file box. Regarding the relationship between the files' location and the file cabinet depth, since the depth of shelf (an internal size) is 400mm and a file box occupies about 310mm, the remaining space (about 90mm) obstructed a person's view of the folder's tab - especially when a folder was kept on the first and sixth shelves.

Concerning the relationship between the files' location and the weight of the file box, about 50% of persons mentioned that they found a little difficulty in accessing a bulky file box from the sixth shelf of the first cabinet due to its heaviness. As for the second factor, the persons mentioned that they spent more time in the first status of test (current situation) than the second one (proposed situation) because in the former one they searched for a file through the whole shelves, however each shelf had a label of its contents. On the other side, in the latter status they focused on the fourth and third shelves to find the needed file.



Test 1 (In the current situation, the required file was on the shelf no. 6 and it was on the shelf no. 4 in the proposed situation)

Test 2 (In the current situation, the required file was on the shelf no. 5 and it was on the shelf no. 3 in the proposed situation)

Test 3 (In the current situation, the required file was on the shelf no. 2 and it was on the shelf no. 4 in the proposed situation)

Test 4 (In the current situation, the required file was on the shelf no. 1 and it was on the shelf no. 3 in the proposed situation)

Fig. 3 Time of File Accessibility Related to File Distribution Within a File Cabinet

Conclusions

From the former results of the experiment, this study concluded that the distribution of files within a cabinet has to be considered based on the status of information. In other words, is it used frequently, moderately or seldom. The intent is to increase worker performance by enabling him/her to access frequently used files quickly and comfortably.

Overall, the most suitable place in a tall unit (e.g. its height is 2100mm) for keeping frequently used files is fourth, third and fifth shelves respectively, as their heights fit well to the Japanese human height. On the other hand, the bottom shelves (e.g. second and first shelves) are devoted to keeping the files that are not used continuously, especially the bulky file tools.

As for the top shelves of file cabinet (e.g. sixth shelf), it is convenient for keeping the files which are seldom used.

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POSTER PRESENTATIONS

SKIN COLD SENSITIVE DIFFERENCE OF HUMAN BODY SECTIONS UNDER CLOTHING

Jun Li[1]*, *Yunyi Wang*[1], *Weiyuan Zhang*[1], *AND Roger L. Barker*[2]

[1]Fashion Institute, Donghua University, Shanghai 200051, People's Republic of China
[2]Center for Research on Textile Protection and Comfort, College of Textiles, North Carolina State University, U.S.A.
*corresponding author lijun@dhu.edu.cn

Introduction

Human thermal sensitivity varies widely across the surface of the body. Clothing has a major effect on modulating the relationship between a cooler environment and the perceived coolness of the wearer. Strategically distributing thermal insulation on the body will benefit the wearer. Therefore, it is necessary to develop a systematic understanding of sensitivity differences to cold of clothed body sections. While other skin sensation studies have focused on human physiology [3, 1], in this study we simulate real wearing conditions and investigate the combined effects of clothing and the environment on human physiological and psychological responses. We studied nine sections of the body, including the front of the right thigh (RT), the right calf (RS), the back of the left thigh (BT), the left forearm (LF), the front of the right upper arm (FF), the left part of the lower back (LW), the left part of the upper back (LS), the left part of the abdomen (LA), and the left part of the chest (LB).

Methods

Experimental Garments

The experimental garments were custom made for each subject participating. Wearing these ensembles, all eight female subjects (ages 21±1 years) felt comfortable while their mean skin temperature was about 33°C at the test condition temperature, which was 20.5±0.5°C, humidity 50±10%, natural air velocity 0.1m/s. Experimental garments were tight-fitting. For each body section investigated, the experimental clothing contained a removable 400cm^2 patch attached by nylon tabs. These patches could be removed to expose that specific body section of the wearer to the ambient environment. Apart from size, the design of the garments and the other physical properties were identical. The test garment was worn only with panties.

Experimental Protocol

In the climatic chamber the subjects rested for 50 minutes after changing their clothes to the experimental garments. Ten minutes after tests were started, one removable patch in the experimental garment was moved away to expose the body section underneath it to the ambient environment. In the second trial, organized according to the Thurstone paired comparisons method [5], two removable patches were simultaneously opened, exposing two body sections underneath them, then the subjects were required to report instantly which unclothed body section was colder. After the 30-minute exposure the removable patches were reattached for a period of 20 minutes, and the whole test took 50 minutes. During the testing time, subjects kept standing posture. The exposure order of body sections was random, and the interval time between tests was enough to avoid the effects of previous perceptions.

Measurements

Body temperature and skin temperature were recorded continuously from patch sensors attached to the skin surface, and data were stored at 42-second intervals. The exposed body section's skin temperature was measured at the center of the exposed area, and deep body temperature is estimated by measurement at the left armpit. Skin temperatures were recorded at twelve different positions and calculated by the method of Hardy and Dubois [6].

Data Analysis and Discussion

Exposing clothed body sections to the ambient environment changes the aspects of the wearer's physiological and psychological responses. Under the condition of this study, the exposed section's skin temperature changed significantly (student's t test, $p<0.05$). On the other hand, for MST and body temperature there is no significant difference between before and after body section exposures ($p<0.05$). No significant difference indicated that the exposed 400cm^2 skin area did not lead to significant human thermoregulation disorder.

Magnitude of local skin temperature decrease

We used the multiple comparisons method to analyze the magnitude of the exposed body section's local skin temperature decrease after the exposure [4]. We took the difference between the exposed body section's average skin temperature in the 5 minute period just before exposure and its skin temperature at the end of the exposure as variable X. Data from nine body sections make nine samples, and each sample has eight observing values from eight subjects (Table 1).

Table 1. Data of X (°C).

	LB	LS	LF	RT	LA	FF	BT	RS	LW
x_1	2.59	1.45	1.69	1.22	2.79	1.83	2.50	2.33	2.10
x_2	2.60	1.36	1.64	1.08	2.78	1.71	2.43	2.50	2.00
x_3	2.81	1.41	1.66	1.25	2.74	1.80	2.41	2.36	1.97
x_4	2.81	1.50	1.60	1.18	2.65	1.76	2.36	2.45	1.80
x_5	2.58	1.40	1.73	1.09	2.69	1.65	2.37	2.40	2.18
x_6	2.70	1.43	1.60	1.21	2.59	1.74	2.54	2.27	2.15
x_7	2.58	1.38	1.76	1.19	2.63	1.63	2.30	2.45	2.15
x_8	2.90	1.60	1.68	1.27	2.67	1.80	2.37	2.25	2.05
$\bar{x}$	2.696	1.441	1.670	1.186	2.693	1.740	2.410	2.376	2.050

First we queue samples according to their mean value, considering a sample's average value as a non-partial estimate of the population's mean. Then we make the hypothesis test to figure out whether or not a difference exists for every r sequential mean value ($r=1\sim 9$) or not. The test statistic R_r is the difference between the maximum and the minimum of r samples' mean values.

The calculation shows no significant difference ($\alpha=1\%$) for three groups in terms of the magnitude of the local skin temperature decrease. The first group is LF and FF. RS and BT are the second group. LA and LB belong to the third group. In general, when stimulated by cold, the magnitudes of the decrease in the exposed body sections' local skin temperature are different. The decreasing order is LB & LA, BT & RS, LW, FF & LF, LS, and RT.

Continuous changing of the local skin temperature

As for the other physiological response, we studied the relationship between the exposed body section's skin temperature's continuous decrease (Table 2) and the elapsed time during the exposure period with the Smirnov test [2].

Table 2. The exposed body section's skin temperature decrease when exposed °C .

Time (×42s)	RT	RS	BT	LF	FF	LW	LS	LA	LB
1	0.07	0.10	0.58	0.16	0.27	0.51	0.25	0.52	0.58
2	0.11	0.40	0.81	0.34	0.43	0.72	0.37	0.80	1.13
3	0.23	0.63	0.99	0.54	0.51	0.83	0.46	1.03	1.43
4	0.31	0.85	1.13	0.71	0.61	0.99	0.54	1.20	1.60
5	0.41	1.02	1.25	0.87	0.67	1.15	0.64	1.37	1.73
6	0.45	1.14	1.33	0.96	0.84	1.27	0.72	1.50	1.88
7	0.50	1.23	1.46	1.06	0.93	1.41	0.78	1.63	1.97

8	0.66	1.40	1.67	1.15	1.06	1.47	0.84	1.70	2.05
9	0.73	1.48	1.76	1.21	1.11	1.50	0.90	1.89	2.14
10	0.83	1.54	1.84	1.25	1.18	1.55	0.96	1.93	2.20
11	0.87	1.63	1.90	1.29	1.28	1.58	1.01	2.05	2.28
12	0.93	1.70	1.94	1.31	1.32	1.63	1.04	2.13	2.37
13	0.97	1.73	1.99	1.34	1.35	1.65	1.05	2.25	2.40
14	1.03	1.81	2.06	1.38	1.38	1.67	1.06	2.30	2.48
15	1.06	1.90	2.10	1.44	1.40	1.70	1.14	2.34	2.50
16	1.08	1.94	2.14	1.46	1.45	1.73	1.17	2.40	2.51
17	1.12	2.00	2.19	1.48	1.48	1.79	1.22	2.43	2.52
18	1.15	2.09	2.22	1.51	1.52	1.81	1.24	2.45	2.55
19	1.16	2.14	2.26	1.54	1.56	1.85	1.28	2.49	2.58
20	1.18	2.20	2.28	1.56	1.60	1.88	1.32	2.53	2.60
21	1.18	2.23	2.30	1.57	1.65	1.92	1.36	2.56	2.64
22	1.18	2.29	2.34	1.60	1.68	1.95	1.42	2.59	2.66
23	1.19	2.32	2.37	1.62	1.71	1.99	1.44	2.62	2.67
24	1.19	2.33	2.40	1.63	1.74	2.02	1.46	2.67	2.70
25	1.20	2.36	2.41	1.66	1.75	2.05	1.48	2.69	2.72

The Smirnov test is a nonparametric statistical method to test whether the distribution is the same among independent samples. Data from nine body sections (random samples k=1-9) of eight subjects (n=8) have their unknown distribution $F_1(X), F_2(X), \cdots, F_9(X)$. Suppose H_0: $F_1(X) = F_2(X) = \cdots, =F_9(X)$ (probability distributions are identical); H_1: $F_i(X) \neq F_j(X) \neq \cdots, \neq F_9(X)$ (probability distribution are not identical). For k samples, we define their maximum value individually as $z_1, z_2, \cdots, z_k$ *to* satisfy $z_1 \leq z_2 \leq \cdots, \leq z_k$. The experience distribution of the sample with z_k is defined as $S^{(k)}(X)$, while the experience distribution of the sample with z_1 is $S^{(1)}(X)$. The test statistic T is the maximum vertical distance between $S^{(1)}(X)$ and $S^{(k)}(X)$, which in mathematics can be written as:

$$T = \underset{x}{Sup}[s^{(1)}{}_{(x)} - s^{(k)}{}_{(x)}] \qquad (1)$$

where the critical value $w_{1-\alpha}$ (α is the level of significance) could be looked up in a given statistic table. If $T \geq \boldsymbol{w_{1-\alpha}}$, then K samples have a difference; if $T < \boldsymbol{w_{1-\alpha}}$, no difference exists among them.

The Smirnov test reveals a statistically significant difference for the nine body sections' skin temperatures' continuous changing processes when being stimulated by cold (α =5%). Within nine body sections are three groups in which each body section has the identical relationship between the local skin temperature's decrease and the elapsed time. The three groups are LS, LF, and FF; BT and RS; LA and LB.

Cold sensitive sequence

We investigated the body sections' sensitivity sequence to cold when exposed to the ambient environment with the Thurstone paired comparisons method. Exposing two body sections (j,k) simultaneously made one pair of stimuli $R(j)$, $R(k)$, and caused two sensations $S(j)$, $S(k)$*in* the wearer. $S(j)$ conforms to a normal distribution whose mean is $S_D(j)$ and the variance is σ_j ; $S(k)$ conforms to a normal distribution which mean is $S_D(k)$ and the variance is σ_k. The probability that body section j is cooler than k ($S(k) > S(j)$) or not ($S(k) < S(j)$) can be derived from the distribution of $S(j)- S(k)$.

In terms of the value of SD(j) (Table 3), the sensitivity sequence of body sections to cold stimuli is (from the most sensitive to the most insensitive) LW, LS, LA, LB, RT, BT, LF, FF, and RS.

Table 3. The Thurstone paired comparisons calculation results.

	LB	LS	LF	FT	LA	FF	BT	RS	LW
SD(j)	0.071	0.476	-0.273	-0.089	0.362	-0.330	-0.110	-0.621	0.514
SD'(j)	0.692	1.097	0.348	0.532	0.983	0.291	0.511	0	1.136
P(j)	75.50%	86.40%	63.70%	70.19%	83.65%	61.41%	69.50%	50%	87.29%

In Table 3 $S_D'(j)$ is calculated by adding 0.6211 to $S_D(j)$ to make Min($S_D(j)$)=0 which conforms to the standard normal distribution N(0,1). Based on $S_D'(j)$, we looked up $P(j)$ in the given statistic table. In this study $P(j)$ is a numeric of psychological sensation. According to the Weber's Law [7], 5% is considered as its classifying value. If the two values' difference is less than 5%, they should be classified as a group with identical sensitivity to cold stimulus. So LW, LS, LA are in one group; RT and BT are in another group; LF and FF belong to the third group.

Conclusions

The cold sensitivity of the human body under clothing shows a spatial distribution that varies over these body sections. Significant changes due to the exposure of clothed body sections to cold include two aspects: local skin temperature changing patterns and psychological sensitivity difference of body sections. However, body sections with codes that share the same underline as follows are similar in corresponding characteristic and should be classified into the same type.

LB, LA, BT, RS, LW, FF, LF, LS, RT are the decreasing order of the magnitudes of local skin temperature decreases.

RT, BT, RS, LW, FF, LF, LS, LB, LA describe the characteristic of local skin temperature continuous changing process.

LW, LS, LA, LB, RT, BT, LF, FF, RS are the cold sensitivity sequence (from sensitive to insensitive relatively).

This grouping indicates that body sections belonging to the same type are always adjacent. The torso is the most sensitive to cold, and the next sections are thighs, upper limbs, and calves. Body sections close to the body core are more sensitive to cold stimulation than limbs.

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THERMAL SENSITIVITY IN HUMAN LONG-TERM ADAPTED TO COLD, HEAT AND EXERCISE

*Tamara Kozyreva**

Department of Thermophysiology, Institute of Physiology, Russian Academy of Medical Sciences, Novosibirsk, Russia
corresponding author: Kozyreva@iph.ma.nsc.ru

Introduction

Adaptation of human to cold and hot climates, as well as to long exercise, is associated with high tension of the thermoregulatory system, which passes to a new functional level of regulation in the course of adaptation (compensatory adjustments). This is paralleled by changes in the thresholds of the thermodefensive responses, which is evidence of altered regulatory characteristics of thermal homeostasis.

The flow of thermal information depends on the magnitude of impulse activity and on the number of the functioning peripheral and central thermoreceptors. In human, the number of functioning cold and warm receptors in the skin can be estimated on the basis of the number of cold and warm spots (3).

Here, we present data showing how cold and warm sensitivity changes in human during long-term adaptation to cold and heat environment and also to conditions of long exercise.

Methods

Four groups of male subjects were studied: 1) cold-adapted, human that lived in Polar conditions for not less than 5 years and continuously working out of doors (in the open air), 34 subjects; 2) heat-adapted, human that lived for not less than 5 years in Turkmenistan, 41 subjects; 3) exercise adapted, human performing heavy manual labor, continuously working in warm premises, 31 subjects; 4) control group, mental workers living in Siberian cities, working and spending free time in warm premises, 65 subjects.

The tests were carried out in a climatic chamber. First, at 26°C (thermoneutral conditions for human without clothes), in subjects the number of cold and warm spots (the number of the skin cold and warm sensitive receptors) was calculated in 100 spot matrix on a 25 cm^2 surface of the internal forearm skin. The receptive field for a single thermoreceptor was 1 mm (1, 3, 4), Taking this into account, a special thermode, 1 mm tip diameter, and tip temperature +3-4° for cold spots and +41°C for warm spots was used to test the cold and warm sensitivity. The temperature of the tested skin area was measured by a thermistor. Tympanic temperature measured with a thermocouple served as core temperature for details see 8, 10). Then the temperature in the climatic chamber was lowered to 13°C and the subject remained at this temperature for 60 min. The measurements of skin and body temperatures and of the number of cold spots on the forearm were repeated.

The data were treated using Student's t-test and correlation analysis.

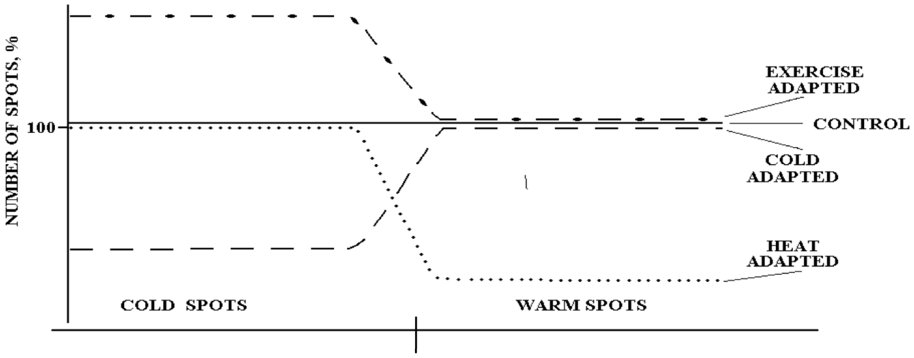
Results and discussion

The values for forearm skin temperature in the area where thermal sensitivity was tested and the body core temperature at 26ºC and 13ºC in the climatic chamber are given in the Table1.

Table 1. Tympanic and skin temperatures in subjects adapted to different conditions at ambient of 26º and 13ºC

Groups	Tympanic temperature (ºC)		Forearm skin temperature (ºC)	
	At 26°C	At 13°C	At 26°C	At 13°C
Control (n=65)	36.8±0.04	36.5±0.03*	33.4±0.35	29.1±0.47**
Cold adapted (n=36)	36.8±0.29	36.7±0.10	32.9±0.41	29.3±0.45**
Heat adapted (n=41)	36.7±0.06	36.2±0.09**	33.9±0.12	28.3±0.56**
Exercise adapted (n=34)	36.8±0.10	36.5±0.09	32.0±0.13	29.7±0.53**

Significant differences from values at 26°C: * - P<0.05; ** - P<0.01.

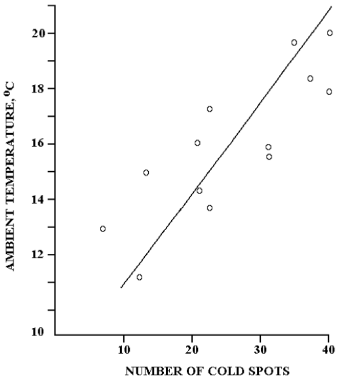


Studies at a temperature of 26°C in the chamber demonstrated the following. In cold-adapted human, the number of cold spots in the forearm area was much reduced, the number of warm spots was unaltered (Fig.1). That meant a decrease in cold sensitivity in cold-adapted subjects. In fact, special test carried out in a climatic chamber showed that ambient temperature sensed as cold by unclothed human is directly related to the number of cold spots on the forearm (Fig. 2).

Human adapted to heat were distinguished by a reduced number of warm spots (i.e. decrease in warm sensitivity), whereas they did not differ in their number of cold spots from subjects of the control group (Fig. 1).

Human adapted to exercise in warm premises showed an increase in the number of cold spots (i.e. an increase in cold sensitivity); however, the number of warm spots remained unchanged (Fig. 1).

A decrease in ambient temperature in the chamber to 13°C produced a decrease in skin temperature and a decrease in cold spot number in all the tested groups (Fig. 3). In cold-adapted human, a decrease in the number of cold spots was retained in the range of all the tested skin temperatures. The dependence of cold spot number on temperature in heat-adapted human did not differ from that in the control group. In adapted to exercise human, a decrease in cold spot number associated with a lowering skin temperature was more pronounced and at a forearm skin temperature of 26-28°C it already did not differ significantly from the one in the control group.



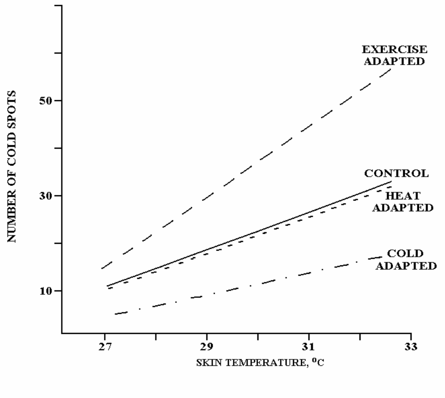


Figure 2. Relation of the number of cold spots and ambient temperature sensed as "cold" by the tested subjects.
y= 12+0.19x; r=0.77 (P<0.01)

Figure 3 . Dependence of the number of forearm cold spots (N) on skin temperature (T°C) in subjects adapted to different conditions. N=-106.6+4.4T°; r=0.57 (P<0.001) – control N=-59.0+2.3T°; r=0.53 (P<0.001) – cold adapted
N=-103.1+4.2T°; r=0.56 (P<0.005) – heat adapted
N=-152.0+6.1T°; r=0.61 (P<0.005) – exercise adapted.

Conclusions

The results provided evidence indicating that human adaptation to different conditions (challenge by cold, heat, and exercise) produced ambiguous changes in thermal sensitivity. In human whose life was associated with continuous cold exposure, cold sensitivity was reduced in all the range of skin temperature 26-34°C. Their warm sensation did not undergo change. In human adapted to heat climate, in contrast, warm sensitivity was decreased without change in cold sensitivity. Long exercise loads under which human was infrequently subjected to overwarming nevertheless did not affect warm sensitivity, but considerably increased cold sensitivity.

The observed changes in temperature sensation may result from both reorganization at the level of the central nervous system and changes in the function of the peripheral skin thermoreceptors. Thus, it was shown for the hypothalamic neurons (7, 11) and cutaneous thermoreceptors (2, 5, 9,) in animals that the temperature-dependent pattern of their impulse activity changed after long-term adaptation to cold. When taking into account that noradrenaline may modulate impulse activity of the central and peripheral thermoreceptors (6), it appears that the sympatho-adrenal system participates in the mechanisms providing appropriate changes in the adaptive thermosensitivity.

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THE MODULATING EFFECT OF WEAK RAPID AND SLOW COOLING OF THE SKIN ON IMMUNE RESPONSE

*Ludmila Tsoy, Ludmila Eliseeva, Galina Khramova, Tamara Kozyreva**

Department of Thermophysiology, Institute of Physiology, Russian Academy of Medical Sciences,
Novosibirsk, Russia
corresponding author: Kozyreva@iph.ma.nsc.ru

Introduction

Maintenance of health is dependent on numerous regulatory interactions between organ systems. The relation between the thermoregulatory and immune systems is an aspect of the unresolved problem, possibly the most important because of the extensive and wide spread influence of temperature on the body. The data in the literature indicating that cold affects also the immune system are scanty. They mainly concern experiments in which animals were exposed at the same time to several stressors and extremely deep cooling. However, much more often human and animals are exposed to weak and short-term cooling.

In recent years, there were single reports providing data for the influence of cold on the immune system in humans (1, 2, 3). Thus, it was demonstrated that cold can result in an increase in the number of natural killers and IL-6 content in blood (1). However, it appeared of interest to know how the function itself of the immune system changes, how the system responds to antigen under conditions of cold exposure. Studies of this kind are difficult to perform in human.

At external weak cooling the afferent signal of the skin thermoreceptors is the starting and forming factor, which provides the interrelation of various systems. Change in the thermal afferent signal under the effect of external cold stimulus may also affect the status of the immune system and, consequently, the formation of the immune response.

The signal of the thermosensitive skin afferents depends on the magnitude, rate, and location of the thermal effect. Depending on the cooling rate, the skin thermoreceptors can change their activity either gradually conforming the dependence of their static activity on the temperature when cooling is slow or, as in the case of rapid cooling, the thermoreceptors also show dynamic activity, a transient excitation followed by a decrease in impulse activity conforming to the established temperature.

Our previous studies provided evidence indicating that the dynamic activity of the peripheral thermosensitive afferents contributes largely to the control of the functional systems involved in the maintenance of thermal homeostasis and also in change in the hormonal status under cold effect (5, 6). The initial period of immunogenesis after antigen challenge is highly important for the immune response formation. In the present study, we are concerned with the modulation of a set of parameters of the immune response to antigen under the weak skin cooling with different rates which was applied immediately after immunization.

Methods

Male Wistar rats weighing 248±6g were used in the experiments. Experiments were performed under deep nembutal (40 mg/kg) anesthesia to exclude the effect of the emotional component of stress. Ambient room temperature was 21-24℃. Using a special thermode and thermostat a depilated abdominal area of 25 cm^2 was cooled at a rate of 0.06 ℃/sec – rapid cooling, on the presence of dynamic activity of the skin cold receptors, or at 0.006℃/sec – slow cooling on the absence of the thermoreceptors dynamic activity. When skin temperature decreased by 1.3±0.1℃, the rat was warmed, rectal temperature did not change.

In the course of the experiment, the temperature of the skin of the auricular floor, isolated from the environment, was recorded. Based on this record, judgments could be made about the onset, rate and intensity of the vascular response to cooling designed to limit heat loss. The rectal temperature, intracutaneous temperature of the cooled abdominal surface, total oxygen consumption and electrical activity of the neck muscles were also continuously recorded. The methods used in recordings have all been described (6). The measured parameters were recorded and treated with the Biopac system MP100.

Rats were intraperitoneally antigen challenged with 5x10^8 sheep blood red cells (SRBC) in 0.5 ml saline 30 sec before cold stimulus was applied. The immune response was estimated 5 days after the antigen challenge. The following methods were used. (1) A mobile preparation was made from a suspension of spleen single cells after 15 min incubation in a thermostat at +37ºC with an equal volume of 3% sheep erythrocyte suspension. Using phase-contrast optics (at a 1 000 magnification), 1 000 cells were examined and the number of rosette-forming cells among them were counted, i.e., the number of antigen binding cells in spleen; (2) the standard method of local hemolysis that allows to determine the number of plaque forming cells secreting IgM, i.e. the number of antibody forming cells per spleen; (3) the standard method for evaluating the humoral response to sheep erythrocytes on the basis of hemagglutination (general antibody titers).

All the data were treated for significance by Student's "t"-test.

Results and discussion

The parameters characterized the initial temperature homeostasis in animals before slow or rapid cooling are given in Table 1. No thermoregulatory responses to the applied slow or rapid skin cooling by 1.3±0.1ºC were observed.

Table 1. Initial parameters in thermoneutral conditions before cooling.

Parameters	Before rapid cooling	Before slow cooling	P
Intracutaneous abdomen temperature, ^{0}C	38,9±0,1	38,6±0,1	>0.05
Rectal temperature, ^{0}C	38,5±0,1	38,3±0,1	>0.05
Ear skin temperature, ^{0}C	32,0±0,4	31,4±0,7	>0.05
Total oxygen consumption, ml/min∗kg	23,8±2,1	22,8±1,6	>0.05
Electrical muscle activity, µV	1,5±0,1	1,5±0,2	>0.05

The values are M±m.

The results given in Figs 1, 2, 3 show that weak cooling of the skin immediately after antigen challenge, without producing a thermoregulatory response, leads to significant changes in the formation of the immune response.

Two types of skin cooling, rapid and slow, result in a stimulation of the immune response. However, depending on the cooling rate cold affects different parameters of the immune response.

On the contrary, when slow weak cooling (without dynamic activity of cold receptors) was applied immediately after immunization there were no changes in antibody formation, but antigen binding in spleen increased by 75% (Fig. 1, 2, 3).

Of interest is that rapid cooling in the presence of the dynamic activity of the skin cold receptors caused an earlier and an exaggerated activation of the sympatho-adrenal system (5). The data are of particular interest because may be helpful in elucidating mechanisms providing the different effects of rapid and slow cooling on the immune response. The changes in the immune response during activation of the sympatho-adrenal system may be dose-dependent.

The differences we revealed in the present experiments in the sensitivity of particular immunological events are also due to the quality of the population of immunocompetent cells implementing the immune response under study.

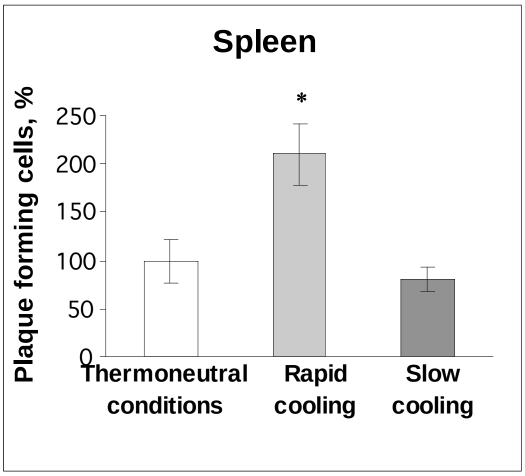

Figure 1. The effect of rapid and slow skin cooling on antibody formation in spleen. * P<0.05

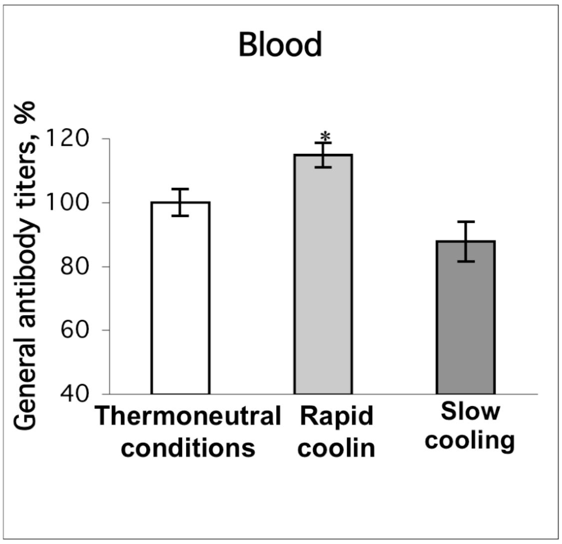

Figure 2. The effect of rapid and slow skin cooling on antibody formation in blood. * P<0.05

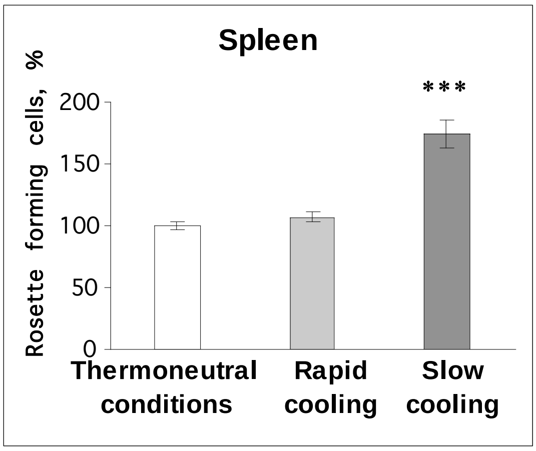

Figure 3. The effect of rapid and slow skin cooling on antigen-binding in spleen. *** P<0.001

Conclusions

Thus, even weak skin cooling can modulate the process of immunogenesis. When weak skin cooling is applied immediately after immunization it results in stimulation of the immune response but the stimulating parameters are different depending on the rate of cooling, i.e. the afferent signal of the skin cold receptors. It is obvious that the static activity of the skin cold receptors was more important for antigen binding function and the presence of its dynamic activity conditioned the marked increase in antibody formation. Elucidation of the role of the thermal factor in the formation pattern of the immune response to antigen during cooling of the body is not only the theoretical interest, but also of applied. It helps to evaluate the formation of immunity and of the immune resistance of the organism under cold exposure. This is of importance, in vaccination of humans and their adaptation to cold environments.

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ENHANCED CUTANEOUS THERMOSENSITIVITY FOLLOWING SPINAL CORD INJURY

*Bradley R. Wilsmore[1], James D. Cotter[2], Guy M. Bashford[3], Nigel A.S. Taylor[1]**

[1] Department of Biomedical Science, University of Wollongong, Wollongong, Australia.
[2] School of Physical Education, University of Otago, Dunedin, New Zealand.
[3]Dept. of Rehabilitation Medicine, Port Kembla Hospital, Warrawong, Australia.
* corresponding author nigel_taylor@uow.edu.au

Introduction

Humans modulate cutaneous blood flow, evaporative heat loss and thermogenesis to regulate the thermal energy content of the body. Thermosensitive tissues transduce local thermal energy into afferent impulses, while heat exchange from the body surfaces is controlled via efferent flow from the hypothalamus to the effector organs of the system. Optimal thermoregulation is reliant upon the integrity of the entire system. People with a complete spinal cord injury, and sympathetic tract transaction, experience isolation of thermosensitive tissues, lose control over thermoeffective structures below the lesion, and have a reduced ability to cope with altered thermal states (Randall *et al*., 1966; Huckaba *et al*., 1976).

Since the spinal cord and sympathetic tract of such people have been severed, there is a reduced number of cutaneous thermoreceptors with which to evaluate the thermal environment, and also a reduced capacity of the thermoeffectors to regulate body temperature. Under such a state, it may be possible that the regulatory system adapts to better ensure regulation might still be achieved. One possible adaptation may be to modify the sensitivity of the remaining, intact thermoreceptive fields. Accordingly, we tested the hypothesis that spinal cord injury would result in an elevated thermosensitivity of the sensate skin.

Methods

Ten subjects with clinically-verified, complete spinal cord injury (C5 to L1) were matched with 10 control subjects. Subjects with spinal cord injury received a physical and medical examination before testing, in accordance with the International Medical Society of Paraplegia (Maynard et al., 1997). All subjects provided written, informed consent, and all procedures were approved by the Human Research Ethics Committee (University of Wollongong).

Subjects rested supine, semi-nude, on a dry floatation cushion (ROHO©), whilst mean body temperature was clamped using a whole-body perfusion suit (T_{water} 38.8°C) within a climate-controlled chamber (38.5°C, 39% relative humidity). This suit consisted of 80, one-metre lengths of polyvinyl tubing (Tygon®; I.D. =1.6 mm, O.D. =3.0 mm) arranged in parallel, with adjacent tubes clipped together at 8-cm alternate intervals to form a diamond-shaped lattice. The suit was made up of trousers (30 tubes) and a long-sleeved jacket (50 tubes). A water-perfusion patch (274 cm^2), positioned over the dorsal surface of the neck, was also supplied with water at the same temperature (Figure 1). After 45 min, this perfusion patch was perfused with cold (7.9°C) water for 5 min.

Local sweat rates were measured at six sites using ventilated sweat capsules (3.16 ±0.05 cm^2: Multi-Site Sweat Monitor, Clinical Engineering Solutions, Australia). Core temperature was measured continuously from the oesophagus (~40 cm from the nares; Mekjavić and Rempel, 1990), rectum (~10 cm beyond anal sphincter) and auditory canal (~20 mm beyond the meatus, and insulated). Skin temperatures were measured from 14 sites, with mean skin temperature calculated using surface area weightings (ISO, 1992). Mean body temperature (T_b) was calculated as: T_b = 0.8 * oesophageal temperature + 0.2 * mean skin temperature.

Local and whole-body thermal sensation was obtained prior to treatment, and at 30 s and 270 s during cooling. Ratings were obtained using a thirteen-point, continuous scale (modified from Gagge *et al.*, 1967), in response to the question: “How does the temperature of your body feel?”.

Results

The spinal cord injured subjects displayed a significantly greater sweat rate suppression (P=0.048) during patch cooling (dorsal neck) than the matched control subjects. Similarly, there was a greater change in local thermal sensation (P=0.031). However, whole-body thermal sensation did not differ between the two subject groups (P=0.124).

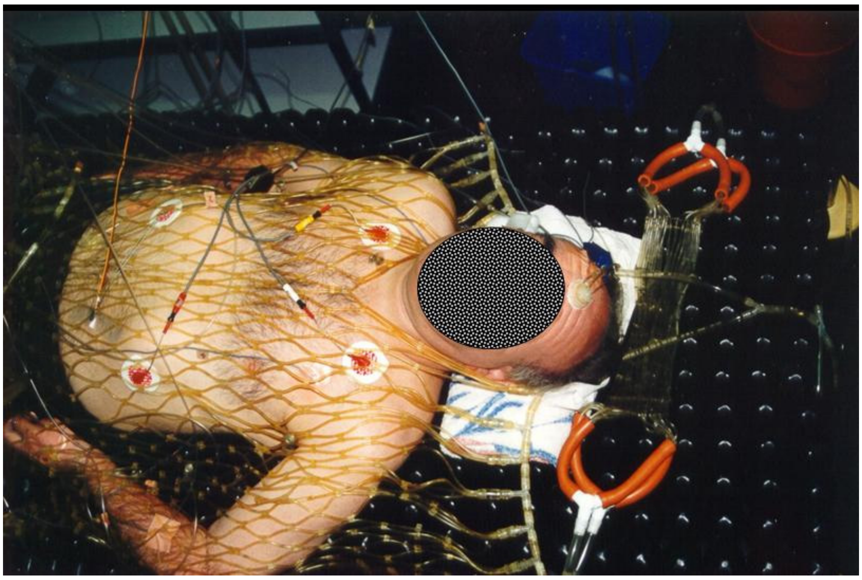

Figure 1. Experimental set-up.

Conclusion

These data are consistent with both a greater perceptual sensitivity and sudomotor thermosensitivity in the subjects with spinal cord injury. This phenomenon might reflect an adaptive modification of cutaneous thermosensitivity, commensurate with a chronic reduction in the total thermoafferent load.

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THE EFFECT ON BODY CORE TEMPERATURE OF THE CHANGE IN PERIPHERAL BLOOD FLOW DURING LOWER BODY NEGATIVE PRESSURE

Masami Hirashita[1]*,Yoko Kajiwara*[2]*, Saburo Yokokura*[3]*, Osamu Shido , Ristuko Kamimura*[5]

[1] Department of Social Welfare , Kinjo University, Japan.
[2] The Faculty of Education , Bunkyo University, Japan.
[3] Material Science Research Center , Meisei University, Japan.
[4] Faculty of Medicine, Shimane University, Japan
[5] The Institute of Tropical sport and health science , Japan.
*masami12@po.incl.ne.jp

Introduction

If body core temperature rises upon exposure of a body to the heat or during exercise, skin blood flow increases markedly, which allows for the transfer of the heat, accumulated within the body, to the surface of the skin via blood flow, and allows for its emission to the external environment by radiation, convection, and conduction. Conversely, in a cold environment or in a situation where body core temperature goes down, skin blood flow decreases, and heat dissipation from the surface of the body to its external surrounding is kept at a minimum. Regulation of cutaneous blood flow thus plays a significant role in homeostasis of body core temperature. In the meantime, exercise in the heat induces profuse perspiration. If the ambient temperature goes beyond 34℃, sweating becomes the only means to take the body heat away. Perspiration reduces body fluid, which, in consequence, decreases venous return, and lowers central venous pressure. If these changes cause a reduction in cardiac output or a decrease in arterial blood pressure (BP), then cardiopulmonary baroreceptor-mediated and arterial baroreceptor-mediated circulatory regulation reflexes take place, and also the increase in heart rate (HR), constriction of peripheral vessels, vasotonia of veins, etc., are induced. Cutaneous vasomotor is also known to be subject to the control of circulatory regulation mechanism. In other words, if there are any changes in the amount of venous return or BP, the skin blood vessels constrict or dilate, mediated by baroreceptor reflex, as if to compensate the changes5). The cutaneous vasomotor, in response to the circulatory regulation reaction, causes changes in the amount of skin blood flow, which may change the amount of heat dissipation from the surface of the body, and may even change the body core temperature with imbalance in net gain and loss of the body heat. This hypothesis, however, has not been examined in depth.
We examine in this study, how the reductions in heat dissipation and venous return affect body core temperature with mediation of circulatory regulation reflex by applying lower body negative pressure (LBNP).

Methods

Procedures
Experimental subjects of this study were nine healthy male humans at the age of twenty . The objective of the experiment was explained to them in advance which they agreed to. All the experiments were done at an ambient temperature of 28℃ and relative humidity of 40% in a temperature- and humidity-controlled chamber . After the subjects went through diet restriction from twelve hours prior to the starting time of the experiment, they entered into an experimental laboratory and stayed quiet for one hour before the experiment. The subjects, only wearing shorts, lied down in a supine position at rest, with the lower body below iliac crest placed in a LBNP box . After all the measurements items were stabilized and the measurements at rest were taken for ten minutes. LBNP was applied for 20 minutes at an intensity of 300 mmH_2O. We used a commercially available reversed air pump to draw out the air from the box and adjusted pressure by varying the diameters of air vent valves attached to it.

2) Measurements
Esophageal Temperature (T_{es}) was measured by thermistor inserted from nasal cavity to esophagus to the level same as that of the right atrium. Skin temperatures were measured by thermistors at seven sites (forehead, forearm, hand, chest/trunk, upper thigh, lower thigh, and foot). Then, mean skin temperature (T_{sk}) was calculated based on the formula written below.

$$\text{Mean } T_{sk}=0.07\ T1 + 0.35\ T2 + 0.14\ T3 + 0.05\ T4 + 0.19\ T5 + 0.13\ T6 + 0.07\ T7$$

(T1, T2, T3, T4, T5, T6, and T7 refer to forehead, forearm, hand, chest/trunk, upper thigh, lower thigh, and foot, respectively.)

Finger blood flow (FBF) at the left middle finger was measured by laser Dopplar flowmetry, and was also estimated at the right middle finger by venous occlusion prethysmography using a mercury-in Silastic tube straingage with 10 gram-tension rolled around the center of the top join of the left middle finger. HR was measured by heart rate meter based on the output from electrocardiogram. Systolic and diastolic BP were measured every one minute and other data were sampled every 30 seconds through an A/D converter connected to a personal computer.

Results and discussion

Fig. 1 shows one example of the changes in HR, BP, FBF, T_{es}, and other skin temperatures (hand, trunk, thigh, and mean) of one subject while applying 300mmH_2O LBNP. All the skin temperatures except that of the head went down after the application of LBNP, among which the change was most conspicuous for the hand. MeanT_{sk} lowered approximately by 0.5℃. Clear changes were not observed for both systolic and diastolic BP. Finger blood flow, measured by Laser Dopplar flowmetry and venous occlusion prethysmography, decreased by half right after the application of LBNP. T_{es} began rising one minute after the onset of the LBNP application, went up by 0.3℃ after approximately 15 minutes later, and remained constant afterwards. HR slightly increased after the onset of the application of LBNP compared to those at rest and of recovery time.

The present study confirmed that light application of LBNP would increase body core temperature. Upon its application, cutaneous temperature went down at almost all the skin sites, with those at limbs showing the most significant fall (Fig. 1). The drop in the cutaneous temperature decreases thermal gradient between the temperatures of skin surface and the surrounding environment4), which physically cuts down the amount of heat dissipation. Although the application of LBNP slightly raised heart rate, its increase generally means heat production. In view of this, the increase in the body core temperature by the application of LBNP is considered to be the result of the increase in the amount of stored heat after the amount of heat loss went down and that of heat production went up.

Cutaneous vasoconstriction, mediated by baroreceptor reflex, could be brought on by such stimulus as application of LBNP that causes a reduction in the amount of venous return 9,13). In fact, in our present study, finger blood flow was decreased by the application of LBNP. However, the vasomotor induces the rise in body core temperature, as mentioned before. We assume, therefore, a competition exists between mechanisms of thermoregulation and circulatory regulation over the cutaneous vasomotor. It was reported that, in an experiment where subjects underwent exercise wearing water-perfused suits to keep their cutaneous temperature constant at 38℃, skin blood flow was inhibited so as to maintain blood pressure even in a situation in which body core temperature was high (Brengelman et al., 1977). There is also a report which suggests a possibility of a reduction in skin blood flow when the 17% of plasma was lost after subjected to an intensive exercise in the heat (Nadel et al.,1971).

In the present study, despite the fact that application of LBNP raised HR and maintained BP, body core temperature apparently went up. We assumed that these experimental results could account for the fact that circulation would prevail and thermoregulation would be sacrificed when a competition arises between the mechanisms of thermoregulation and circulatory regulation, which seems to support other’s result (Morimoto et al.1990). It is known that inputs from baroreceptor could be non-thermal inputs to thermoregulatory mechanism in animals13). Rise and fall of blood pressure inhibit shivering and non-shivering thermogeneses, and low blood pressure, caused by blood removal, promotes thermo-neuron activity of anterior hypothalamus. All these reports suggest that the body temperature was brought down by baroreceptor-mediated pressor reflex. In the present study, on the contrary, body temperature went up upon the application of LBNP. The rise in the body core temperature presumably attributes to the decrease in skin blood flow mediated by baroreceptor and its resultant decrease in heat dissipation. Thus, we consider it as a passive response and therefore, it is hard to think of it as a response regulated by thermoregulatory center.

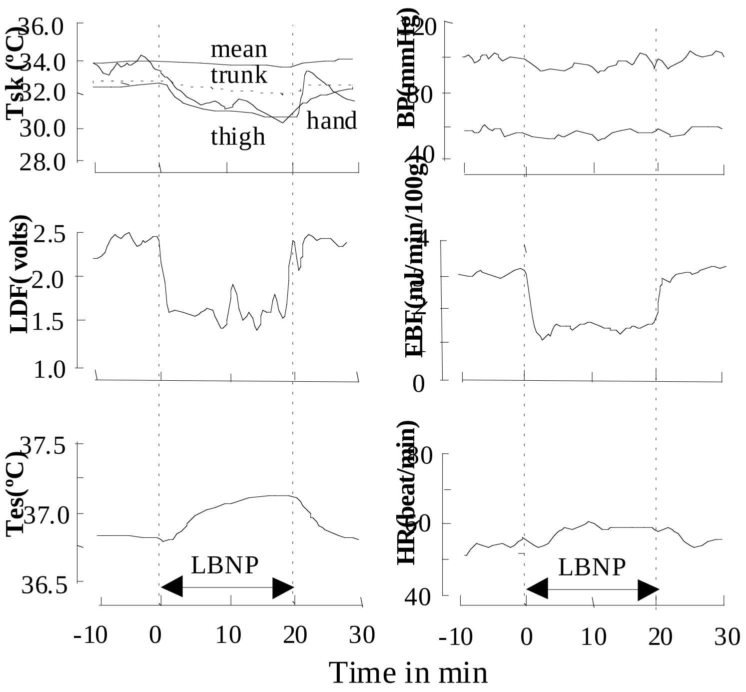

Fig.1 Changes in skin temperatures(Tsk),esophageal temperature (Tes), finger blood flow (LDF and FBF), systolic and diastolic blood pressure(BP),and heart rate(HR) in one subject during lower body negative pressu(LBNP). LBNP was applied between 10 and 30 min.

FBF decreased considerably by LBNP. Cutaneous blood flow at distal portion of the extremities, where many arteriovenous anastomoses (AVAs) exist, has a great impact on body temperature even enough to change it[8)]. During cycle erogometer exercise in the heat, perspiration increases and cutaneous vasodilation at other regions occurs if blood flows at both wrists are constricted (Nagasaka et al.,1997). In fact, it is reported that despite the fact that compensatory response takes place, the body core temperature goes up, and suggested that limbs are very important regions for heat dissipation. Thus, we assume that the decrease in the amount of blood flow at the extremities with abundant AVAs contributes to the rise in body core temperature during the application of LBNP.

Conclusions

The present study investigated core temperature and cardiovascular responses to a low level of lower body negative pressure (LBNP) in male subjects. LBNP was applied in a supine position for 20 min at an intensity of 300 mmH_2O at an ambient temperature of 28℃ and relative humidity of 40%. Esophageal temperature (T_{es}), skin temperatures (7 sites), arterial blood pressure and heart rate were measured before and during LBNP application. LBNP significantly increased Tes and decreased mean skin temperature. Heart rate slightly but significantly increased due to LBNP, while blood pressure did not alter during LBNP. The results suggest that cutaneous vasoconstriction took place during LBNP through baroreceptor unloading, which resulted in a reduction of heat loss and then in a rise in core temperature.

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GENDER DIFFERENCES IN CUTANEOUS TEMPERATURE SENSITIVITY

Petra Golja[2] and Igor B. Mekjavic[1]*

[1] Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute,
Jamova 39, SI-1000, Ljubljana, Slovenia
[2] Nova Gorica Polytechnic, Kostanjeviska cesta 16, Pristava, SI-5000 Nova Gorica, Slovenia
*corresponding author: petra.golja@p-ng.si

Introduction

We investigated whether gender-specific differences existed in the cutaneous sensitivity to cold and warm stimulation. A previous study by De Neeling et al. (1) reported no evidence of such gender-specific thermosensitivity, but failed to monitor skin temperature and only included elderly subjects. The available evidence suggests that females have better thermal discrimination than males (2), and a lower threshold for thermal pain stimuli (3).

Several psychophysical methods have been developed to assess cutaneous thermosensitivity. In general, warm and cold stimuli of a fixed and well-defined rate of change of temperature, but variable duration, are applied to a defined area of the skin. Subjects are requested to respond to each perceived stimulus and the threshold for thermal sensation is calculated as the arithmetic mean between the stimulus intensities perceived by the subject, and those that are not. Such psychophysical tests provide an indication of the minimal temperature change perceived by the subject, i.e. the cutaneous thermal threshold.

The aim of the present study was to evaluate whether cutaneous thresholds for thermal sensation differ between males and females.

Methodology

Cutaneous thresholds for cold and warm sensation were determined on the forearm and on the foot with a Middlesex Thermal Testing System. The MTTS consists of a thermode (Peltier element) with a surface area of 24 cm^2 and mass of 165 g, and a control unit connected to a computer. The MTTS control unit initiates the thermal stimuli and determines their magnitude and duration. Thermal stimulation of the skin is achieved with a Peltier element attached to the skin with medical adhesive tape.

The assessment of cutaneous thermosensitivity of the forearm and leg was conducted in two separate subject populations. The protocol of the study was approved by the National Ethics Committee of the Republic of Slovenia.

Forearm cutaneous thermosensitivity

Twenty healthy subjects (10 males and 10 females) participated in the study. The mean (SD) age of the males was 31(9) years and 28(2) years for females. They were all familiarised with the protocol and gave their consent to participate in the study.

During the tests, the ambient room temperature was maintained at 26°C, and the subjects wore normal clothing. The thermode of the MTTS system was positioned on the volar side of the left forearm, at the midpoint between the elbow and the wrist. Cold (CT) and warm (WT) thermosensitivity tests were performed on each subject in one sitting, and the order of the two tests was balanced between the subjects. The steady state temperature of the thermode corresponded to the adapting temperature of the skin (T_{ad}; °C) and was measured with a K-type thermocouple. The thermosensitivity tests were performed on three different occasions, separated by an interval of one to seven days. For each subject, the lowest threshold from the three tests was chosen for the analysis.

A one-way ANOVA for independent samples was used to assess the differences in cutaneous thresholds for thermal sensation between males and females. The limit of statistical significance was set to 0.05.

Foot cutaneous thermosensitivity

Eighteen young, healthy subjects, nine males and nine females, with an average (SD) age of 23 (3) and 26 (2) years, respectively, participated in the study.

The ambient air temperature was maintained at 25°C. The subjects, dressed in their normal clothing, were equipped with skin thermocouples (Concept Engineering, Old Saybrook, CT, USA) at four sites (arm, chest, thigh, calf). They placed their bare feet in a polyurethane bag and immersed them in 30°C water for 20 minutes to stabilise local skin temperature. Following the 20 min immersion, their feet were removed from the bath, the polyurethane bags removed, and the subjects requested to lie barefoot on a deck chair.

Subjects' thermal sensation was determined on three different locations on the foot: on the plantar side of the big toe and heel, and on the dorso-lateral surface of the instep. On each location, CT and WT were performed to determine cutaneous thresholds for both, cold and warm sensitivity.

The surface of the stimulating thermode was sufficiently small to provide full contact between the thermode and skin on the heel and on the dorso-lateral instep. The surface of the thermode was, however, larger than the plantar surface of subjects' big toe. Therefore, the area of the thermally stimulated skin of the toe was determined by pressing a sheet of Plexiglas, with the same dimensions as the thermode, against the toe, and marking the skin area in contact.

Results

In both studies there was no difference in the ambient air temperature between trials conducted on the male and females subjects.

Forearm cutaneous thermosensitivity

Adapting temperature of the skin (T_{ad}; °C) was similar for males and females ($P>0.05$) in the CT (females: 30.0 (0.9); males: 30.2 (1.2)°C) and WT (females: 31.3 (0.5)°C; males: 32.0 (0.8)°C) trials. There was also no significant difference in tympanic temperature between males and females ($p > 0.23$) during the WT (females: 37.3 (0.2)°C; males: 37.1 (0.4)°C) and CT (females & males: 37.2 (0.4)°C).

Cutaneous thresholds for both, cold ($P<0.005$) and warm ($P<0.05$) sensation, were significantly lower in females than males. The cutaneous threshold for cold sensation was 0.3 (0.2)°C in females and 0.7 (0.7)°C in males, and for warm sensation it was 0.7 (0.4)°C in females and 1.2 (0.7)°C in males.

Foot cutaneous thermosensitivity

T_{ad} of the foot did not differ significantly between males and females in either CT or WT trials, and was also similar between different locations on the foot in both, females and in males. T_s was calculated as an unweighted average from the four skin sites. Average (SD) T_s was 32.9 (0.6)°C in females and 32.8 (1.0)°C in males at the beginning of the first thermosensitivity test. T_s did not differ significantly between males and females ($P> 0.50$), and was constant throughout both trials. There was no significant difference ($P > 0.27$) in T_{ty} between males (37.1 (0.3)°C) and females (36.9 (0.4)°C).

The stimulated area on the big toe was 5.4 (1.0) cm^2 for males and 4.4 (0.6) cm^2 for females.

Table 1. Average (SD) cutaneous warm and cold thresholds males and females.

	COLD THRESHOLDS (°C)				WARM THRESHOLDS (°C)			
	Forearm	**Heel**	**Big toe**	**Instep Laterally**	**Forearm**	**Heel**	**Big toe**	**Instep Laterally**
Males	0.7 (0.7)	6.7 (2.4)	6.0 (2.8)	2.9 (0.9)	1.2 (0.7)	14.2 (1.7)	14.0 (3.0)	10.2 (4.0)
Females	0.3 (0.2)*	3.2 (0.9)*	4.0 (3.0)	2.3 (0.7)	0.7 (0.4)*	9.3 (3.9)*	10.3 (5.6)	7.4 (4.3)

* denotes statistically significant difference between male and female subjects.

As can be seen from the average cutaneous temperature thresholds of three foot sites presented in Table 1, females had a lower cutaneous threshold for the sensation of warmth ($p < 0.006$) and cold ($p < 0.002$) at the heel. Thermal thresholds at the other two sites (big toe, lateral side of the instep) were not significantly different between males and females. The cutaneous thresholds for thermal sensation were lowest at the lateral side of the instep, as compared to the other two locations. At all locations, in both males and females, the cutaneous threshold for the sensation of cold was smaller than that for the sensation of warmth ($p < 0.01$).

Discussion

Our results indicate that females have a greater cold and warm skin thermosensitivity than males. This is in agreement with the findings of Liou et al. (4), who observed higher thermal thresholds on the hand in males than in females. However, this observation was not reflected in the thermosensitivity of the foot, where no gender-related differences in thermosensitivity were noted (4).

In the present study, a greater thermosensitivity in females than in males has also been observed on the foot, but only at the heel, and not on the big toe and lateral instep. The observed lower thermal sensation thresholds in females could be explained on the basis of previous observations in other cutaneous sensory systems. It has been observed that females have a higher spatial sensitivity for mechanoreception (5), and a better temporal summation for thermal pain than males (3). Both, spatial and temporal summation may account for the observed differences in thermal sensitivity between the two genders.

Since the latency of the thermoreceptor's response depends on its position in the skin (6), possible reasons for the differences in thermosensitivity at the heel, for example, may be due to greater skin thickness in males than females. Alternatively, an increased density of thermoreceptors may also improve spatial summation, and thus cause a reduction in thermal thresholds, as observed in females at certain sites. However, since neither the skin thickness, nor the density of thermoreceptors was measured in this study, the nature of the observed gender-specific differences in thermosensitivity at some sites remains unresolved.

Conclusions

The results of the present study demonstrate a greater cutaneous sensitivity to cold and warm stimulation of the forearm and select regions of the foot in females compared to males.

Acknowledgements

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A LONGITUDINAL STUDY OF LOCAL TEMPERATURE SENSITIVITIES AT WHOLE BODY SITES

Kazuyo Tsuzuki[1]**, Kazue Mizuno*[1]*, Tomonori Sakoi*[1] *Matsutaro Yoshioka*[2]*, Yasuhiko Ooshiro*[3]

[1] National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan
[2] Research Institute of Human Engineering for Quality Life, Oosaka, Japan
[3]Ibaragi Industrial Technology Center[2] Ibaragi Industrial Technology Center, Mito, Japan
* corresponding author k.tsuzuki@aist.go.jp

Introduction

There are few studies on temperature sensitivity of the body surface(1-5). The distribution of sensory spots—warm spots, cold spots, etc.—in various cutaneous areas had been investigated in considerable detail in the 1920s. Most of the recent studies used the stimulator based on the Peltier module and the methods to investigate the detection of thermal threshold were developed. The detection thresholds for warming and cooling were measured by a computer controller. The temperature of the stimulator automatically rises or falls at a fixed rate and at the first warm or cold sensation, the subject presses a switch. A fixed stimulus level, defined as an upward (warm) or down ward (cool) temperature displacement from a neutral adaptation temperature (approximately 33°C, or normal skin temperature), was maintained. However, the temperature threshold might be influenced by the initial surface skin temperature. Specifically, the skin temperatures over the body surface are not always homogeneous in distribution even in a thermoneutral environment. Therefore, in the present study, we tried to obtain data on temperature thresholds over the body surface under neutral condition. Warm and cold thresholds were detected under the neutral condition by the new technique using both temperature and the heat flux.

Methods

Subjects

The ages and physical characteristics of the four subject groups are shown in Table 1. The 57 subjects were distributed into four groups comprising of 15 young women, 14 middle-aged women, 16 young elderly women (60s), and 12 older elderly women (70s). The elderly subjects were recruited through the local elderly resource center, and the aim and the nature of this experiment was described by a worker in the center, prior to the study. The general nature of the study was first explained to the young and middle-aged subjects through telephone or e-mail. The subjects were notified that they must be living independently, should be able to come to the laboratory for testing, should be free of diabetes, and that they would be paid for their participation.

Procedure

The first session began with a description of the experiment and informed consent was obtained from all the subjects. The time schedule and measurement points on the body surface were explained by the experimenter, and the subject was instructed to press a switch at the first warm or cold sensation. The subject was asked to handle the switch with the dominant hand because the local thermal sensitivities for the non-dominant side of the body were measured with respect to warm and cold thresholds. The subjects were then given a questionnaire that covered their health and medication status, history of occupation, and smoking and physical activity. The subjects changed into a loose-fit, thinner bra and shorts and thermistor probes were attached to the body surface. The subject’s height, body mass, and skinfold thickness were measured by the experimenter. After a 30 min sitting, the subject was asked to fill out the thermal comfort questionnaire, and the first measurement for threshold began at the thenar eminence of the non-dominant hand. Subsequently, the warm and cold thresholds were detected at 18 sites on the whole body surface. Warm or cold thresholds for the first experiment were randomly assigned for each subject. As it was not favourable for a single experiment to last more than 3 h, the elderly subjects were assigned to two morning sessions from 9 AM or two afternoon sessions from 1 PM, at intervals of 2-3 days. The subjects in the young and middle-aged groups were assigned to sessions in the morning or the afternoon, as these subjects did not require more than 4 h for the detection of both warm and cold thresholds. Prior to the measurement, the stimulator was heated up to the temperature which had been obtained from the preliminary experiments and then placed on the region; the surface of the stimulator was controlled to maintain a balance with the skin surface. Measurement was not initiated until the heat flux between the skin and the stimulation surface became nearly zero (+/-30 W/m-2) and a stable heat flux was confirmed for an additional 15 s. The stimulation surface either warmed or cooled at a speed of 0.1°C/s. The subject was instructed to press a switch at the first warm or cold sensation. Warm or cold temperature sensitivity was derived from the calculation which subtracts the neutral skin temperature from the skin temperature that the subject feels when exposed to a warm or cold sensation from the stimulator. All sessions were carried out in a climate-controlled chamber at 28°C with 60% RH during winter.

Measurements

The 18 sites of area 2 cm × 2 cm were in the following regions (with the exception of the forehead, front, and back of the neck on the body side of the non-dominant hand, e.g., on the left side of a right-handed person): (1) forehead (frontal region); (2) cheek (buccal region); (3) front neck (submental region); (4) chest (mammary region); (5) abdomen (umbilical region); (6) back of neck (posterior neck region); (7) back (infrascapular region); (8) lower back (lubar region); (9) upper-arm (anterior branchial region); (10) forearm (medial antebranchial region); (11) back of the hand; (12) thenar (thenar eminence); (13) hip (gluteal region); (14) anterior thigh (anterior femoral region); (15) posterior thigh (posterior femoral thigh); (16) calf (lateral crusical region); (17) foot (lateal malleolar region); and (18) sole of the foot. Figure 1 shows the skin regions used for detecting warm and cold thresholds.

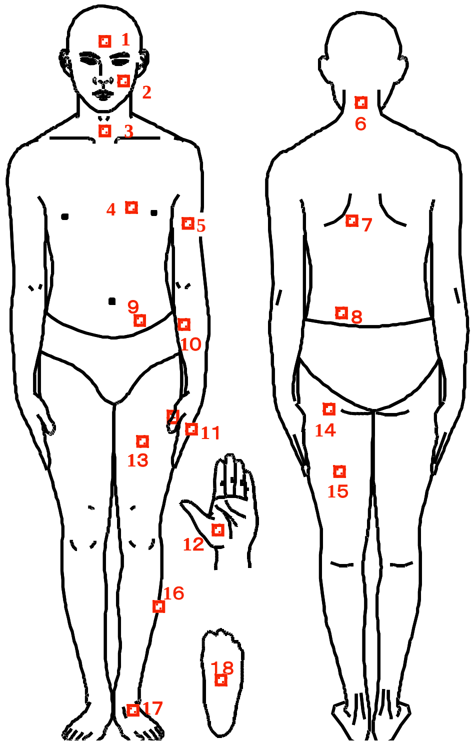

Figure 1. The skin regions used for detecting warm and cold thresholds.

Stimulator

The stimulator was composed of a heat flux sensor Peltier modules, aluminum plates, a fan, a switch, and film of heat flux mounted on the aluminum plates wit the skin temperature was attached at the edge of the heat flux sensor on the surface of the stimulator (interface of the stimulator and the skin). Therefore, all stimulus temperatures and heat flux represent the interface between the skin and the heat flux sensor.

Statistical analysis

To test the statistical significance of the data, one-way ANOVA (groups) was applied to analyse the effects of age on skin temperatures and heat fluxes. Fisher's PLSD was applied for the post-hoc pair-wise comparison. The significance level was set at P<0.05.

Table 1. The physical characteristics of the subject groups.

	n	Age (years)	Height (cm)	Weight (kg)	Skinhold thickness (mm)				
					Abdomen	Back	Upperarm	Thigh	Calf
Young	15	24.7	159.9	54.6	14.4	18.2	16.0	20.7	15.3
		2.4	5.7	11.4	6.6	7.9	4.7	5.7	4.0
Middle-aged	14	49.2	156.8	59.4	19.9	26.0	18.6	22.6	15.2
		1.8	5.8	10.7	11.9	10.6	6.2	8.5	5.0
Young elderly	16	64.9	150.5	60.2	22.8	31.7	20.8	18.6	14.8
		3.0	5.3	8.9	7.4	5.9	5.1	6.6	4.9
Older elderly	12	73.9	145.3	50.8	22.7	24.9	15.5	16.2	12.9
		3.0	4.7	7.0	11.9	8.1	3.7	6.2	5.4

Upper row is the average of the group; Lower row is the SD.

Table 2. The thermal comfort questionnaire and body temperatures.

Results and discussion

Table 1 shows the physical characteristics of the subject groups and Table 2 shows the results of the thermal comfort questionnaire and body temperatures prior to the experiment.

Figure 2 portrays maps of average warm and cold temperature sensitivities for the young, middle-aged, young elderly, and older elderly subject groups. For the warm thresholds, remarkable temperature sensitivities were observed at the forehead, front neck, abdomen, forearm, hand, hip, leg and foot, and the differences among the four age groups were large although, all the temperature sensitivities for warm thresholds increased in accordance with the age of the subjects. With respect to cold sensitivity, the temperature sensitivities in the older elderly age group were remarkably higher than in the other subject groups at all sites, particularly cheek, around the neck, abdomen, upperarm, hand, anterior thigh, foot and sole of foot. In our study, the initial skin temperature was measured under thermoneutral conditions and the heat flux was within +/-30 W/m^2(5). The local temperature sensitivity for warmth and cold was investigated, and it was found to be significantly age-dependent for all body sites. The trends of the temperature sensitivities for warm and cold thresholds were similar to those observed by Stevens and Choo(4) at the body sites, particularly for the lower limbs. In fact, the temperature sensitivities in the present study are higher than those observed by Stevens and Choo. The difference might be due to the method, i.e., the stimulation of the experiment. A study by Meh and Denislic(2) that used the same Marstock method showed a great variation in the warm-cold difference of different body parts along with a greater sensitivity of the face area in comparison with other skin areas. In our study, a large difference among the body sites was confirmed; however, the facial sensitivities were not so large in comparison with the other sites.

	Tympanic temp(°C)	Oral temp(°C)	Subjective sensation			
			Thermal	Comfort	Acceptability(%)	Satisfactory(%)
Young	37.6	37.1	0.6	0.1	80.0	73.3
	0.3	0.2	1.6	0.9		
Middle-aged	37.7	37.2	1.3	0.2	66.7	33.3
	0.3	0.4	1.7	0.9		
Young elderly	37.9	37.4	0.9	1.0	96.9	87.5
	0.3	0.1	1.2	0.9		
Older elderly	37.8	37.3	1.2	1.5	95.8	95.8
	0.4	0.3	0.8	0.7		

Upper row is the average of the group; Lower row is the SD.

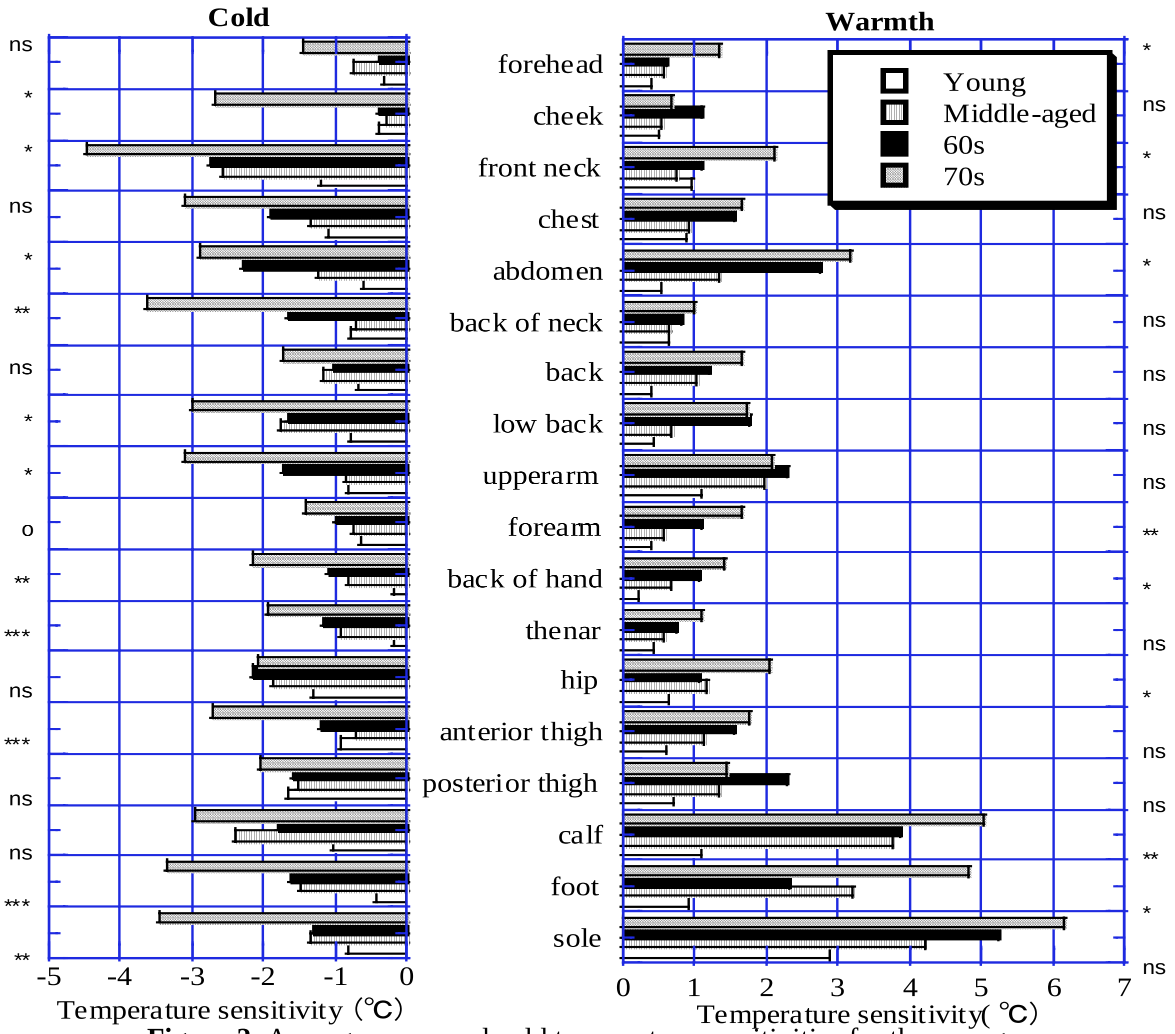

Figure 2. Average warm and cold temperature sensitivities for the young, middle-aged, young elderly, and older elderly subject groups.
*** P<.001, ** P<.01, * P<.05

Conclusion

Temperature sensitivities were significantly different in several local body surface areas even when the body was maintained at thermal neutral condition. In addition, the temperature sensitivities were significantly larger in proportion to age.

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THE EFFECT OF LOCAL FINGER CONTACT PRESSURE UPON CUTANEOUS BLOOD PERFUSION OF THE FINGERTIP AT DIFFERENT SKIN TEMPERATURES

*Ollie Jay and Matthew D. White**

Laboratory for Exercise and Environmental Physiology, School of Kinesiology, Simon Fraser University, Burnaby, British Columbia, V5A 1S6, CANADA.
* corresponding author: matt@sfu.ca

Introduction

For workers operating in a cold working environment, accidental skin contact exposure and the resultant skin cooling could pose a health and safety risk in terms of discomfort, pain, numbness and skin damage (1). Thus far, the effect of skin blood flow of the local contact area upon the rate of skin cooling has remained inconclusive. Two earlier contact cooling studies both found the effect of varying intensities of step activities to significantly effect contact cooling rate (2, 3) and a more recent study (4) suggested that the local effects of increasing single finger contact force may give a further increase in skin cooling rate. A study by Jay and Havenith (5) found no differences in skin cooling behaviour during finger contact with a force of 2.9 N (300 g) when comparing a vasodilated and occluded condition. It was reasoned that this was since their applied finger contact force exceeded a typical finger cutaneous capillary perfusion pressure of about 18 to 30 mmHg.

In order to allow a point of reference for the studies on the influence of skin blood flow upon finger skin contact cooling rates, the aim of the current study was to assess if there are distinct relationships between finger contact force or contact pressure, skin temperature and cutaneous blood perfusion during hand cooling in resting individuals.

Methods

Participants. Six healthy male participants volunteered (aged 27.3 ± 1.9 years (mean ± SE); height: 1.80 ± 0.02 m; weight: 82.4 ± 8.3 kg) after signing an informed consent. They did not suffer from vascular diseases and had not received treatment for high blood pressure.

Instrumentation. Resting blood pressure was measured using an automatic blood pressure monitor (Sunbeam Ltd. Brantford, ON, Canada). Cutaneous blood perfusion of the finger-pad was estimated using 2 laser-Doppler probes (Moor Instruments Ltd, UK), embedded flush on a plexiglass (thermal conductivity = 0.17 to 0.19 $W \bullet m^{-1} \bullet K^{-1}$) contact surface. The probes were located 6.5 mm and 13 mm from the edge of this contact surface. Mean cutaneous blood cell velocity (CBV) of the finger-pad was calculated using the un-weighted mean of the laser-Doppler values from each measurement site. The contact surface was placed on an electronic scale (Acculab®, London, ON, Canada). The appropriate finger contact force (FCF) was maintained by the participant who viewed the scale's digital display. Participants had their finger-pad contact areas calculated by scanning a fingerprint, at the appropriate contact forces, into a customized computer program (6) and this allowed expression of their finger contact pressures. The finger contact pressure (FCP) for each FCF is given in Table 1.

Skin temperature of the fingertip (T_{fing}) was maintained by immersing the non-dominant hand and forearm up to the elbow in a water bath connected to a chiller/heater unit (VWR, Mississauga, ON, Canada) set to 5°C, 13°C or 32°C. These temperatures were selected to elicit 3 critical levels of fingertip skin temperature (T_{crit}), after ~2 min of hand immersion, for the onset of numbness (7°C) (7), the onset of cold-pain (15°C) (1, 3) and a typical thermoneutral state for males (32°C) (8). To maintain skin temperature after removing the hand from the bath the participant wore a 85% wool, 13% nylon, 2% Lycra glove (Model #9490, Fox Riv. Mills Co, Osage, IA, USA) with the distal portion of index finger cut out to allow the CBV measurement.

Table 1. Mean finger contact forces (FCF), index finger contact areas (FCA) & finger contact pressures (FCP).

FCF (N)	***0.5***	***1.0***	***1.5***	***2.0***	***4.9***	***9.8***
FCA (cm^2)	*1.6 ± 0.1*	*2.0±0.2*	*2.2 ± 0.2*	*2.4 ± 0.3*	*2.6 ± 0.2*	*2.8± 0.3*
FCP (mmHg)	*23.1 ± 2.0*	*37.7 ± 4.6*	*47.9 ± 5.6*	*61.9 ± 6.4*	*138.7 ± 10.8*	*262.2 ± 26.8*

1 kiloPascal (kPa) = 7.5 millimeters of mercury (mmHg); 1 kiloPascal (kPa) = 0.1 $N \cdot cm^{-2}$

Protocol .The participant immersed their gloved non-dominant hand in the stirred water bath at 5℃, 13℃ or 32℃. For the 5°C and 13°C water the withdrawal point was set at: $T_{fing} = T_{crit}$ - 1℃. Upon withdrawing their limb from the water the participant stood with his arm extended, the upper forearm resting on a sponge cushion individually adjusted to heart level. Next, he placed the distal phalanx of the index finger of the cooled hand on the contact surface. Once the correct contact force was achieved, CBV of the contact finger-pad was recorded for a period of 15 s. The next exposure did not start until both the participant's finger skin temperature had re-warmed to ± 0.5℃ of its' initial value and 20 min had elapsed. The 6 levels of FCF were tested in the same session in a randomized order. Each water temperature was tested on a different day in an experimental design balanced using a Latin Square.
Statistical Analyses. The data was evaluated using repeated measures analyses of variance. Factors of FCF (Levels: 0.5 N, 1.0 N, 1.5 N, 2.0 N, 4.9 N and 9.8 N) and water temperature condition (Levels: 5℃, 13℃ and 32℃) were employed with the dependent variable of mean CBV. The level of significance was set at an alpha level of 0.05 and alpha level and was adjusted for multiple comparisons by the Bonferroni method. All statistical analyses were performed with SPSS, (ver. 11.5 for Windows, SPSS Inc. Chicago, IL, USA). The mean CBV of the finger-pad as a function of FCF in each water temperature condition was also fitted by least-squares to a mono-exponential decay model as follows:

$$\mathrm{CBV}(_{\mathrm{FCF}}) = \mathrm{CBV(end)} + \mathrm{amplitude} \bullet e^{-\mathrm{FCF}/d}$$

Where: $\mathrm{CBV}(_{\mathrm{FCF}})$ is cutaneous blood cell velocity as a function of FCF, CBV(end) is the final CBV at FCF = 9.8 N, amplitude is the difference between CBV at FCF = 0.5 N and FCF = 9.8 N, d is the decay constant of the mono-exponential model. Adjusted R-square was employed as an indicator of the relative predictive power of the model.

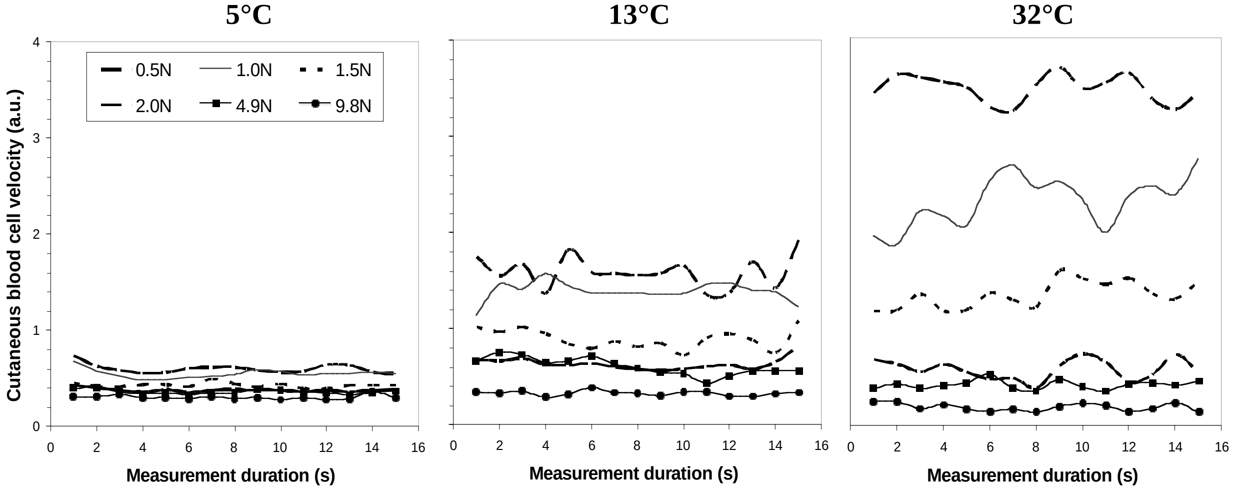

Fig. 1. An individual example of CBV at different the 6 levels of FCF throughout the 15-s measurement period after 2-min hand immersion in 5, 13 and 32ºC water.

Results

Cutaneous blood cell velocity (CBV). There were significant main effects of FCF ($p<0.001$) and water temperature condition ($p=0.002$) upon CBV. Irrespective of water temperature a significant decrease in CBV ($p<0.05$) was observed when increasing FCF from 0.5 N to 1.0 N, 1.5 N, 2.0 N, 4.9 N and 9.8 N and from 1.0 N to 1.5 N, 2.0 N, 4.9 N and 9.8 N. Also, irrespective of FCF, a significant decrease in CBV ($p<0.001$) was observed for both the 5℃ and 13℃ relative to the 32℃ condition. No difference was evident in CBV between the 5 and 13℃ conditions. An example of the effect of FCF upon CBV across the 15-s measurement period after immersion is given (Fig.1).

Discussion

The main result indicated that CBV, expressed as a function of FCF, demonstrated 3 separate mono-exponential functions that were separated by finger temperature (Fig. 1). The decay constants of these functions were dependent upon water temperatures, with a largest decay constant in the 5°C condition and the smallest in the 32°C condition (Fig. 2).

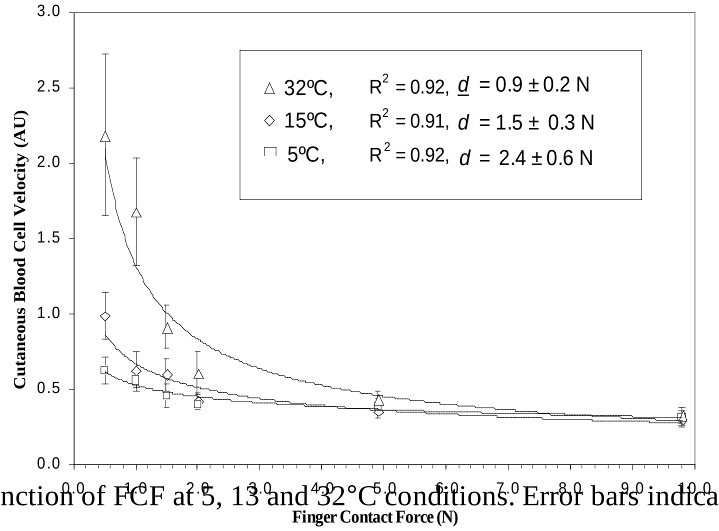

Fig. 2. CBV as a function of FCF at 5, 13 and 32°C conditions. Error bars indicate the SD.

There was a significant interaction between the main effects of FCF and water temperature condition (p=0.001). Three separate mono-exponential decay functions of CBV with FCF were evident for the 5, 13 and 32ºC conditions. Mean decay constants (*d*) were 2.4 ± 0.6 N, 1.5 ± 0.3 N and 0.9 ± 0.2 N respectively. There was a significant main effect of water temperature condition upon *d* (p<0.001) and amplitude (p<0.001) with *d* significantly smaller in the 32°C in comparison to 13°C (p=0.018) condition and significantly smaller in the 13ºC in comparison to the 5ºC condition (p=0.013). Amplitude was significantly larger at 32°C in comparison to the 13°C condition (p=0.002) and significantly larger at 13ºC in comparison to the 5ºC condition (p=0.011). No significant differences were found in CBV(end) any immersion condition. The interaction plot between each condition and FCF is given in Figure 2. A near perfect correlation was found between FCF and FCP (R^2 = 0.99).

The near perfect correlation between FCF and FCP supports that in the mono-exponential functions (Fig. 1) FCF and FCP can be used interchangeably. For contact pressure, as opposed to contact force, the highest CBV values were found at a lowest mean contact pressure of 23.1 ± 2.0 mmHg that corresponds to an FCF of 0.5 N. This pressure of 23.1 ± 2.0 mmHg is similar to a typical capillary pressure of 18.1 ± 2.3 mmHg for healthy males (9) and suggests a contact force that gives a pressure above a value of ~18 mmHg would begin to impede cutaneous perfusion. The rapid reduction of CBV with small initial increases in FCF from 0.5 N (Fig. 1 and 2) suggests that the capillaries of the finger pulp begin to collapse and the amount of blood pushed out of the local area increases exponentially with FCF. The sharp reduction in CBV continued up to a contact pressure of 61.9 ± 6.4 mmHg (FCF = 2.0 N) that is a value similar to 71 mmHg that is the highest reported pulsatile pressure of the human nailfold (10). Any increase in FCF beyond 61.9 ± 6.4 mmHg had a much lesser influence upon CBV irrespective of finger temperature. This indicated that at the higher contact pressures the vast majority of capillaries are occluded at the sampling depth of the laser-Doppler probes.

The effect of FCF upon CBV was diminished at colder hand skin temperatures, as indicated by significantly greater decay constants at lower immersion temperatures. This appears to be a consequence of a strong sympathetic adrenergic induced constriction of cutaneous blood vessels resulting in a reduction of hand and finger blood flow (11). However, in all temperature conditions changes in FCF between 0.5 N and 2.0 N continued to reduce CBV.

Conclusion

The findings support that fingertip CBV given as a function of finger contact force/pressure is described by distinct temperature dependent mono-exponential equations. At finger pressures in the range of ~18 to ~65 mmHg cutaneous blood cell velocity is progressively reduced as finger skin temperature is decreased from 32 to 8°C. Finger pressures greater than ~ 60 to ~65 mmHg have little effect upon CBV irrespective of thermal state of the hand.

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EFFECT OF INDIVIDUAL VARIABILITY IN BODY SIZE ON EMPIRICAL MODEL PREDICTIONS OF EXERCISE ENDURANCE TIMES

L.A. Blanchard, R.F. Wallace, W.R. Santee, L.G. Berglund, and M.A. Kolka*

US Army Research Institute of Environmental Medicine, Natick, MA
*corresponding author laurie.blanchard@na.amedd.army.mil

Introduction

Prevention of heat illness is an important part of Army training and doctrine. Heat illness has historically been a substantial problem in military operations and training and continues to affect modern forces, increasing morbidity, mortality, and use of health care resources.[1-4] If adequate hydration and emergency medical management are not available, many cases of exertional heat illness (EHI) are potentially fatal.[2,5-8] Therefore the US military is attempting to minimize the risks to Warfighters through predictive modeling and mission planning. Environmental conditions, clothing worn, and activity level can contribute to excess heat storage making it difficult to maintain thermal balance with the environment. This imbalance can eventually lead to the development of heat illness ranging from relatively minor heat exhaustion to life threatening heat stroke. In addition to weather, clothing, and exertion, increased body mass index (BMI) has recently been shown to increase the likelihood of developing exertional heat illness.[9-11] USARIEM has developed several models to predict Warfighter performance and requirements. One of these models was retrospectively tested on a database of Marine Corp Recruits to determine how sensitive predictions of exercise endurance time are to individual anthropometric differences.

Methods

The model chosen for the simulations is an empirically derived model (EM) with documented performance for Warfighter populations working in the heat.[12-17] USARIEM has compiled a database of test results from more than 30 years of experiments. From these, a set of predictive equations was developed for soldiers performing physical work in various clothing configurations under a range of environmental conditions. These algorithms are periodically modified as new data are acquired.

All EHI cases occurring among 217,000 male and female Marine Corps recruits entering 12-week basic training at Marine Corps Recruit Depot, Parris Island, SC from 1988-1992 were collected from medical records.[11] The dataset for the simulation was limited to 2453 Marine Corps recruits (669 cases of EHI and 1723 controls matched by training platoon) for whom weather and anthropometric data were available. Both heat acclimatization[18] and lower BMI [9-11] have been shown to improve heat tolerance. Since Marine Corps recruits generally increase their physical fitness and decrease BMI throughout this demanding training and since the heat acclimation status of arriving Marine Corps recruits was unknown, the dataset was further constrained to weeks 2-5 of training in order to ensure Marine Corps recruits were fully heat-acclimatized and to decrease the likelihood of large changes in BMI compared with later weeks of training. This reduced the number of EHI cases to 263 with 702 controls matched by training platoon.

The environment chosen for the simulation was T_{db} = 27°C, RH = 70%, MRT = 77°C, and wind speed = 2.5m/s based on average ambient conditions faced by this population. Clothing input for EM was the desert battle dress uniform (dBDU) with insulation or R_T=0.2 m^2*K/W. Analysis required some assumptions regarding conditions faced by individual Marine Corps recruits which we accounted for in part by matching EHI cases with controls from the same platoon. These matched Marine Corps recruits should have been exposed to similar conditions during training in terms of uniform, activity, and environment.

Results and Discussion

The risk of EHI was found to increase 18% per kg/m^2 BMI (Odds Ratio = 1.18, 95% CI 1.12-1.24) and 4% per kg weight (Odds Ratio = 1.04, 95% CI 1.02-1.05) for this subgroup of Marine Corps recruits. In this population, weight (76.7±13.8 kg) and BMI (25.0±1.9 kg/m^2) of subjects experiencing EHI were both significantly greater than weight and BMI of controls (71.9±12.1 kg, 23.4±3.1 kg/m^2, $P<0.01$) as shown in Table 1.

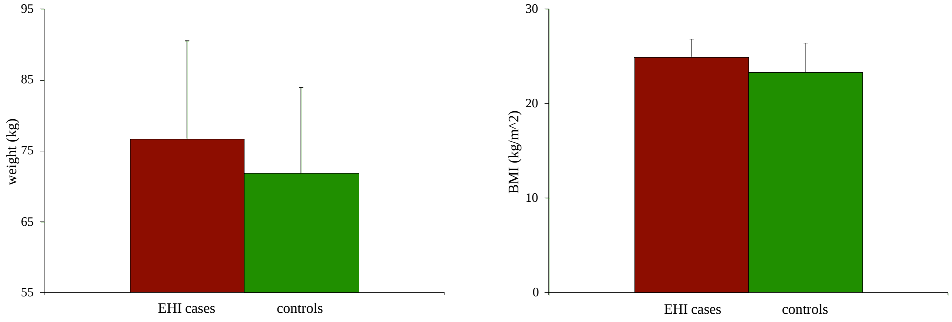
Table 1. Marine Recruit Anthropometry.

	weight range (kg)	mean weight ± std dev (kg)	height range (m)	mean height ± std dev (m)	BMI range (kg/m^2)	mean BMI ± std dev (kg/m^2)
EHI Cases	41.2-119.0	76.7±13.8*	149.9-198.1	174.9±8.2	17.4-32.6	25.0±1.9*
Controls	44.3-109.1	71.9±12.1	149.9-198.1	175.1±8.1	13.1-31.4	23.4±3.1

* t-test $p<0.01$

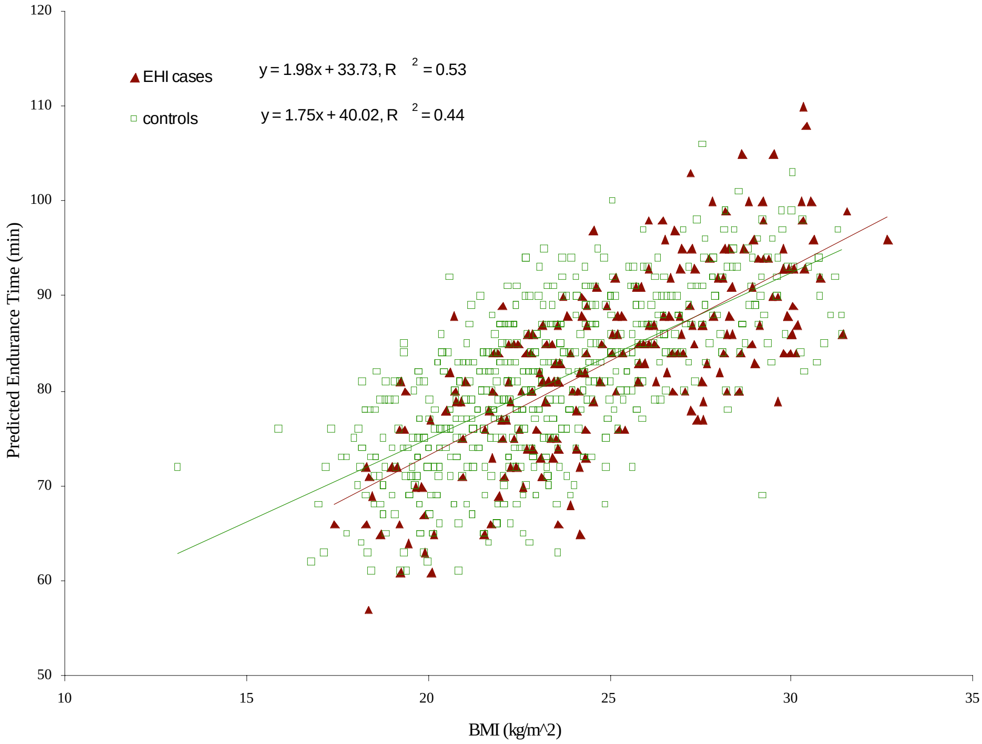
BMI can affect physical performance in various ways. Heat transfer is slower for larger masses with proportionally lower surface areas. Furthermore, a higher BMI could indicate lower fitness; a risk factor of EHI.[9] In this empirical model, height and weight are considered for estimation of heat transfer rate between body and environment but are not factored into adjustments for physical fitness or relative work loads. EM is based primarily on data obtained from experiments on fit young men and does not make allowances for individual variations in physiological response. Comparisons of Marine Corps recruit anthropometry of EHI cases and controls are shown in Figure 1.

Figure 1. Weight and BMI of Marine Corps Recruits



The primary output variable of this model is predicted endurance time. Typically this refers to how many consecutive minutes of exercise could be performed at a given work rate. For this study, we were not looking at responses to one specific exercise bout but instead at how well the Marine Corps recruits fared over the course of several weeks with multiple work episodes of varying difficulty and duration. Figure 2 shows EM predicted endurance times during sustained heavy work (600W) of 83±9 min for the EHI cases and 81±8 minutes for controls ($P<0.01$).

Figure 2. Predicted Endurance Time vs BMI



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METABOLIC RATE PREDICTION BY MASSLESS ACTIGRAPHY FOR OUTDOOR ACTIVITIES

*Shai Berlin[1], Liron Shalit[1], Yoni Yarom[2], Daniel S. Moran[1]**

[1] Heller Institute for Medical Research, Chaim Sheba Medical Center, 52621, Tel-Hashomer,
Sackler School of Medicine, Tel-Aviv University, Israel
[2] Meuhedet Sport Medical Center, Ramat-Gan, Israel
*corresponding author dmoran@sheba.health.gov.il

Introduction

Physical activity monitoring has been the target of a multitude of techniques, though none have been proven to be as highly accurate as the indirect calorimetry or the "doubly labeled water" (1-4). Such techniques comprise numerous disadvantages, where cost, complexity, duration and invasiveness are just a sample of their limitations. These concerns have given rise to various new methods, the most common of which are motion-sensors such as accelerometers (also known as actigraphs). Numerous studies have reported the positive and encouraging results of such devices (1, 5, 6). It was previously shown that the actigraph was able to differentiate between different metabolic rates while walking/running on a treadmill at various velocities (2-7 miles/h) (5). Moreover, the benefits of using the proportional integral mode rather than alternate modes currently under study (zero-crossing and time above threshold) were also demonstrated. Kumahara et al. reported in their study, which was comprised of 79 Japanese subjects, that they were able to precisely evaluate the energy expenditure by actigraphy measurements with a correlation of R= 0.928 (7). King et al. evaluated 5 different activity monitors and reported high correlations for different running velocities (R= 0.65-0.83) (8). While the use of heart rate (*fc*) alone may seem to provide a fair quantification of physical activity, it was found to have inherent problems, making it's use impractical for the sole evaluation of energy expenditure (9). However, the assimilation of both the accelerometer and *fc* data was shown to have favorable and promising results (10-12). Strath et al. found that the use of accelerometry in conjunction with *fc* data yields high correlation of R^2=0.81 for free-living activities and time spent in various intensity categories (10). However, their study did not take into consideration the type and time spent in different free-living outdoor activities and therefore did not evaluate the ability of their technique for such activities. In the present study, a new type of accelerometer has been introduced. The new, custom-made, massless Octagonal Basic Motionlogger Actigraph has been specifically desensitized in order to filter out non-significant small frequencies resulting from irrelevant and non-specific movements. Furthermore, with the use of both the proportional integral mode, as previously described (5), and the monitored *fc* data simultaneously, we attempt to refine our newly developed regression equations, thus enabling accurate estimation of energy expenditure for multiple outdoor activities. The aim of this study was to evaluate an Octagonal Basic Motionlogger Actigraph for 2 groups of males and females performing outdoor activities.

Methods

Subjects- The study included 10 male volunteers ranging in age from 17–26 yrs (22±3), average weight 68.64±10.16kg with an average A_D of 1.83±0.18m^2 and 10 female volunteers ranging in age from 18-27 yrs (23±3), average weight 63.50±15.75kg with an average A_D of 1.69±0.22m^2. Only healthy subjects participated in the study, after signed consent forms, according to the protocol of the Helsinki Human Use Committee of the Sheba Medical Center, which approved the study.

Protocol- Each participant performed 6 different types of exercise representing 6 different metabolic rates including 5 outdoor activities: walking, running, sweeping, ascending and descending stairs, and 1 indoor activity: shopping. The subjects wore a single type of accelerometer, the massless Octagonal type (OBMA, PCD, USA), on the non-dominant hand and on the corresponding hip, while connected to an indirect portable metabolic cart (K4-b^2, COSMED, Italy) and a *fc* measuring wristwatch (POLAR, Finland) on the other hand. During each hour-long session, participants began walking (at their own pace) for 5 min around a soccer stadium. Subjects were asked to climb steps in a 2-story high stadium (60 steps) for approximately 2 min, and then descend for approximately 2 min. The climbing and descending of the steps was performed twice. Afterwards, the subjects were asked to sweep the floor for 5 min. After completing the sweeping, the subjects then ran around the stadium's soccer field for a further 5 min, followed by an additional 5 min walk. Thereafter, the subjects were asked to shop for 10 min using a four-wheeled adjustable cart. Between each different outdoor and indoor activity, participants were given a 5-10 min resting period, until *f*c returned to baseline values.

Statistical Analysis – For the development of the usage of actigraphy data and *fc* measurements for metabolic rate, we used a multiple regression analysis to construct a series of models for metabolic rate prediction. A new model to predict oxygen consumption (VO_2) from actigraphy data was constructed as a linear model that fitted by the least square method. Using the SAS 8.0 software, Procedures CORR and GLM by adding to the new developing prediction model *fc* measurements we constructed a new prediction model for VO_2. Correlation coefficients between these new models and measured data (VO_2 and *fc*) were computed using Pearson correlation analysis. All statistical contrasts were accepted at the $P<0.01$ level of significance.

Results

Analysis of the actigraphy and *fc* measurements has made it possible for us to construct a new prediction model for VO_2 (PVO_2) as follows:

$$PVO_2=1.9347-8.069\cdot10^{-3}A+5.530\cdot10^{-2}\,fc + 8.107\cdot10^{-5}A\,fc$$

where: A= actigraphy counts

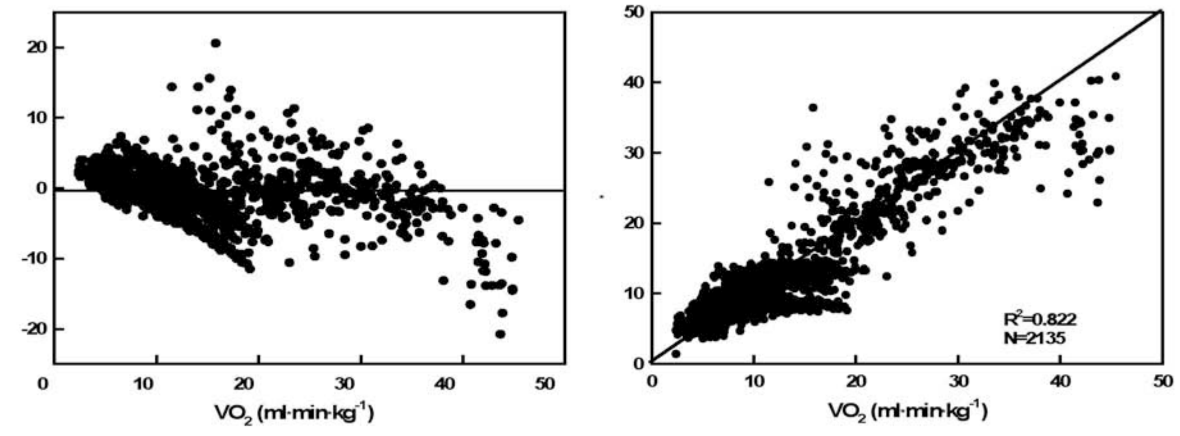

Figure 1- A comparison between VO_2 measurements and the predicted measurements from actigraphy pooled data, monitored from the wrist, and including *fc* data, showing correlation (right) and residuals (left) scattergram, for all 20 male and female participants.

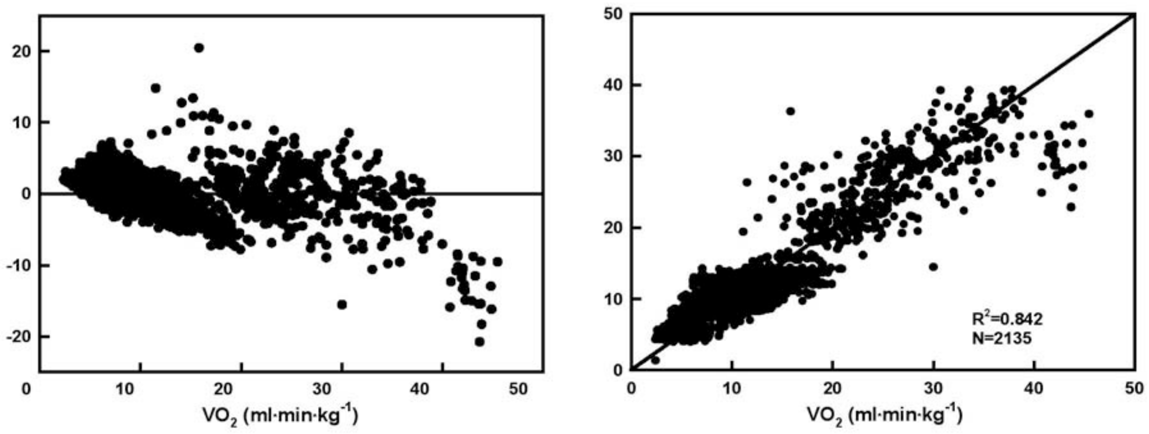

Figure 2- A comparison between VO_2 measurements and the predicted measurements from actigraphy pooled data, monitored from the hip, and including *fc* data, showing correlation (right) and residuals (left) scattergram, for all 20 male and female participants.

The application of the newly developed model on the pooled data of both male and female groups revealed a high correlation between the measured and the predicted values of VO_2, with significant coefficients for the wrist and hip, (R^2= 0.822 and 0.842, respectively) (Figures 1 and 2). Furthermore, the assimilation of the *fc* data within the regression equation for both male and female groups contributed significantly to the homogenization of the scattergrams. By analyzing the correlation for both placements (Figures 1 and 2-right panels), we notice the high correlation between measured VO_2 and predicted VO_2, with symmetrically distributed results around the zero line.

Discussion

In the present study, we found that without the use of *fc* measurements in the prediction model for VO_2, we were able to show a correlation of R^2= 0.795 for all subjects when the actigraphy was placed on the wrist. When *fc* data was incorporated in the prediction model, we noticed a significant increase in the accuracy of the VO_2 prediction model with a correlation of R^2= 0.822 (Figure 1). Likewise, by comparing results with and without *fc* data when placement was on the hip, we showed a correlation factor of R^2= 0.795 without *fc*, while the addition of the *fc* data contributed to the increase in accuracy, thus rendering a correlation factor of R^2= 0.842 (Figure 2). However, by examining the results for the male and female groups separately, we observed that throughout the experiment the newly developed prediction model tended to yield significantly higher correlations for the female group (Table 1).

Table 1- Comparison of correlation factors between measured and predicted VO_2 for the male and female groups, with and without *fc* data, at the 2 different body placements (wrist and hip).

	Placement	Male	Female
Without *fc* data	Wrist	0.770	0.813
	Hip	0.767	0.839
With *fc* data	Wrist	0.802	0.843
	Hip	0.823	0.858

Conclusions

Although the sole use of body movements and accelerations for the prediction of energy expenditure has been the main objective of numerous studies, the addition of a complementary parameter such as *fc* has been proven to increase the method's sensitivity towards accurate estimation of VO_2. Moreover, while *fc* has been proven to be an essential parameter for better metabolic rate assessments, body placement should also be considered. We have shown that with the use of both *fc* and accelerometry data taken simultaneously from monitors placed on the subject's hip, we were able to predict with high correlation (R^2= 0.842) the VO_2 of multiple outdoor and indoor free-living activities. However, in spite of the encouraging results of this study, which depict the combination of actigraph and *fc* as a potential unique method to predict VO_2, further studies should be executed for a larger sample size at different age groups and daily activities.

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SWEATING AND THERMOREGULATORY RESPONSES DURING G_Z ACCELERATION

Hirokazu Ozaki[1], *Eriko Takei*[2], *Takenori Nomiyama*[1] *and Yasuhiko Nakata*[3]

[1] Ergonomics Section, Aeromedical Laboratory, Japan Air Self-Defence Force
[2] Spatial Orientation Training and Research Section, Aeromedical Laboratory, Japan Air Self-Defence Force
[3] Medical Evaluation Section, Aeromedical Laboratory, Japan Air Self-Defence Force
* corresponding author aml034@asdf.mail.jda.go.jp

Introduction

Aircrew conducting flight operations in hot environments are susceptible to heat stress, which can invoke physiological and psychological responses that inhibit performance and lead to declines in safety. Advanced aircrew clothing for fighter aircraft pilots integrates items required for protection from fire, hypoxia, acceleration, immersion, and NBC weapons. However, it also imposes a high degree of thermal insulation, which can lead to an unacceptable level of thermal strain on the aircrew (1), as additional impermeable layers over the chest and lower body found in modern pressure suits reduce the area available for evaporation of sweat. Compression of the human body by a modern pressure suit decreases the sweat rate from the compressed regions, thus the amount of body heat dissipated is also decreased. Further, metabolic rate is increased by skeletal muscle contraction during an anti-G straining manoeuvre (AGSM) and may also decrease the sweat rate by hyper-tonicity, thereby decreasing the amount of body heat dissipated. In the present study, we investigated the inhibition of sweating caused by anti-G suits and expedition of the skin pressure-sweating reflex from the compensation function in the non-compressed regions of the body in a high G_z environment in humans.

Methods

The human-use centrifuge at the JASDF Aeromedical Laboratory (Iruma Air Base, Saitama, Japan) was utilized for the experiments. We studied 15 volunteers (3 females, 12 males), who ranged in age from 22 to 45 years (34±6; mean±SD). Their mean height was 168±7 cm and mean weight was 64±11 kg. The study was approved by the local ethics committee of the Aeromedical Laboratory and written informed consent was obtained from each subject.

We used 3 different centrifuge profiles. Profile 1 was a gradual onset run (GOR) of AGSM without anti-G suit inflation with an onset rate of 0.1 G_z per second ($\cdot s^{-1}$), in which the G_z level was increased until the subject experienced 100% peripheral light loss or G-induced loss of consciousness, up to a maximum of $+8G_z$. During the G_z exposure, the subjects were told to relax until they experienced gray out. Profile 2 was a series of short-term exposures, consisting of $+3\ G_z$ for 15 seconds, $+4\ G_z$ for 15 seconds, $+5\ G_z$ for 15 seconds, $+6\ G_z$ for 5 seconds, and $+7\ G_z$ for 5 seconds. Onset was a rapid onset run (ROR) of $1.0\ G_z \cdot s^{-1}$. There was a 60-second rest period following each exposure. The subjects performed the AGSM without anti-G suit inflation from the beginning of exposure to the baseline level of $+1.4\ G_z$. Profile 3 was the same pattern as Profile 2, except that the subjects performed the set with anti-G suit inflation. The subjects were aware of the profiles in advance and given a 5-second countdown prior to onset. A 10-minute rest period was allowed following each profile, and Profiles 2 and 3 were performed randomly.

Standard flight clothing used during the summer, which consisted of cotton underpants, a polyester t-shirt, a flight suit, a standard five-bladder anti-G suit, socks, boots, a torso harness, survival vest, life preserver, helmet, mask, and gloves (It=1.5 clo) were worn. In addition to that ensemble, the subjects wore a counter-pressure vest, though it was not inflated and they did not perform positive pressure breathing.

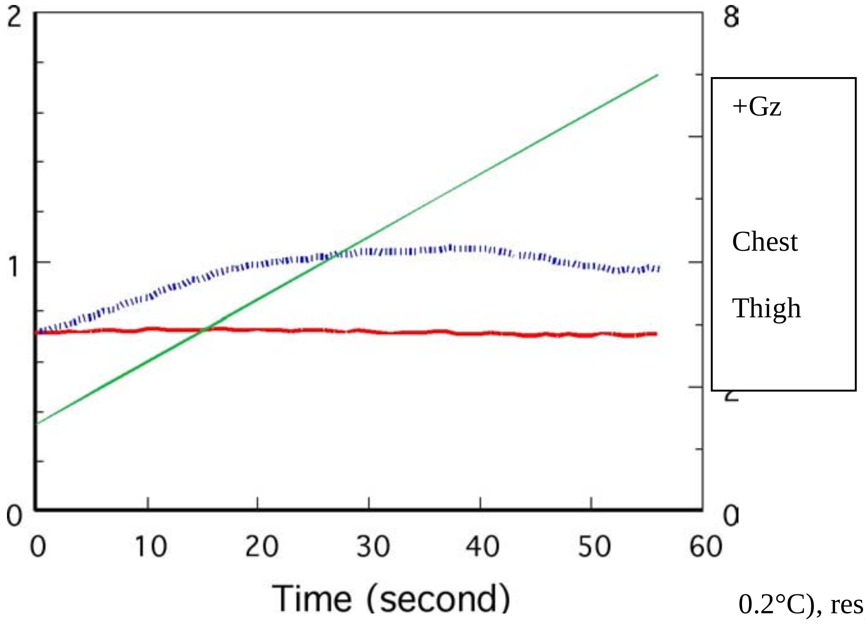
Instruments for the measurement of rectal temperature (T_{re}) and skin temperature (T_{sk}) were placed at six different sites (forehead, chest, back, forearm, thigh, and leg) (LT-8A; Gram, Japan). Heart rate (HR) was monitored continuously using an electrocardiogram (RJG/4128; NIHON KOHDEN, Japan), while arterial blood pressure was measured noninvasively from the earlobe (RBP-100; KANDS, Japan). Local sweat rate (m_{sw}) was measured at four sites (chest, anterior thigh, posterior knee, and forehead) using ventilated papery capsules (AMU-100F; KANDS, Japan). Skin blood flow was measured on the thigh, using laser Doppler flowmetry (FLO-C1; OMEGAWAVE, Japan). Total body sweat rate was determined from weighing the nude body mass and clothing, and measured to an accuracy of 5 g before and after each test (UC-300; A and D, Japan).

The microclimate (temperature and relative humidity) of the clothing was collected at two sites: between the counter-pressure vest and the flight suit, and the anti-G suit and flight suit (LT-8B; Gram, Japan).

Results

The environmental conditions in the gondola of the human-use centrifuge were in the range of 23-27°C and 45-65 %RH. At the end of the experiment, T_{re} and mean T_{sk} increased by mean 0.3°C (SEM 0.1°C) and 1.4°C (SEM 0.2°C), respectively. The average HR and arterial blood pressure at AGSM were higher than those when relaxed. During Profile 1, m_{sw} from the thigh did not change from start to finish. The chest area values increased slightly during GOR, then remained the same after starting AGSM (about 4 G) (Figure 1). A comparison of the values in m_{sw} during AGSM without the anti-G suit inflation (Profile 2) and those with anti-G suit inflation (Profile 3) are shown in Figure 2. The m_{sw} increased gradually as a result of the repeated +G_z exposure in Profiles 2 and 3. Repeated pressure caused steeply increases in sweating inducement and inhibition in the thigh area (Figure 2, lower panel). In contrast, the m_{sw} in the chest area without counter-pressure vest inflation (no pressurization) increased linearly during high +G_z exposure (above 5 G). The total body sweat rate was 396.2 (SEM 42.5) g. The microclimate values under the counter-pressure vest were slightly elevated as compared to those measured under the anti-G suit during the early stage of the experiment, subsequently, the microclimate values under the anti-G suit were considerably higher than those under the counter-pressure vest during the late stage.

Figure 1. Representative data regarding local sweat rate (m_{sw}) during G_z exposure in Profile 1.



Discussion

A G suit increases blood vessel resistance in the lower body, which leads to increased blood pressure, induces intra-abdominal pressure, elevates the heart, and shortens the heart-brain distance. It is designed to keep venous blood from pooling in the lower body so that the heart has enough blood to pump to brain. However, fighter pilots that wear anti-G suits on hot, humid days often experience excessive heat stress, as the impermeable layer of the anti-G suit over the lower body prevents body heat loss. Further, it is possible that the suit affects human thermoregulation in addition to the increasing of metabolic rate at AGSM, by decreasing the m_{sw} through restraint.

The present findings confirmed that compression of the human body by the anti-G suit decreases the m_{sw} in the areas being compressed (Figure 2, lower panel). On the other hand, the non-compressed region of the upper body showed a significantly increased the m_{sw} during high +G_z levels. We considered that this phenomenon was caused by pressure reflection, which is one of the compensation functions resulting from pressurization of the lower body.

Heat stress lowers the gray out threshold and +G_z acceleration tolerance by 0.5 to 1.0 G, primarily because vasodilatation promotes the pooling of blood in the legs. In addition, dehydration by 2% to 3% of body weight seriously reduces the tolerance of aircrew to high-G exposure (2). Total body sweat rate in the present experiments averaged 0.6% of body weight and the maximum lost by a single subject was 650 g. A modern anti-G suit provides bladder coverage and uniform pressure application to the entire lower body, excluding the buttocks and feet. Such extended bladder coverage to the legs might impose a higher risk of heat stress and dehydration than the standard anti-G suit (3). In addition, modern aircrew clothing (e.g., Combined Advanced Technology Enhanced Design G-Ensemble, COMBAT EDGE) provides positive pressure to the oxygen mask in proportion to acceleration and eases the work of breathing by use of a counter-pressure bladder over the chest. However, the chest bladder prevents the evaporation of sweat from the upper body, the only area that is available for evaporative cooling in standard flight clothing, and thus is expected to increase aircrew susceptibility to heat stress (1). The present results show that an effective microclimate cooling system constructed for optimum sweating activity should be considered.

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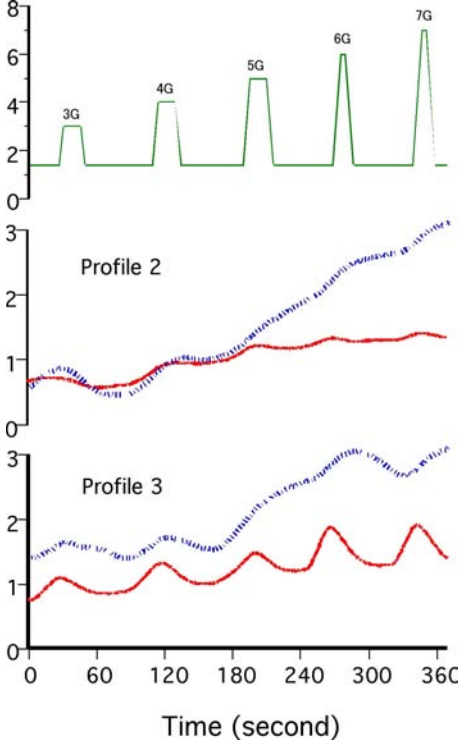

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CHANGES IN SWEATING RESPONSE WITH AGING IN HEALTHY OLDER MEN: 10-YR FOLLOW-UP

Yoshimitsu Inoue[1], Hiroyuki Ueda[2]*

[1] Laboratory for Human Performance Research, Osaka International University, Japan
[2] Osaka Shin-Ai College, Japan
* corresponding author inoueyos@hus.oiu.ac.jp

Introduction

Sweat gland function has been found to decrease with aging (1, 2). In cross-sectional studies, the age-related reduction of sweat gland function was found to be associated with a lower sweat output per gland (SGO), while the density of heat-activated sweat glands (HASG) did not change at any body site (3, 4). In contrast, a longitudinal study suggested that regional differences exist in the age-related decrement in not only SGO but also HASG, that the former declines before the latter, and that the decline may proceed from the lower limbs to the upper body (5). However, the suggestion was based only on longitudinal data for a 5-yr period (mean age 65 →70 yrs old) on thigh and back.

In the present study, we examined the longitudinal changes of sweat rate, HASG, and SGO during a 60-min passive heating over a 10-yr period, to test the hypothesis that: 1) the aging-related decrement in SGO occurs before the HASG density is reduced, and 2) the decrement proceeds from the lower limbs to the back of the upper body, the front of the upper body, then the upper limbs and finally to the head.

Methods

Subjects. Four healthy older men from the group initially tested (Ini-Test) (3) were retested after 5 years (5-Test) and 10 years (10-Test). Over the 10-yr period, Subj. No. 2 and 3 performed regular moderate walking on a mountain path or flat land and Subj. No. 4 was a competitive master's runner. Subj. No. 1 started to play a ground-golf after the 5-Test. All subjects were normotensive, none were taking medication at the time of the study, and none had a history of cardiovascular or respiratory complications. At the time of the 10-test, Subj. No. 1, 2, 3 and 4 were aged 74, 72, 76 and 81 yrs, respectively. All subjects were given oral and written information about the procedures and possible risks involved in the study, and all gave written informed consent.

Experimental procedure. Insofar as was possible, the conditions for the Ini-Test were duplicated for the 5-Test and 10-Test. Subjects wore only swimming trunks and maintained a sitting position on a chair in the chamber anteroom maintained at an air temperature of 28°C and relative humidity (rh) of 45 % for at least 60 min while instrumentation was attached. They were then given a passive heat test, in which each subject immersed his legs to the knee in a stirred water bath at 42°C while sitting for 60 min in the environmental chamber maintained at 35°C and 45 % rh. The Ini-Test, 5-Test and 10-Test were conducted in January and February.

Measurements. Rectal (T_{re}) and skin (at 7 sites) temperatures were measured every minute during the heat test, and the mean skin (T_{sk}) and mean body (T_b) temperatures were calculated. Total body sweat rate was determined from nude weight (±5 g accuracy) obtained before and after the heat test. Local sweat rate (SR) was measured on the forehead, chest, back, forearm, and thigh in the 5-Test and 10-Test, and on only the back and thigh in the Ini-Test. SR was measured by the ventilated capsule method was used in the 5-Test and 10-Test and the filter paper method in the Ini-Test. The HASG density and SGO on the measurement sites of SR were determined at 50-55 min from the start of heat exposure. The densities of HASG were determined by placing starch-impregnated paper on the test site (a site adjacent to the sweat capsule) which had been painted with tincture of iodine. SGO were calculated by dividing SR by the number of HASG. During the test, heart rate (HR) and blood pressure were measured every 5 or 10 min. Mean arterial pressure (MAP) was calculated from systolic and diastolic pressure.

Maximal O_2 uptake (VO_2max) was estimated for each subject during exercise at a submaximal level: subjects pedaled on a cycle ergometer at a constant frequency of 50 rpm for 5 min at four different exercise intensities. The number of steps taken by each individual during daily life was counted continuously by use of a pedometer for 2 weeks after the heat test, and the daily mean pedometer reading was calculated.

Statistics. All data were expressed as means and SEM. A one-way analysis of variance [within-subject factor (test; Ini-Test, 5-Test, and 10-Test)] and a two-way analysis of variance [one within-subject factor (test; Ini-Test, 5-Test, and 10-Test) and one within-subject factor (times)] were used for statistical analysis. Post-hoc analysis was performed by Tukey's test. All statistical analyses were performed using commercially available software (SPSS version 11.5). We took $p < 0.05$ to indicate statistical significance.

Results

In Subj. No. 1, the pedometer readings (7180 vs. 5170 vs. 11820 steps/day in the Ini-Test vs. 5-Test vs. 10-Test period) and estimated VO_2max (33 vs. 31 vs. 39 ml/kg/min) increased remarkably from the 5-Test to the 10-Test, since the subject started and continued to play ground-golf (approximately 1-2 h/day, 3-4 days/wk) after the 5-Test. However, the remaining three subjects showed no significant differences in the pedometer readings (15380±4110 vs. 14890±3850 vs. 14070±4740 steps/day) and VO_2max (43±4 vs. 45±3 vs. 41±3 ml/kg/min; $p = 0.08$ in the 5-Test vs. 10-Test) over the 10-yr period. Total body sweat rate decreased significantly from the Ini-Test (256±17 $g/m^2/h$) to the 5-Test (201±21 $g/m^2/h$) in all subjects. Subsequently, Subj. No. 1 showed an increased total body sweat rate from the 5-Test (203 $g/m^2/h$) to the 10-Test (281 $g/m^2/h$), but the remaining subjects showed no change in the same period (200±29 $g/m^2/h$ vs. 206±20 $g/m^2/h$).

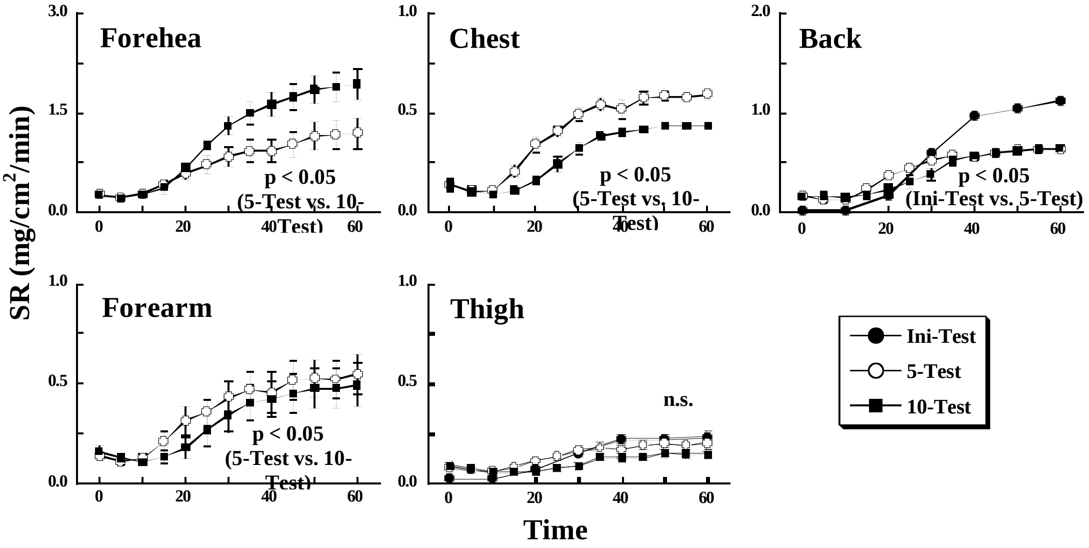

Figure 1. Time courses of local sweat rates (SR) on the forehead, chest, back, forearm, and thigh during the Ini-Test, 5-Test and 10-Test in Subj. No. 2, 3 and 4.

The changes in SR responses on the chest, back and forearm from the 5-Test to the 10-Test in Subj. No. 1 were also different from those in the remaining three subjects, although those in SR on forehead and thigh were similar. In Subj. No. 1, the time required for the onset of sweating tended to be shorter at all sites except for the thigh, and the SR on the forehead, chest and back (but not on the thigh and forearm) tended to be greater from the 5-Test to the 10-Test. Figure 1 shows the SR responses on the forehead, chest, back, forearm, and thigh during the Ini-Test, 5-Test and 10-Test in Subj. No. 2, 3 and 4. The SR on the thigh was remarkably low even in the Ini-Test and did not change over the 10-yr period. The SR on the back decreased significantly from the Ini-Test to the 5-Test, but did not change between the 5-Test and the 10-Test. The SR on the chest and forearm decreased significantly from the 5-Test to the 10-Test, and the magnitude of the decrease was greater on the chest SR than on the forearm SR. In contrast, the SR on the forehead increased significantly from the 5-Test to the 10-Test. The statistical results with respect to the SR on the forehead, back and thigh in the four subjects were similar to those mentioned above in the three subjects other than Subj. No. 1.

The decreases of SR on the back from the Ini-Test to the 5-Test (observed in all subjects) and on the chest and forearm from the 5-Test to the 10-Test (observed in Subj. No. 2, 3 and 4) were the result of the decrease in SGO rather than a decrease in the recruitment of HASG. Furthermore, the increase of SR on the forehead from the 5-Test to the 10-Test (observed in all subjects) was due to the increase in SGO rather than an increase in HASG. The HASG density on the back and thigh decreased significantly from the 5-Test to the 10-Test, but not on the other body sites. Furthermore, in Subj. No. 1, the increases of SR not only on the forehead but also on the chest and forearm from the 5-Test to the 10-Test were due to the increases of SGO.

In all subjects, the T_{re}, T_{sk}, T_b, HR and MAP responses during the 60-min heating exposure did not change significantly over the 10-yr period, although ΔT_{re} tended to be greater from the Ini-Test to the 10-Test.

Discussion

We have reported previously that aging-related decrements in sweat gland function may not occur at a uniform rate over the whole body, based on the findings of cross-sectional studies (3, 4) and a longitudinal study in older men over a 5-yr period (5). To determine how the decrement occurs, we performed a 10-yr longitudinal study of four older men. The SR responses on the chest, back and forearm of Subj. No. 1 (whose pedometer readings and VO_2max increased from the 5-Test to the 10-Test) were different from those of the remaining three subjects (whose pedometer readings and VO_2max did not change over the 10-yr period), although the SR on the forehead and thigh was similar among the four subjects. Therefore, by using data obtained from Subj. No. 2, 3 and 4, the effect of aging on sweat responses was examined; and by using data obtained from Subj. No. 1, the effect of physical training on sweat responses in older men was examined.

In Subj. No. 2, 3 and 4, the SR on the thigh (which was substantially lower than that of young men in the Ini-test (3)) was no different over 10-yr period. The SR on the back (which was similar to that of young men in the Ini-Test (3)) decreased significantly from the Ini-Test to the 5-Test, but did not change after that. The SR on the chest and forearm (which were similar to those of young men in the 5-Test (4)) decreased significantly from the 5-Test to the 10-Test, and the magnitude of the decrease was greater on the chest SR than on the forearm SR. In contrast, the SR on the forehead (which was similar to that of young men in the 5-Test (4)) increased significantly from the 5-Test to the 10-Test. The results of SR responses over the 10-yr period in the present study, over a 5-yr period in an earlier study of eight older men (5), and in cross-sectional studies (3, 4) suggest that regional differences exist in the aging-related decrement in sweating, and that this decrement may proceed sequentially from the lower limbs to the back of the upper body, then to the front of the upper body, thereafter to the upper limbs, and finally to the head.

The decreases of SR on the back from the Ini-Test to the 5-Test and on the chest and forearm from the 5-Test to the 10-Test were due to the decrease in SGO rather than a decrease in the recruitment of HASG. The aging-related decrements in SGO agree with our previous findings on the thigh (3) and on the thigh and back (4) in cross-sectional studies and on the back in longitudinal studies over a 5-yr period (5). Based on the findings that people with lower SGO and functionally inactive sweat glands possess smaller sweat glands and a lower cholinergic sensitivity (6), the decrease in SGO with aging might reflect aging-related changes in the sweat glands themselves (sweat gland atrophy) or a decrease in cholinergic sensitivity. Such changes may proceed gradually over the surface of the body to produce the distinctive regional differences that characterize the aging-related decrement in sweating. In the present study, the density of HASG on the thigh and back decreased from the 5-Test to the 10-Test in association with a decrease in SGO. Similarly, in the longitudinal study of 8 older men over a 5-yr period, the density of HASG on the thigh (but not on the back) decreased significantly from the Ini-Test to the 5-Test (5). In contrast, the density of HASG did not change at any body site in two cross-sectional studies (3, 4). It is possible that the progressive atrophy of sweat glands leads to a decrease in sweat output; that is, the aging-related decrement in SGO may occur before the HASG density is reduced.

In contrast, in Subj. No. 1, who started and continued sports activity after the 5-Test, SR increased not only on the forehead but also the chest and forearm. The increased SR was due to the increase in SGO rather than in HASG density. The results suggest the possibility that, even in a man over 70 yrs old, sweat gland function may improve with physical training. The forehead SR increased significantly from the 5-Test to the 10-Test in all subjects. This finding may imply that the central sudomotor activity in response to a given thermal input can be augmented to compensate for aging-related impairment of peripheral mechanisms; this augmentation would take the form of an increase in SR on the forehead without the impairment of peripheral mechanisms.

Conclusions

Our longitudinal results suggest that the age-related decrement in SGO may occur before the HASG density is reduced. The decline does not occur at a uniform rate over the body surface, and may well proceed from the lower limbs to the back of the upper body, the front of the upper body, then the upper limbs and finally to the head. Furthermore, even in an older man over 70 yrs of age, sweat gland function may be improved by physical training.

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STRESS, IMMUNE AND THERMAL EFFECTS OF ULTRA-ENDURANCE RACING WITH SEVERE SLEEP DEPRIVATION

James D. Cotter[1], Christian J. Cook[2], Samuel J.E. Lucas[1], Warren S. Roberts*

[1]School of Physical Education, University of Otago, Dunedin, New Zealand
[2] Human Health and Performance Programme, HortResearch, Hamilton, New Zealand
*corresponding author jcotter@otago.ac.nz

Introduction

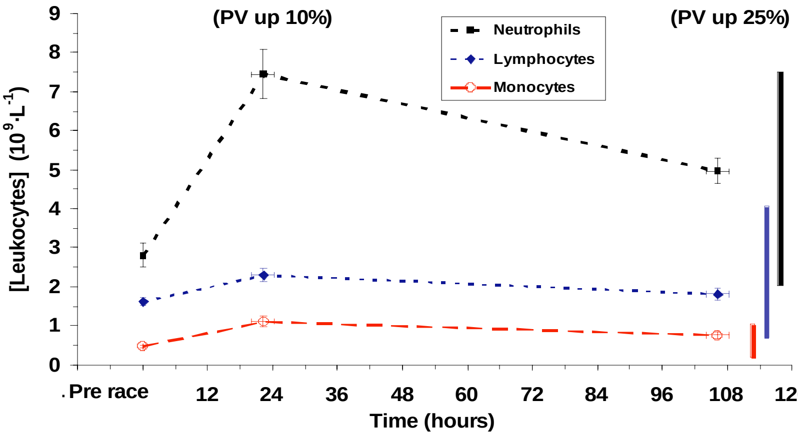
Immune status is important but is also potentially compromised for adventure racing athletes, who exercise almost continuously for 3-14 days in wilderness terrain. Immune status is altered by endurance exercise, partly via thermal and related stress responses to sustained exertion. The concentration and activity of neutrophils rise, whereas those of lymphocytes drop and remain depressed following exhaustive exercise, in association with elevated cortisol. However, the thermal, neuroendocrine and immune responses to self-paced exercise lasting several days are apparently unknown, hence the reason for this study.

Methods

Data were obtained from eleven athletes (5 females) competing in the 2003 Southern Traverse. Core temperature was obtained using gastro-intestinal pill thermometry. Venous blood and saliva (both *n*=11) were obtained 48 h before race onset, at a fixed location early in the race (15-30 h), and at the finish (96-126 h). Saliva was also sampled periodically while racing. Testosterone and cortisol were calculated from saliva.

Results

Core temperature was recorded for a total of 311 h across 7 athletes, during which time it exceeded 39°C for only 1.5 h (<1%), remaining mostly 38-39°C (22%) or 37-38°C (67%), and reached a minimum of 36.0°C. As shown in the figure, plasma concentrations of neutrophils, lymphocytes and monocytes increased ($p<0.05$) early in racing, by 2.7, 2.3 and 1.4 fold, respectively, despite increased plasma volume, but by race completion had returned to be 1.8 ($p<0.05$), 1.6 ($p>0.05$) and 1.1 fold higher. Mean pre-race salivary cortisol and testosterone concentrations were elevated by 2.9 and 1.5 fold, respectively, above expected basal levels. During racing, cortisol remained high (2.5-5.3 fold above baseline), increasing with time. In contrast, testosterone gradually fell, reaching a minimum of 40% of baseline. Data further indicate, albeit without statistical inference, that circadian pulsatility in testosterone may have been suppressed after 24 h. Salivary IgA showed no significant change across the race.



Conclusions

Elevated pre-race hormone concentrations may indicate preparatory or anticipatory effects of prolonged racing. Irrespective, pre-race concentrations of leukocytes were within normal ranges. Elevated neutrophils and cortisol, and reduced testosterone during racing were anticipated in view of the prolonged physical stress and sleep deprivation. However, the lack of a fall in salivary IgA and lymphocyte concentrations was unexpected and requires further investigation.

THE IMPACT OF 100 HOURS OF EXERCISE AND SLEEP DEPRIVATION ON PHYSICAL CAPACITIES

*Samuel J.E. Lucas**, *James D. Cotter, Craig D. Palmer, J. Greg Anson*

School of Physical Education, University of Otago, Dunedin, NZ
* corresponding author slucas@pooka.otago.ac.nz

Introduction

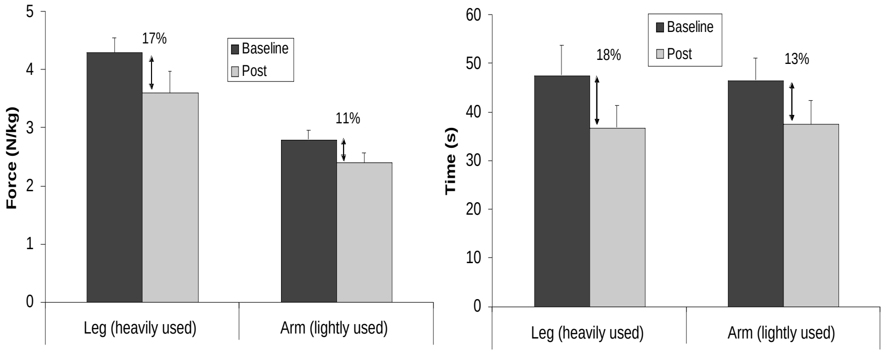
Athletes substantially reduce power output during the very prolonged competition of an adventure race, but it is unknown whether this coincides with reductions in peak functional potential (eg. power and strength). Military-based research indicates that general skill tasks and occupational physical performance tasks are maintained adequately after prolonged sleep deprivation. However, these studies do not involve the volume or intensity of sustained exercise or sleep deprivation that occurs in adventure racing. The purpose of this study was to examine the effects of ~100 hours of almost continuous exercise on explosive power, very high intensity power (30 s), strength and strength endurance in athletes participating in an adventure race.

Methods

Participants were tested before and after (<60 min) participating in the 2003 Southern Traverse adventure race. Explosive power (*n*=24) was measured using a vertical jump test. Maximum, mean, and end power (*n*=27) were measured during a 30-s cycling Wingate test. Strength (*n*=9) and strength endurance (*n*=8) of knee extensor and elbow flexor muscles were measured from separate participants. Strength was measured from three maximal voluntary contraction (MVC) efforts. Strength endurance was measured as time to failure at 70% of current MVC force.

Results

Vertical jump height was reduced by 9% (47 to 43 cm; $p<0.01$) post race. In the 30-s Wingate peak power decreased by 9 % (1006 to 940 W; $p=0.03$), mean power by 9% (701 to 651 W; $p<0.01$), and end power by 9% (542 to 487 W; $p<0.01$). Individual differences were evident, with peak power in one athlete dropping by 45%, whilst another athlete increased by 18%. The MVC force during knee extension and elbow flexion (see figure, left panel) decreased consistently for both leg and arm muscle groups ($p=0.02$ and 0.01, respectively). Similarly, time to failure at 70% MVC (right panel) decreased for both muscle groups, however not consistently ($p=0.09$ and 0.40, respectively). These decreases in MVC and time to failure were equivalent between knee extensions and elbow flexions, ($p=0.44$ and 0.74, respectively).



Conclusion

In general, functional performance is only modestly impacted by 100 hours of almost continuous exercise, although some participants suffered substantial impact. Upper and lower limbs were affected similarly despite being used disproportionately. This finding may support a centrally mediated model of fatigue.

SIGNIFICANCE OF FIT ON THE PERFORMANCE OF LIQUID CIRCULATING GARMENT AND PERSONAL COOLING SYSTEM

Jinkai Wang, Jean-Philippe Dionne, Aris Makris*

Department of Research and Development, Med-Eng Systems Inc, Ottawa, Ontario, Canada
* corresponding author fwang@med-eng.com

Introduction

Individuals involved in a number of different occupations, such as explosive ordnance disposal, hazardous materials clean up, fire fighting, crowd management, war fighting, millwork and welding, are required to wear protective clothing ensembles and often exposed to harsh environmental conditions. The use of protective clothing ensembles increases thermal resistance and reduces vapour permeability between the body and the environment. Those involved in physically demanding activity require high metabolic efforts that produce high physiological heat dissipation. As a result, individuals may be affected by heat stress.

One solution is to incorporate the use of Personal Cooling Systems (PCS) within the protective clothing ensembles. PCS are designed to counteract the effects of heat stress. They can help maintain the body core temperature within safe limits for extended periods of time (3). This is achieved through the control of the internal body temperature by removing internally generated physiological heat and/or blocking external heat. The use of PCS often results not only in safer work conditions, but also in increased work productivity and comfort.

Liquid Circulating Garments (LCG), commonly designed as an integration of flow network with fabric material structure, can be used as a component of PCS, functioning as a heat sink to body heat dissipation and/or environmental heat source. LCG can take the form of either a vest or a full body suit, and are often available in various sizes to best fit each individual wearer. As a result, the fit of an LCG is likely to vary with user and selected size. The fit will in turn influence the LCG effectiveness for physiological heat removal in terms of heat transfer between the cooling liquid and the body. The purpose of the study was to identify the significance of fit on the LCG's ability to remove body heat production through dry heat transfer.

Methods

The heat removal rate of an LCG can be described, on a macroscopic scale, as:

$$Q = KA\left(T_s - \frac{T_{out} + T_{in}}{2}\right) \qquad (1)$$

where Q (W) is the heat removal rate, A (m^2) is the area covered by the LCG, T_s (°C) is the body surface temperature, T_{in} (°C) is the cooling liquid temperature at inlet, T_{out} (°C) is the cooling liquid temperature at outlet, and K (W/m$^2 \cdot$°C) is the Heat Transfer Coefficient (HTC). The HTC, evaluated at unit LCG coverage and the temperature difference between the body surface and the arithmetic mean temperature of the cooling liquid, represents the heat exchange effectiveness between the cooling liquid and the body. An increase in heat transfer effectiveness due to a better fit can be reflected as an increase in the HTC value.

Thermal manikins are valuable tools for quantitatively evaluating the performance of protective clothing ensembles and PCS. A dry thermal manikin torso was used for identifying the influence of fit on the HTC. The manikin was equipped with a water-circulating system heated electrically. For the purpose of obtaining uniform temperature distribution on the manikin surface, the water was mixed throughout the interior of the torso via a circulation pump and a manifold consisting of a tube pierced with multiple holes, which extended from the base of the torso to the tip of the arms. The manikin surface temperature was monitored by means of 18 surface-mounted thermistors that were positioned to cover similar amounts of surface area. They were distributed in the following locations: four each on the front and rear of the torso, respectively, two on the shoulders, and four on each arm. Power input to the water heater was controlled to maintain the mean surface temperature at desired value through a data acquisition system, which also monitored the ambient temperature through a sensor. In order to determine the rate of heat absorption by the PCS, the flow rate and the temperature of the cooling liquid entering and exiting the

PCS were measured using a flow sensor and two thermocouples, respectively. The cooling liquid used in the study was water.

An LCG of vest configuration was used in the study. The vest consisted of tubing network sewn into the fabrics, and was worn on top of a T-shirt, which is adjacent to the manikin surface. The vest coverage was about 0.52 m^2. A HAZMAT Level B suit was used as the outer garment, worn on top of the LCG. To examine the significance of fit on the LCG performance, the LCG was worn on the manikin in two fit configurations. The “Natural” configuration consisted of wearing the LCG on top of the T-shirt without any other measures for fit adjustment, whereas the “Snug” configuration consisted of using tape wrapping around the torso area to provide a better fit between the LCG and the manikin.

For both Natural and Snug configurations, three tests were conducted with different combinations of cooling water temperature and flow rate. For all tests, the manikin was placed in a climate chamber controlled at 35°C, with the surface of the manikin also maintained at 35°C. Since the manikin surface temperature was the same as the ambient temperature, there was no direct heat exchange between the manikin surface uncovered by the LCG and the ambient. At steady state, the power input to the manikin became the direct heat transfer from the manikin to the cooling water, namely the heat removal rate. The HTC was then determined using Equation (1).

Results and discussion

Significance of fit on LCG performance

Table 1 presents the detailed test data for all test cases. Listed are the temperature of the cooling water entering and leaving the LCG, flow rate of the water, the heating power required by the manikin to maintain its surface temperature at 35°C, water heat absorption rate within the LCG, and LCG efficiency, defined as the ratio of the heat removal rate to the heat absorption rate of the cooling water. Figure 1 compares the experimentally determined HTC between the Natural and Snug configurations. Obvious increases in HTC for the Sung configuration were observed in all three cooling water conditions. In agreement with the results reported in a separate study (1), the HTC was found to be not significantly sensitive to the water conditions. Among the three cooling water conditions, the HTC varied between 5.22 and 5.34 $W/m^2{\cdot}°C$, with an average value of 5.28 $W/m^2{\cdot}°C$, for the Natural configuration; whereas the HTC varied between 10.55 and 11.35 $W/m^2{\cdot}°C$, with an average value of 10.97 $W/m^2{\cdot}°C$, for the Snug configuration. The increase in HTC as a result of a better fit was found to be between 5.20 and 6.07 $W/m^2{\cdot}°C$, with an average of 5.69 $W/m^2{\cdot}°C$.

As already observed in a previous study (2), the heat removal rate is influenced by the flow rate and temperature of the cooling water. However, at any combination of the water flow rate and temperature, an enhanced heat removal rate can be found as a result of improved fit, as shown in Figure 2. For example, when the water inlet temperature and flow rate were 8°C and 0.35 L/min, respectively, the increase in heat removal rate was 59 W. This increase is, of course, dependent on the coverage of the LCG and the temperature difference between the manikin and the water. Figure 3 presents the projected increase in heat removal rate as a function of LCG coverage and average temperature difference between the cooling water and the manikin surface, using the average increase in HTC found in the current study. Clearly, the greater the LCG coverage and/or the temperature difference, the higher the increase in the heat removal rate.

Table 1. Detailed results from thermal manikin testing.

LCG fit configuration	Inlet temp. (°C)	Outlet temp. (°C)	Flow rate (L/min)	Heat abs. (W)	Heating power (W)	LCG efficiency
Natural	8.12	12.98	0.350	118.67	67.93	0.572
Natural	13.82	16.72	0.500	100.82	53.59	0.532
Natural	19.84	21.45	0.648	72.92	39.41	0.541
Snug	8.18	15.48	0.350	178.24	126.99	0.713
Snug	14.03	18.15	0.502	144.35	108.14	0.749
Snug	19.97	22.44	0.652	112.52	81.36	0.723

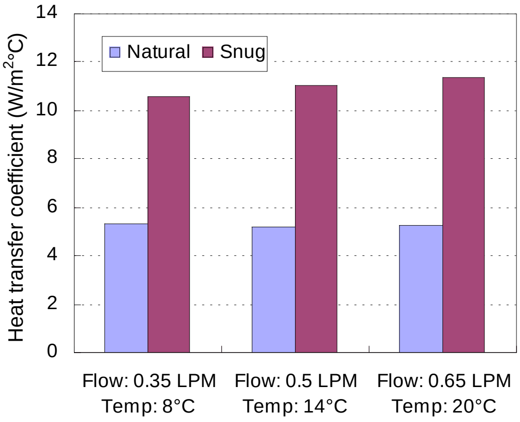


Figure 1. Comparison of heat transfer coefficient.

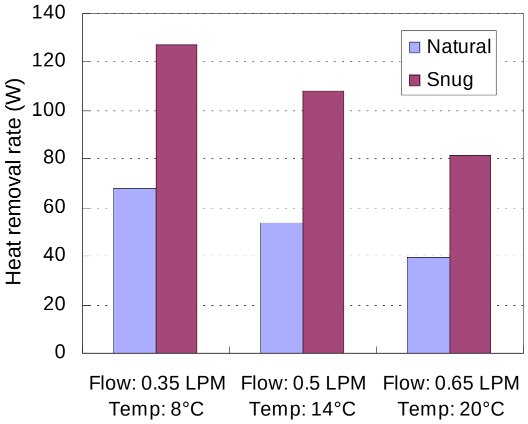


Figure 2. Comparison of heat removal rate.

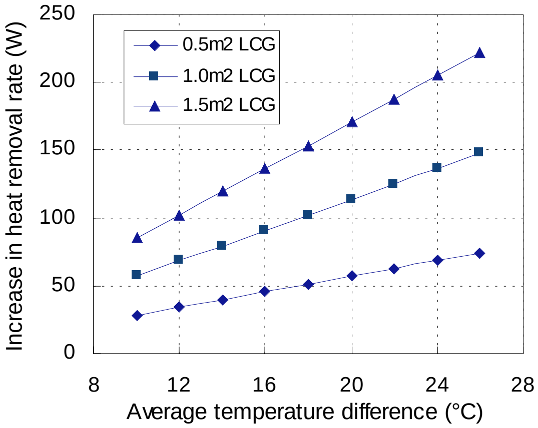


Figure 3. Projected increase in heat removal rate as a result of fit improvement.

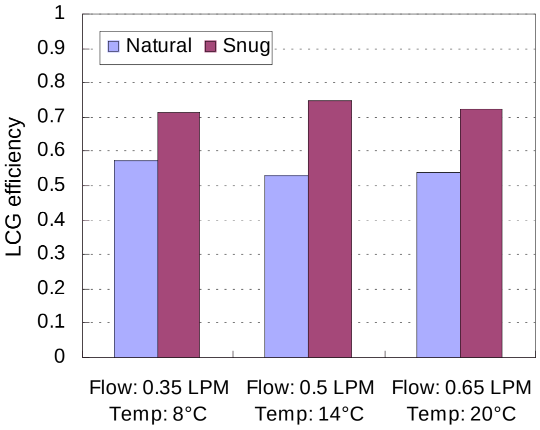


Figure 4. Comparison of LCG efficiency.

The benefits of a snugger fit can also be observed from improved LCG efficiency. An increase in the LCG efficiency was observed for all three water conditions, as shown in Figure 4. The LCG efficiency was not sensitive to the cooling water conditions for both Natural and Snug configurations, the same as observed in a separate study (1).

Importance of fit to VCC-based PCS

The HTC is basically a heat transfer characteristic of an LCG. In order to understand the benefits of increasing the HTC, the heat flux capability should be examined. The required heat flux capability of an LCG is determined by the amount of heat extraction and the LCG coverage. With a targeted heat flux capability, the required temperature difference between the cooling liquid and the body increases with decreasing the HTC. Equally, for a given temperature difference and an LCG area, an increase in the HTC will increase cooling capability of the LCG. Therefore, it is clear that increasing the HTC will increase the cooling capability of the LCG for a given temperature difference, or reduce the required temperature difference between the cooling liquid and the body for a required cooling capability.

For a PCS employing Vapour Compression Chiller (VCC), a reduction in the temperature difference implies the possibility of increasing the cooling liquid temperature that is of importance not only for thermal comfort, but also for improving the power efficiency of the VCC unit. The liquid temperature entering the LCG determines the operating evaporation temperature of the refrigerant, which is a significant variable determining the VCC Coefficient of Performance (COP). For a given cooling capacity and operating environment, an increase in the evaporating temperature will reduce the power consumption of the compressor as the difference between the evaporating and condensing temperatures is reduced. Therefore, the COP of the VCC unit will increase. This will translate into an increased duration of the battery power source. Moreover, increased COP will lead to reduced heat dissipation from the condenser. For a VCC unit of a specified cooling capacity, an increase in temperature of the cooling liquid flowing through the evaporator may imply a reduction in physical size of such components as the evaporator and condenser. This will in turn lead to a potential reduction in weight of the whole VCC unit, which is significantly important for person-mounted PCS.

Conclusions

The results of the experiments demonstrated the significance of fit on the thermal performance of the LCG. In particular, the HTC between the cooling water and the manikin was increased by at least 5.2 $W/m^2 \cdot °C$ when a snugger fit was provided. Moreover, with the manikin surface temperature of 35°C, the heat removal rate was increased by 59W for the water flow rate and temperature of 0.35 L/min and 8°C, respectively. The increased heat removal rate was a result of enhanced heat transfer between the cooling water and the manikin due to a better fit. As found in a separate study (1), an LCG has a much higher cooling capability in sweating condition (1, 4). Based on the results of the current study, a snugger fit has the potential to increase the cooling capability in sweating condition to an even greater level.

The importance of increasing the HTC between the cooling liquid and the body to improving the performance of PCS combining an LCG and VCC unit was demonstrated through a qualitative analysis. It was shown that the benefits of increasing the HTC include: 1) improved thermal comfort as a result of smaller temperature difference between the body and the LCG; 2) reduced power consumption and increased energy efficiency of the VCC unit; and 3) increased battery life and reduced system weight.

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EFFECTIVENESS OF FORCED AIR-VENTILATED JACKETS IN A HOT OUTDOOR ENVIRONMENT

Shin-ichi Sawada (1), Tatsuo Oka (1), Hideki Fukuda (1), Yasuki Kobayashi (2)

(1) National Institute of Industrial Health, Kawasaki, Japan
(2) Graduate School of Medicine, The University of Tokyo, Japan

A forced air-ventilated jacket which is newly developed for mitigating heat stress at work was evaluated in a hot outdoor environment. Eight healthy male subjects (22-24 years old) dressed in summer daily clothing walked at a speed of around 5km/hr for 45 minutes with and without the jacket in a tennis court in summer. The climate condition during the experiment (13:00-16:00) was sunny and windy: the ambient temperature, 32.2-35.5°C; the relative humidity, 30-43%; the globe temperature, 41.1-49.3°C; wind velocity, 4.8-5.3m/sec; the WBGT, 28.0-30.2°C. Oral temperature, skin temperature at eight sites of the body, heart rates, blood pressure and body weight were measured for assessing the physiological thermal strain. Thermal discomfort, thermal sensation, sweating sensation, thermal preference, thermal tolerance, thermal acceptability and fatigue feeling were reported for assessing the subjective thermal strain. There were no significant differences between the two clothing conditions (i.e. those with and without the jacket) in most of the physiological variables measured except for skin temperature at a few sites. There were also no significant differences between the two conditions in many of the subjective responses except for thermal discomfort feeling, the degree of which was relatively greater in the condition with the jacket. This was mainly caused by the subjects' cumbersome feeling while wearing the jacket. The present study suggests that a forced air-ventilated jacket has no marked effectiveness in terms of the mitigation of physiological and subjective heat strains in sunny and windy outdoor environments in summer. Further studies are necessary to explore the other climatic conditions where the jackets function more effectively.

RISK FACTORS, DESIGN NEEDS AND PREVENTIVE MEASURES FOR SLIPS AND FALLS IN COLD CLIMATE AMONG OUTDOOR WORKERS

Chuansi Gao[1], Ingvar Holmér[1], John Abeysekera[2]*

[1] Thermal Environment Laboratory, Division of Ergonomics and Aerosol Technology, Department of Design Sciences, LTH, Lund University, PO Box 118, Lund 221 00, Sweden
[2] Work Science Academy, Rydsvägen 394C, 584 39 Linköping, Sweden
∗corresponding author Chuansi.Gao@design.lth.se

Introduction

Slip and fall accidents and associated injuries on icy and snowy surfaces are common among the public and outdoor workers (forest workers, construction workers, service workers, etc.) in Nordic countries and other regions of the world in winter (1-7). Almost everyone with any ice and snow living experience has experienced slips. Bruises, sprains, and fractures are common injuries caused by slipping and falling on ice and snow. The direct and indirect costs to rescue agencies, emergency care services and society are tremendous (5).

Many factors contribute to slip and fall risks. Grönqvist pointed out that the risk factors for slips and falls may include extrinsic (environmental), intrinsic (human) or mixed (system) factors (8). The primary risk factor for slipping accidents is poor grip or low friction between footwear and an underfoot surface. Secondary risk factors for slipping accidents include a large variety of environmental factors and human factors. In winter, there exist various types of underfoot surfaces such as ice, melting ice, snow, melting snow, compressed snow, ice covered with snow or anti-slip materials, etc. How do these types of surfaces affect slips and falls? Are outdoor workers satisfied with professional footwear provided? What are their demands on the professional footwear for use in winter? What are the preferred preventive measures for slips and falls on ice and snow? These are the research questions in this investigation.

The objectives of this study were to further describe the consequence of slips and falls on ice and snow and associated injuries, assess the risk of various icy and snowy surfaces, identify the design needs of footwear for use on ice and snow, and ascertain the preference of preventive measures by the experienced outdoor workers in winter.

Method

A questionnaire survey was conducted for one winter season (October 2000 – April 2001) among outdoor workers in the northernmost province of Sweden (Norrbotten). The investigated organizations involving outdoor work were newspaper delivery service, north military regiment, mining and construction industries. Included in the questionnaire were general information (age, gender, occupation, average outdoor working hours, years of service), slip and fall events (how often slipped, slip initiated fall events, injuries and sick leave), type of underfoot surfaces on which falls occurred, rating of the slipperiness of different types of icy and snowy surfaces (5-point scale, 5=very slippery), type of footwear worn, ranking of property importance for designing professional footwear for use outdoors in winter and preferred preventive measures, etc. The persons who were in charge of work environment within the organizations delivered the questionnaire to the employees who were involved in outdoor work in the winter. All together 181 workers responded (150 males, 31 females, average age 39.5±11.8, response rate 86%).

Results

Fall and injury

Of the respondents, 69.8% fell at least once for the winter investigated, and 41.3% were injured due to slips or falls on ice and snow. Sick leaves were 4.4% (55.5 days lost) as a result of injuries. Injuries were distributed to the whole body: head (5.0%), hand (9.4%), wrist (11.0%), arm (11.6%), trunk (3.9%), low back (13.3%), hip (9.4%), leg (5.5%), knee (17.1%), ankle (3.9%), foot (6.1%) and other parts (2.8%). Falling events were not statistically different between male and female workers ($\chi^2 = 0.503$, $p=0.478$), nor were injuries ($\chi^2 = 0.768$, $p=0.381$).

Among the four organizations, fall events happened most frequently in the military, fall associated injuries occurred mostly in newspaper delivery service (Figure 1).

Underfoot surface

The distribution of fall accidents on different type of underfoot icy and snowy surfaces showed that fall events happened mostly on ice covered with snow (Figure 2).

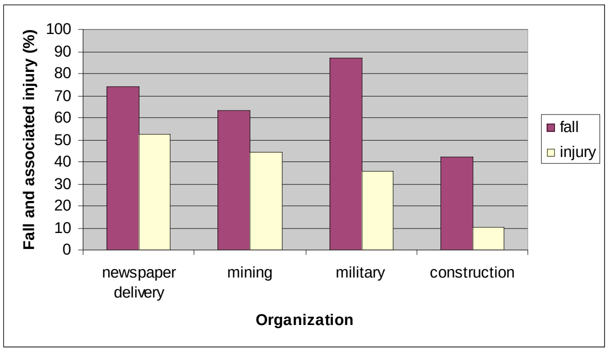

Figure 1. Fall events and associated injuries among different sectors

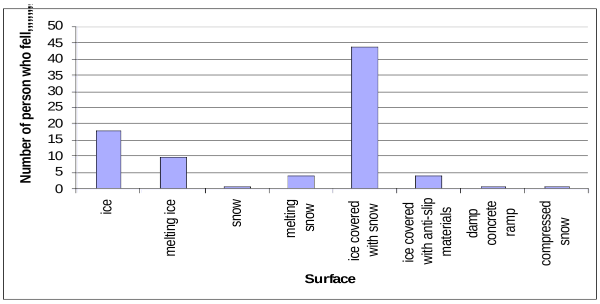

Figure 2. Distribution of fall accidents happened on icy and snowy surfaces

According to the rating of the slipperiness of icy and snowy surfaces by the respondents, ice covered with snow was also rated as the most slippery one (Table 1). Friedman test showed that the rank among these types of underfoot surface are significantly different (χ^2 =476.226, N=166, df=4, $p< 0.001$).

Footwear

Special protective footwear were not provided in newspaper delivery service, but in military, mining, construction organizations. However, the protective footwear provided was rated as "uncertain" (mean score=2.8, on the 5-point Likert scale, 1= strongly disagree, 5=strongly agree in the statement "The footwear provided by the employer is slip resistant on ice and snow in winter.").

The ranking of the importance (1=extremely important, 2=least important) of properties to be considered for designing professional outdoor footwear for use in winter is in Figure 3, where we can see that five most important properties are protection against cold, anti-slip, and good fit, comfort, and easy to walk. On the other hand, cheap price, aesthetic factor were ranked least important. Friedman test showed that the rank of the importance of the properties are significantly different (χ^2 =991.979, N=166, df=11, $p< 0.001$).

Table 1. Rating of the slipperiness of icy and snowy surfaces (1= not slippery, 5=extreme slippery)

Surface	Mean rank
Ice covered with snow	4,5
Melting ice	3,6
Ice	3,5
Melting snow	1,9
Snow	1,5

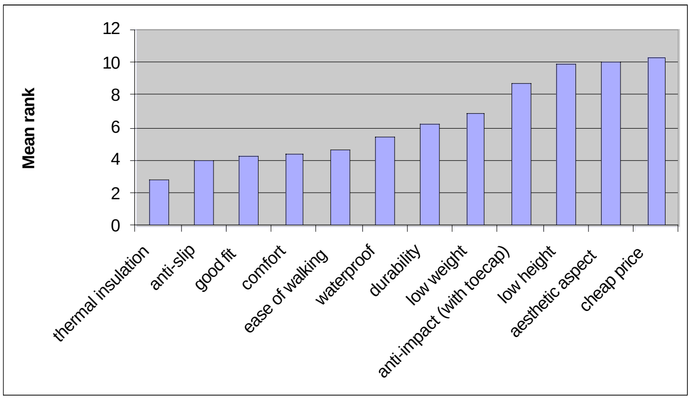

Figure 3. Rank of the importance of properties for the design of professional footwear for use in winter

Preventive measures on ice and snow

To provide special protective measures is necessary according to the outdoor workers. The rank of the preferred (1=least preferred, 9= most preferred) preventive measures for slips and falls on ice and snow showed that the spread of anti-slip materials and the use of slip resistant footwear were the most preferred two means (Table 2).

Discussion

This investigation showed that falls and associated injuries on icy and snowy surfaces are not a trivial problem as are other types of occupational slips and falls (4), rather they are prevalent among outdoor workers in winter. The results showed that on average, more than two thirds fell at least once, of which about two thirds happened on icy and snowy surfaces. Fall events happened most frequently in military. This might be due to the fact that the exposure hours were the longest (7.3 hours on average). However, injury rate was most frequent in newspaper delivery, which could be attributed to the age discrepancy. The slip or fall associated injuries were 41.3% although majority of the injuries were minor ones (slightly wounded, swelling, or slight pain, etc.). Previous investigation showed that fracture and even fatal cases are not uncommon (5). These serious injuries were not shown in this investigation. It could be explained by the differences of the populations investigated, gender and age constructs, etc. Serious injured cases might not be reached, for instance, if they were on sick leave. The injuries were distributed to the whole body, especially the knee, low back, arm and wrist. This did demonstrate that the prevention of slips and falls and associated injuries should be a priority.

Table 2. Rank of preferred preventive measures for slips and falls on ice and snow

Preferred preventive measures	Mean rank
Spread of anti-slip materials	6.5
Use of slip resistant footwear	6.3
Walk carefully	5.4
Remove of snow	5.3
Use of attachable anti-slip device	5.0
Walk slowly	4.7
Take small steps	4.3
Use only ordinary shoes	4.3
Special measures unnecessary	3.4

One interesting finding was that the fall accidents happened mostly on ice covered with snow (Figure 2). Previous laboratory studies showed that melting ice is more slippery than hard ice (8, 9). However, the slip resistance between footwear and ice covered with snow surface has not been reported in laboratory studies. On such a surface, the slip may occur between snow and ice rather than between footwear and ice. This result is in well agreement with the rating of the slipperiness of the different icy and snowy surfaces by the respondents (Table 1). One possible factor is that ice is hidden under snow making workers difficult to perceive the risk of the slipperiness of ice. Therefore, they were unprepared to adjust their gaits accordingly. Literature showed that proactive gait strategies are used to prevent slips and falls when anticipating a slippery surface (10, 11).

Special work footwear was provided in military, mining industry, construction industry. However, the protective footwear provided was rated as “uncertain” in terms of anti-slip effectiveness, implying that outdoor workers were not satisfied with the footwear. This study further asked the outdoor workers to rank the importance of properties for designing professional footwear for use in winter. The respondents rated that thermal insulation and slip resistance were the two most important protections, followed by three ergonomics requirements among the nine properties evaluated. This further revealed that outdoor workers in winter do need protection against slips, which is even more important than protection against impact by falling objects.

Preferred preventive measures by respondents also showed that the use of anti-slip footwear is one of the most preferred means (Figure 3). This further emphasizes that professional footwear to be used on ice and snow in winter should be re-designed according to the users’ needs, by integrating thermal insulation, slip resistance, and usability (12).

Conclusions

Slip associated falls and injuries are prevalent among outdoor workers in winter. Fall events happen mostly on ice covered with snow due to the difficulty to perceive the hidden risk. According to the experience of the outdoor workers, ice covered snow is also rated as the most slippery one among the five types of icy and snowy surfaces investigated. The provided footwear does not provide enough protection against slip and fall risks. The importance of slip resistant property is ranked as one of the top requirements by the users. The provision of anti-slip property for footwear and spread of anti-slip materials are the most preferred preventive measures for slips and falls on ice and snow.

Acknowledgement

The project was financed by RALF and VINNOVA. The data collection was carried out when the first author was at the Department of Human Work Sciences, Luleå University of Technology. The authors thank the participation of the organizations and individual respondents. Thanks also go to Dr. Emma Christin Lönnroth for the translation of the questionnaire into Swedish.

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A SUN SHADING HEADGEAR USED BY A DUTCH OLYMPIC SCULLER: A COMPARATIVE STUDY

Niels Bogerd[1]*, *Ronald Heus*[2], *John Willems*[2]

[1] Faculty of Human Movement Science, Vrije Universiteit, Amsterdam, The Netherlands
[2] Department of Product Ergonomics, TNO Science and Industry, Eindhoven, The Netherlands
* corresponding author Ronald.heus@tno.nl

Introduction

Due to their high metabolic rate during a competition endurance athletes produce much heat. It is calculated that an Olympic Dutch sculler produces around 1200 W*m^{-2} during a race[7]. As long as heat is dissipated to the environment it will not lead to any problems. However, these high rates are uncompensable and heat will be stored in the body. It is believed that high heat storage reduces endurance performance[2].

In the onset of the Olympic Games 2004, held in the hot Athens summer, Dutch Olympic sculler Dirk Lippits and his personal sponsor DSM teamed up with research institute TNO Science and Industry to develop products that would enhance his performance during this Olympic Games. It was predicted that the Athens summer climate[1] would not be able to facilitate a sufficient heat loss and therefore would induce heat storage. Next to the insufficient heat loss due to the climate it would also warm up the body due to the high radiant (solar) temperature (T_r) which was estimated to be 45°C (670 W*m^{-2}).

From research it is known that cooling of the head skin is very effective in reducing heat strain[5] and enhancing ratings of perceived exertion[1] and perceived comfort[4]. Therefore, a sun shading headgear was developed which shades the head from the solar radiation without compromising the heat loss from the head (figure 1).

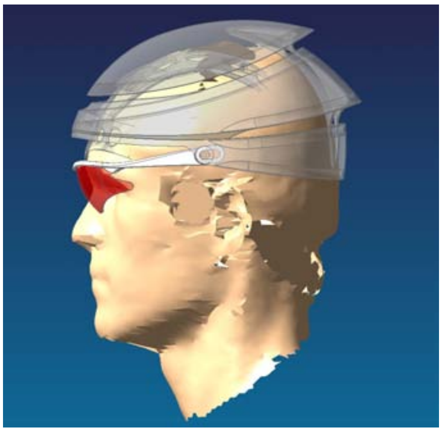

Figure 1. The overleaping but hanging panels shade the head from solar radiation without obstructing the heat loss under the headgear.

The purpose of this study is to compare rowing with the new developed headgear (N) with rowing bareheaded (B) and rowing with a standard 100% cotton cap (C) in a radiant rich environment with regard to head skin temperature, heart rate (HR) and subjective sensations (perceived exertion, wetness, comfort and temperature[3]).

Methods

Six healthy male subjects were subjected to three 30 min rowing exercise bouts on a row ergometer (Concept2, Morrisville, USA). Conditions B, C and N were provided in a random order, on different days but during the same time. In a conditioned room (ambient temperature 21.4 (± 0.2) °C and relative humidity 65 (± 5) %) two infrared lamps (1 kW per lamp) were placed on either sides of the row

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[1] The climate during the races of the Olympic sculler was predicted from historical observations of the National Technical University of Athens www.meteo.ntua.gr.

ergometer, perpendicular to the direction of movement and in the middle of the movement range (figure 2). The minimal distance to the lamps was ~80 cm, and at this distance produced a T_r of 50°C.

Figure 2. The experimental setup

Four well trained subjects rowed the entire exercise bouts at an external power of 2.5 W*kg^{-1}, two less trained subjects rowed at 1.5 W*kg^{-1}.

Head skin temperature ($\overline{T}_{h-s}$) was measured symmetrically and as high up the forehead as possible with two thermocouples. $\overline{T}_{h-s}$ was registered every 3 s, HR every 5 s and the sensation scales at 10, 20 and 30 min after the start of the exercise.

An ANOVA repeated measures was used to test for within subject differences in the overall results and between the average values of 1 min. Significance was reached if $p \leq 0.05$. The study was approved by a medical ethical committee.

Results

Head skin temperature (figure 3)

Two complete $\overline{T}_{h-s}$ datasets were lost due to the detrimental effect of the sweat on the used tape. The ANOVA repeated measures did no indicate any differences. However a clear trend of a lower $\overline{T}_{h-s}$ was observed in N compared to B and C, therefore a paired t-test was used and indicated a significant lower temperature in N compared to C from t=13 min until the end of exercise.

Heart rate

HR increased throughout the exercise bouts but did not reach significance.

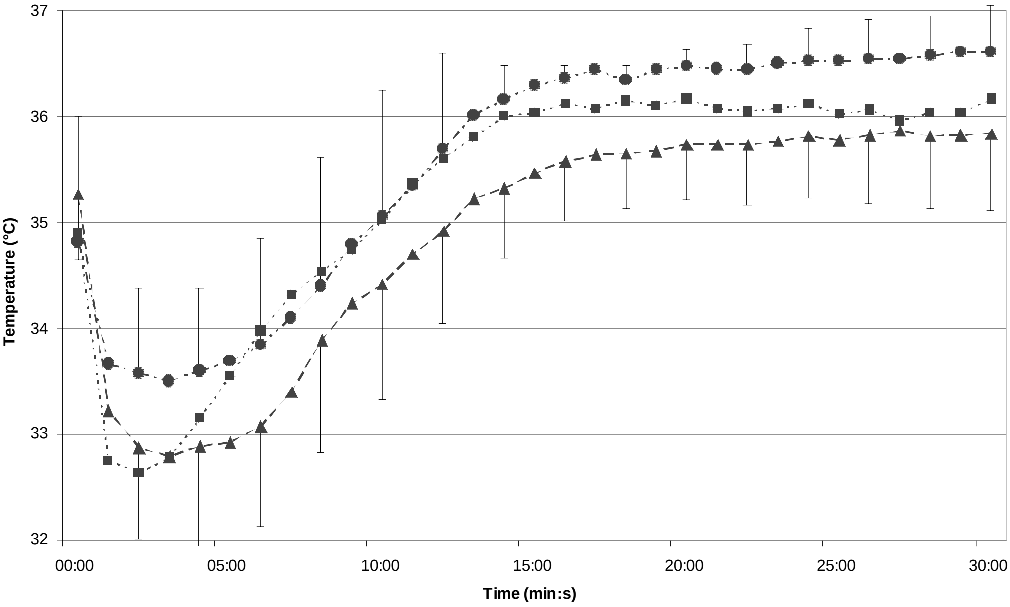

Figure 3. The average head skin temperature (n=4) in all conditions; bareheaded (B: ■), cap (C: ●) and new headgear (N: ▲). Standard deviations are only shown for condition C and N.

Subjective sensations

The sensation scales did at first not result in any significant difference. However, the relatively great standard deviation of the perceived temperature at t=30 min drew the attention and appeared to be caused by a subject with a voluminous hairstyle (figure 4). There appears a significant difference if this subject is excluded from the statistical analysis indicating a favourable thermal comfort for C and N compared to B.

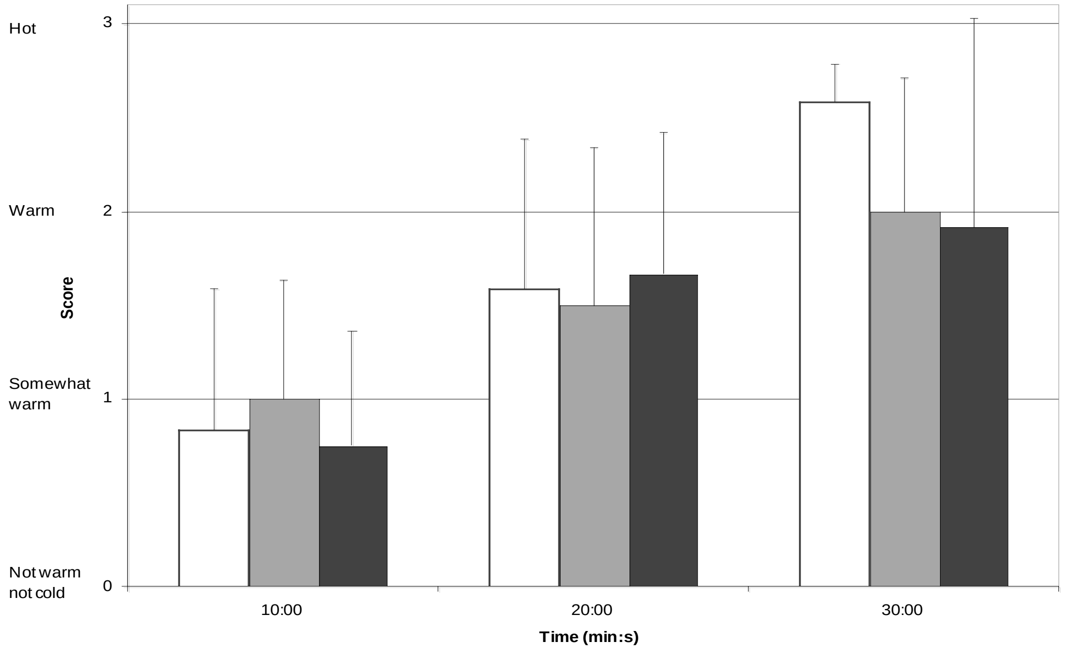

Figure 4. The average perceived temperature (n=6) in all conditions; bareheaded (B: white), cap (C: gray) and new headgear (N: black). Note the relative great standard deviation of condition N at t=30 min.

Discussion

It is calculated that the new headgear could shade the head from 60 W (30 W*m^{-2}). The cool capacity of the devices used in other research was at leased 90 W*m^{-2} or the whole body[1,4,5] was shaded. This could explain why the ANOVA revealed no difference in $\overline{T}_{h-s}$, while the more sensitive paired t-test did. It could also explain the small (if any) difference in the subjective scales.

The perceived temperature along with $\overline{T}_{h-s}$ reached significance after 30 and 13 min respectively. It is likely that the heat production is of direct influence on these time periods. Therefore, the time until effectiveness is predicted to be smaller in elite athletes due to their higher heat production.

Furthermore the new headgear appears to work best on a head with a non voluminous hair style. A voluminous hair style could reduce heat loss from sweating on the head skin by obstructing the airflow over the skin in addition of increasing the insulating capacity.

Due to the favourable perceived temperature the new headgear and the cap could enhance endurance performance in a radiant rich environment by increasing the mental status of an athlete[6]. The lower $\overline{T}_{h-s}$ only observed in the condition with the new headgear could also benefit endurance performance by reducing or blocking the warming of blood in the head skin due to solar radiation and thereby reducing heat storage.

Conclusion

Despite the small ‘cooling’ capacity, this new headgear is a functional way of lowering head skin temperature along with improving temperature sensation. Therefore it holds the potential of enhancing endurance performance in a radiation rich environment. However, more research is required to test if this new concept in (rowing-)sports, enhances performance.

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*Department of Product Ergonomics, TNO Science and Industry (NL)
Department of Comfort and Performance, TNO Defence, Security and Safety (NL)

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BODY SHAPING EFFECTS AND CLOTHING PRESSURE OF CORSETS

Eun Joo Park [1]*, *Chuyeon Suh*[2]

[1] Department of Fashion Design, Division of Domestic Science, Yuhan College, Puchon, Korea
[2] Division of Fashion and Textiles, Dong-A University, Busan, Korea
* corresponding author ejoopk@yuhan.ac.kr

Introduction

In the modern life, the consumer is becoming a more aware and self-assured shopper and wants to buy clothes not only for protection from the environment but also for her or his self-expression. This reason makes the fashion consumers find the aesthetic and functional garments that can give them the ideal body images, which leads most fashion marketers to have a marketing information system designed to provide data on what consumers do and why. Such a system is obviously important in understanding consumer behavior and developing marketing strategies (1-2). Especially, data on the body sizes of individual consumers provide the apparel manufacturers and consumers with useful information about the fit in wearing.

In the daily life, we should select the suitable clothing to circumstances in order to keep our lives healthy and comfortable (3). In particular, foundation garments, one of the lingeries for body shaping, have changed into many styles with various types, functions and wearing purposes as the consumers' modes have been varying in their attitudes, interests, and opinions. The foundation garments have been changed in types and materials according to the ideal body shape and silhouette of the time and social environments (4). Modern people show the high interest in not only the aesthetic role of clothing that express themselves but also the functional role of clothing such as shaping the body to the more ideal shape. The reason people wear a corset is that it shapes the lower body more thin through giving the pressure on the hip and the lower abdominal part, and dispersing the under-skin fat. However, at the same time people often complain against the uncomfortable feeling caused from the excessive pressure generated by wearing corsets.

Nowadays, female consumer's needs are increasing about the functional inner wear, especially expensive tailor-made foundation garment to make body slim. Yet, there is no evidence to prove the body shaping effect in wearing the corsets. We first investigated corsets wearing conditions of female college students and then surveyed the wearing sensation of persons selected with convenient sampling.

Therefore, in the present study, we tested the effects of the body shaping according to the types of corsets, and identified the relationship between the clothing pressure and the clothing discomfort of corset.

Methods

1. Subjects and Data Collection

Data were collected by convenient sampling method, and 10 female adults in 18 to 24 years participated in this research. They were operationally selected by the hip girth and waist girth that are within the range of 25% to 75% of the distribution of the standard body sizes of Korean in the 1997 National Anthropometric Survey, body sizes of subjects ranged within the 25~75% in the percentiles, of 18~24 years-old woman showed 62.1~68.5㎝ in waist girth, 85.4~93.0㎝ in hip girth.(Table 1)

The shaping effects on the body according to the corsets types were pictured by Moiré topography. In addition, clothing pressure on the body measured using Oxford interface pressure monitor. SPSS/WIN program was employed for sample descriptive statistics and multiple comparison tests.

Wear test in this study was also performed to identify the effect of corsets types on subjective sensations. Each response was judged after wearing the 4 different types of test corsets in random order. In wearing test, four types of corsets were used; ‘brief type(F1)’, ‘long leg type(F2)’, ‘high waist type(F3)’, and ‘long leg and high waist type(F4)’ (Figure 1). The subjective sensations were evaluated with 21 descriptive words.

2. Data Analysis

Collected data were analyzed statistically with SPSS package using frequency, percentage and cumulative percentage. Pearson's correlations of 4 body parts is considered with at the 0.01 and 0.05 level with 2-tailed significances test.

Body shaping effect and comfort of commercial corsets in wear test were investigated for understanding the principal components influenced on somatotype and evaluative components using the moiré topography for more comfortable corsets.

Table 1. Body Measurement

Subject	Waist girth (cm)	Abdomen girth (cm)	Hip girth (cm)	Full length()
S_1	67.5	74.0	85.5	156.7
S_2	62.0	73.0	85.0	160.3
S_3	69.0	75.3	92.8	166.8
S_4	64.0	76.0	89.0	164.2
S_5	62.2	67.4	86.7	162.3
S_6	68.0	81.5	88.5	165.0
S_7	62.5	64.0	81.0	160.5
S_8	68.5	84.0	92.3	167.5
S_9	61.2	68.0	82.7	158.5
S_{10}	68.0	75.0	93.0	158.0

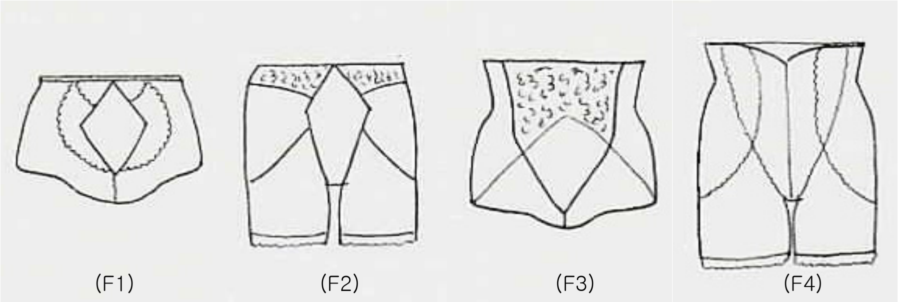

Figure 1. Corsets types.

Data were collected by convenient sampling method, and sample size was 252 subjects in 18 to 29 years. Questionnaire was composed of 5 parts: experience of corsets wearing, the preference of corsets type, and degree of dissatisfaction/discomfort in wearing corsets, wear sensation evaluation of corsets fabrics, including demographic and anthropometrical data.

Results and discussion

1. Wearing test

In wearing test, effects of the body shaping according to the types of corsets were investigated. The most comfortable corsets type was F1 and F2.

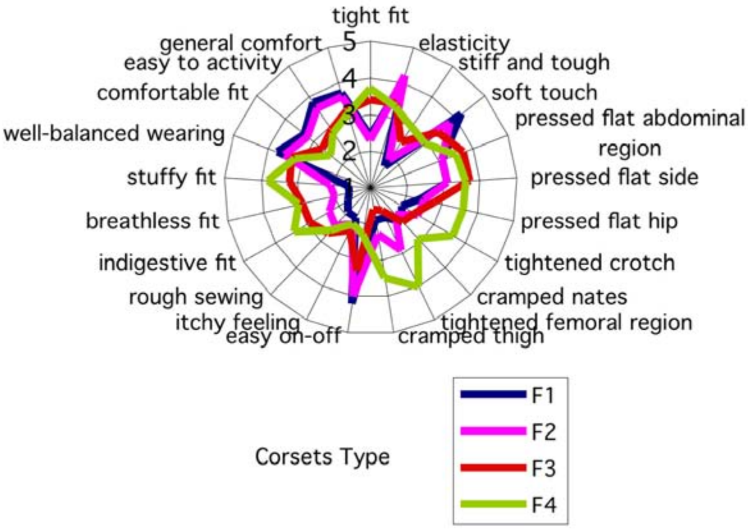

Figure 2. Wearing sensation evaluation.

Sensation of corsets wearing (tight fit/elasticity/stiff and tough/soft touch/pressed flat abdominal region/pressed flat side/pressed flat hip/tightened crotch/cramped nates/tightened femoral region/cramped thigh/easy on-off/itchy feeling/rough sewing/indigestive fit/breathless fit/stuffy fit/well-balanced wearing/comfortable fit/easy to activity/general comfort) was examined. The somatotype is the most outer shell which is determined by the bone, the muscle, subcutaneous fat, and posture. The foundation garments are used to make body an ideal form. Wearing the foundation garment brings body to shape properly, which results in garment material's distortion (5-6). That is, foundation garment is helpful for getting a desirable somatotype. It is necessary to investigate the effect of foundation garment by deformation and extension on body shaping in order to design comfortable foundation garments. Therefore, it is useful to get hold of consumer's foundation wearing experience, especially for corsets. Especially body parts to be shaped by corsets were in order of abdomen> hip > thigh > waist-hip sideline. Therefore, it would be considered that women in twenties want to care about bodyline of abdomen or hip.

2. Body Shaping Effect Evaluation through Moiré topography

This study was also performed to identify the effect of corsets types on body shape modification by moiré topography and subjective wearing sensation by questionnaire. Moiré topography shows the shaping effects of the body. Especially, shape variations in abdomen and hip girth region were given. All the four types of corsets showed the increments of 2.32 cm approximately toward the upper direction of hip and lessening effect of the waist girth was 3 to 8 centimetres.

3. Clothing Pressure of Corsets

Figure 3 shows clothing pressure in wearing corsets and sitting on the chair. Panty type of corsets (F1) has the lowest value of clothing pressure on all the measuring points of body in general. In contrast, high waist types of corsets (F3 and F4) have the higher values in clothing pressure. Some researches(7-8) on feelings of wearing and clothing pressure of corsets have reported that the pressure of trochanter endpoint broke out skin allergy and pain, and especially there is pricking in the connection point of trochanterion and folded body part. Curling-up at the end parts, low absorbency and ventilation, and poor tactile sensation were pointed out as the problems. Moreover, the results on the body correction effect of corsets (7) in waist part found that middle-size corsets showed a large aesthetic effect, but large-size corsets did not. And middle and large size corsets did not give much difference in aesthetic effects in both abdomen and hip parts. In other words, the body correction effect by corsets wearing will be influenced by the body size, and so each person wants different body parts to be shaped by corsets wearing.

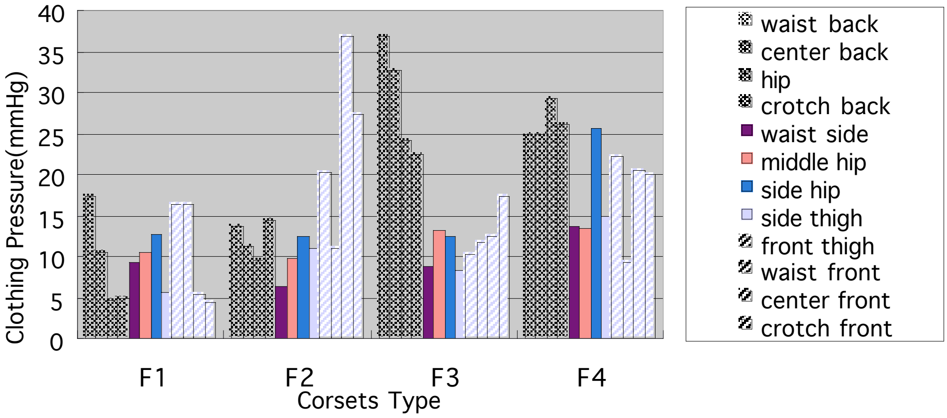

Figure 3. Clothing pressure with corsets types.

Conclusions

Body shaping effects were confirmed through Moiré topography and horizontal section mapping. In Moiré topography, all the ten subjects showed body shaping effects on the waist girth, the abdominal part, and the hip. Especially in the backside silhouette of the hip, all the ten subjects showed hip up effects. ‘Long leg type’ corset was found to make more smooth side body line in the hip and the thigh part. The effect of lessening the waist girth was 3 to 8 ㎝. More pressed body parts were found to be the front waist, the abdominal part, the hip, and the thigh part and more uncomfortable parts were the same in wearing test. Interestingly, body shaping effects and discomfort caused by wearing corsets were different according to the corset lengths and types. Therefore, selecting a right corset considering wearers’ body shape is very important.

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DEVELOPMENT OF A FITTED TORSO SLOPER FOR ELDERLY WOMEN USING BY THEIR DRESS FORM

Chuyeon Suh [1]**, *Eunjoo Park* [2]

[1] Division of Fashion & Textiles, Dong-A University, Busan, South Korea
[2] Department of Fashion Design, Yuhan college, Gyeong-ki Do, South Korea
* corresponding author chuyeon@daunet.donga.ac.kr

Introduction

Modern society shows an increase of average life span thanks to medical development and cultural-level improvement. Another main characteristic is the lowering rate of birth along with the increasing proportion of elderly people in society. Among the chief characteristics of the aged are bending waist, shrinking height, thickening waist and abdomen, increasing hip girth, rounding shoulders, extending breasts, and thinning lower body in general. These physical changes, occurring with one's increase in age, have a major influence on clothing fit and appearance, therefore, correct body measurement is a must.

The purpose of this study is to develop a fitted torso sloper, including darts, for elderly women fitted according to their somatotype, which can be used for improving the fit of garments and patterns.

The Purpose of This Study

1. This study classified and analyzed elderly women's somatotypes into three groups such as very short, short, and average group based on the KS K 0055(2002).
2. The fitted torso slopers developed by the draping method were applied to subjects in order to compare the difference between space (ease) amounts of their somatotypes, which would be helpful to get appropriate clothing ease amounts.
3. To calculate dart amounts through the analysis of overlapped cross section, and to compare them among 3 subject groups.
4. Based on the results of the above analysis, this study was to suggest a fitted torso sloper for elderly women.

Methods

Subjects: 15 subjects were selected based on the KS K 0055(2002) and *Report of Body Measurement for Elderly Women* (Korean Agency for Technology and Standards, 2002), and were classified into 3 types (very short, short and average heights type-each 5) based on the KS K 0055(2002).

Direct Body Measurement: From Jul. 30th to Jul. 31st, 2004, direct body measurements for the subjects were taken and recorded. The following basic measurements required for pattern making were taken: neck girth, bust circumference, waist circumference, abdomen circumference, hip circumference, thigh circumference, back length, back width, center-front length, front width, shoulder width, shoulder length, front length, back length, as well as stature and weight.

Fitted Torso Sloper: To obtain a fitted torso sloper, the draping method of pattern making was used on dress form-TTR which was produced in Tokyo, Japan.

Scanning: After the direct body measurements were taken, the basic body and wearing body were scanned using the Cyberware Whole Body scanner. Basic body condition and posture of subjects where standing with both arms slightly lifted to the side about 30 degress.

Ease & Waist Dart Amount Calculation: To acquire ease measurements and waist dart measurements, 3D data were converted into *.dwg with which all data was analyzed using AutoCAD program. Cross section measurement parts consist of 7 parts including chest circumference, bust circumference, under bust circumference, waist circumference, abdomen circumference, hip circumference and crotch circumference. Each part of the body cross section and the wearing body cross section was calculated. Ease measurements were calculated by subtracting body cross section area from wearing body cross section area. Calculation method of darts is illustrated in Figure 2.

Data Analysis: For statistical analysis, the spss/win (ver 10.1) program was used. The descriptive statistics analysis, t-test, and ANOVA were held to reveal significances.

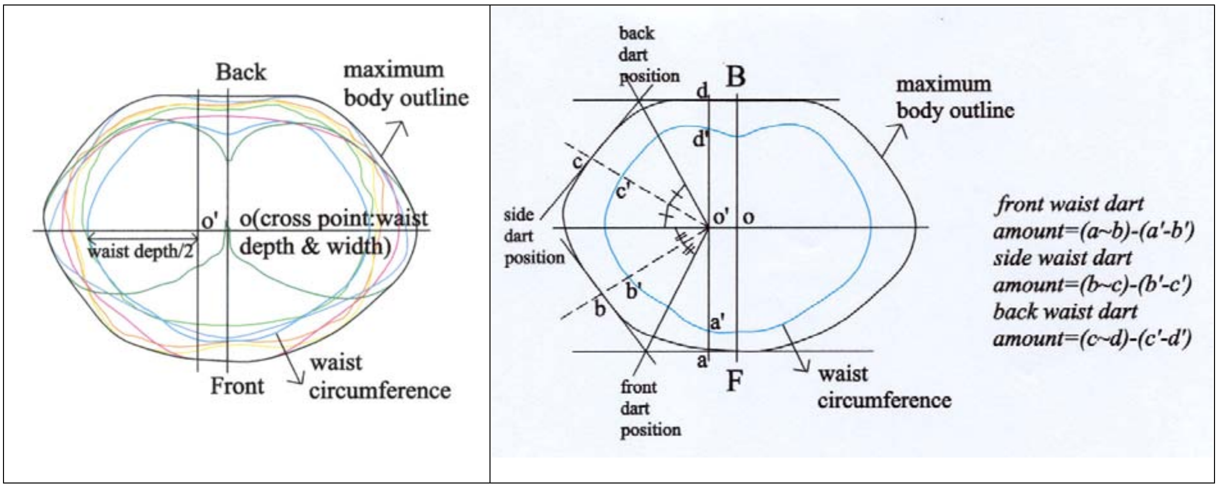

Figure2. Calculation method of waist darts

Results and discussion

Analysis of Direct body Measurement: Most of the items, except stature and front length, show no significant difference among the 3 subject groups. Therefore, it can be concluded that somatotype classification for elderly women would be improved if it were based on the side silhouette, which reflects the symptoms of senility (bending back, projecting abdomen, etc.), rather than the stature.

Analysis of Ease Measurements: According to the results of the analysis of ease measurements, significant differences were non existent. However, space area of abdomen is not sufficient, the other side, space area of hip is too much. This means that the dress form didn't reflect characteristics of body for elderly women. These matters must be an essential factor in pattern design.

Analysis of Waist Dart Measurements: The results of comparison analysis between waist dart measurements, which was attained through Figure 2, and waist dart measurements of the fitted torso sloper are illustrated in Table 1.

Table 1. Comparison of Average Waist Dart Amount (based on Right Body)

(unit=㎝)

Parts	Fitted torso sloper (%)	Overlapped body cross section (%)
Front	2.83(29.0)	2.90(31.6)
Side	3.20(32.8)	3.48(37.9)
Back	3.73(38.2)	2.81(30.5)
Total	9.76(100.0)	9.19(100.0)

As done when drafting a pattern, measurements were only taken on the right side of the body to obtain dart measurements. Since there was no significant difference among their somatotypes, only the average waist dart measurements were presented. According to the comparison analysis, the darts, calculated from overlapped body cross sections, were more efficient in terms of dart distribution than the fitted torso sloper. Also, total waist dart amounts of the overlapped body cross section were less than that of the fitted torso sloper demonstrating the lack of sufficient waist ease that the fitted torso sloper exhibits. These results illustrate that the existing dress form for elderly women didn't reflect their somatotypes appropriately.

Due to restricted number of subjects, this study has a limitation to generalize the results. Future studies should be comprised of a sufficient number of subjects in order to support the results of this study.

Conclusions

This study is to develop a fitted torso sloper with darts for elderly women according to their somatotype, which can be used for improving the fit of garments and pattern. Conclusions are as follows;

Most of the measurements, except stature and front length, have no significant difference among the 3 subject groups. Therefore, somatotype classification for elderly women could be improved by basing it on the side silhouette, which reflects the symptoms of senility (bending back, projecting abdomen, etc.), rather than the stature.

According to the results of the analysis of ease measurements, significant differences were non existent. This means that the dress form didn't reflect elderly women's body characteristics.

The dart amount calculated from overlapped body cross section was more efficient in terms of dart distribution than the fitted torso sloper. Also, total waist dart amounts of the overlapped body cross section were less than that of the fitted torso sloper, which showed that the fitted torso sloper was lacking waist ease.

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AN OBJECTIVE EVALUATION STANDARD FOR MOISTURE MANAGEMENT FABRICS

Li Chu Wang, Hsien Chen Chou, Der Huah Wu, and Yang Ping Shih*

Dept. of Product Development and Promotion, Taiwan Textile Research Institute
*corresponding author lcWang.0269@ttri.org.tw

Introduction

The performance of moisture management fabrics are determined by the characters of fibers and yarns, the fabric structure design, and finished treatments. These fabrics based on thermal comfort of human body that keep away from sticky and cling feeling after sweating are very popular and become basic component to design for sportswear and underwear of protective clothing system(1~5). Unfortunately, the mechanism of moisture transportation is so complicated that international evaluation standards are not set up yet. The evaluation methods may include objective and subjective ones. The former one is easy and fast to set up in an in-house factory lab or testing center. It is important in practical use. This paper tried to establish objective evaluation methods and a performance index of moisture management fabrics.

Methods

Five evaluation methods such as diffusion ability, evaporation ability, isolation ability, absorbency speed, and wicking height were selected to meet different stages of liquid water transportation.

Diffusion ability

Diffusion ability is defined as the diffusion area (mm^2) of a drop of water in the fabric. It is used as measuring water-absorbing and transferring ability of a fabric soon after the inside layer of the fabric was touched by a water drop. This is similar to a drop of sweat was absorbed by the clothing once it comes out of human skin.

All specimens are required to store at standard conditions at least 24 hours for moisture regain. The measurements were progressed by using an image analysis system and a drop of 0.2 ml distilled water was carefully dropped into the specimen. The diffusion images of the water were captured by the connecting computer system at 5, 10, 20, 30, 60, and 90 seconds individually. The diffusion areas (mm^2) that changed in 90 seconds were calculated and repeated for 5 times. The average of the data was further saved in the database of Moisture Management Fabric Evaluation System (that developed in Taiwan Textile Research Institute, abbreviated as TTRI). This allowed showing diagrams and the comparison of the diffusion ability of different fabrics. The diffusion area of 20 sec. was chosen for the comparison between different fabrics. A Diffusion Area Index was used to diminish the influence of fabric thickness.

Diffusion Area Index = [Diffusion area of 20 sec. (mm^2) × Fabric thickness (mm) / 0.2] × 10^{-3}

Evaporation ability

Evaporation (or drying) ability is defined as evaluating the Remained Water Ratio (RWR, %) of a drop of water in the fabric in the evaporating period.

The specimens were cut from the submitted samples at the size of 5cm*5cm (1.97”*1.97”) and stored at standard conditions for at least 24 hours. The measurements were progressed by using a microbalance and a drop of 0.2 ml distilled water was carefully dropped in the center of the specimen (original wet weight-W_0). The dry weight (W_f) and the evaporation weights (W_i) of the sample were collected by a connecting computer system. The evaporation rate curve of the sample was obtained automatically. Again, the data was further connected and saved in the database of Moisture Management Fabric Evaluation System of TTRI. The RWR of 40 min. was chosen for the comparison of the drying ability between different fabrics.

RWR of 40 min. (%) = $(Wi - W_f) / (W_o - W_f) \times 100\%$

Isolation ability

Isolation ability is a specially designed method for evaluating the moisture retained or revealed on the inside surface of double layered moisture management fabrics. The better the isolation ability, the drier the inside of the fabrics that keeps the skin feel dry and comfortable.

A specimen at the size of 10cm*10cm (3.94”*3.94”) was put with inside down on a drop of 0.2 ml distilled water for 1 min. Put the specimen on a piece of filter paper (with dry weight of W_0) and add on another loading of 0.5 g/m^2 above the specimen. The weight of the paper was measured after 30 seconds (W_a). Repeat 5 times to get average results of the Moisture Picking Ratio (abbreviated as MPR).

MPR (%) = $(W_a - W_0) / 0.2 \times 100$ %

Absorbency speed

Absorbency speed is tested by AATCC 79-2000 (Absorbency of Bleached Textiles) and JIS L 1907-1994 methods. This is a simple and fast method to know if the fabric can absorb a drop of water at a very short time or not.

Wicking height

Wicking height is a relatively traditional method showing the capillary ability of a strip of fabric against gravity. It is according to JIS L 1907-1994 method.

Results and discussion

More than two thousands of moisture management fabrics were tested and recorded in the database of TTRI Evaluation System these years. The tested data of fabrics were then analyzed by Kmeans cluster analysis, Excel analysis, and professional experience to get grades for aforementioned evaluation tests. Figure 1 showed the 20-sec. diffusion area index of 433 pieces of woven fabrics, which were classified into 5 grades by Kmeans cluster analysis.

The data was graded into different classification for each test. Table 1 showed the grades of the diffusion ability. Table 2 showed the grades of the evaporation ability. In the isolation ability test, MPR data that larger than 30 was considered as ‘fair’ by specialist. Figure 2 showed the data less than MPR of 30 and graded into 4 classes. Table 3 showed each grade of the isolation ability. The first essentiality of a fabric named as moisture management should be excellent absorbency. The ‘pass threshold’ of the absorbency test was set by specialist. The average absorption speed shouldn’t be longer than 2 sec. for knits and 5 sec. for woven fabrics. The last test and grades of wicking height was shown in table 4.

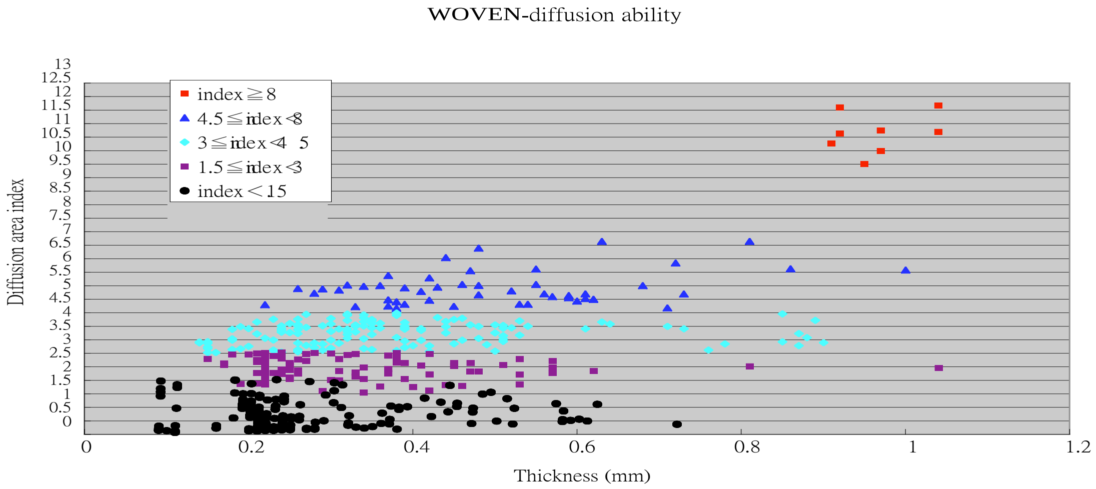

Figure 1. The 20-sec. diffusion area index and grades of 433 woven fabrics.

Table 1. The grades of the diffusion ability.

Diffusion Area Index of 20 sec.		Grade	Classification
Knits	Woven		
X 10	X 8	5	Excellent
5 X 10	4.5 X 8	4	Very Good
3 X 5	3 X 4.5	3	Good
1.6 X 3	1.5 X 3	2	Moderate
X 1.6	X 1.5	1	Fair

Table 2. The grades of the evaporation ability.

RWR of 40 min. (%)		Grade	Classification
Knits	Woven		
X 18	X 10	5	Excellent
18 X 35	10 X 25	4	Very Good
35 X 48	25 X 44	3	Good
48 X 67	44 X 63	2	Moderate
X 67	X 63	1	Fair

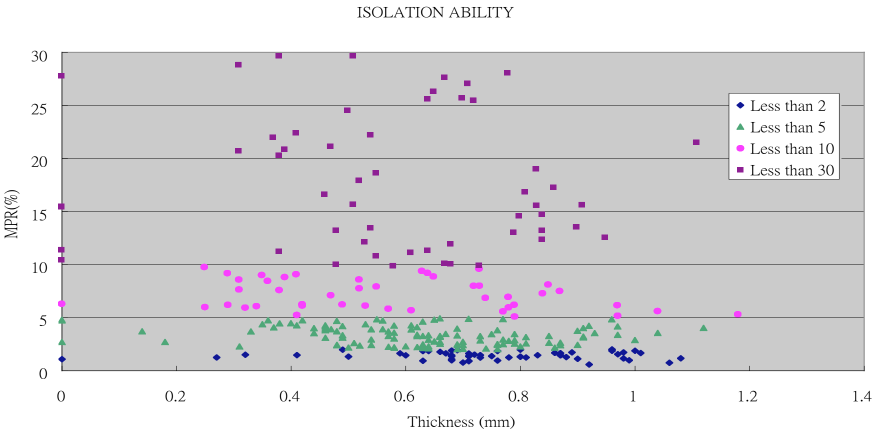

Figure 2. The isolation ability and grades of 271 fabrics.

Table 3. The grades of the isolation ability.

MPR (%)	Grade	Classification
X 2	5	Excellent
2 X 5	4	Very Good
5 X 10	3	Good
10 X 30	2	Moderate
X 30	1	Fair

Table 4. The grades of wicking height.

Wicking height (mm)	Grade	Classification
Knits / Woven		
Warp / Weft		
X 100	3	Very Good
50 X 100	2	Good
X 50	1	Fair

Conclusions

The process of liquid sweat transported in a fabric should be absorbing from the skin, moving to the outer layer of the fabric, diffusing into a larger area, and evaporating into the air. A series of tests were set here for evaluating the whole phenomenon. However, a standard is necessary for trading use, thus the grades for each test were developed. Further more, performance labelling is very important in communication with buyers or consumers. A simplify or integral standard, as an index, was necessary to be established for resolving the problem. Each so-called moisture management fabrics should be tested to tell their liquid water transportation performance and get a proper label. We suggest a labelling system, here named as “type” I~IV shown in table 5, which may be an optimal solution for the performance evaluation of moisture management fabrics.

Table 5. The types of liquid water transportation ability of moisture management fabrics.

Type*	Diffusion ability	Evaporation ability	Isolation ability	Absorbency speed	Wicking height	Classification
	5	5	5	Pass **	3	**Excellent**
	4	4	4	Pass **	3	Very Good
	3	3	3	Pass **	2	Good
	2	2	2	Pass **	2	Fair

* : At least pass 2 items of “Diffusion ability”, “evaporation ability” or “Isolation ability”, and must pass “absorbency speed” and “wicking height” for each type.

** : The average absorbency speed should be ≦ 2 sec. for knits and ≦ 5 sec. for woven fabrics.

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THE INFLUENCE OF A BACK OPENING ON CLOTHING VENTILATION IN RAINWEAR

Hiroyuki Ueda[1]*, *Yoshimitsu Inoue*[2], *George Havenith*[3]

[1] Osaka Shin-Ai College
[2] Laboratory for Human Performance Research, Osaka International University, Japan
[3] Department of Human Sciences, Loughborough University, U.K.
* corresponding author ueda@osaka-shinai.ac.jp

Introduction

Skin temperature and skin wettedness both have to be within the comfort range for the body to be kept in thermal comfort (1). After the onset of sweating, it is important for comfort to facilitate moisture transport through the fabric and apertures of clothing (2). The exchange of air between the clothing microclimate and the external environment, i.e. clothing ventilation, strongly affects both the evaporative and the dry heat loss of clothed people (3,4).

Sweat rate is known to differ from one region of the body to another and, individual differences notwithstanding, it is generally higher on the trunk than on the limbs (5). Since regional differences in the sweat rate are affected by such factors as exercise intensity, age and sex (6,7), it is necessary to use a method of evaluating clothes based on the different air exchange at each body region for the evaluation, development and design of comfortable clothes.

Though providing protection against wetting by fog or rain, rainwear, given its low air and vapour permeability often limits evaporative heat loss, which in this case relies mainly on convection through apertures for the transportation of sweat evaporation. The present study investigated the influence of a back-aperture on clothing ventilation in a novel design of rainwear, and estimated its convective properties in relation to the required clothing ventilation for comfort. This was done for different body regions in relation to their local sweat rates.

Methods

The rainwear for this experiment was made of impermeable textile. The skirt was open and stretch fabric closed the wrist cuffs. The front-fastener was a zip that closed to the top of the collar. In the back there was a 40-cm horizontal aperture with a fastener that the wearer could open and close. The microclimate volume was hardly changed by the opening or closing of the fastener. Two-piece cotton work-wear and underwear were worn under the experimental rainwear. The rainwear was tested with the back-aperture opened and closed under the same environmental conditions (18ºC, 40%rh). The Ventilation Index (VI, litre/min) at four body sites was measured with a subject walking (1 m/sec) in still air and in a headwind (1 m/sec relative to the person), and with an unheated manikin standing in still air and in a headwind (1 m/sec). VI was defined as the product of the air exchange rate and the microclimate volume:

Ventilation index (litre/min) = Air exchange rate (1/min) x Microclimate volume (litre)

First, the microclimate volume of the internal layer was estimated by measuring the circumferences of the nude and clothed body, using an approximation with the cylinder model (8). Next, the air exchange rates between the clothing microclimate and ambient air were measured at four body sites, namely, chest, back, upper arm and forearm, using a tracer gas technique (4,9). Nitrogen was flushed into the microclimate under the work-shirt to reduce the concentration of oxygen from the natural level (20.9%) to approximately 10% using a distribution tube system fixed to the body surface. The nitrogen injection was performed carefully to reduce the concentrations at the four sites at the same rate and to the same level.

The gas concentration in the microclimate at the four body sites was separately sampled using sampling tubes and sent to four oxygen analysers. The return of oxygen concentration in the microclimate to the natural environmental level (approximately 20.9%) was monitored over an extended period after stopping the nitrogen influx. The oxygen levels increased exponentially in this period from 11% to the natural level, and the resultant rate of air exchange was calculated using the following equation.

$$O_2(t) = A - B(0) \cdot e^{-Rt}$$

with: $O_2(t)$ is the oxygen concentration (%) at time t, A is the eventual value of $O_2(t)$, $B(0)$ is a constant given by $A - O_2(t)$ at $t = 0$, and R is the air exchange rate calculated using least squares analyses of the oxygen re-entrance curve.

The measurement of air exchange rate was repeated at least five times for each condition. The difference between the opened and closed conditions was examined by Student's t-test. Significance was set at $p<0.05$ in the statistical tests.

Results

The microclimate volume of the internal layer on the trunk, upper arm and forearm was 29.2, 4.7 and 2.6 litre in the manikin, and 33.2, 6.5 and 3.8 litre in the subject, respectively. For convenience, the microclimate volumes on the chest and back regions were assumed to be a half of that on the trunk. The data obtained with the subject are presented in Fig.1. The VI was significantly higher on the chest and back when the back-aperture was open aperture than when it was closed when the subject was walking in still air ($p<0.05$). There was no significant difference in VI on the upper arm and forearm between the conditions with the opened and closed aperture. By opening the aperture VI increased by 6 litre/min on the chest and 5 litre/min on the back. When the subject was walking in the headwind, the open aperture gave a significantly higher VI on the back than the closed aperture ($p<0.05$). The VI on the upper arm also tended to be higher when the aperture was open. No significant difference in VI was found on the chest or forearm between the open and closed aperture. The increase of VI on the back by opening the aperture in the wind condition was 11 litre/min.

Fig. 2 shows the VI obtained with the manikin. In still air, the VI values for open and closed aperture were similar in each body region. In the headwind, VI on the back was significantly higher ($p<0.05$) with the aperture open than with it closed. There were no significant differences in VI on the chest, upper arm and forearm between the open and closed aperture condition.

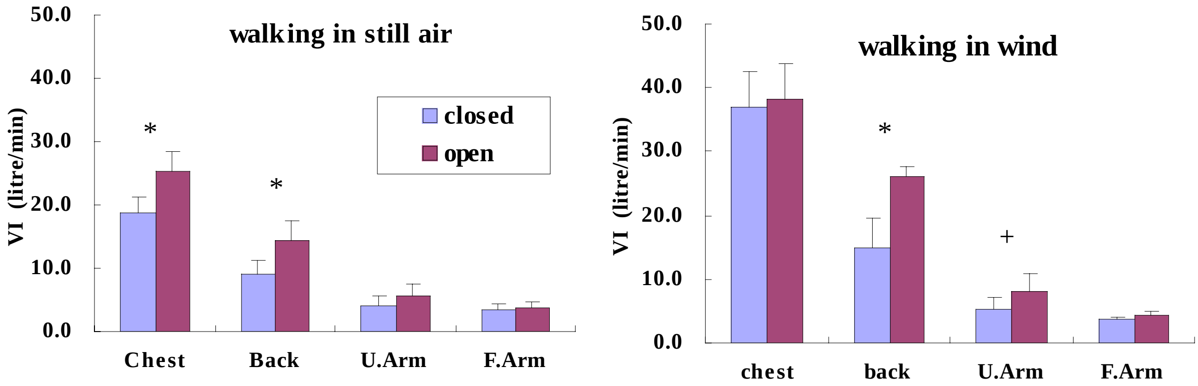

Figure 1. Ventilation index (litre/min) measured on a subject while walking. * $p<0.05$ $^{+}p<0.10$

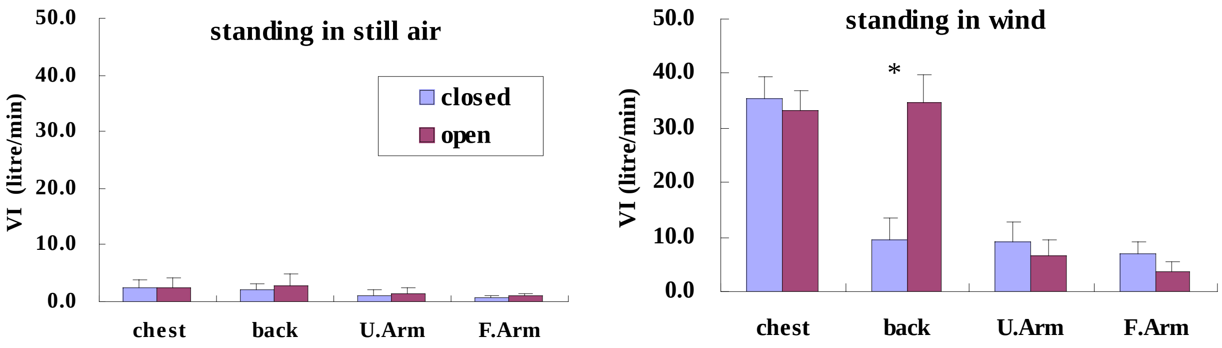

Figure 2. Ventilation index (litre/min) measured on a manikin while standing. * $p<0.05$

Discussion

A quantitative measurement of the clothing ventilation is convenient for evaluating the heat transfer performance of protective clothing. Some methods of measurement have been established, and they provided indices for average ventilation of clothing as a whole ensemble (4,9). However, as there are body regional differences in thermoregulatory responses it is preferable to measure the clothing ventilation in specific body regions for designing clothing with efficient heat dissipation. In the present study, clothing ventilation was measured at four body sites. The aim of this study was to examine the influence of a back-aperture opening on clothing ventilation at four body sites. It was observed that opening of the back aperture did not increase clothing ventilation at any site in the manikin standing in still air. The major reason for this is probably the lack of a vertical updraft, normally caused by the heat released from the skin, but absent in the unheated manikin. It was recognized that the effect of the aperture on clothing ventilation depended strongly on wind and the wearer's movement. Ventilation in air-impermeable clothing is caused by the convective exchange arising from the ducts at apertures in the clothing. In the manikin tests in the head wind, the air blowing in from the front of the neck or through the open skirt at the waist quickly replaced air in the clothing microclimate on the chest. The open aperture at the back drew the air from the front to the back, because the low pressure on the leeward side of the body drew air out of the aperture.

As the microclimate volumes and body shapes were different between the manikin and the subject, their VI values cannot be directly compared. However an increase in clothing ventilation from manikin to subject due to movement could be expected. The back-aperture facilitated the pumping effect of walking. In still air, consequently, the air exchange was increased between the external environment and the microclimate of the back, and also between the microclimates of the back and chest. In the headwind, the back aperture drew the air from the front of the neck or skirt, as mentioned above, but it hardly promoted the air exchange between the microclimates of the back and chest. If the jacket would be closed at the waist and the nape of neck was tighter, the open aperture at the back might lead to an increase in clothing ventilation on the chest. VI on the upper arm tended to be higher with the open aperture than the closed one when the subject was walking in the wind. Although the aperture was inferred to facilitate the effect of pumping on the clothing ventilation, the closure at the end of the arms at the cuffs limited the effect to the upper part of sleeves. If the cuffs were open, the back aperture would have increased the ventilation on the upper arm and forearm.

It is desirable to predict the wearer's heat dissipation quantitatively for designing clothing suitable for a particular working situation. A method has been proposed by which the clothing is evaluated based on the required ventilation for comfort, that is, the minimal amount of ventilation by which sweat can be removed from the skin to outside the clothes (10). This is based on the assumption that sweat evaporates ideally on the skin surface and that the microclimate air is well mixed with the incoming ventilation air. The required ventilation, giving the possible moisture removal capacity, can be calculated as:

$$\text{Required ventilation} = \frac{\text{sweat rate}}{[\text{moisture concentration of microclimate}] - [\text{moisture concentration of ambient air}]}$$

Here, we attempt to evaluate the effect of a back-aperture on the clothing ventilation during walking, based on the required ventilation. A previous study (11) reported thermoregulatory functions with three subjects and ten different fabric types of clothing, namely, sweat rate, skin temperature, microclimate temperature and humidity at chest, back and upper arm, during a 30-min walk at an intensity of 30%VO_2max in a neutral condition. Assuming that these sweat rates can be applied to the body surface area of the subject in this experiment and that the microclimate environment is also applicable to this experimental wear under condition of 15ºC 100%rh, the required ventilation in each body region can be calculated from the average microclimate temperature and humidity at each region at the end of the exercise and the ambient temperature and humidity. The required ventilation rates for these data on the chest, back and upper arm are, respectively, 25.4, 40.0, 20.0 litre/min under conditions of 15ºC 100%rh. With the back-aperture open, the percentage of the clothing ventilation on the chest relative to the required ventilation increased from 75% to 99% for walking in still air, and that on the back increased from 22% to 35%. In the same way, the percentage on the back increased from 37% to 65% for walking in the wind in the condition of 15ºC 100%rh.

Conclusions

The back-aperture by its self hardly increased clothing ventilation while stationary. Clothing ventilation is increased by wind and movement, and the back-aperture facilitated these wind and pumping effects. Regional differences in the clothing ventilation were recognized, and the increase at each body site brought about by opening the back-aperture depended on the design of the clothing and the environmental conditions. The evaluation of clothing based on the required ventilation for comfort was a convenient way to understand its transpiration properties with respect to sweating. The clothing ventilation was increased on the chest and back when the subject was walking in still air by opening the back-aperture, and that on the back was increased in the same way in the wind.

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DESIGNING SURGICAL GOWNS – BALANCE BETWEEN COMFORT VS BARRIER PROPERTIES

Abreu, M.J. [1]; Silva, M. E. [1]; Schacher, L. [2]; Adolphe, D. [2]*

[1] Departamento de Engenharia Têxtil - Universidade do Minho, 4800-068 Guimarães – Portugal
[2] Ecole Nationale Supérieure des Industries Textiles de Mulhouse, 68093 Mulhouse Cedex – France
* corresponding author josi@det.uminho.pt

Introduction

In the past, the main reason of using protective clothing in the hospitals was to protect the patient from the medical staff. Today, this situation is reversed, since the manifestation of the Aids virus, Hepatitis B infection and other diseases that have led to more restrictions in the protection of the healthcare workers from the patient with the use of appropriate clothing and single-use materials. Therefore, the interest in protective clothing has grown in the past years, because of the concern about worker safety and health in the different environments. Generally, we can consider all clothing protective to some extent, but is it the degree of protection from a specific risk that determines the type of clothing to use. On the other hand, the selection of the most appropriate form of protection is very complex, because of the type of material and the compromise between the barrier and comfort properties. The combined assessment of different factors shows that the barrier properties are very important, but not forgetting that this has to be complied with the requirement for the fabric to be breathable such that it is comfortable to wear, as well as general recognition of physiological safety and sterilization capacity. The problem for the manufacturer is that the optimisation of one fabric property is often at the detriment of another and many factors affect fabric performance. New materials and gowns are being developed and the selection of the most appropriate gown is vital. At present, producers and users are not getting enough information about the suitability of the materials used in surgery and the impact of the sterilisation. In this paper we will present our approach to illustrating the performance of materials used for the manufacturing of surgical gowns, especially the results of the objective assessment of the barrier and thermal comfort properties, before and after different sterilisation methods.

Comfort

When dealing with textile and allied assemblies we are dealing with elements contributing to the external thermal comfort sensation. The skin has a special role, because it is the interface between the thermal core of the body and the environment by being the comfort sensors. Two conditions must be fulfilled to maintain thermal comfort. One is the actual combination of skin temperature and the body core temperature providing a sensation of thermal neutrality. The second is the fulfilment of the body's energy balance: the heat produced by the metabolism should be equal to the amount of heat loss from the body. It is unlikely that a comfortable garment could be totally resistant or impermeable to liquid penetration when rubbed or subjected to the pressures present during its usual conditions of use and at the same time be breathable. The only reasonable conclusion appears to be a compromise between liquid resistance, air permeability, and thermal properties for the sake of comfort.

Characterisation of Barrier Materials

By definition, a barrier is something that hinders or restricts; it may be something that impedes entry or passage; or it may be something that stops or prevent passage. Hence, the fabric barrier properties can be defined as the ability of a material to resist the penetration of liquids and/or microorganisms, referred to as strike-through. As suitable as that description may be for general use, there is reason to question just how appropriate are the different materials used in surgery. The essential barrier performance required from materials used to fabricate gowns depends on the amount and time of liquid exposed and the direct or indirect contact with the wound during an operation. Therefore, different requirements might be found for materials used for short and long operations, for dry and wet operations and those used in sterile or conventional atmosphere. So, the manufacturer is obliged to communicate to the user the intended use of the product and the user is supposed to define the use and the clinical requirements of the gown [1].

Methodology

Research subject: Surgical Gowns

According to the Medical Device Directive 93/42/EEC, surgical gowns, drapes and air suits are considered to be medical devices, whether they are reusable or single-use gowns and drapes. The European standard EN 13795 -1 [2] define surgical gown "as the product used in the operating theatre to prevent transfer of infective agents". In the case of operation room gowns it is advisable to use the reinforced gowns. The gowns must be reinforced at the thoracic and abdominal region and also the forearms must be reinforced. These parts of the gowns are considered as the critical zones with the major possibility to contact with blood and other saline solutions present during an operation. The gown must prevent the contact of these solutions with the medical and nurse staff, but also protect the patient from contamination by pollutant particles in the air during the operation [3].

Purpose and Importance of Sterilisation

The primary purpose of sterilising an item is to render it safe for use by destroying all living microscope organisms. Because bacteria multiply very quickly, the sterilisation process must be absolute. Even a few organisms invading the patient's body during a surgical procedure can reproduce rapidly and contribute to post-operative complications [4]. Four common types of sterilisation are in use today: gas, irradiation, steam autoclave, and dry heat. The two first types of sterilisation are also called low temperature sterilisation methods, applied to single-use products and the last to second types, high temperature sterilisation methods, applied to reusable products. Many sterilisers use saturated steam and dry heat, but these methods are not practical for plastics and other synthetic materials because high temperatures damage them. These materials require low-temperature sterilisation. Gamma and electron beam radiation are the most widely used low temperature sterilisation methods after oxide ethylene gas and the fastest growing of all sterilisation methods [3].

Experimental Details

For gamma and electron beam irradiation the minimum dose of 25 kGy is, according to the European standard EN 552 "Sterilization of medical devices - Validation and routine control of sterilization by irradiation", the most suitable dose to use. The products were processed in industrial irradiation process, with validated parameters for a sterilisation process established for these medical devices -- a real case study.

Three different types of based materials -- nonwoven (45% polyester, 55% cellulose, 70 g/m^2 , thickness 230 µm), laminate (1st layer: LDPE film; 2nd layer: nonwoven (70% viscose, 30 % polyester; 40 g/m^2 , thickness 150 µm) and a polyethylene (47 g/m^2 , thickness 50 µm), were irradiated. The gowns were single-use and the basic material common for all gowns is the repellent finished spunlaced nonwoven, with inner and outer layers of laminate and polyethylene to reforce the barrier's function (Table 1).

Table 1. Test Gowns.

Gown Identification	Gown Materials	
	Outer Layer	**Inner Layer**
A	Nonwoven	Nonwoven
B	PE	Nonwoven
C	Nonwoven	Laminate

Table 2. Comfort properties.

Property	Reference	Units
1.Electrostatic Surface Resistance	Manufacturer	**Ω**
2.Air Permeability	ERT 140.2-99	l^2/m/s
3.Drapeability	ERT 90.4-99	-
4.Bending Length	ERT 50.5-99	mN cm
5.Water Vapour Permeability	BS 7209	g/m^2/day
6.Water Vapour Permeability Index	BS 7209	%
Thermal Properties:	Manufacturer	
7.Heat absorption		W/m°K
8.Thermal conductivity		W/m^2
9.Thermal Insulation		%
Objective Evaluation of Fabrics Properties:	Manufacturer	
10.Friction and Roughness		µm,
11.Compression*		Nm/m^2, %
12.Bending		µN.m^2/m
13.Tensile and Shear		%,N.m/m^2,N/mradian,N/m
14.Thickness	See[*]	mm

Studied Properties

The European Disposables and Nonwovens Association (EDANA) has published an increasing number of test methods (ERT) for measuring various properties of nonwovens or other related products. They have several recommended evaluation procedures for several products, like for nonwoven based surgical gowns [5].

The International Nonwovens and Disposable Association (INDA) has more impact in the United States of America. They have also a number of test methods for gowns, some different from the EDANA test methods and because of that must be analysed and also considered [6].

The tables 2 and 3 show the applied test methods and references in this study to ascertain the barrier and comfort properties of nonwovens used for surgical gowns.

Table 3. Barrier properties.

Property	Reference	Units
15.Hydrostatic Head Liquid Repellency	ERT 160.0-89	mbar/min
16.Alcohol Repellency	IST 80.8-98	Repellency Rating
17.Surface Wetting	IST 80.1-95	Wet rating
18.Impact Penetration Test	IST 80.3-98	g
19.Mass per Unit Area	ERT 40.3-90	g/ m^2

Results and Discussion

The work was focused on three aspects: design and production of nonwoven based surgical gowns, incorporating of different sterilisation treatments and evaluation of the relevant fabric properties before and after the sterilisation treatment.

Multivariate Analysis (Factor Analysis) optimisation was used upon to carry out the optimisation task. The results were studied using multivariate techniques (Factor Analysis) to show the effect of the sterilisation over the studied materials and properties. The correlation matrix for all data was computed and the appropriateness of factor model was evaluated.

To obtain more interpretable results we rotated the solution, using varimax rotation, although there are others techniques. The following table 4 indicates the properties that we obtained after the factor analysis.

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[*] ***The thickness is measured during the compression test***

Table 4. Selected Properties.

Comfort Properties:	**Barrier Properties:**
Air Permeability	Hydrostatic Head Liquid Repellency
Water Vapour Permeability	Alcohol Repellency
Heat Absorption	
Thermal Conductivity	
Friction and Roughness	
Compression*	

Conclusions

It was very interesting to use these statistical techniques in the healthcare and hygiene industry and to study the behaviour of materials used for the manufacturing of nonwoven based surgical gowns, by application of multivariate analysis.

The factor analysis reduced the number of significant properties showing that the number of comfort properties is still very high and that in future studies these properties can’t be forgotten.

Also reducing the number of properties, we help future studies and also the healthcare and hygiene industry to reduce the amount of properties for testing, just to the most significant statistically.

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2 CEN/TC 205/WG 14, EN 13795-1: Surgical drapes, gowns and clean air suits, used as medical devices, for patients, clinical staff and equipment-part 1:General requirements for manufacturers, processors and products (2003).

3 Abreu, M.J; “Contribuição para o Estudo da Parametrização de Têxteis Hospitalares”, PhD Thesis, Portugal, (2004).

4 The Effect of Sterilization Methods. Plastics Design Library, USA, (1994).

5 EDANA , www.edana.org, 2004.

6 INDA , www.inda.org, 2004.

DEVELOPMENT OF PROTECTIVE CLOTHING USING TEMPERATURE-SENSITIVE POLYURETHANES

X. M. Ding[1,3], X.Y. Wu[2], J. L. Hu[3], X. M. Tao[3]*

[1] Institute of Fashion and Clothing, Donghua University, Shanghai, P. R. China
[2] Shanghai Entry-exit Inspection and Quarantine Bureau, P. R. China
[3] Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong, P. R. China
* Corresponding author: e-mail fddingxm@dhu.edu.cn

Introduction

Temperature-sensitive polyurethane (TS-PU) is one novel type of smart polymers. The water vapor permeability (WVP) of its membrane could undergo a significant increase as temperature increases within a predetermined temperature range [1-6]. This smart property enables this material to have a broad range of applications to textile industry, medicine, environmental fields and so on. For example, composing ordinary fabrics with TS-PU membranes can develop a type of smart textiles. Such smart textiles would not only be waterproof at any temperature, but also provide variable breathability in response to the climate temperature [7, 8].

Great potential applications attract a great deal of research interest in preparation of TS-PU for smart textiles. However, although some researchers already do research in preparation TS-PU, contradicting results were found based on the literatures[9-15]. Moreover, the switching temperature range is so high as to restrict their applications in many areas, particularly in textile industry and medicine area [16]. Therefore, the objectives of this project are to synthesize a series of TS-PUs with a broader switching temperature range including ambient range, and then investigate the relationships between microstructure and water vapor transport properties of TS-PU. Such researches enable to identify the key parameters governing the water vapor permeability of TS-PU membrane and open the way for new tailor-made polymeric materials with specified properties.

For this purpose, in this paper, through molecular design, a series of TS-PU would be first synthesized with the broader switching temperature range including ambient range. The microstructure and tensile properties of these PUs were investigated using Differential scanning calorimetry (DSC), Wide angle X-ray (WAXR), Polarizing Microscopy (POM) and Instron 4466 Universal Tester respectively. The water vapor permeability of the TS-PU membrane would be measured at the temperature of 10 °C, 15°C, 20°C, 30°C and 40°C according to ASTM E96-00 accordingly.

Experimental

A series of segmented polyurethane were prepared using five different polyols and hexamethylene diisocyanate (HDI) as mixing soft segment, 4,4'-diphenylmethane diisocyanate (MDI), hydrophilic segment poly (ethylene glycol) 200 (PEG 200) and chain extender 1,4-butanediol (1,4-BDO) as triblock hard segment. Microstructure of the PUs was investigated by Differential scanning calorimetry, Wide angle X-ray diffraction and Polarizing microscopy. Tensile property was measured, and water vapor transport property of the PU membranes as a function of temperature was tested accordingly.

Results and Discussion

Microstructure and morphology

DSC and WAXD results suggest that polyols in PBA-PUs, PCL-15-PU and PHA-15-PU form distinct crystallization and the crystal melting of the PUs takes place over the room temperature range. Thus, it could be observed the crystalline texture through POM between polarized cross. With temperature rising, crystallites melting take place. Therefore, the crystallites in these PUs decrease gradually till disappear completely at Tm. However, their crystallinity of PEA-15-PU and PTMG-15-PU are too low to be detected around the temperature of 20°C. Therefore, in the segmented PUs, these polyols form crystallites, and the crystalline properties of the PUs, including degree of crystallinity and crystal melting temperature (Tm), depend on chemical structure of the polyols and hard segment concentration (HSC).

Water vapor permeability

The results shows that the WVP of these membranes except PTMG-15-PU increases significantly as temperature increases, while the WVP of PTMG-15-PU decreases in the same temperature range.

Therefore, it is evident that PBA-PUs, PCL-15-PU, PHA-15-PU and PEA-15-PU are temperature-sensitive in the measured temperature range from 10 °C to 40°C, while PTMG-PU is not. Based on the morphology study, these temperature-sensitive PUs (TS-PU), such as PBA-PUs, are crystalline, while PTMG-15-PU is non-crystalline in the measured temperature range from 10 to 40°C. When crystal melting of soft segment takes place, the motion of soft-segment molecular chain is trigged and the free volume among soft segments increases according. Such significant increase in free volume can provide more paths for water vapor to pass through the membranes. Therefore, TS-PU can exhibit smart behaviors, and such property can be applied to develop smart textiles.

Conclusions

Morphology of temperature-sensitive polyurethanes was investigated by DSC, WAXD and POM. Water vapor permeability of the TS-PU membranes as a function of temperature was measured in the temperature range of crystal melting. The results show that the only polyols form crystallites in the segmented PUs, and the crystalline properties of the PUs, including degree of crystallinity and crystal melting temperature (Tm), depend on chemical structure of the polyols and hard segment concentration. Within the temperature range of crystal melting from 10 to 40°C, water vapor permeability of the PU membranes increases significantly with temperature rising, which is triggered by crystal melting of crystalline soft segment. Such property can be applied to develop smart textiles.

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EFFECTS OF LAYER DESIGN ON CONDENSATION WITHIN COLD WEATHER CLOTHING ENSEMBLES

Shinjung Yoo,Eun Ae Kim*

Functional Textile System Research Laboratory, Department of Clothing and Textiles, Yonsei University, 134
Shinchon-dong Seodaemoon-gu, Seoul, 120-749, Korea
* corresponding author sjyoo@yonsei.ac.kr

Introduction

When water vapour concentration in a clothing system exceeds the saturation level for the local temperature, condensation takes place throughout the layers of the clothing system. Functional garments for cold weather are likely to be exposed to conditions conducive to condensation since they usually consist of several layers of high insulating textiles and a waterproof breathable fabric as an outer shell. Consequently, the vapour permeability of the clothing system easily deteriorates, and large temperature gradients are developed within the system. Accumulated moisture may then freeze and be trapped within the clothing system and cause a reduction in heat resistance as well as wearer discomfort. As such, it is critical that condensation in the clothing system be prevented, especially under cold weather conditions and when the clothing is used in high activity levels that raise production of sweat such as winter sports and other physical activities.

The moisture vapour transfer properties of a fabric are dependent not only on the water vapour resistance but also on the thermal resistance of the fabric. Several researchers have developed numerical models for heat and vapour transfer with or without condensation [1, 2, 5], and some studies focused on condensation and its effects on the water vapour permeability of waterproof breathable fabrics [6]. However, since a clothing system seldom consists of a single layer, especially for cold weather, the experimental data from an individual layer in a clothing system [3] is not relevant to the prediction of the performance of the fabric under real use conditions.

In this study, we investigate condensation on the individual layers of multilayer cold weather protective ensembles. To consider the effects of layer design, three different layer layouts comprised of identical fabrics are assessed and a series of experiments on combined heat and moisture vapour transfer through the clothing systems is performed. We examine the condensation profiles of individual layers in the three layouts as well as the effects of sweat amount on the condensation profile by applying a different amount of water to simulate light and heavy sweat rates.

Methods

We used a newly developed Human-Clothing-Environment (HCE) simulator [4] for the experiment. The HCE is comprised of a vertical type-sweating hotplate with multiple cartridges for fabric layers to simulate a clothing system and two independent climate chambers. Utilizing this device, we can monitor the effects of cyclic changes of environmental conditions if a test material is subjected to two different sets of conditions by attaching the vertical type hot plate to the both chambers alternately. In addition, the vertical type sweating hot plate provides effective simulation (better than what? Or do you mean "effective"?) of the heat and moisture transfer mechanism from the body surface through a clothing system to the environment. Further details of the simulator can be found in a previous paper [4].

For a cold weather clothing system, five layers of fabric were selected. A PET underwear fabric was utilized for the innermost layer and three identical PET fleece fabrics were employed for the 2nd to 4th layers. A waterproof breathable fabric was added as an outer shell. The properties of the PET fleece fabrics are 246.9g/m^2 weight, 1.63mm thickness, 103.33 ㎤/㎠/s air permeability, water vapour resistance R_{et}=11.68 m^2 Pa/W, and thermal resistance R_{ct}=0.083 m^2°C /W. The waterproof breathable outer shell is a 2-layer-laminate with microporous PTFE membrane and 100% PET surface layer, 120 g/m^2 weight, water vapour resistance R_{et}=7.29 m^2 Pa/W, and thermal resistance R_{ct}=0.019 m^2°C /W. The five layers of fabrics were mounted on the fabric frames and placed on the sweating hot plate in different layouts, as outlined in Figure 1. Between each fabric layer there are temperature and humidity sensors for real-time monitoring of the microclimate temperature and humidity within each layer.

For the test, the hot plate temperature was set at 33±0.5°C to simulate the human body's skin temperature at a comfortable condition, and the plate was covered with an absorbent fabric to function as a sweat distributor. To simulate light and heavy sweating, 2 and 5ml of distilled water were applied respectively. These are approximately equivalent to 65 and 160 g /m^{2}hr of sweat rate. The test was conducted at -15±0.5°C, 20±5% to simulate cold conditions.

The data of the temperature and the relative humidity between each layer were collected and recorded every 30 seconds through a data logging system over a period of 1 hour and the vapour pressure profiles were calculated from the data. The amount of condensation on each layer was measured by weighing each fabric layer before and after the test for further analysis.

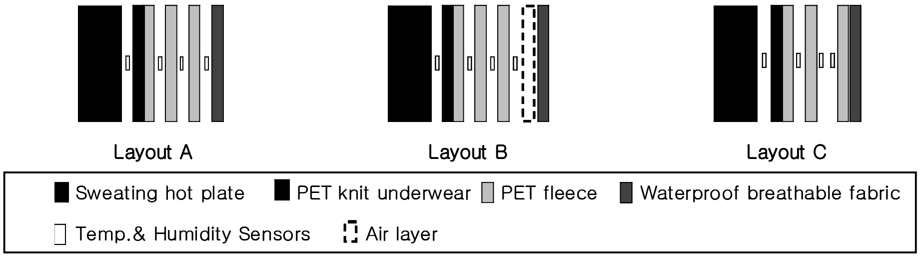


Figure 1. Five-layer cold weather clothing layouts
(Layout A: All separated; Layout B: separated with an extra air layer; Layout C: 4th and outer shell combined)

Results and discussion

Figure 2 shows the vapour pressure profiles between layers for the two different sweat amounts. In the case of light sweat (60g/m^{2}hr), vapour pressures between the skin and underwear fabric (innermost microclimate) and the 2nd and 3rd layers start to drop after about 30~40 minutes, indicating that most of the applied moisture on the skin moves toward the outer layers. In contrast, the vapour pressures of the heavy sweat condition were maintained at a high level throughout the test. Comparing the vapour pressures of the different layouts at the light sweating condition (Figure 3), layout “B”, which is identical to layout “A” except for an extra air layer between the 4th layer and outer shell, has the highest vapour pressure and layout “C” (4th and outer shell combined) dries more rapidly than the others. However, for the heavy sweating condition, a clear trend for the effects of layout on the vapour pressure profile cannot be found. Even though the extra air layer in layout “B” provides higher vapour pressure within the clothing system, it does not seem to affect moisture condensation. As presented in Table 1, while the total amount of condensation is similar for the three layouts, a slightly larger amount of condensation takes place within layout “A” and the smallest condensation level is found in layout “C”. This basic pattern recurs for the heavy sweat condition as well. However, it is clear that quite different behaviours are produced in individual layers as a function of the layer layout. The amount of condensation in the individual layers for three layouts at different sweat levels is presented in Figure 4. Most condensation takes place at the 3rd and 4th layers and more condensed moisture is trapped on the outer side of the 4th layer of layout “A” at the light sweat condition. On the other hand, in the case of layout “C”, for both sweat levels the largest portion of condensation takes places at the 3rd layer. Fukazawa et al. [2] have shown that condensation mass flux can be estimated by condensation potential and condensation resistance, which are a function of the moisture vapour and thermal resistance of a material. In this experiment, since we used identical fabrics and environmental conditions, the vapour and thermal resistances of the overall clothing systems might be very similar. Thus, the total amount of condensation could show little variation for the three layouts. However, the individual layers have different condensation profiles; layout “A” could have advantages in terms of wearer comfort because the condensed moisture is kept away from the body as compared to Layout “C”.

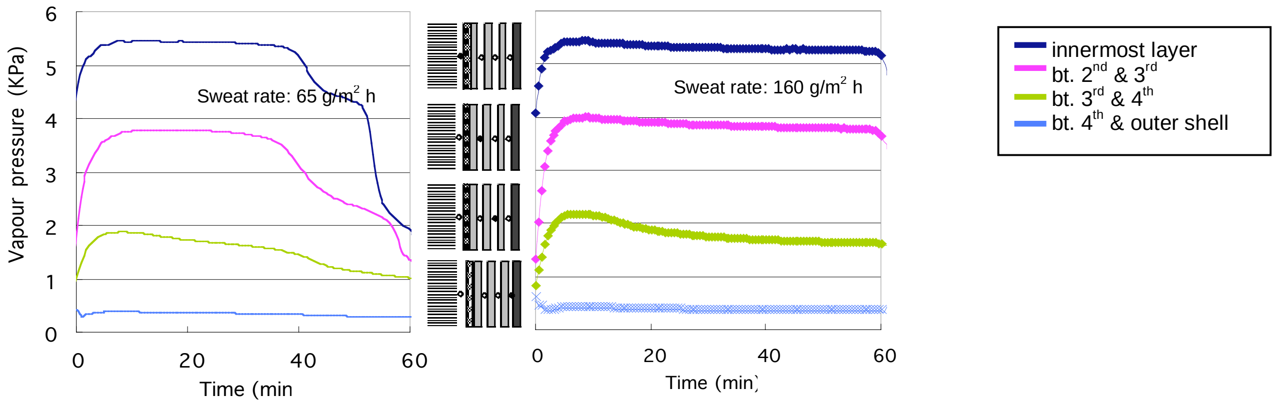


Figure 2. Microclimate vapour pressure between layers at different sweat rates (Layout A)

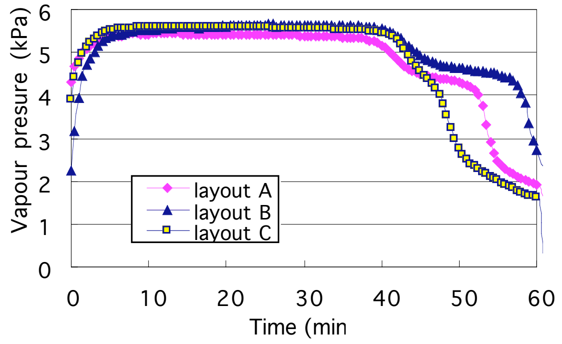
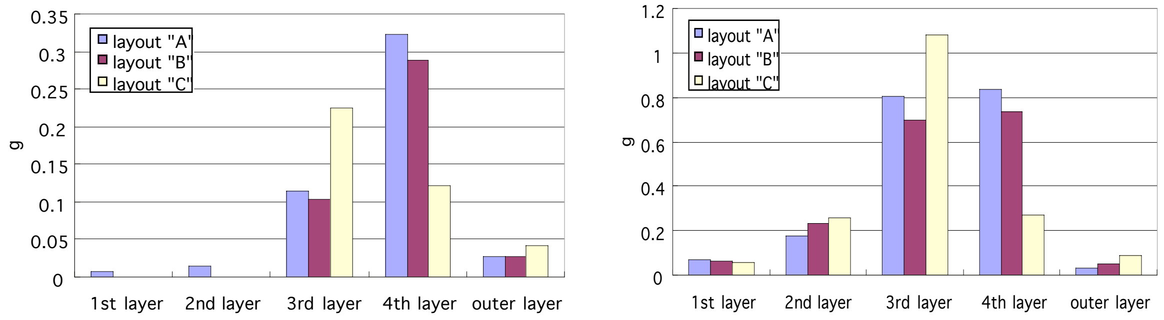


Figure 3. Microclimate vapour pressures of innermost layer for different layouts at sweat rate=60g/m^2h, Layout A:separated; B:separated with extra air layer; C:4th and outer combined.

Table 1. Total amount of condensation of different layer layouts of cold weather ensembles at two sweat rates

Layout	**Sweat Rate**	
	65 g/m^2 hr (light sweat)	**160 g/m^2 hr (heavy sweat)**
A	0.485	1.792
B	0.418	1.779
C	0.388	1.755



(A) Sweat rate 65 g/m^2h

(B) Sweat rate 160 g/m^2h

Figure 4. Amount of condensed moisture in each layer at different sweat rate

Conclusions

Because of the importance of condensation with respect to clothing comfort and thermal physiology, many researchers have attempted to predict condensation within cold weather clothing systems by using numerical models [1, 2]. We have shown that the layer layout of a multiplayer clothing system can alter the condensation profile within each garment layer, even if the total condensation mass flux is almost the same. When the insulating layer is separated from the waterproof breathable fabric, condensed moisture is kept away from the body efficiently. The results obtained here can provide useful insight into the layer design of cold weather protective gear.

Acknowledgement

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EVALUATION OF EN 13537 AND OTHER MODELS FOR PREDICTING TEMPERATURE RATINGS OF SLEEPING BAGS

Elizabeth A. McCullough[1]**, Jianhua Huang*[1]*, Byron W. Jones*[1]

[1] Institute for Environmental Research, Kansas State University, Manhattan, KS USA
* corresponding author lizm@ksu.edu

Introduction

Manufacturers label their sleeping bags with temperature ratings to help consumers select the bags that will provide them with thermal comfort during the expected conditions of use. However, there is no consistency among companies in the United States regarding their methods for determining temperature ratings. Some companies use feedback from consumers who slept in their bags under different field conditions to establish temperature ratings. Others relate bag loft (thickness) and amount of fill to a comfort temperature. Some manufacturers have the thermal insulation of their sleeping bags measured with a heated manikin according to ASTM F 1720 (2). Then a heat loss model is used to predict the lowest acceptable air temperature for sleeping bag use (7). In Europe, manufacturers are beginning to follow EN 13537, "Requirements for Sleeping Bags," and label their bags with a range of thermal utility (5). This standard requires the thermal insulation of a sleeping bag to be measured as part of a system (including clothing and a pad). The insulation value of the bag system is used in heat loss models to predict different temperatures for comfort and risk during use.

Heat loss models

The body heat loss models for predicting the air temperature for comfort are all based on the classic heat balance equation (1). However, their inputs (e.g., skin temperature, metabolic rate), assumptions (i.e., gender), and applications (e.g., military vs. consumer use) vary slightly. The models are usually reduced to a linear equation that relates sleeping bag insulation to comfort temperature. (See Table 1.) As the insulation value of a sleeping bag system increases, the air temperature for thermal comfort decreases. Under steady-state conditions, the models predict the lowest air temperature for thermal comfort without heat debt occurring. For limited exposures of 4-8 hours of sleep, models can predict the lowest air temperature for acceptable thermal comfort where the body has incurred some heat debt, but not enough to cause the person to wake due to feeling cold. The air temperature predictions from these models are lower since a person's body temperature is allowed to decrease.

Table 1. Heat loss models for predicting the lowest temperature for comfort in sleeping bags[a]

Author	Steady-state equations	Author	Steady-state equations
Belding (3)	$T_a = 33.33 - 5.39\ I_t$	den Hartog et al. (4)	$T_a = 32 - 7.32\ I_t$
Goldman (6)	$T_a = 32 - 5.4\ I_t$	EN 13537 (5) comfort temp[b]	$T_a = 32.24 - 4.80\ I_t$
KSU Model (7)	$T_a = 32.79 - 4.82\ I_t$	EN 13537 (5) limit temp[c]	$T_a = 32 - 7.32\ I_t$

[a] T_a = lowest air temperature for comfort (°C); I_t = insulation of sleeping bag system (clo)
[b] Higher comfort temperature is based on a standard woman.
[c] Lower limit temperature is based on a standard man.

Purpose

This study evaluated different heat loss models (including those given in EN 13537) for predicting the lowest air temperature for thermal comfort under steady-state conditions. Male and female subjects slept in cold environmental chambers in sleeping bag systems at three levels of insulation at different air temperatures to determine 1) the air temperatures at which the majority of people had acceptable levels of thermal comfort while sleeping in each bag and 2) which model's air temperature predictions were the most consistent with the temperatures predicted from the analysis of the subjects' responses.

Methods

Sleeping bag system insulation

The insulation values of three sleeping bag systems were measured with a heated manikin according to ASTM F 1720 (2). The systems included the bag, thermal long underwear, socks, and a 1 ½ inch self-inflating pad. A bed pillow and knit hat were used with the rectangular bag since it had no hood; a small camp pillow was used with the two mummy bags. The manikin was placed in an environmental chamber and dressed in the bag system. The bag system was tested on an elevated floor so that it was surrounded by the same air temperature during the test. Ten samples of each bag type were tested, and the sample variability in insulation values was very low. Therefore, the temperature predictions for each model were determined based on the mean insulation value of each set of 10 sleeping bags:

- low level of insulation – rectangular bag system (4.3 clo or 0.67 m² · °C/W)
- medium level of insulation – mummy bag system (5.6 clo or 0.87 m² · °C/W)
- high level of insulation – mummy bag system (6.6 clo or 1.0 m² · °C/W).

Human subject trials

The participants were 30 men and 30 women between the ages of 18 and 30, with a healthy body mass index between 19 and 25, and camping experience. The experiment took place in two adjacent climatic chambers. Wooden floors were built 10 inches above the chambers' insulated floors so that air could circulate under the floor and cause the floor to be approximately the same temperature as the air. The chamber air temperature ranged from -15°C to 10°C in 5°C intervals on different nights. The range was determined from different model predictions for the three levels of insulation.

Five men were tested in one environmental chamber and five women in the adjacent chamber during each night test session. The first night was a preconditioning session at the highest air temperature of the series, where subjects got accustomed to their surroundings and the test procedures. (These data were not used.) The next nights were the actual test sessions starting with the highest air temperature and lowering it 5°C on each subsequent night. Each subject slept in the same bag system every night, and the garments were laundered each day between sessions. A thermocouple was taped to the base of each subject's big toe, and toe skin temperature data were collected every 10 minutes throughout the night. A subject was removed from the experiment if 1) the toe skin temperature dropped below 15°C or 2) the subject wished to quit the experiment. An experimenter monitored the test sessions at all times. In the morning, each subject filled out a subjective questionnaire which included a form of the thermal sensation scale ranging from 1 (very cold) to 5 (neutral) to 9 (very hot). For safety reasons, we added 0 (intolerably cold). If a subject selected the 0 response, he/she was not allowed to continue the experiment under colder conditions.

Results and discussion

The calibration statistical method was used to determine the 95% prediction limits for thermal sensation at three levels of insulation (8). The steady-state models were evaluated using a response of 5 (neutral) on the nine-point thermal sensation scale. First, the point estimate of thermal sensation at each air temperature was determined. The analysis also generated an upper limit and lower limit for thermal sensation at different air temperatures in 1°C intervals. The upper and lower limits for thermal sensation correspond to a 95% prediction interval, meaning that 95% of the subjects would have a thermal sensation response within this range at a specific air temperature and insulation value. Regression equations were then solved to determine the point estimate of air temperature for comfort (where thermal sensation = 5 for neutral) at each of the three levels of insulation.

The point estimates of the air temperature for comfort under steady-state conditions at three levels of insulation are graphed with the 95% confidence intervals in Figure 1. The different model predictions are shown also. The model reported by den Hartog et al. (4) is not shown on the graph because its predictions were considerably lower than the other models.

All of the steady-state models did a good job of predicting the lowest air temperature for comfort for typical men and women using sleeping bag systems at different levels of insulation. The predictions from the Belding steady-state model (3) were within the 95% confidence interval developed from the human subjects' responses at all three levels of insulation. The KSU model (7) and the EN 13537 *comfort* temperature predictions (5) were slightly higher than the subjects' responses at the highest level of insulation. The Goldman model (6) predicted air temperatures slightly lower than the 95% confidence limit for the two lower levels of insulation. The EN 13537 *limit* temperature predictions were consistently below the 95% confidence interval for all levels of insulation. In the EN standard, the *limit* temperature was calculated using a higher metabolic rate than was used in calculating the *comfort* temperature. It is supposed to represent the lower temperature limits for comfort that would be acceptable to some men. Since half of the thermal sensation data used to validate the models was generated from women in this study, the point estimates for the comfort temperatures at each level of insulation were probably higher than if we had only studied males. Thus, the lower limit temperatures in the EN standard did not fall within the 95% confidence interval associated with the point estimates for steady-state comfort temperatures at different levels of insulation.

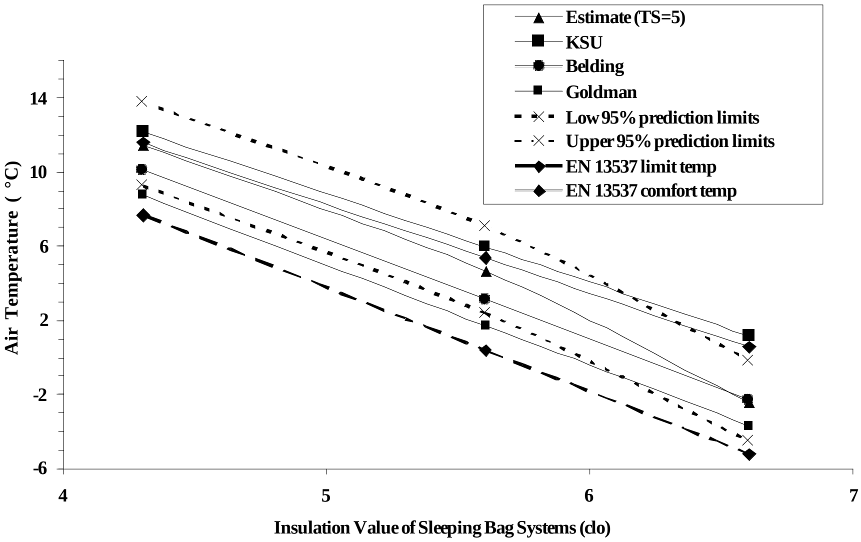

Figure 1. Steady-state model predictions as compared to the point estimates of thermal neutrality generated from the analysis of human subject data.

Conclusions

The thermal sensation responses of 60 males and females sleeping in three bag systems at different air temperatures were used to validate steady-state heat loss models for predicting the air temperature for comfort from the insulation value of a sleeping bag system. Several models (3, 5, 6, 7) predicted the temperature for comfort of recreational bag users reasonably well. The *comfort* temperature predictions in EN 13537 were validated by the subjects in the study, but the comfort *limit* temperature predictions were too low. Consequently, some people – particularly women – would probably experience some heat debt at the lower *limit* temperature.

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EFFECTIVENESS OF WATERPROOF CLOTHING OR A SURVIVAL BAG IN A SIMULATED COOL, WET AND WINDY ENVIRONMENT.

Clare Eglin

Department of Sport and Exercise Science, Institute of Biomolecular Sciences, University of Portsmouth, Portsmouth, PO1 2DT UK
clare.eglin@port.ac.uk

Introduction

Survival bags have been developed to protect against the incidence of accidental hypothermia in a casualty by reducing heat loss through convection and evaporation. In a cold, wet, windy environment survival bags have been found to have no effect on the fall in deep body temperature but did attenuate shivering compared to no protection (6). This indicated that the metabolic demand required to maintain deep body temperature was reduced. Therefore in an extreme or prolonged exposure where shivering may be compromised through fatigue (8), hypoglycaemia (2), or decreased body temperature (1) the use of a survival bag should delay the onset of hypothermia.

There are many scenarios in which an individual may undertake outdoor activities and be prepared for cool/cold wet and windy weather by taking waterproof clothing but not a survival bag. The aim of this study was to compare the thermal responses of subjects to a 60 min exposure simulating a cool, wet and windy environment whilst wearing either a survival bag, waterproof clothing, or no additional protection.

Methods

The experimental protocol was approved by a local ethics committee. Six healthy men volunteered to participate in the study after giving their informed written consent. Each subject undertook three, 60 min, resting exposures in air at 11°C wearing either light clothing (C), light clothing and waterproof clothing (WP), or light clothing and a survival bag (SB). The exposures were conducted at similar times of the day and were separated by at least 3 days. The order in which the exposures were undertaken was counterbalanced. Two hours before arrival at the laboratory, subjects ate a light meal and had refrained from alcohol, caffeine, and nicotine in the previous 24 hr.

The light clothing ensemble consisted of a long-sleeved cotton top, trousers, socks, and walking boots. The survival bag (2.2 m by 0.8 m) was made from rip-stop nylon and incorporated a hood. The waterproof clothing was single-layered, 100% nylon and comprised of trousers and jacket with a drawstring hood. Both the survival bag and waterproof clothing were worn with the hood so that just the face was exposed.

Following instrumentation with the physiological monitoring equipment the subjects were dressed in light clothing. They were then sprayed with 750 mL of water at approximately 10°C to saturate their clothing and hair. They then entered the environmental chamber and depending on the condition donned either the waterproof clothing (WP), a survival bag (SB), or were given no additional protection (C). The subjects lay on a foam mat (thickness 10 mm) with their feet 50 cm away from a fan blowing air at 13 $m.s^{-1}$. The subjects remained still, lying on their back with their legs straight and their arms at their side for 60 min.

Deep body temperature was measured using a rectal thermistor inserted 15 cm beyond the anal sphincter. Skin temperature (T_{sk}) was measured on the chest, arm, thigh, and calf with skin thermistors and used to calculate mean T_{sk} (7). Rectal temperature (T_{re}) and Tsk were recorded every minute. Oxygen consumption (VO_2) was calculated from measurement of expired air collected in a Douglas bag for 3 min periods prior to wetting the clothing (resting) and every tenth minute of the exposure. Thermal comfort and temperature sensation were recorded every 5 min using a 7 point (1 = very comfortable; 7 = unbearably uncomfortable) and 13 point subjective rating scale (1 = unbearably cold; 7 = neutral; 13 = unbearably hot) respectively.

All data are shown as arithmetic mean ± standard deviation. T_{sk}, $T_{re,}$ and VO_2 were analysed using a one-way analysis of variance (ANOVA) followed by a Tukey post-hoc test. The effect of time was investigated using a repeated measures ANOVA followed by a simple MANOVA and Tukey post hoc tests. Thermal comfort and sensation were analysed using a Wilcoxon Signed Ranks test. Statistical significance was taken at the $P< 0.05$ level.

Results

The physical characteristics of the subjects were as follows: age: 20.3 ± 1.4 y; height: 1.81 ± 0.05 m; body mass: 75.5 ± 8.3 kg; sum of skinfold thickness (abdomen, triceps, subscapular and suprailiac): 36.0 ± 12.1 mm; and predicted VO_2max: 64.7 ± 8.5 $ml.kg^{-1}.min^{-1}$. Ambient temperature and relative humidity were similar for each condition (C: 11.2 ± 0.4°C and 74 ± 7 %; WP: 11.1 ± 0.2°C and 76 ± 4 %; SB: 11.6 ± 0.4°C and 78 ± 1 %).

T_{re} at the start of the exposure did not differ between conditions (C: 37.16 ± 0.30°C; WP: 37.28 ± 0.31°C; and SB: 37.05 ± 0.22°C), neither was there any significant difference in the change in T_{re} over the 60 min exposure time (C: -0.38 ± 0.23°C; WP –0.38 ± 0.12°C; SB: -0.33 ± 0.14°C).

Mean T_{sk} at the start of the WP exposure averaged 29.96 ± 0.88°C and was warmer than either the C or SB condition (28.19 ± 0.52°C and 28.52 ± 0.42°C respectively; $P<0.05$, n=5). Over the 60 min exposure there was little change in mean T_{sk} in the SB condition (Figure 1; $P>0.05$). In C and WP mean T_{sk} fell progressively during the first 40 min of the exposure being lower than resting values from 25 min in C ($P<0.05$) and from 40 min in WP ($P<0.05$; Figure 1). Mean T_{sk} was significantly cooler in the C condition compared to WP and SB from 5 min ($P<0.05$, n=5). Although mean T_{sk} in WP did fall, due to the higher resting temperature, mean T_{sk} did not differ between WP and SB during the exposure (Figure 1).

Resting VO_2 was similar prior to each condition and averaged 0.39 ± 0.09 $L.min^{-1}$. In WP and SB, VO_2 was not significantly elevated above resting levels ($P>0.05$). In exposure C, VO_2 was elevated above resting levels at 50 and 60 min ($P<0.05$; Figure 2) and was significantly higher than SB and WP from 20 min and 40 min onwards respectively. No significant difference was observed between SB and WP at any time points. Mean VO_2 over the 60 min exposure was significantly higher in C compared to WP and SB (C: 0.58 ± 0.06 $L.min^{-1}$; WP: 0.42 ± 0.05 $L.min^{-1}$; SB: 0.38 ± 0.07 $L.min^{-1}$; $P<0.001$).

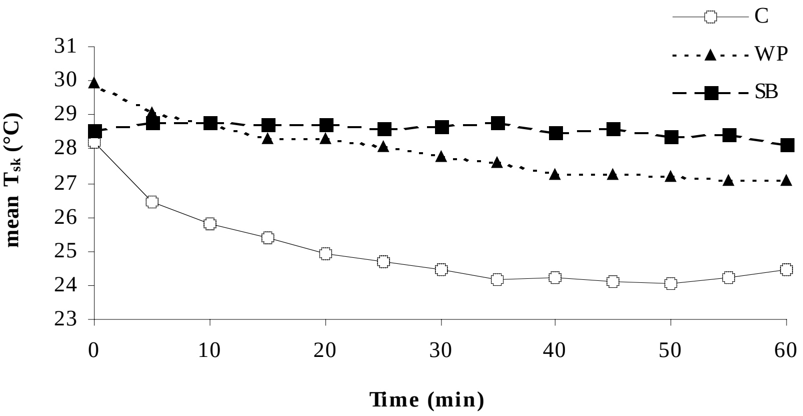

Figure 1. Mean T_{sk} during the 60 min cold exposure in the three conditions, control, waterproof clothing and survival bag (n=5).

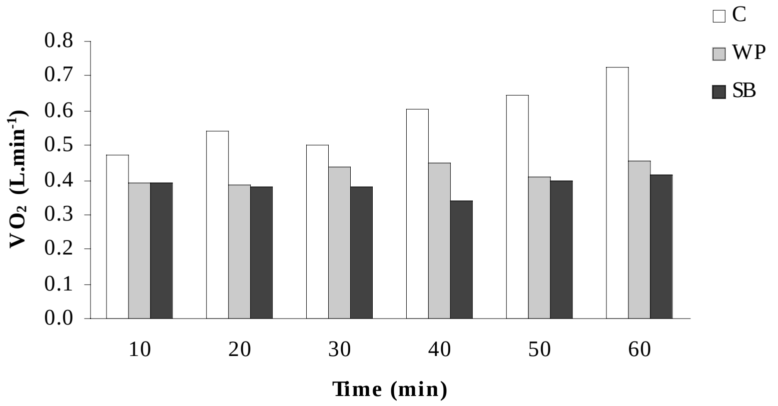

Figure 2. Mean VO_2 during the 60 min cold exposure in each condition, control, waterproof clothing and survival bag (n=6).

The subjects perceived condition C colder than both WP and SB (2.8 ± 1.1 vs 1.5 ± 0.5 and 2.2 ± 1.4 respectively, $P<0.05$). The subjects also reported C as being less comfortable than WP and SB, although significance was only achieved between C and WP (C: 3.7 ± 1.3, WP: 5.3 ± 1.7, $P<0.05$, SB 5.8 ± 2.0 $P=0.068$). No differences in thermal comfort or sensation were observed between WP and SB.

Discussion

Rectal temperature fell by an average of only 0.36 °C over the one hour exposure period and was not attenuated by wearing either a survival bag or the waterproof clothing. The lack difference in T_{re} profile between conditions was due to an increase in metabolic heat production (Figure 2) in the C exposure that offset the greater heat loss in this condition. Therefore both WP and SB appear to be equally effective in reducing the metabolic cost of the cold exposure. This supports previous findings where no difference in the rate of fall in deep body temperature was observed between different types of survival bags (4-6).

Although the fall in T_{re} was similar during each exposure, VO_2 was increased only in C (Figure 2) indicating that the reduced T_{sk} in this condition (Figure 1) was the stimulus for shivering. The greatest increase in VO_2 was seen in the last 10 min of exposure and this level of shivering was equivalent to 15 ± 3 % predicted VO_2max. This is well below the maximum level of shivering of approximately 50% VO_2max (3) suggesting that the subjects were not under severe thermal stress even in the C condition and were within their thermoregulatory zone. As expected, with a lower mean T_{sk} and greater shivering in C, the subjects perceived this condition as colder and less comfortable than either WP or SB.

The exposure used in the current study could be considered to be mild as although the subjects' clothes were saturated with cold water at the start, air temperature was 11°C, wind speed 13 $m.s^{-1}$ and the duration was only 60 min. However very similar results have been obtained during a 2 hour exposure with and without survival bags in a colder but less windy environment (5°C with a wind speed of 4 $m.s^{-1}$) following saturation of the subjects underclothing (6). The duration of the exposures was only 60 min and therefore it could be argued that a longer exposure period may result in greater differences between conditions. However previous studies (up to 3 hr in duration) have show the rate of fall of T_{re} being greatest in the first hour (5,6) suggesting the findings of the current study are probably valid for much longer exposure times.

In conclusion, neither SB or WP attenuated the fall in T_{re} in supine subjects during the simulated cool, wet and windy exposure investigated in the current study, however they both reduced the metabolic stress and maintained higher T_{sk} compared to the control condition. The lack of difference in T_{re} between conditions demonstrated that the environment was such that the subjects remained within their thermoregulatory zone. In circumstances where shivering was inhibited e.g. by hypoglycaemia (2), fatigue (8) or by severe hypothermia (1), waterproof clothing or a survival bag would attenuate the fall in T_{re} to a similar extent and therefore be equally effective at providing thermal protection against hypothermia.

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METHODS FOR MEASURING THE CLOTHING AREA FACTOR

Elizabeth A. McCullough[1]**, Jianhua Huang*[1]*, Shawn Deaton*[2]

[1] Institute for Environmental Research, Kansas State University, Manhattan, KS USA
[2] North Carolina State University, Raleigh, NC USA
* corresponding author lizm@ksu.edu

Introduction

There are several standards for measuring clothing insulation: ASTM F 1291, ENV 342, ISO/FDIS 15831, and ISO 9920 (1, 2, 4, 5). These documents require measuring the insulation of a clothing ensemble using a heated manikin that is either standing or walking. The total insulation (I_t) provided by the clothing and the external air layer is actually measured. Then it is necessary to subtract the air layer resistance measured on a nude manikin (I_a) from the total resistance (I_t) to determine the intrinsic or basic clothing insulation (I_{cl}). However, the resistance provided by the boundary air layer around a clothed body is less than the air layer resistance around a nude body because it is spread out over a larger surface area. Therefore, the air layer resistance measured on a nude manikin (I_a) is usually divided by the clothing area factor (f_{cl}) before subtracting it from the total insulation. The f_{cl} is not used in ENV 342 because the effect is assumed to be low with highly insulative cold weather ensembles.

The clothing area factor (f_{cl}) is an indicator of the increase in surface area for heat loss from the clothed body to the environment. It is usually measured by taking photographs of a manikin – nude and clothed – from different angles and comparing the projected areas. The areas are determined by cutting out the images and weighing the paper or tracing the images with a planimeter. The f_{cl} is then defined as the ratio of the projected area of the clothed manikin to the projected area of the nude manikin. The resulting index ranges from 1.01 for very tight-fitting clothing (leotard) to 1.50 or higher for protective ensembles (8). Early researchers (3, 6, 10) tried to capture the three-dimensional nature of the manikin from two-dimensional images by taking photographs from a variety of azimuth angles ranging from the front view ($\alpha = 0°$) to the profile ($\alpha = 90°$) to the back view ($\alpha = 180°$) and a variety of altitude angles ranging from horizontal ($\beta = 0°$) to vertical (looking straight down, $\beta = 90°$). Then Olesen et al. (9) used statistical analyses to determine which combinations of azimuth and altitude angles best estimated the clothing area factor calculated with a large number of angles. This method called for taking photographs at two altitudes, $\beta = 0°$ and 60° and three azimuth angles, $\alpha = 0°$, 45°, and 90° (for a total of six views). Since then, the procedure has been used in several studies (7, 8) and incorporated into standards (1, 4, 5).

Measuring the clothing area factor is time-consuming and expensive, so many researchers estimate the f_{cl} for clothing ensembles by examining values in data bases and standards. The purpose of this study was to compare different methods for determining the f_{cl} from photographs taken from different angles and to evaluate the effectiveness of using a 3D body scanning system to determine f_{cl}. The measurements were made on protective clothing systems because there is little f_{cl} data available on these types of clothing ensembles except for cold weather garments.

Methods

Nine protective ensembles were evaluated. (See Table 1.) The ensembles were photographed at different angles at KSU; then the garments and front photographs were sent to NCSU so that their manikin could be dressed the same way for 3D scanning.

Photographic method

Photographs of the ensembles were taken from the six angle combinations mentioned above: two altitudes, $\beta = 0°$ and 60° and three azimuth angles, $\alpha = 0°$, 45°, and 90°. One digital camera was positioned on a tripod at the height that corresponded to a point at the manikin's waist for the horizontal altitude angle (0°). A second digital camera was positioned high on a platform so that the line of site to his waist formed a 60° angle. Both cameras were exactly 3.4 m from the manikin. Once the focus adjustment was set, it was not changed during the photographic session. For the azimuth angles, the manikin was rotated from the front view, to the 45° view, to the profile view. After the photographs were printed on the same type of paper, the projected areas of the clothed and nude manikin were determined by 1) using a planimeter to trace the areas (vernier units), 2) cutting out the areas and weighing them (grams), and 3) using Photoshop® to change the background to white, the manikin areas to black silhouettes, and determine the pixel counts of the silhouettes as an indicator of relative size. The clothing area factor value for each ensemble and each method was calculated by:

$$f_{cl} = \frac{\sum_{i=1}^{6} A_{cli}}{\sum_{i=1}^{6} A_{ni}} \qquad (1)$$

f_{cl} = clothing area factor
A_{cli} = the projected area of each ensemble at the i^{th} angle (3 azimuth × 2 altitude)
A_{ni} = the projected area of nude manikin at the i^{th} angle (3 azimuth × 2 altitude)

Table 1. Description of protective clothing ensembles.

Ensembles	Description
1. Warm weather indoor clothing (base ensemble)	Short-sleeve shirt, men's underwear briefs, khaki pants, belt , socks, athletic shoes
2. Cold weather clothing	Base ensemble, knit hat, fiberfill jacket, knit mittens
3. Chemical protective level B ensemble	Base ensemble, chemical protective hood, jacket, pants, and gloves; belt
4. Surgical ensemble	Surgical gown, mask, cap, and gloves; scrub shirt, scrub pants, socks, athletic shoes, shoe covers
5. Extreme cold weather expedition ensemble	Thermal underwear (top and bottom), cold weather expedition suit, fiberfill mittens, men's underwear briefs, socks, work boots
6. Flame resistant protective clothing (calibration ensemble)	Flame resistant long sleeve shirt and pants, men's underwear briefs, socks, athletic shoes
7. Tyvek® coverall ensemble	T-shirt, men's underwear briefs, socks, athletic shoes, Tyvek® coverall (no hood)
8. Fire fighter turnout gear	T-shirt, fire fighter turnout jacket and pants, helmet, leather gloves, men's briefs, socks, work boots
9. Chemical protective level A ensemble with respirator	Level A one-piece suit, respirator, men's underwear briefs, socks, athletic shoes

3D scanning procedure

A 3D body scanner with Geomagic® imaging software was used to measure the surface area of a manikin clothed and nude. The body scanning system (developed by the Textile Clothing Technology Corporation) works by scanning a subject standing with legs apart and arms extended away from the torso while taking still pictures of reflected white light. Two cameras are placed in front of the subject and two are placed behind the subject. Utilizing the scanning software, captured images are processed into one image comprised of numerous points resulting in a 3D image useful for calculating body measurements and studying garment fit.

A display manikin, similar in size and stature to the KSU thermal manikin, was selected for use at NCSU. The fixed posture of this manikin, arms by its side and legs close together, along with system constraints of camera positioning perpendicular to the subject, made it difficult to obtain a 3D image with the single scan procedures used during a body scan of a person. The cameras were unable to capture reflections of white light from the sides and within creases of clothing. Therefore, it was necessary to rotate the manikin on a turntable and conduct three scans from different azimuth angles: 0 ° facing the front cameras, 45 °, and 90 °. Using the Geomagic® imaging software, point clouds captured during three scans were compiled into one true 3D image allowing calculation of surface area measurements. Since the body scanner uses reflected white light during scans, problems occurred when the ensemble materials were of a dark color, clear plastic, or contained a florescent material. Dark colors absorbed too much of the light, clear plastic allowed the light to pass through, while fluorescent trim absorbed the light only to emit the light at different wave lengths. Therefore, modifications had to be made to some ensembles (e.g., applying masking tape to the clear shield on the chemical protective suit). Two ensembles did not generate usable 3D images.

Results and discussion

The clothing area factors determined by each method are shown in Table 2. Statistics could not be used to compare the f_{cl} values determined from 3D scans to those determined with photographs taken at different angles because the body scanner generated only one f_{cl} value for each ensemble and two ensembles could not be scanned. In general, the body scanning method generated slightly higher f_{cl} values than the photographic method. The fact that the photographs and 3D scans were made on two different manikins may have contributed to this.

Table 2. Clothing area factors measured with different methods.

Ensembles	Photographic Methods			3D Scanner
	Weight	Planimeter	Image Pixels	
1. Indoor base ensemble	1.18	1.17	1.19	1.25
2. Cold weather clothing	1.33	1.31	1.34	
3. Chemical protective level B	1.57	1.57	1.56	1.58
4. Surgical ensemble	1.33	1.35	1.36	1.34
5. Cold weather ensemble	1.51	1.47	1.47	
6. Flame resistant clothing	1.21	1.21	1.22	1.27
7. Tyvek coverall ensemble	1.15	1.20	1.21	1.31
8. Fire fighter turnout gear	1.44	1.46	1.45	1.60
9. Chemical protective level A suit with respirator	1.63	1.63	1.64	1.71

An analysis of variance indicated no statistical difference among the three methods of determining the projected areas from photographs taken at six different angles. The weighing method was the simplest technique since only scissors and a precision balance were needed. Experiments with printing on different paper and in color vs. black/white indicated that all photographs should be printed in black and white on high quality paper from one package (i.e., different color inks have different weights and affect results). The planimeter method took longer since it takes skill to trace the images accurately, and the procedure was repeated to check for errors. The manipulation of the photos in Photoshop® was time-consuming since silhouette edges needed to be smoothed and areas needed to be filled in so that solid black and white areas were created.

The f_{cl} values were calculated for each of the six photographs taken from different angles for each ensemble (as opposed to dividing the sum of the six areas of an ensemble by the sum of the nude areas). Regression analysis revealed that for protective clothing (which covers the majority of the body surface), taking one photograph from the front ($\beta = 0°$ and $\alpha = 0°$) approximates the clothing area factor determined using all six angles (R-square = 0.99; mean square error = 0.015).

Conclusions

Taking one photograph of a manikin nude and clothed from the front ($\beta = 0°$ and $\alpha = 0°$), cutting it out, and weighing it appears to be a simplest method to use for determining the clothing area factor (f_{cl}) of protective ensembles.

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FUNCTIONAL PROTECTIVE CLOTHING FOR FISHERMEN

Ingunn Holmen Geving, Hilde Færevik, Mariann Sandsund, Jarl Reitan, Randi Eidsmo Reinertsen, Halvard Aasjord[1)]

SINTEF Health Research; SINTEF Fisheries and Aquaculture[1)] N-7465 Trondheim, Norway

The fishing industry is the most risk exposed occupation in Norway. In the period 1998-2002, 1690 injuries and 50 deaths were reported. The complexity of the fishing fleet, ranging from large, sea going trawlers to one man operated smaller vessels in coastal areas, raises great challenges when aiming to improve the safety for the fishermen.

Our project aimed to contribute to the reduction of work accidents and health injuries in the fishing fleet in Norway through development of functional protective clothing. We hypothesized that it is possible to produce protective clothing that satisfy a specification of requirements covering the fishermen's needs for protection during work.

An end user-centred process was used to clarify the fishermen's needs and wishes before detailed design and product development. On the basis of preferences indicated by the fishermen, we aimed to identify an overview of all their needs for protection during work, as well as to produce a prioritised list of functional requirements for the clothing. The implementation of the project was based on a concept development method, and the first step involved the specification of requirements. This stage was performed in the course of interviews with 23 employees in the fishing fleet in Norway. Further, a questionnaire including 47 requirements was sent out to 1100 fishermen.

Based on the interviews and the questionnaire survey, the following three requirements were given the highest priority: The clothing and PPE should provide 1) protection against drowning in case of an accident; 2) protection against wet and cold environments and 3) freedom of movements . The results revealed different priorities between different types of fishing vessels, and also between different tasks performed aboard.

A selected number of prototypes of work suits for fishermen were developed on the basis of the established specification of requirements. The prototypes was evaluated through test methods designed to provide measures of the most crucial requirements regarding protection against accidents and health injuries. The results from laboratory and field testing aboard a fishing vessel demonstrated that the performance of the new protective clothing met with the specification of requirements.

SMART FIRE SUIT INCREASING OCCUPATIONAL SAFETY

Satu Kärki[1], Markku Honkala[2], Luc Cluitmans[3], Alper Cömert[4], Jaana Hännikäinen[5], Jussi Mattila[3], Harriet Meinander[2], Päivi Peltonen[2], Kari Piipponen[6], Tomi Tieranta[5], Antti Väätänen[3], Jari Hyttinen[4], Jukka Lekkala[1], Raimo Sepponen[6], Jukka Vanhala[5], Heikki Mattila[2]*

[1] Institute of Measurement and Information Technology, Tampere University of Technology, Finland
[2] SmartWearLab, Tampere University of Technology, Finland
[3] VTT Information Technology, Finland
[4] Ragnar Granit Institute, Tampere University of Technology, Finland
[5] Institute of Electronics, Tampere University of Technology, Finland
[6] Applied Electronics Laboratory, Helsinki University of Technology, Finland
* corresponding author satu.karki@tut.fi

Introduction

In Clothing Area Network (CLAN) project, started at the beginning of year 2004, a smart clothing for fire fighters was implemented. Smart clothing can be described as a garment, which can better fulfil its primary function as clothing and also give some added value to the user [1]. Nowadays fire fighters are equipped with a special protective clothing which on the other hand protects them longer when exposed to a fire, but on the other hand, prevents them from sensing the dangerous intense heat of a fire [2]. This lack of sensing can be provided artificially with different kind of sensors integrated in the garment. Fire fighting operation creates a challenging environment for smart clothing. Not only the high temperatures, but also the moisture and mechanical stress are critical factors in designing and implementing smart clothing for fire fighters. Sensors and electronics need to be extremely reliable, lightweight and durable. They should work under a wide range of very demanding operating conditions [3]. In addition, smart clothing for fire fighters needs to be comfortable and easy to wear and use - the technology integrated in the clothing must not demand any additional operations compared to conventional fire suits.

In the ICEE2005 paper, design of the smart fire suit for fire fighters will be described. Also the hardware and software will be discussed. In addition, test results including the performance of the suit will be analyzed, and conclusions of the project will be presented.

Methodology

Data and power transfer

Smart fire suit measures information from the fire fighter and also from the environment. Data from the sensors is transferred to a central processing unit, called the ClanBox, located inside the fire suit. ClanBox controls the data and power transfer inside the fire suit and also between the suit and external devices carried with, e.g. compressed air bottle. From the ClanBox the data is sent to a portable laptop computer located in a leader fire engine by using a custom wireless communication protocol and radio modems. A rechargeable battery is used as a power supply for the smart fire suit.

Sensors integrated in the fire suit are connected to the ClanBox via sensor and communication network designated the CLAN-network. Wireless data transfer between the CLAN-network and external devices carried with is implemented by using inductive links. Wireless power transfer is not used in the first prototype suit, and the external devices carried with are equipped with batteries.

Measurement targets

At the beginning of the project, fire fighters were interviewed to find out the most important measurement targets. Based on the interviews, measurement targets were chosen to be ambient air temperature, temperature inside the fire suit, remaining air in the compressed air bottle and fire fighter’s heart rate. Heart rate was determined by measuring electrocardiogram (ECG) by using textile electrodes. The remaining air in compressed air bottle was monitored by using a commercial wireless tank pressure transmitter (Suunto). As a reference, heart rate was also measured by using a commercial heart rate monitor (Polar). In addition, temperature was measured from the fire fighter’s glove and boot sole to get more information from the ambient temperature. Wireless data transfer from the ECG electrodes and boot and glove temperature sensors was implemented by using inductive links.

Ambient air temperature was measured using a sensor on the outer surface of the fire suit at the location of left shoulder blade. Temperature inside the fire suit was recorded from two places: one of the sensors was fixed at the corresponding location inside the suit as the ambient air temperature sensor outside the suit to determine the thermal insulation capacity of the suit. The other inner sensor was located in the hem of the fire jacket, where are also placed the ClanBox, radio modem and rechargeable battery. These devices are most vulnerable to the heat and hence their temperature conditions were monitored.

Ambient air temperature is nowadays commonly measured by exploring the air on different levels with uncovered hand. This is a risky method and to avoid burns a temperature sensor was integrated also on the surface of a glove. Temperature from the fire fighters boot was measured to find out the temperature of the surface fireman is walking on. The boot sole can melt if the surface temperature is too high, but the fireman may not feel this because the boot has so good thermal insulation capacity.

Fire fighter's heart rate was measured by using textile electrodes integrated into a fire fighter's undershirt. Electrodes were produced by embroidering them to the undershirt by using a silver-polyamide yarn. Heart rate is measured to find out the fire fighter's stress and exertion level.

Clothing design

Smart clothing for fire fighters was implemented to a conventional fire suit by integrating sensors and electronics into it. CLAN-network was hidden inside the fire suit by using alleys stitched in the suit. Sensors and electronics were integrated so they wouldn't disturb wear and use of the garment. Fig. 1 visualizes the smart clothing for fire fighters.

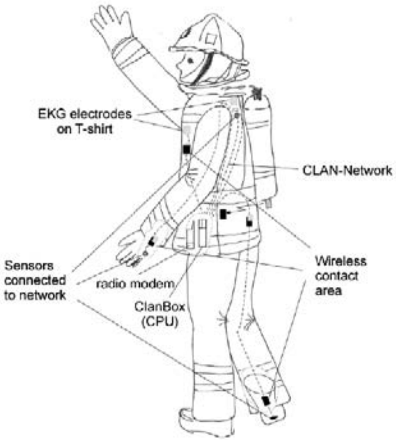
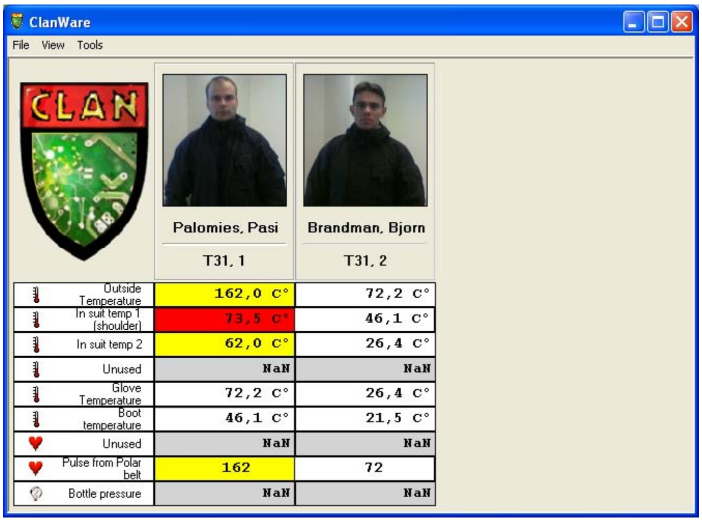


Figure 1. Visualization of the smart clothing for fire fighters.

Software

The software presenting the measurement results is called the ClanWare. The ClanWare identifies the fire fighters whose ClanBox is switched on and shows directly the information concerning the fire fighter. Before presenting the results some signal processing is made. ClanWare shows the measured parameters and values in real time. If some of the values outreach the allowed limits, value is marked with yellow or red colour, and the rescue operation supervisor can call the fireman away from the ongoing situation. In Fig. 2 the ClanWare user interface is presented.



	Palomies, Pasi T31, 1	Brandman, Bjorn T31, 2
Outside Temperature	162,0 C°	72,2 C°
In suit temp 1 (shoulder)	73,5 C°	46,1 C°
In suit temp 2	62,0 C°	26,4 C°
Unused	NaN	NaN
Glove Temperature	72,2 C°	26,4 C°
Boot temperature	46,1 C°	21,5 C°
Unused	NaN	NaN
Pulse from Polar belt	162	72
Bottle pressure	NaN	NaN

Figure 2. ClanWare user interface.

Results and discussion

Live-fire training exercises

A working prototype of the smart clothing for fire fighters was also tested in practice in live-fire training exercises. The exercise simulates a real fire fighting operation.

Live-fire training exercises were arranged in a container, shown in Fig. 3. A typical exercise takes approximately a quarter of an hour. During the exercise time fireman extinguishes the fire by using an aggressive fire fighting technique. In aggressive fire fighting technique water is squirted in short periods towards the fire. Heat binds up to the water vapour and temperature goes up temporarily [4]. However, the temperature of the burning object decreases.

Figure 3. Live-fire training exercises.

Results

After the live-fire training exercises the measurement results were analyzed. From the data temperature versus time graph was drawn, as well as heart rate versus time graph. Also some parameters were calculated, e.g. average temperature, maximum temperature etc. The temperature versus time graph is shown in Fig. 4. Ambient air temperature, temperatures inside the suit and temperatures from the boot and glove are presented.

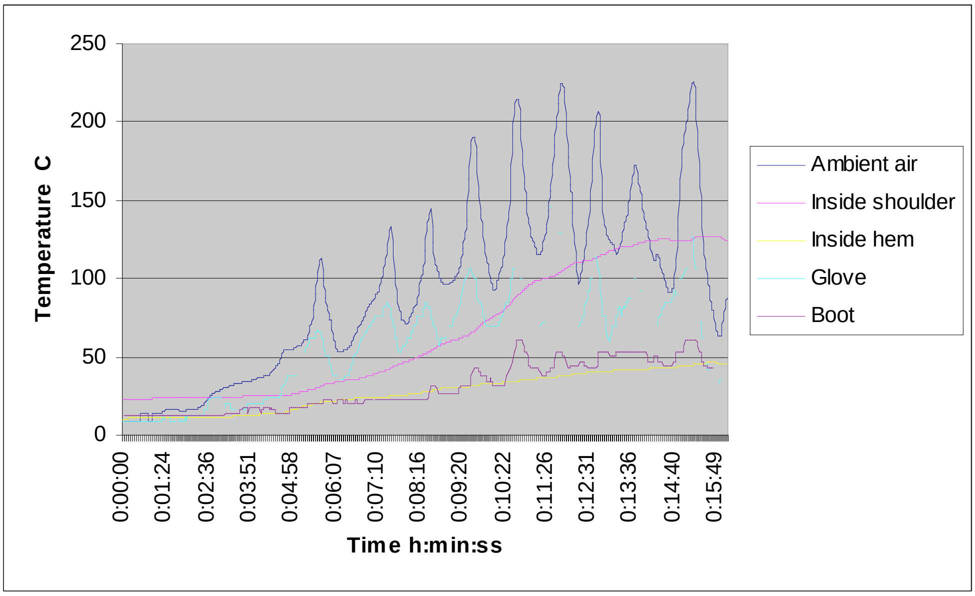


Figure 4. Temperature versus time graph.

As presented in Fig. 4, the ambient temperature increases temporarily during the water squirts. This wave motion can be seen best from the ambient air temperature graph, but it is also on view in boot and glove temperature graphs. There were some breaks in inductive data transfer, and the results are not complete. In the internal temperature measurements similar wave motion is not seen due to the high thermal insulation capacity of the fire suit.

Conclusions

In the Clothing Area Network project a smart clothing for fire fighters was implemented. The attitude among firemen towards the project was very positive. New means increasing occupational safety were seen to be highly important.

Some imperfections were found when testing the prototype suit. Despite of these, the prototype of smart clothing for fire fighters was a working system. Results from live-fire training exercises were promising. The evolved technique is easily applied to other, less challenging applications and it gives a good base for further development.

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EFFECTS OF MOISTURE ON THE HEAT TRANSFER THROUGH CLOTHING MATERIALS

Harriet Meinander[1], Mark Richards[2] and THERMPROTECT network*

[1] SmartWearLab, Tampere University of Technology, Finland
[2] Laboratory for Protection and Physiology, EMPA St Gallen, Switzerland
[3] P. Bröde, V. Candas, E. den Hartog, G. Havenith, I. Holmér
* corresponding author harriet.meinander@tut.fi

Introduction

Most of the standards on protective clothing deal with purely protective requirements. Only few of them address the need for ergonomic design and function. Uncomfortable and inefficient protective clothing may be avoided by the workers or worn in an inappropriate way, endangering also the protective function.

The European THERMPROTECT project was initiated to create basic knowledge about the influence of radiation and moisture on the thermal stress caused by protective clothing. The results of the project will be used for the revision and extension of European protective clothing standards to include requirements concerning the influence of the clothing on the thermal comfort of the user.

The first phase of the project was to assess the thermal insulation and water vapour permeability properties of a set of fabric combinations, in order to choose fabrics, from which garments then were made for the subsequent manikin and physiological tests.

Methods

Materials selection

The first task was to choose a set of suitable underwear and outerwear materials. In order to represent the range worn in practice, the underwear were chosen with the following absorptive properties: hydrophilic, hygroscopic and hydrophobic. The outer layers were chosen with different water vapour transport properties: permeable, semipermeable and impermeable. In order to facilitate direct comparison of different clothing combinations of underwear and outerwear, where possible the materials were selected to have very similar thermal insulation values when dry.

Table 1. Properties of the chosen materials

Underwear	Description	R_{ct} (m²·°C/W)	R_{et} (m²·Pa/W)	I_{mt}	Properties
CO	100 % cotton	0,024	4,2	0,34	Hygroscopic
PES	100 % polyester	0,029	3,4	0,51	Rel. hydrophilic
PP	100 % polypropylene	0,026	3,5	0,44	Hydrophobic
Outerwear					
IMP	PA fabric with PVC coating	0,007	∞		Impermeable
SEMI	Hygrophilic fabric with outer PFTE membrane	0,023	18,6	0,07	Semipermeable
PERM	Hydrophobic fabric with inner PFTE membrane	0,025	5,6	0,25	Permeable

EN 31092/ISO 10092 (1) measurements of single layers were carried out to determine the thermal and evaporative resistance properties. Table 1 shows the results of the standard measurements for the selected materials.

Sweating cylinder measurements

Two different sweating cylinders were used for the further measurements, figure 1. The cylinders are electrically heated to a set temperature (+34/35 °C), and a controlled amount of water is submitted to the surface. Textile materials form a resistance between the cylinder surface and the environment, and the influence of the material on the dry and evaporative heat loss is determined. More detailed information about the method is given in references (2) and (3).

Figure 1. The sweating cylinders of EMPA (left) and SWL (right) with spacer rings.

The tested combinations consisted of an underwear layer and an outerwear layer, which were separated with a spacer ring by an air gap of 8 mm. Two different climates were used (20 °C/65 % RH and 10 °C/65 % RH), and in the sweating phase the sweating level was 200 g/m²·h.

In addition to normal dry + sweating tests, wetting of the outer layer was also performed, to define the effect of rain on the thermal properties. 200 g/m² water was sprayed on the fabric surface.

Results and discussion

Heat loss in dry and sweating conditions, thermal insulation values and condensation in the material layers are determined using the sweating cylinder measurements.

Figure 2 shows the heat loss values in the dry (H_{dry}) and the sweating (H_{wet}) situation for the material combinations at the two temperatures. The amount of moisture that has condensed in the layers in the sweating tests at 10 °C/65 % RH are shown in figure 3.

The heat loss from the cylinder in the dry measurements is approximately 50 % higher at 10 °C than at 20 °C, whereas in the sweating measurements the difference is much smaller. The condensation of moisture in the lower temperature is higher and the evaporation lower, particularly for the impermeable material combination. At 20 °C there is no significant

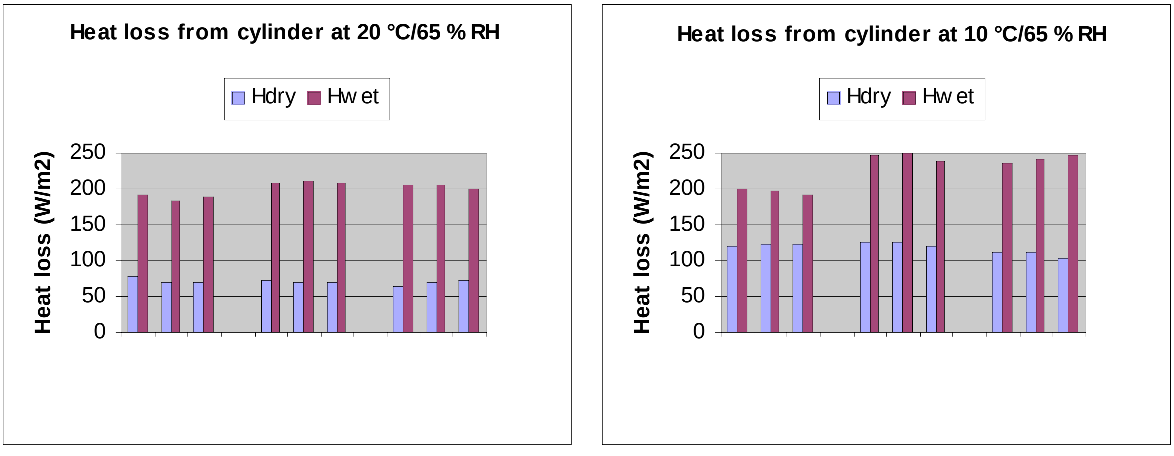

Figure 2. Heat losses from the cylinders

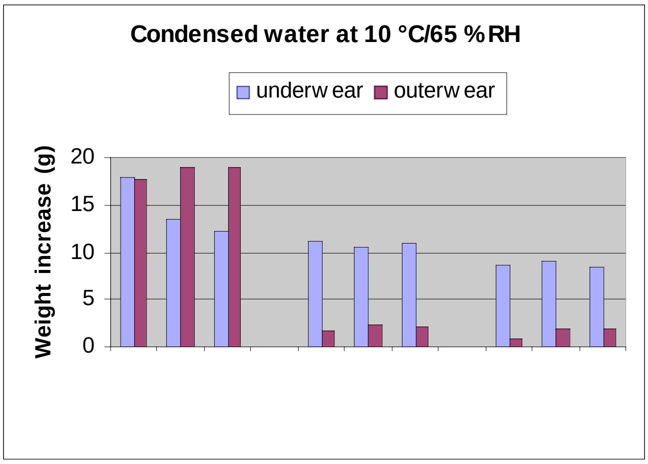

Figure 3. Condensation in the underwear and outerwear layers at 10 °C/65 % RH

difference in the heat loss between the combinations. The influence of the different underwear layers on the heat loss is small and not systematic in the different combinations.

Comparing combinations with the outer permeable layer sprayed with 200 g/m² with those not sprayed showed that most of the sprayed water had evaporated out after 2 hours. After one hour still 30 to 40 g of the 90 g sprayed remained. Thus the effect of spraying should be most noticeable in the first hour after wetting.

Wetting the outer layer has an effect of reducing the apparent insulation but increasing the water vapour resistance of the outer layer. Thus the evaporative heat loss is roughly halved from non-wetted to wetted states one hour after wetting.

Conclusions

The total heat loss of combinations with an impermeable outer layer is lower than for combinations with semipermeable or permeable outer layers.

Different underwear layers with the same dry thermal insulation do not alter the overall heat loss significantly for a given outer layer.

The absorption of moisture in the clothing layers is decreasing with increasing outer layer permeability. Condensation in the impermeable outer layer is substantial, as well as particularly in the cotton underwear. In the case of semipermeable and permeable outerwear, most of the condensed moisture was in the underwear.

Acknowledgements

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CALCULATION OF CLOTHING INSULATION BY SERIAL AND PARALLEL MODEL, THEIR EFFECT ON CLOTHING CHOICE BY IREQ AND THERMAL RESPONSES IN THE COLD

Kalev Kuklane[1], Chuansi Gao[1], Ingvar Holmér[1] and Thermprotect study group[2]

[1] Thermal Environment Laboratory, Department of Design Sciences, LTH, Lund University, Sweden
[2] Represented by P. Broede (D), V. Candas, (F), E. den Hartog (NL), G. Havenith (UK), I. Holmér (S), H. Meinander (FIN) and M. Richards (CH)
* corresponding author kalev.kuklane@design.lth.se

Introduction

Several questions that rose in the course of Subzero project (1) were left open when project ended. Some questions were related to the calculation models ("serial" and "parallel") referred in manikin and testing standards (2, 3). The clothes with evenly distributed insulation were used during Subzero. However, the differences between 2 models are biggest if insulation is unevenly distributed. Other questions were related to miscalculation of required insulation for activity at –25 °C regarding the effect of clothing weight and stiffness on energy expenditure. Also, no standing tests were carried out earlier. Those tests were expected to give the best correlation with manikin results. In order to answer these questions, complementary tests within work package 3 (Cold protective clothing) in Thermprotect project were suggested.

The tests on manikins that were required for human tests' planning were carried out earlier within this project and the results were discussed elsewhere (4).

Methods

Eight healthy non-smoking male subjects (age 28±5 years, weight 71.6±11.1 kg and height 181±6 cm) volunteered to participate in the experiment. None of them was working in the cold but all had a previous experience of cold exposures to at least as low temperatures as –20°C. Tests were carried out during winter season (January-February). The ensembles A, B, and C from Subzero project (5) were used in total 5 conditions (Table 1). Each subject performed each activity - walking on treadmill (Exercise x-track elite, Exercise x.tech AS, Norway) or standing - during the same time of the day with the intervals of at least one day in between the experiments. Ensemble B was used as a control condition in order to see if new subject group behaves in a similar way as Subzero group (6) and if results are comparable.

Table 1. Experimental conditions.

Code	**Clothing**	**Clothing (footwear) weight (kg)**	**[1]Insulation I_{cle} (m^2°C/W)**	**Activity (duration, min)**	**Metabolic rate (W/m^2)**		**T_a (°C)**
					[2]Predicted	**Measured**	
BM	Ensemble B	6.2 (2.3)	0.375	3.5 km/hour (90)	135	162±10	-10
P	Uneven	3.9 (0.9)	0.281	4.9 km/hour (90)	182	194±17	-10
S	Uneven	3.9 (0.9)	0.398 (serial)	3.5 km/hour (90)	130	161±12	-10
CM	Ensemble C	7.4 (2.3)	0.469	3.0 km/hour (90)	155	152±17	-25
CS	Ensemble C	7.4 (2.3)	0.469	Standing (60)	70	55±7	+4

[1] Insulation I_{cle} calculated by parallel model, unless defined differently, that was used in IREQ calculation.
[2] Predicted metabolic rate (12) used in IREQ calculation.

Ensemble A was modified in order to introduce uneven insulation and create big difference between insulation values calculated by serial and parallel models (3) of the same garment ensemble. The underwear pants were removed (only outer layer on legs) and intermediate layer jacket was added (3 layers on upper body). In order to compare these methods both insulation values were used in IREQ calculation (7) to correspond thermal neutrality.

Activity level for ensemble C was reduced compared to Subzero condition by 20 % by taking into account weight distribution (footwear weight) and effect of stiff and bulky clothes (8-11). A standing condition at +4 °C was introduced with ensemble C.

The effective clothing insulation (I_{cle}) was measured on the thermal manikin (1, 4). Walking speeds was chosen (12) so that activity level at chosen ambient condition should correspond to thermal neutrality according to IREQ (7) as was done also in Subzero project (13).

Heart rate (Sport Tester, Polar Electro Oy, Finland), body core (rectal probe at a depth of 10 cm, YSI-401 Yellow Springs Instrument, USA, accuracy ±0.15°C) and skin (14) (NTC–resistant temperature matched thermistors ACC-001, Rhopoint Components Ltd, UK, accuracy ±0.2°C, time constant 10 seconds, fixed to skin with 3M Blenderm ™ surgical tape, type 1525 covering the thermistors), and ambient air temperatures (PT100, Class B sensor accuracy ±0.3°C at 0°C, logger PT-104; Pico technology Limited, accuracy ±0.01°C) were recorded each 15 seconds. Each clothing piece (Sartorius 3804MP, Sartorius GMBH, Göttingen, Germany weighing scale, accuracy ± 0.1 g) and subject (GWB Mettler ID2 MultiRange, Albstadt, Germany weighing scale, accuracy ±0.002 kg) was weighed separately and altogether in the beginning and at the end of each test. Oxygen consumption was analysed (MetaMax I, Cortex GmbH, Germany) for 5 minutes at each half an hour of the activity. The thermal sensation (15) was asked each 10 minutes (scale from -4 to +4). Mean body temperature was calculated as having coefficient 0.2 for mean skin and 0.8 for body core temperature.

Results and discussion

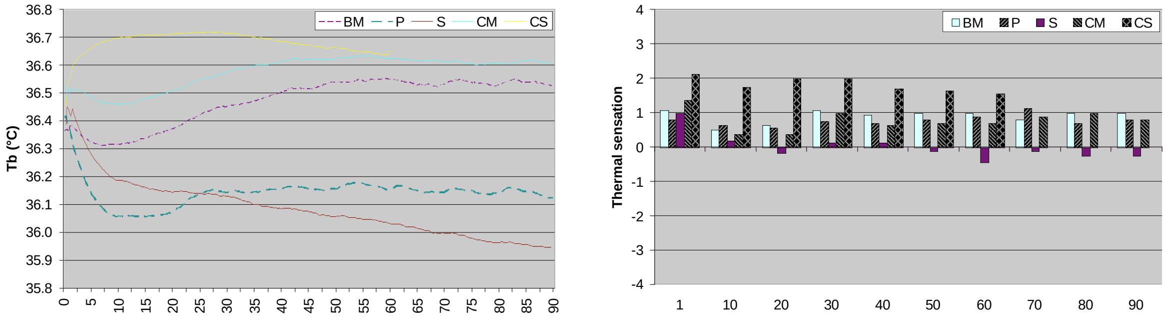
According to control condition (ensemble B) the subject groups of present study and Subzero project were similar (1, 6). The measured metabolic rates were higher than the predicted (Table 1) similarly to earlier results. Therefore, we were able to extend the database and include new data for comparison of the tested conditions. Figure 1a shows mean body temperature (T_b) and Figure 1b thermal sensation over time for all described conditions.

As seen in Figure 1 T_b of condition P stabilized after initial drop and stayed constant. This suggests that the subjects could continue working at IREQ defined conditions. The subjects felt in average between neutral and slightly warm. Table 1 shows that chosen activity level provided very close measured metabolic rate to the predicted one.

In condition S T_b continued to decrease at constant rate after about 30 minutes of exposure. Difference between P and S by the end of 90 minutes was not big and due to inter-individual variation not significant, but still clear. The difference was also confirmed by thermal sensation of the subjects. In average it stayed slightly below neutral. With less sweat produced condition S would be more favourable in cold: 102.7±29.8 g vs. 136.6±79.2 g in P (Figure 2a). Although, the absolute quantities were still quite low in both cases, the cooler condition of subjects did damper sweat production in S.

Table 1 shows that actual measured metabolic rate was considerably higher for condition S than predicted one. It is not clear why metabolic rate was so much higher. Shivering was not present. Muscle tension due to cold could be one explanation but it was neither observed nor reported. Anyway, the cooling rate of the subjects could actually have been much higher if lower activity had been selected in order to match predicted metabolic rate that was used in IREQ calculation. Thus, insulation values calculated by serial model should not be used in IREQ-standard (7), especially if clothing insulation is unevenly distributed.

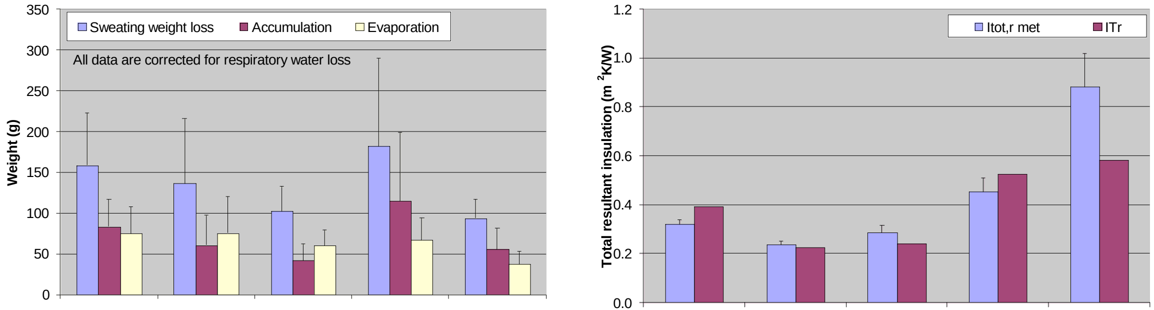
Reduction of original predicted metabolic rate by 20 % gave desired results. The measured metabolic rate was very close to expected one. The total weight loss by sweating was reduced from 315.2±116.3 g during Subzero test to 182.2±107.7 g during these trials (Figure 2a). Thus, the data from human tests may be easier compared to manikin trials carried out during Subzero project (1, 16).



a) b)

Figure 1. a) Change in mean body temperature (T_b), and b) thermal sensation over time.

Figure 2b shows total resultant clothing insulation acquired from subject data and dry manikin. Lower insulation values for subjects in conditions BM and CM could be related to somewhat higher sweat rates and accumulation in the clothing. In condition CS the sweat rates were not high but the insulation differed a lot. As seen in Figure 1 the subjects did not reach the stable state. Initial warming was most probably present due to dressing activity of the thick clothes. It was followed by cooling during continued standing. Also, thermal responses indicate strongly that the subjects were not at comfort. As stable state was not reached then for condition CS the comparison between human trials and manikin is not valid.



a) b)

Figure 2. a) Sweating weight loss, accumulation and evaporation, and b) The total resultant clothing insulation measured on subjects and calculated from static thermal manikin data (2, 17).

There is only a small insulation difference between human and manikin for condition S, although, the stable state was not reached. On the other hand, strong built-up of heat as in CS was not present in this condition. It must be also noted that insulation from the subjects is more closer to the manikin values calculated by parallel method.

Conclusions

We observed the effect of garment weight and weight distribution in condition CM where predicted and measured metabolism differed during Subzero project and were similar during present trials. We also noted the effect in condition BM (same as Subzero). We observed also continued cooling in the condition S even when the measured metabolic rate was higher than predicted.

Serial insulation calculation model gives higher insulation value for clothing ensemble that allows using them at lower temperatures. However, subjects do not achieve heat balance and cool down under these conditions. Common tables for metabolic rate, but also equations for its calculation often do not take into account the effect on metabolic rate of garment bulkiness, weight and weight distribution (footwear weight). These 2 errors may compensate each other. If to choose correct activity level then the insulation values from the parallel calculation model only, should be used together with IREQ.

Acknowledgements

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FUNCTIONAL GLOVE COMBINATIONS FOR COLD CONDITIONS

Hannu Anttonen, Katja Kinnunen , Juhani Niskanen.*

Oulu Regional Institute of Occupational Health, Oulu, Finland
* corresponding author hannu.anttonen@ttl.fi

Introduction

The aim of this research project was to improve hand performance in cold conditions. Due to marked cold problems in hands, a hand wear system for different conditions was developed in co-operation with Finnish Defence Forces in the area of the Northern Finland among conscripts, during military exercise and in the cold laboratories.

Methods

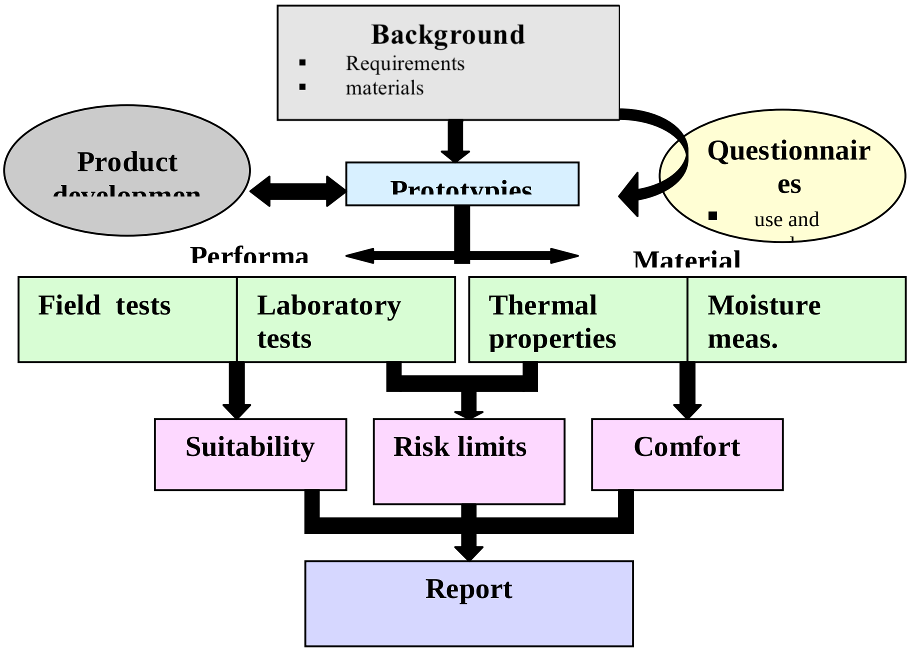

Figure 1. Study Design

Both human and material measurements were performed in this project. Questionnaires and physiological measurements were used in human studies. In physiological measurements, carried out either in field or laboratory, skin temperature and physical performance were determined. Material measurements were performed by using thermal manikin, sweating hot plate as well as hand and foot models.

Results

Because the performance of hands is of vital importance, we tested in laboratory and field tests both survival and dexterity of developed gloves for military tasks. The aim was to determine the system of hand wear suitable for temperature range from -40 C to 30 °C. To find out the solution we made field queries, clothing physiological measurements, performance and survival tests.

The needs concerning gloves in key military tasks were determined. A good combination of hand wear for winter use consists of an inner glove, a mitten shell and an insert combination, fingered winter glove with membrane and extreme cold weather mitten put on the normal hand wear. According to questionnaires most tasks in all task groups were carried out barehanded (40 - 70 %) due to gloves affecting the performance. Cold caused greatest problems in the task groups of shooting, communications and repairs .

The thermal insulation of the gloves was measured using a standardised hand model and contact cooling speed with a finger model. According to the measurements, the addition of glove layers increased the thermal insulation when dry. In damp and in windy conditions the effect of layers decreased because damp inner gloves conduct heat. Adding a membrane increased thermal insulation in damp measurements, the effect on mittens being 42 %. Contact cooling was distinctly quicker with fabric gloves than with leather ones.

Table 1. The effect of different parameters on thermal insulation of fingered gloves and mittens (%). Wind was 4 m/s (3).

Parameter	**Finger.glove**	**wind**	**wind**	**Mitten**	**wind**	**wind**
	dry (%)	**wet (%)**	**wet (%)**	**dry (%)**	**dry (%)**	**wet (%)**
Effect of wind	-45			-27		
Thin underglove	10	34	16	13	15	-10
Lining	22	54	21			
Inner mitten				46	62	61
Membrane	10	14	16	8	7	11

Survival and performance using seven different glove combinations were tested (+2 °C and -20 °C, 2 m/s) with six volunteers. The effect of glove thickness and finger skin temperatures on shooting accuracy, magazine loading and survival was determined. Gloves had a significant statistical effect on the results. The thin inner glove can be considered the best and the fingered winter glove with lining the worst. The lining decreases the performance measured as time delay by 11 % and the stiffness of glove material by 18 %. From gloves with different trigger finger solutions, results were least affected when a knitted trigger finger mitten was used. The performance in the loading test decreased as the thickness of the glove increased. The effect of hand temperature on the diameter of the shooting pattern was 1.5 mm/°C. The time spent on loading when using leather gloves grew by 50 % in warm and 30 % in cold (-20 °C) compared to barehanded times. In cold conditions thin inner glove didn't decrease the performance but it increased finger temperature. By using the glove correctly the hand skin temperature could be lifted by 15 °C in short term and 5 °C in long term exposure.

According to reference values finger temperatures can be retained above 0 °C at ambient temperatures over -10 °C wearing the recommended gloves. At the temperatures of -20 °C frostbite in hands are likely, if heat production of the subject drops below 200 W. Even with good gloves light work can not be done longer than 2 to 4 hours in -20 °C. Thermal balance of the body effects on finger temperature 10 to 15 °C.

Discussion and conclusions

According to the field questionnaires the hand wear needed development most often. Especially exact work in wet condition was the most problematic and very often these tasks were done barehanded. However, at temperatures of -20 °C frostbite of the hands is likely, if heat production of the subject is low. The thermal balance of the body effected on the finger temperature more than by 10 °C. The effect of lining and semipermeable lining was also important on thermal insulation. Although gloves always decrease the performance of hands, it also improves it in cold conditions by raising the skin temperature.

Concerning individual gloves, better protection of the wrist, choosing the right size of glove, use of inner contact gloves, development of a lined glove with membrane, use of membrane in mitten shell and insert combination and use of trigger finger mitten in connection with mitten shells still need to be considered.

Acknowledgements

The study was financed by Finnish Defence Forces. The help of all subjects and units participating in the study is gratefully acknowledged.

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USING 3D WHOLE BODY SCANNING TO DETERMINE CLOTHING AREA FACTOR

Chuansi Gao, Kalev Kuklane and Ingvar Holmér

Thermal Environment Laboratory, Division of Ergonomics and Aerosol Technology, Department of Design Sciences, Lund University, Box 118, 22100 Lund, Sweden

Introduction

To determine the intrinsic/basic clothing thermal insulation, a thermal manikin is used in climatic chamber to measure the total thermal insulation of clothing, which is dependent on the intrinsic clothing insulation and surrounding air layer insulation (1). The latter is usually measured using a nude thermal manikin. However, the surface area of a clothed body is larger than nude body area. Increased surface area increases also the dry heat transfer from the surface to the surrounding environment. Therefore, a correction using clothing area factor is needed.

Clothing area factor (fcl) is the surface area of the clothed body (Acl) divided by the surface area of the nude body (AD) (1). For manikin, clothing area factor (fcl) is the surface of the clothed manikin (Acl) divided by the surface area of the nude manikin (A) (2).

fcl = Acl/AD (for clothed body)
fcl = Acl/A (for clothed manikin)

ISO 9920 (2) recommends a photographic method to measure fcl. Pictures of the projected area of the nude manikin are compared with pictures of the projected area of the clothed manikin from the same directions. Pictures of the projected area are taken from six directions. Another method using computer aided anthropometric scanners was cited by Parsons (1).

The objective of this investigation was to use a new 3D whole body scanning method to determine fcl using human subjects, and to compare the results with those obtained by photographic method (2 photos, front and side) on manikin (3).

Method

Clothing

Nine types of clothing were worn by the subjects (Table 1 and 2). “Nude” subjects only wore briefs.

Subjects

Four male subjects participated in the 3D whole body scanning (Table 3).

3D body scanner and software

VITUS/smart 3D whole body scanner (Human Solutions, Germany) was used, which is a modular system and consists of four thin columns (standing in the four corners of the scanning cubicle). The total base is 200 x 180 cm, it is 275 cm high. Each column is equipped with two CCD cameras and a laser. The scanner operates by laser triangulation. VITUS/smart’s software is based on Windows NT. The body only needs to be scanned once for nude and for each clothed condition by optically lasers in about 15 seconds for each scanning. The standing still position and posture remained the same for each scanning, which measures 100,000 points from 43 tailor’s measurements. This high resolution scan produces digital 3 D images (Figure 1).

Using Adobe Photoshop program, the pixels of the digital 3D images can be calculated at any angle and direction. In this investigation, pixels were calculated by manipulating the image into four azimuth angles: 0o (front), 30o, 60 o and 90 o (profile), and four altitudes angles: 0 o (horizontal), 30 o, 60 o and 90 o (vertical) at 0o azimuth angle. Therefore totally 8 (4+4) images were used for the area calculation of each clothing condition for each subject. The pixels were counted for nude and for dressed conditions, respectively and the ratio was calculated.

Clothing area factor for each subject and each type of clothing and nude condition was estimated according to the following formula.

$$f_{cl} = \frac{\sum_{i=1}^{8} p_{cli}}{\sum_{i=1}^{8} p_{ni}}$$

where i designates the angle, pcli is the pixels of angle i of the clothed image, pni is the pixels of angle i of the nude image.

Table 1. Clothing type and weight

Clothing	Garment (see Table 2)	Weight (g)
U1 (HH1)	Underwear 1, socks 1	337
U2 (Ulf 1)	Underwear 2, socks 1	912
M1 (HH1+HH2)	Underwear 1, intermediate, socks 1	1562
M2 (Ulf1+ HH2)	Underwear 2, intermediate, socks 1&2	2137
Winter clothes A		2996
Winter clothes B		5541
Winter clothes C		7146
Winter clothes D		8075

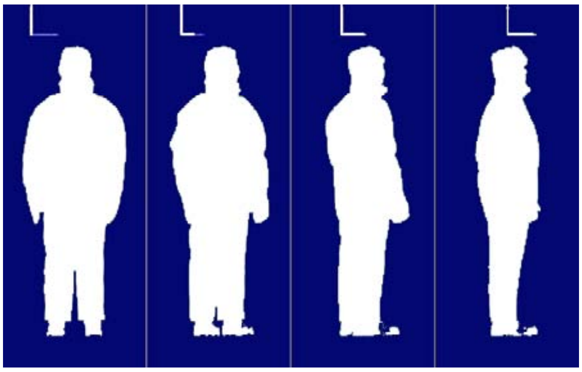
V (office clothes) Subjects' own office clothes for summer use (shirts with short or long sleeves, trousers, and socks)

Table 3. Subject's information

Subject	Height (m)	Weight (nude, kg)	Body surface area∗ (AD, m2, nude)
C	1.74	60.5	1.73
I	1.79	86.0	2.05
K	1.71	90.5	2.02
M	1.83	82.0	2.04

∗ DuBois surface area (4)

Figure 1. Scanned sample images, viewed from four azimuth angles: 0o(front), 30o, 60 o and 90 o (profile).Calculation



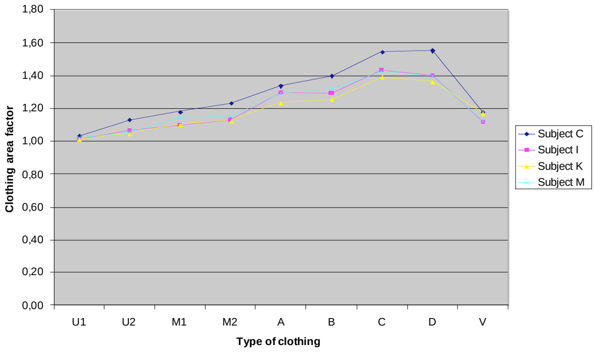
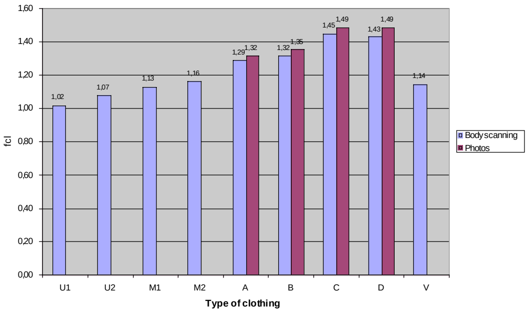


Figure 2 (right). Clothing area factors (fcl) of 9 types of clothing worn by four subjects

Figure 3 (below). Comparison of estimated clothing area factor using 3D whole body scanning and photographic (2 photos, front and side) method



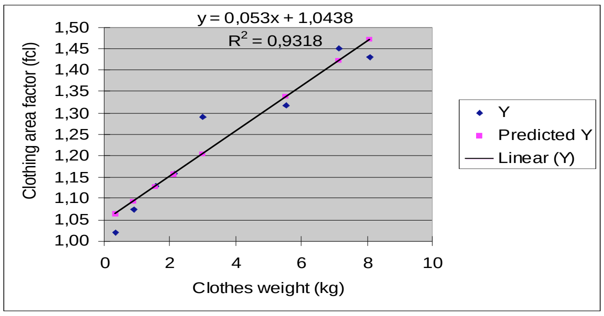


Figure 4. Simple estimation of clothing area factor by clothes weight

In addition to clothes weight, clothes size and subject's body shape and their match also affect fcl. As an example, the body surface area AD of subject C (Table 3) was smallest, which resulted in the fcl as the highest among the subjects (Figure 2).

Results and discussion

The analysis of variance (ANOVA) of the results showed that clothing area factors are significantly different among the nine types of clothing (p< 0.01) and among four subjects (p<0.01) (Figure 2). Clothing area factor estimated on subjects is probably more realistic to be used in IREQ calculation for real work environments than that estimated on manikin. T-test showed that the estimated fcl values are significantly lower by 3D body scanning method than by picture (2 pictures, front and profile) method on manikin (3) among the 4 types of winter clothing (p<0.01) (Figure 3). This difference might be attributed to the body shape difference between the subjects and manikin used and the number of photos used in the pixel calculations.

The regression analysis showed that the clothing area factor is significantly correlated with clothes weight for the 4 types of underwear and 4 types of winter clothing (p<0.01) (Figure 4) although scattering points can be seen. This may be used as a simple and quick method to roughly estimate winter clothing area factor. But it may not apply to other types of clothing.

Conclusions

3D whole body scanning showed that clothing area factors differs among different subjects as well as among the nine types of clothing. 3D body scanning on the subjects generated in general lower clothing area factors than photographic method on a manikin. Clothes weight may be considered as a simple, quick and rough way to estimate winter clothing area factor.

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RESPIRATION AND AIRFLOW PATTERNS DURING INCREMENTAL EXERCISE WITH RESPIRATORS

Ingvar Holmér, Kalev Kuklane, Chuansi Gao*

Thermal Environment Laboratory, Division of Ergonomics, Department of Design Sciences
Faculty of Technology, Lund university, Sweden
* corresponding author ingvar.holmer@design.lth.se

Introduction

Respirators are commonly used to reduce the inhalation of hazardous substances in contaminated atmospheres. The final protection is determined by inherent properties of the filters, the breathing mask and the equipment design, but also factors such as fit, breathing patterns and head movements contribute. Filters are tested for leakage at a constant airflow rate of 95 l/min (EN141, EN143??). Such a flow rate would be expected for only a fraction of the breath during light work and a minute ventilation at around 30 l/min. At higher levels of activity, for example associated with firefighting and rescue and emergency operations, much higher minute volumes are experienced (1-4). Certain types of respirators cannot be used in these condition due to the increased breathing resistance and impaired protection level (5). Technical development, such as filters with lesser breathing resistance and fan-supported respirators, allows more heavy work and longer work periods without unacceptable physiological strain (6). For design of such equipment and for assessment of the final protection offered by the equipment, the respiratory load and the associated air flow dynamics of the respiratory must be known.

The purpose of the present study was to measure metabolic and respiratory responses to incremental exercise with respirators and simultaneously determine the instantaneous air flow pattern during the breath cycle.

Methods and Procedure

Eight subjects (age 36±3, weight 80±11 and height 178±9) volunteered for the study. They were informed about purpose, measures and procedures before giving their consent to participate. They performed a 25-30 min exercise test on a treadmill in a climatic chamber kept at 22 °C and 30-40 % relative humidity. Subjects were dressed in t-shirt, shorts, socks and jogging shoes.

The exercise comprised walking at 5 km /h on a treadmill for consecutive periods of 5 minutes. During the first 5 minutes the inclination of the treadmill was 0 %. After every 5 minutes the inclination was raised by 5 %. All subjects completed walking at 5 km/h and 20 % inclination. Five subjects also managed 1-5 minutes at 6.5 km and 22 % inclination. At the end of the exercise each subject was at or near maximal exhaustion. During the final minute of each work period, the subject read a standard text with load voice at his preferred speed. Measurements were continuously monitored and recorded during minute 3-4 (no speech) and 4-5 (speech). The average of the last 30 sec of each minute was used for the analysis.

Subjects performed the exercise tests on two separate days. One test was done with the Metamax measurements only. The second test was done with the subjects breathing through a respirator. The respirator comprised a half facemask (similar to the Metamax mask) equipped with one particle filter just in front of the mask (Sundstroem SR100).

Oxygen uptake, minute ventilation and airflow rates were measured with Metamax 1 (Cortex, Germany). Special software modules for metabolic and spirometric measurements were used. The flow meter of the Metamax is a turbine with a sampling frequency of 50 Hz. Heart rate was measured with chest electrodes and radio transmission using the Polar system (Polar Electro, Finland).

In the second test with the respirator, minute ventilation and flow rates were measured during the inhalation cycle. This was done by connecting the Metamax flow meter on top of the filter connector. With this arrangement it was not possible to measure oxygen uptake. This requires air sampling through the flow meter during the exhalation cycle. For the analysis the oxygen uptake measured during the first exercise test with the complete Metamax was used.

Results and Discussion

Oxygen uptake increased with inclination of the treadmill (Figure 1). All subjects completed 5 minutes at 5 km/h and 20 % inclination. For 3 subjects this was maximal work and they stopped due to exhaustion. The average oxygen uptake at 5 km/h and 20 % was 3,36 l/min (table 1). Two subjects continued a few minutes at 6 km/h and 22 % until exhaustion. Another three subjects completed also this activity for 5 minutes, but admitted that they were close to exhaustion. For 3 of the subjects oxygen uptake was higher than 4 l/min when they stopped (Figure 1).

Respiratory minute ventilation was almost linearly related to oxygen uptake for all activity levels (Figure 2). The regression line indicates a respiratory exchange ratio of about 27 l of air per minute for 1 l of oxygen per minute. During speech the inhalation times is shortened, as more time is needed for talk during exhalation. Minute ventilation is reduced by approximately 10 %, in particular at high activity levels (Figure 2).

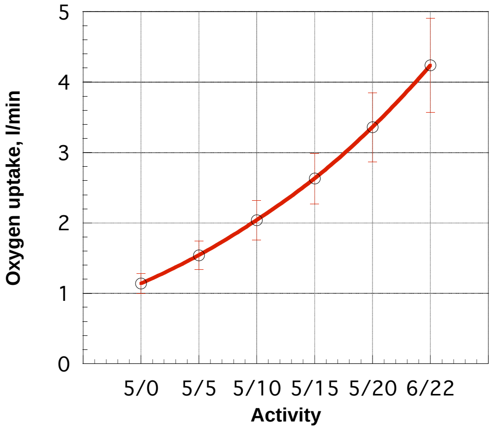

Figure 1. Oxygen uptake in relation to work for 8 subjects (3 at 6/22).

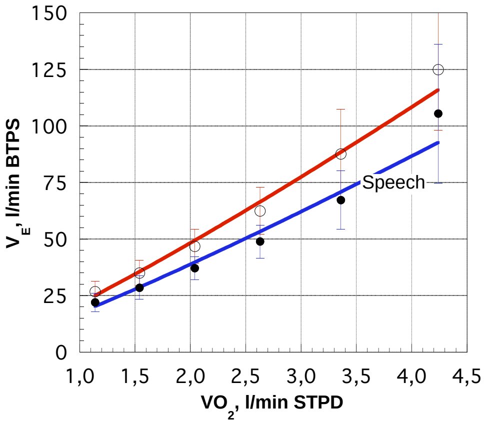

Figure 2. Minute ventilation in relation to oxygen uptake for periods of speech and no speech

Table 2 shows results for the final work period that all subjects completed. Oxygen uptake at this activity level was 3.36 l/min. Corresponding metabolic rate was 582 W/m^2. Minute ventilation was 93 l/min. In this study it was possible to measure the peak inspiratory flow rates (PIFR). The mean PIFR at a minute ventilation of 93 l/min was 4.4 l/sec (Figure 3). The highest individual PIFR during the 30 sec sampling period was approximately 10 % higher. The value during speech was 5.9 l/sec. The peak inspiratory flow rates (PIFR) during the test are given in Figure 3.

Table 1: Mean values and 1 S.D. for measured parameters for 5 km/h and 20 % inclination.

Subjects N=8	VO_2 (l/min) STPD	VO_2 ml kg^{-1} min^{-1}	M (W/m^2)	V_E (l/min) BTPS	PIFR (l/sec) BTPS	PIFR (l/sec) BTPS Speech
Mean	3.36	42	582	93	4.4	5.9
1 S.D.	0.49	2	89	20	0.5	0.6

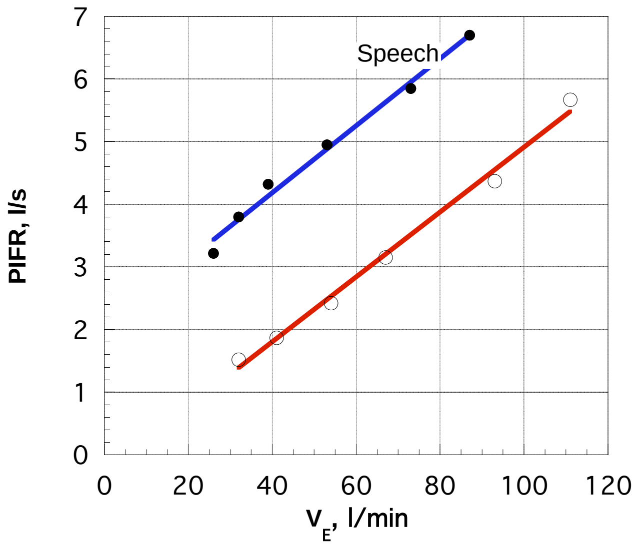

Figure 3. Peak inspiratory flow rates in relation to respiratory minute volume.

It is clear from Figure 3 that PIFR increases linearly with minute ventilation. During speech the curve is shifted upwards by approximately 2 l/sec. Accordingly, the percentage increase in PIFR is higher at low minute volumes.

Berndtsson (6) reported similar results from measurements on subjects during incremental bicycle exercise with filter respirators, although his subjects did not reach as high activity levels as in this study.

Conclusions

High work rates can be sustained for several minutes with modern type of passive filter respirators, at least when particle filters are used. Minute volumes may exceed 100 l/min and is associated with instantaneous flow rates in the mask that exceeds 4-5 l/sec. During speech the flow rate is further increased by about 2 l/sec. Such high peak flow rates necessitates that filters be tested at higher flow rates than are required in today standards.

Acknowledgements

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INWARD LEAKAGE IN RESPIRATORS

Lars Ronner

Sundström Safety AB
Lagan, Sweden
lars.ronner@srsafety.se

Introduction

The final protection offered by a respiratory protective equipment is much determined by the inward leakage through the mask. This leakage is influenced by many factors such as design, connections and filters but also by individual factors such as fit, face form, beard or not are important. Several authors have reported values for inward leakage under more or less realistic user conditions (1-5)

Methods

This study was performed at Sundstrom Safety AB in Lagan, Sweden. Twelve test subjects, nine male and three female, participated in the study. No beard growth was allowed. General physical fitness was established with each subject before the test. Subject data were on average: age 35 years, weight 82 kg and height 1.8 m.

Four different RPD’s (Sundstrom Safety AB, Lagan, Sweden) with different performance characteristics were used (See Table II).

Table 1. RPD used for this test

Respirator model	Class
Hood SR 520 + Fan unit SR 500	TH3
Hood SR 530 + Fan unit SR 500	TH3
Shield SR 540 + Fan unit SR 500	TH3
Full Face Mask SR 200 + Fan unit SR 500	TM3

Note: TH3: 0.2%, TH2: 2%, TH1: 10%, TM3: 0.05%, TM2: 0.5%, TM1: 5%
According to European standards EN 12941:1998 and EN 12942:1998

The fan unit SR 500 was equipped with two combined filters (Gas filter SR 597 ABEK1, particle filter SR 510 and pre-filter SR 221). The fan unit is calibrated at one particular flow, 175 l/min.

Table 2. Performance Characteristics of the RPDs Used Test Flow Rate 175 l/min

Respirator Model	Inhalation (Pa)	Exhalation (Pa)
SR 520 + SR 500	15	143
SR 530 + SR 500	20	181
SR 540 + SR 500	4	151
SR 200 + SR 500	49	200

Note: Pressure measured according EN 12941:1998 and EN 12942:1998

Test Equipment

Ergometer

A bicycle Ergometer (Monark 839 E, Monark Exercise AB, Vansbro, Sweden) was connected to a computer, and calibrated in accordance with the manufactures instructions. A test protocol was developed by means of the software supplied with the bicycle. The heart rate was measured using a heart rate monitor (Monark 839 E Analysis Software with Monark chest belt).

Aerosol chamber

The tests were made in an aerosol chamber, (Sundström Safety laboratory)

Aerosol generator

Equipment for aerosol generation (Regener) was used to generate a corn oil aerosol, the test aerosol produced by this generator is polydisperse. The particle size distribution is a logarithmic normal distribution with the medium stoke diameter of 0.4 micron (for the number distribution).

Aerosol measurement

The inward leakage was measured with an Aerosol Photometer (ATI TDA-2G).

Atmospheric pressure measurement

The atmospheric pressure in hPa was noted at each test with a barometer, Testo 511.

Data collection

All data were collected and placed together in two computer programs, Dasylab 6 and Microsoft Excel.

Pressure measurement

The pressure inside the RPDs, was measured with Digima FP Special Instruments.

Temperature and humidity measurements

Temperature and humidity were recording by GHTU 2K HO Greisinger electronic.

Figure 1. Full face mask SR 200 with fan-unit SR 500.

Test procedures

The subjects were dressed in gym clothing (shorts, t-shirt and sneakers). All test subjects were in good health.

A medical doctor performed a physical examination. An introduction was given as to the procedures of the test, after which the test subjects had an opportunity to familiarize themselves with the different test masks. The test was divided into seven five-minute periods, each with a different external workload. The external workloads used were:

50, 75, 100, 125, 150, 175 and 200 W

Table 3. Summary of leakage per minute

Workload (W)	n*	Inward leakage third minute**	speech minute**	fifth minute**
RPD Model SR520				
100	11	0,0005	0,0033	0,0007
200	2	0,0072	0,0264	0,0264
RPD model SR530				
100	12	0,0009	0,0010	0,0011
200	3	0,0019	0,0020	0,0020
RPD Model SR540				
100	11	0,0014	0,1853	0,0248
200	2	1,0701	1,8446	1,9595
RPD Model SR200				
100	10	0,0016	0,0015	0,0012
200	3	0,0046	0,0057	0,0069

* n represent number of data sets.

** The inward leakage was measured in percent where 100% represent by the surrounding test atmosphere.

During the fourth minute, the test subject was asked to read alphabet aloud for one minute. During the fifth minute (the recovery minute), the subject pedalled without any interference. At the end of the fifth minute, the Ergometer automatically increased the workload by 25W. The protocol was then repeated. The test officer terminated the test if the test subject felt uncomfortable, or when the theoretical max heart rate was reached (227 minus the subjects age for women or 220 minus the subjects age for men), whichever occurred first.

Data Collection

Pressure, inward leakage, temperature and humidity were collected the entire test at 14 samples per second and presented as one average value per minute in the three last minutes in each five-minute period.

Results and discussion

As expected there is a variation inward leakage among the different types of respirators and at different levels of activity.

The highest protection is offered by the units 530 and 200. These are the units that offers the most efficient tightening against the human face. The effects of exercise is also small with these types of respirators.

The other two models provide slightly lesser protection and is also more sensitive to the effect of exercise.

Conclusions

It can be concluded that it is possible to achieve very high protection with fan-operated filter respirators. The design of the head and face mask, however, is also important for the final protection value. The body motions associated with physical exercise affect protection – more so for respirators with less tight fitting around the head and face.

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EFFECTS OF HEAT AND MOISTURE TRANSPORT IN FIREFIGHTER A STUDY OF THE EFFECT OF UNDERWEAR ON PHYSIOLOGICAL PROPERTY AND THERMAL PROTECTION IN FIREFIGHTER’S CLOTHING ASSEMBLY

Yu-wei Lin[1*], *Gwo-tsuen Jou*[1],*Martin Camenzind*[2], *Georg Bruggmann*[2], *Walter Bolli*[2], *Rene’ Rossi*[2]

[1]Center of Testing and Certification, Taiwan Textile Research Institute, Chinese Taipei
[2]Laboratory for Protection and Physiology, EMPA, St. Gallen, Switzerland
*corresponding author

Introduction

It is commonly recognized that firefighters are required not only to execute their work in an extremely hot environment with highly insulating and heavy clothing, but also to cope with time and their phsiological condition. The ambient temperature during fire incident is very high as well (typical work condition reported by Abeles et al. 38 °C to 66 °C [1]), which restricts the evaporative cooling. As a result, an appropriate clothing system is required to buffer the heat and moisture effect on human body and prolong the tolerant time in this enviorment. Barnard and Duncan [2] investigated the influence of the highly insulating clothing of firefighter’s turnout suits on the heart rate, oxygen uptake and other physiological parameters. They reported that firefighters sometimes have to work for a certain period of time near or at the maximum heart rate due to the heat stress derived from their equipment and firefighters’ suits [3]. It is considered to be a very important task to do on the study of physiological properties and thermal protection through the selection of appropriate underwear for entirely protective clothing system.

Material and Method

Four different underwear and eight types of firefighter’s clothing were prepared by Taiwan Textile Research Institute (TTRI) and EMPA. The mateial and basic properties of garments were listed in Tables 1 and 2:

Table 1 Properties of the underwears

Code	Material	Weight
UCOM	Coolmax	117.7g
UCOT	Cotton	231.5g
UCPE	70% Cotton, 30% Polyester	235.4g
UTHM	Soft thermo	220.0g

Table 2. Properties of the protective clothing

Code	Out shell	Moisture barrier	Thermal Liner	Weight
FTJAP	100%Cotton coated with aluminum powder	---	---	1977g
FTUSA	100% Nomex quilt	Neoprene + Polyester / cotton fabric	100% Nomex III	2728g
FTCTI	Preoxidized PAN + Para -aramid	Gore-Tex + Nomex nonwoven	100% aramid nonwoven +100%Nomex RS lining	1956g
FTEUR	100% Nomex Delta TA	Sympatex +Nomex/Viscose FR backing	100% aramid nonwoven +Nomex/Viscose FR lining	1617g

FTTWN	60%Kevlar+40% Nomex	Sontara E89+FR Aerotex membrane	100% Sontara E quilt + Nomex/Viscose FR lining	1613g
FTIMP	NomexIII	impermeable PU coating on the innerside of out shell	Wool and FR viscose lining	1733g
FTLEA	Chrome tanned goat leather	---	Aramid fleece(kermel)/quilted with FR viscose lining	3287g
FTBRE	Nomex Omage	Goretex laminated to fleece	Aramid fleece(kermel)/quilted with FR viscose lining	1829g

Microclimate measurement

The microclimate temperature near the inner side of underwear for totally clothing system, which included a underwear and firefighting clothing, was examined by the Sweating Torso in EMPA. The clothing was placed on the Torso in a way in which the folds were avoided and the fabric was in close contact to the apparatus surface. The experiment was conducted in 4 phases as shown in Table 3, which illustrates the measurements on the combinations between underwear and jackets.

Table 3. Phase profile

Climate	Phase 1	1 h, Torso at 35°C dry thermal insulation
20 °C and 65 % R.H.	Phase 2	Moderate metabolic rate and sweating: 3/4 h, metabolic rate 82.5 W (350 W/human), 100 g/h sweat rate (415 g/h human)
	Phase 3	Recreation 3 h, Torso at 23.5 W (100 W/human)
	Phase 4	high metabolic rate and sweating: 1/2 h, metabolic rate 118 W (500 W/human) 300 g/h sweat rate (1250 g/h human)

Radiant heat protection

Normally firefighters executing their job will keep a certain distance from the fire. In this circumstance only low to intermediate heat exposures are experienced. To simulate such a low risk scenarios a radiant heat source in combination with an instrumented manikin “Henry” was used. Nine sensors in chest region were selected in the analysis of this protection as these sensors with reliably good contact with the manikin surface and lined up to the radiant source. The maximum temperature and heat flux after 5 minutes under 5 KW/m^2 and 3 minutes under 10 KW/m^2 of heat exposures were determined. The burn risk was also evaluated through the response of 22 sensors (10 in chest and 12 in abdomen) on manikin “Henry”.

Result

Microclimate measurement

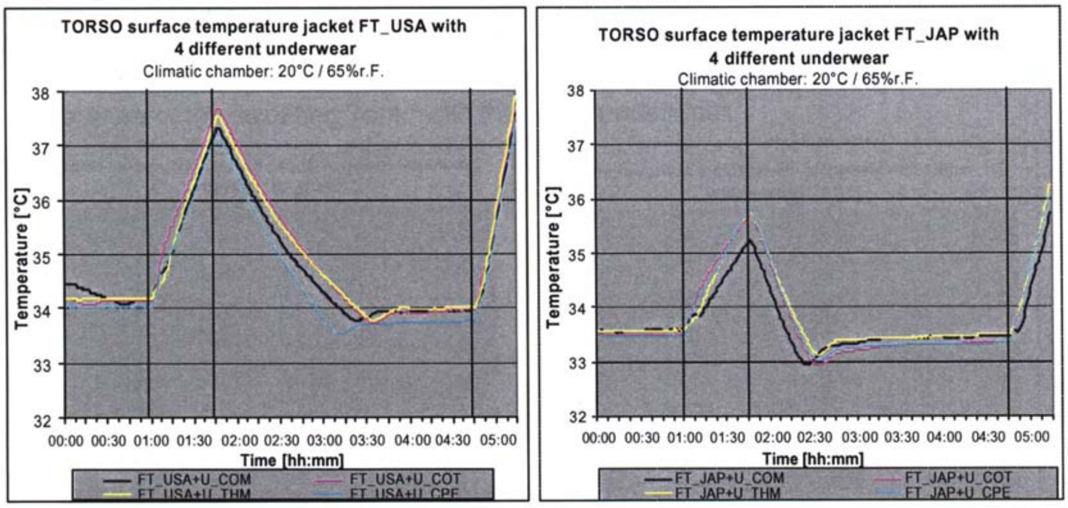

Figure 1 The variation of microclimate temperature for different underwear when FTUSA and FTJAP were dressed.

Figure 1 shows that the behavior of microclimate temperature in four phases for different underwear as jacket FTUSA and FTJAP were dressed. The trends for the other samples behaved somewhat similar. In general, the temperature rise for UCOT (cotton) is the highest among four different underwear material composition due to the fact that it absorbed water at the beginning and evaporated after a while when the material was sufficiently moistened. This can be seen in the diagram from the different slope of the temperature rise after approximately 10 minutes of phase 2 for the samples containing cotton.

In order to have a better estimation of the influence of the underwear on the microclimatic temperature, an average temperature for different jackets has been plotted, and the result is shown in Figure 2. It clearly demonstrates the above mentioned tendency of the different underwear. At the end of phase 2 a clear ranking can be observed for four underwear materials ranging from UCOM with the most efficient evaporation cooling to UCOT with the highest temperature peak. The differences are even bigger when the samples are compared after ¼ hour. For a short period of high physical activity, sample UCOM might be the best choice. Sample UCOT scores the least favorable results due to the hygroscopic properties of cotton. It can be seen that the influence of the underwear is more obvious for moderate physical exercise than for heavy sweating (Figure 2 sweating phase 1 and 2). It seems that the type of underwear is not so significant when a certain amount of sweat is generated and is released from the body.

Radiant Heat protection

Table 3 shows the maximum temperature and average heat flux measured during the 5 kW/m^2 tests.

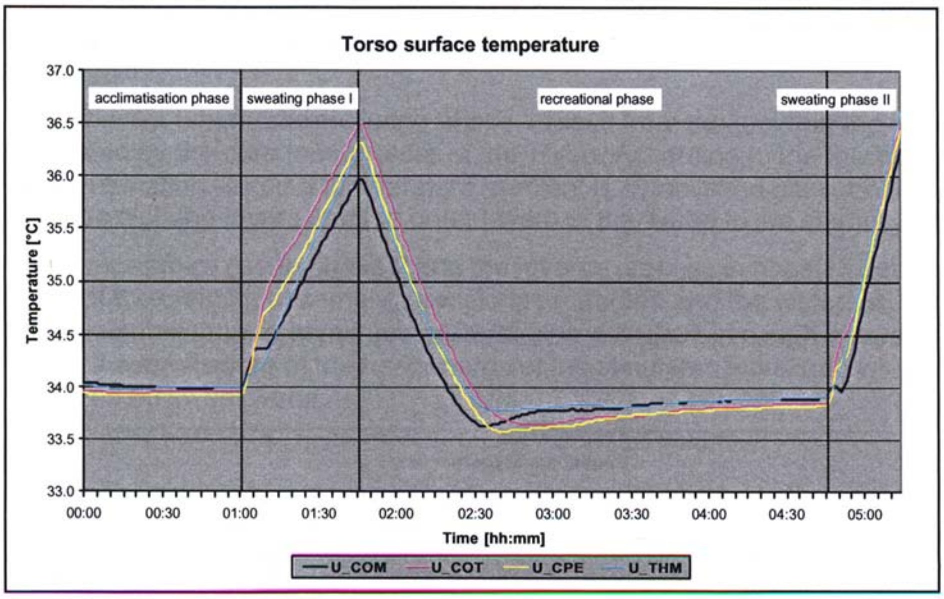

Fig.2 The average influence of the underwear on the mircoclimate temperature

Table 3 Average Heat Flux and maximum temperature for wearing different clothing system

Firefight suit	underwear	Heat flux	Max. temp. /Chest		Firefight suit	Underwear	Heat flux	Max. temp. /Chest
FTIMP	UCOM	930.6	58.2		FTJAP	UCOM	879.7	54.9
FTIMP	UTHM	887.9	45.7		FTJAP	UTHM	689.7	43.8
FTLEA	UCOM	582.3	43.3		FTTWN	UCOM	733.7	41.1
FTLEA	UTHM	631.5	39.1		FTTWN	UTHM	668.9	42.2
FTCTI	UCOM	796.2	40.0		FTUSA	UCOM	496.3	39.3
FTCTI	UTHM	778.5	37.7		FTUSA	UTHM	484.6	42.5
FTEUR	UCOM	838.9	51.7		FTBRE	UCOM	376.6	38.5
FTEUR	UTHM	991.6	48.0		FTBRE	UTHM	392.2	36.7

In Table 3, it shows that the average maximum temperature is roughly 3 % lower for UTHM compared to UCOM. UTHM also reduces the average heat flux by approximately 2 % (mean value over all samples). Compared the heat flux to the burn risk shown in Figure 3, the result indicated burn risk condition heavily depend on the intensity of the incident heat flux in which the clothing system can allow to pass through. These results indicated that the underwear may affect the protection of clothing assembly even though the influence is not so obvious as that of the firefighter’s suit.

Conclusion

In order to be able to cope with the extreme requirements for firefighters’ garments, the whole clothing system including underwear should be integrally considered. As firefighters are obliged to execute strenuous tasks in warm environment wearing highly insulating garments, underwear material which has good cooling and better thermal insulation property has been considered to be a very important factor in optimizing a firefighter’s clothing system assembly.

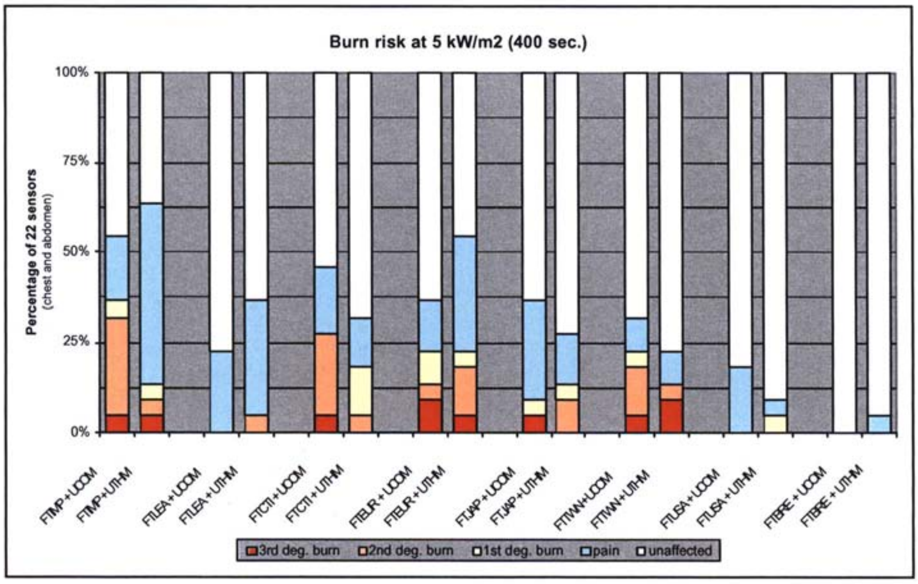

Fig. 3 Burn risk at 5kW/m^2

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MONITORING THERMAL STRESS OF FIREMEN DURING TRAINING IN REALISTIC WORKCONDITIONS

Ronald Heus [1]*, *Ed S. Schols* [1], *John W.M. Willems* [1], *Emiel A. den Hartog* [2]

[1]Dept. of Product Ergonomics, TNO Science and industry, Eindhoven, The Netherlands
[2]Dept. of Human performance, Business Unit Human Factors, TNO Defense and safety, Soesterberg, The Netherlands
* corresponding author ronald.heus

Introduction

Fire fighters and heat stress seems to be a logical combination. However, fire fighters in the Netherlands are only 5% of their working time exposed to heat and flames (Schols et.al, 2003) and work even less time in indoor fire attacks. Their own heat production during work is even a larger problem[1] , accompanied by sweat production as a potential identified risk for skin burns, the so called "steam burns"[3]. During realistic training, fire fighters are regularly exposed to high temperature environments. In these activities thermal, physical and mental stress can be (very) high. To study these risks on skin burns, we carried out measurements of various physical parameters during realistic training conditions. An important issue was that it was not allowed to hinder the fire fighters during their normal training activities and routines.

Figure 1. Example of a realistic training situation

Method

In November 2004 four different brigades of the Utrecht region in the Netherlands have participated in training sessions. The focus was to train in realistic fire fighting circumstances which was carried out at the Swedish Rescue Services Agency (SRSA) in Revinge (Sweden). Exercises implied various fires in cellars, apartments, houses and complex company buildings as well as flash over situations.

During various training sessions temperature and humidity were recorded at three sites (arm, breast and back) every 10 seconds. We collected data on four fire fighters of one brigade each day. So data of 16 subjects were collected at the end of the training week.

The sensors (Feuchte / Temperaturlogger DK 812, Driesen + Kern GmbH, Germany) were situated on the skin as well as on the underwear of the subjects. To have an indication of the workload during their jobs, heart rate was recorded every five seconds (Polar S 810, Finland) and in some cases breathing parameters were recorded.

Results

Temperature humidity measurements and heart rates

Only the data of the fire fighters who entered the buildings with the fire were analysed. The maximum temperatures, relative humidity and heart rates of the subjects, averaged per exercise, can be seen in table 1. The last column of the table shows the intensity of the complete action.

Critical temperatures for potential skin burns were only seen in some of the exercises on the third and fourth day of the training week. These were exercises with complex situations in which some of the fire fighters were inside the building, near the fire for more then 30 minutes and during which skin temperatures were above 40ºC for about 5 minutes.

Table 1. Maximal temperature, maximal relative humidity on skin and underwear, maximal heart rate and mean heart rate during exercise.

Day	Exercise	subjects	T skin	T underwear	RH skin	RH underwear	HR max	HR average
1	1	2	36.7	34.3	77.9	62.0	156.0	134.5
1	2	2	33.9	31.0	85.4	74.0	126.5	106.5
1	3	4	33.3	28.7	80.3	74.8	151.7	122.4
1	4	2	33.3	30.8	90.5	93.1	123.0	91.3
1	5	2	34.0	30.4	92.2	85.8	165.0	133.4
2	6	3	33.9	28.0	88.3	75.2	150.0	107.1
2	7	4	33.1	30.1	80.5	88.2	156.7	97.7
2	8	1	31.9	25.3	58.5	62.1	121.0	92.7
2	9	2	34.0	27.4	79.3	71.0	168.5	113.1
3	10	4	33.6	30.7	79.8	65.6	164.0	139.3
3	11	4	32.3	29.2	85.1	75.5	166.7	137.5
3	12	4	32.0	28.7	87.2	80.7	163.3	123.7
3	13	4	38.4	39.2	94.8	92.7	168.3	129.6
3	14	4	41.1	46.4	96.5	95.5	-	-
4	15	4	37.1	36.5	81.1	75.0	-	-
4	16	3	39.7	49.1	89.7	94.4	-	-
4	17	2	33.5	30.5	95.7	92.2	-	-

Marked cells of the table show critical values, which means mean skin temperatures above 40°C, mean underwear temperatures above 50°C,RH above 90% a HRmax above 160bpm and an average HR above 130bpm

The highest individual temperature measured on the skin was 43.7°C and on the underwear even 57ºC. Humidity on skin and underwear reached values of above 90% within 5 minutes after starting the rescue exercises.

In figure 2 the results are shown of a typical example of a fire fighter being into the burning building for about 20 minutes during which skin temperatures of 42°C were reached. In figure 3 it is shown that the relative humidity can suddenly increase during an exercise from 50% till 95% within 5 minutes.

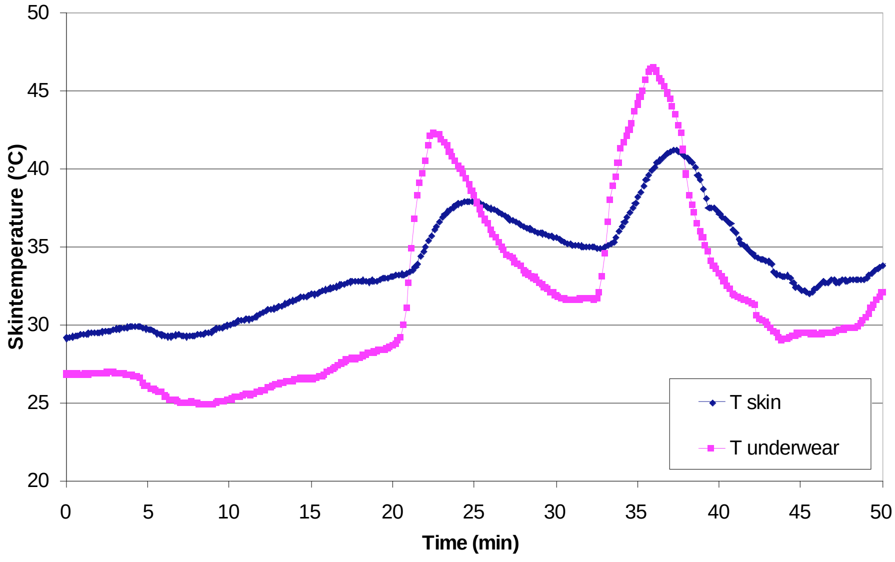

Figure 2. Typical example of skin temperatures (°C) during a training session

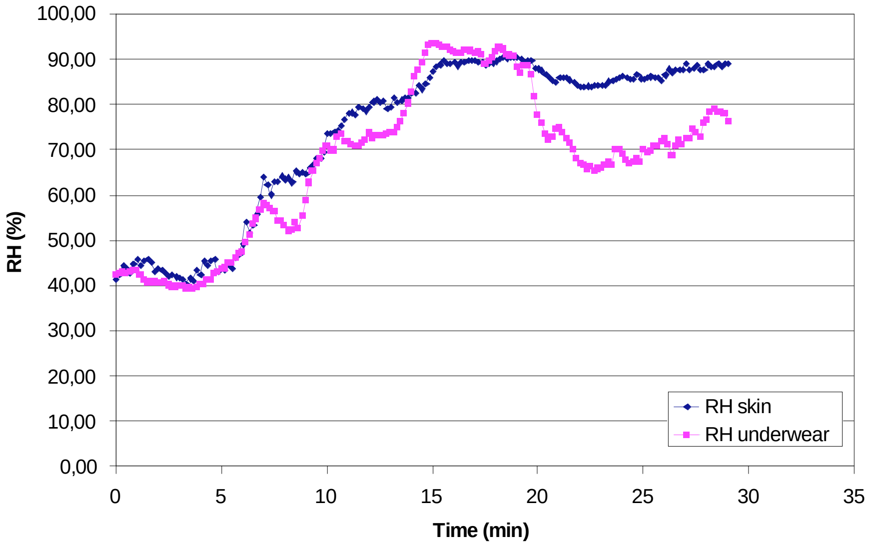

Figure 3. Typical example of increase in relative humidity (%) during a training session

Subjective findings and reports of the subjects

On the third day of the training week a subject attacking an incident and who was inside the building for 20 minutes complained about steam underneath her clothing. The same day during a second large attack she went in again and after 45 minutes inside the building she went out with red spots on her skin. During the latter incident one of her colleagues came out of the building before finishing the job because of steam underneath his outerwear.

Also, on the last two days of the training week more fire fighters complained about the high temperatures and one of the fire fighters got hurt because of steam coming from outside (from the water extinguishing the fire) through the openings of his trousers. During the very last exercise, one of the fire fighters was fully exhausted and was almost unable to report his findings to the researchers. It took more then 20 minutes in a cold environment (about 5°C) to get him on his feet again. Unfortunately we did not measure these individuals when they reported these extreme thermal stresses.

In some cases the fire fighters reported steam and the skin burns and a coolpack was used to relieve the pain.

Discussion

Physical and thermal load vary largely between the exercises. In general, it can be said that the average intensity is not too high, but sometimes very high peaks in the workload were registered. The side effect of repeated expositions to heat must not be underestimated. During the week fire fighters got more and more exhausted, but his was not clearly reflected by the rest heart rates, because every day another group of subjects was followed. The reason to do this is that we wanted to have as many as possible fire fighters entering the fires, as the focus was on skin temperatures and not on work load.

Although some fire fighters reported steam burns, the potential risk (Schols et.al. 2004) was not widely present during the training week. However, this is in line with the actual daily work situation in which only 5% of the fire fighters' working time contains fire fighting and even less concerns indoor fire fighting attacks. Rossi et.al. (2004) reported that with the tendency of making the clothing more breathable and thinner, the risk on steam burns will increase in future.

We also noticed an increased RH after the first exercise. The main cause for these higher values was not changing the underwear after an exercise and certainly not the outerwear. So to decrease a potential risk of steam burns we adviced to change immediately after an exercise underwear and if possible the outerwear.

Conclusions

Physical and thermal stress vary a lot between different sessions. From the data we can conclude that short peaks of high physical stress are noticed during an indoor fire attack.

Thermal stress with risks of skin burns were seen during fires in complex buildings. Peak values of the skin temperature around 44ºC and of underwear temperature of 57ºC were measured. Together with the RH under the clothing of more then 90% the capacity of the evaporation to the environment of the moisture is limited and give a potential risk of steam burns.

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OBSERVATION OF THE THERMAL CONDITIONS AND THERMAL RESPONSES OF THE ELDERLY IN WELL-INSULATED AIRTIGHT HOUSES IN WINTER IN JAPAN

Hikaru Koshimizu[1]*, *Mika Takahashi*[2], *Yumiko Nagai*[3], *Yutaka Tochihara*[4]

[1] Department of Environmental Health, National Institute of Public Health, Wako, Japan
[2] Department of Architectural Hygiene and Housing, National Institute of Public Health, Wako, Japan
[3] Health Science Course, Department of Arts and Sciences, Osaka Kyoiku University, Kashiwara, Japan
[4] Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka, Japan
* corresponding author koshimizu@niph.go.jp

Introduction

Generally, Japanese houses seldom have central heating systems, and the level of insulation of conventional houses is not high. Therefore, there are large temperature differences between the heated areas (living room, etc.) and the others (e.g. toilet, corridor) in the houses. It is known that these large temperature differences contribute to serious medical conditions such as strokes.

Compared to younger people, the elderly's ability to regulate body temperature decreases (1, 2), and they tend to have more diseases. The elderly seem to be affected more than the young by their living environment (3, 4).

Since the lowering of body function with aging causes a decrease in various physiological abilities such as resistivity and adaptability to environmental factors (5-7), it is important for the elderly to secure safe and comfortable residential environments.

Recently, well-insulated and airtight houses are increasing in the Tokyo area. The inside of these houses tends to be kept in good thermal condition and it is considered a good environment for elderly people, especially those who have a risk of hypertension or stroke.

We performed an investigation to examine and compare the thermal environments of conventional houses and well-insulated airtight houses, and the human responses of the elderly who live in there.

Methods

The survey was conducted in the Tokyo area; including Tokyo metropolis, Kanagawa prefecture, Saitama prefecture, and Chiba prefecture. All houses are in the suburbs of Tokyo, within about 1 hour from the center of Tokyo.

The survey was conducted in winter, between December 1996 and February 1997.

The subjects of this survey were 17 elderly people (8 male and 9 female) who were living basically healthy and independently. They were divided into two groups – eight elderly who lived in well-insulated airtight houses (shown as “well-insulated”) and nine elderly who lived in conventional house (shown as “conventional”).

Thermal conditions in and out of the houses, including living room, bedroom, kitchen, toilet, dressing room, bathroom and corridor were measured every 10 minutes for a week by data loggers. Dry bulb temperatures at heights of 0.1, 0.6, and 1.1m and wet bulb and globe temperatures at 1.1m were measured.

As a human response, skin temperatures at seven sites on the subjects were measured by data loggers every two minutes for 25hours during the environment survey. Blood pressures were obtained every one hour except when sleeping by an automatic tonometer. Oral temperatures were also measured with a precision thermometer for five minutes in every hour. As a psychological response, thermal and comfort sensation of the subjects was also measured when blood pressures and oral temperatures were measured.

Results and discussion

Living conditions

Table1. showed the characteristics of the houses and the elderly people who live there. Almost all were wooden houses. Among the eight conventional houses four were relatively old and more than 20 years had

passed since they were built. The rest of the conventional houses were less than 10 years old. All the well-insulated airtight houses were newly built, within three years. The mean age of the subjects was approximately 70 years old. The number of male subjects was 8, and female 9.

Table 1. Conditions of the subjects and their houses.

	Sub.	Sex	Age	Pref., City	Material and Style of the house	Yrs.	BMI
Conventional	NY	F	65	Tokyo, Nakano	Wooden Scaffold	29	24.4
	YM	M	74	Tokyo, Shinjuku	Concrete and Wooden	7	26.2
	MM	M	67	Saitama, Soka	Wooden 2*4	7	19.3
	YC	M	79	Saitama, Misato	Wooden Scaffold	21	18.1
	MI	M	65	Kanagawa, Yokohama	Wooded Prefabricated	10	24.6
	NZ	F	66	Kanagawa, Yokohama	Wooden Scaffold	23	19.9
	SM	M	71	Tokyo, Mitaka	Wooden Scaffold	23	25.0
	TY	F	72	Tokyo, Katsushika	Wooded Prefabricated	2	26.2
	TT	M	69	Tokyo, Katsushika	Wooded Prefabricated	2	19.8
Avg.			69.8			13.8	22.6
Well-insulated Airtight	KN	F	73	Tokyo, Mitaka	Wooden Scaffold	3	18.9
	TN	F	67	Tokyo, Kodaira	Wooden Scaffold	2	22.4
	YG	M	71	Saitama, Fujimi	Wooden Scaffold	1	27.2
	OR	F	74	Saitama, Shiki	Wooden Scaffold	1	27.2
	WN	F	72	Saitama, Iruma	Concrete and Wooden	2	23.3
	OK	M	77	Kanagawa, Zama	Wooded Prefabricated	1	22.2
	OB	M	71	Tokyo, Nerima	Wooded Prefabricated	2	22.8
	IM	F	60	Chiba, Narashino	Wooden Scaffold	3	25.1
Avg.			70.6			1.9	23.6

Mean Skin Temperatures

Figure 1 shows the mean, 10th percentile, and 90th percentile of the mean skin temperatures of each subject. The average values of those data are also shown. On waking, mean skin temperatures in the conventional houses ranged from 32.2°C to 34.2°C, and the mean value was 33.2°C. The values of the subjects who lived in well-insulated houses ranged from 32.6°C to 34.6°C and the mean was 33.7°C, it was 0.5°C higher than in the conventional houses.

The difference between the 10th percentile and 90th of the mean in the conventional houses was more than 2.5°C, but the difference in the well-insulated houses was less than 2°C. The mean skin temperature in the well-insulated houses while sleeping was 35.2°C compared with a significantly lower temperature of 34.7°C in the conventional houses. There was no significant difference between female and male data.

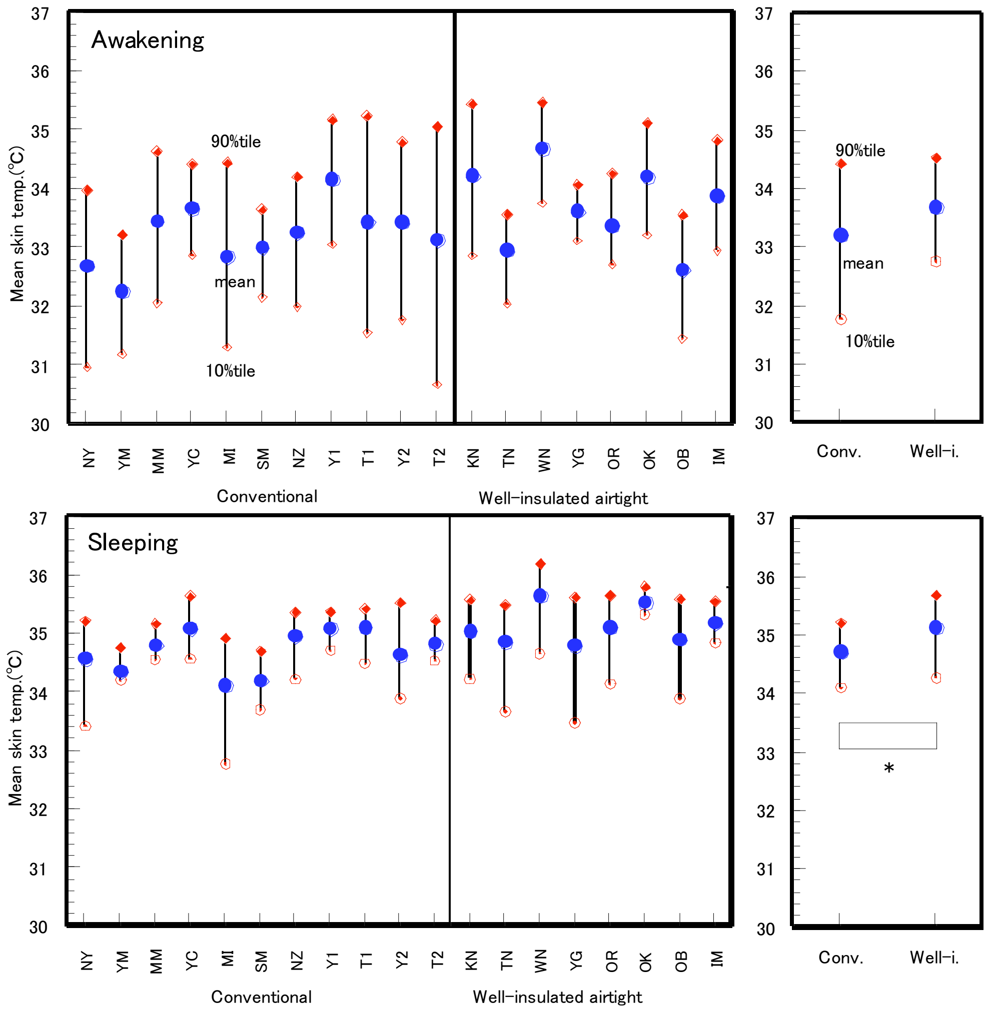

Figure 1. Mean skin temperatures of the subjects during daytime and nighttime.

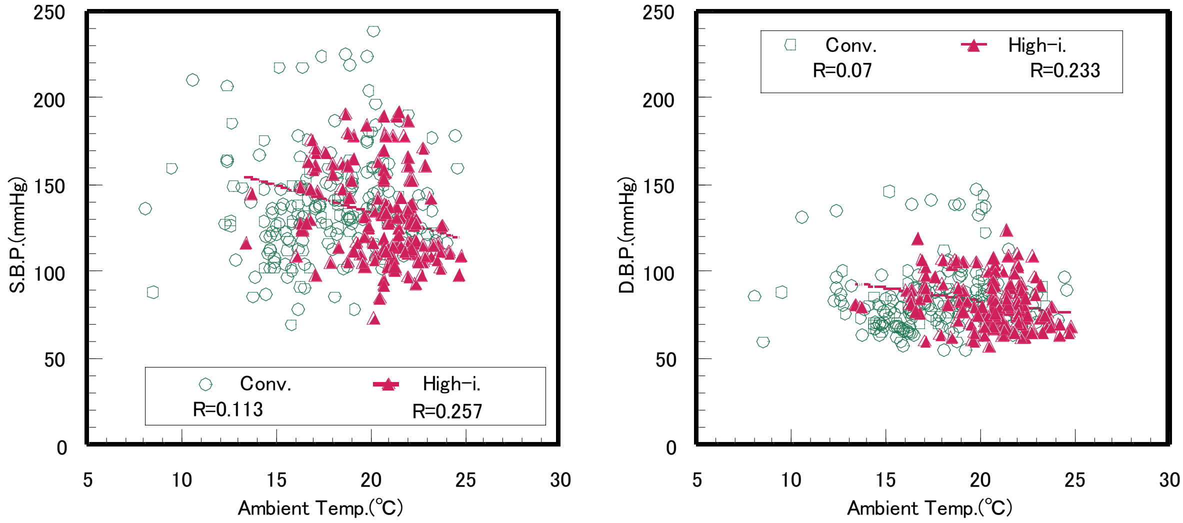

Figure2. Relationship between the ambient temperatures and blood pressures of the subjects.

Blood Pressures

Figure 2 shows the relationship between the ambient temperature and blood pressures of the subjects. The measured systolic blood pressures (SBP) ranged from 70 mmHg to 240 mmHg in conventional houses while in well-insulated houses it ranged from 70 mmHg to 190 mmHg, and the dispersion was larger in conventional houses. The same tendency was shown in diastolic blood pressures (DBP). As temperature rose, blood pressures fell.

Subjective Sensations

Figure 3 shows the mean, 10th percentile, and 90th percentile of the thermal sensation and comfort vote of the conventional and well-insulated houses. For thermal sensation, mean values were 1.2 in the conventional houses and 0.9 for well-insulated houses. But as for the comfort vote, the means of both groups were the same. Not only the indoor climate, but also the state of the clothing of each subject seemed to influence the vote.

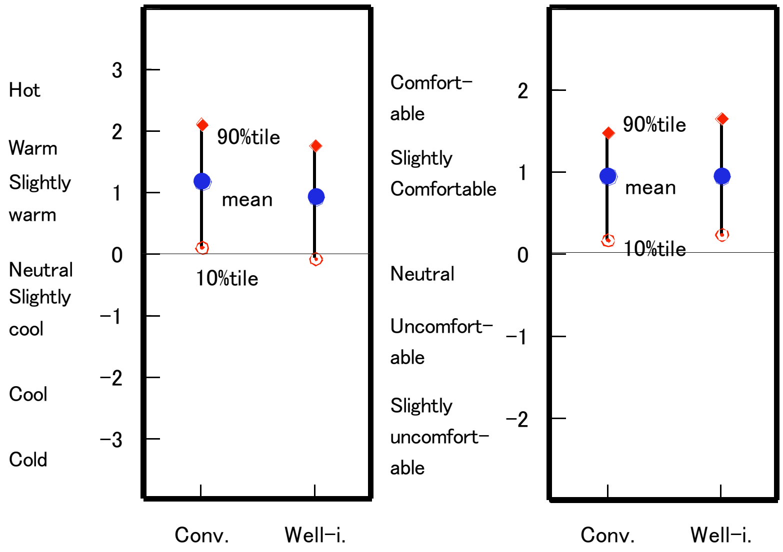

Figure 3. Thermal sensation and comfort vote of the subjects.

Conclusions

It is important for elderly people to have a heating system that includes areas where people do not stay for a long time (e.g. toilet, corridor). It is concluded that well-insulated airtight houses are able to provide healthy and comfortable thermal conditions in winter for the elderly.

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WARM FLOOR IMPROVES PHYSIOLOGICAL AND SUBJECTIVE RESPONSES DURING SHORT-TERM MILD COLD EXPOSURES

Tadakatsu Ohnaka, Tomoko Ueno

Department of Living Environmental Science, Fukuoka Women's University, Fukuoka
* corresponding author ohnaka@fwu.ac.jp

Introduction

Most Japanese do not have central heating systems in their homes, so they heat individual rooms and the use of heating is often restricted to the living room because of the high running cost. Therefore, there are large temperature differences between heated rooms (living rooms) and the others (e.g. toilet, passageways). Recently, an underfloor heat storage system run on diurnal solar radiation and/or electivity and gases, has been installed. That heating system provides warm floors at night when all heaters are off. There are few studies on the effect of warm floor under mild cold conditions which are experienced during winter in Japanese houses on psychological and physiological responses. The purpose of this work is to investigate the thermal responses due to warm floors under cold conditions.

Methods

Environments

A room was a thermo-neutral room (living room) kept at 24°C. The other was a cold room kept at 11, 14, 17 or 20°C. Floor was heated at the surface temperature of 3°C higher than air temperature by an electric keep warm mat. The thermal conditions of this experiment were 11/11°C (air temp./floor temp.), 11/14°C, 14/14 °C, 14/17 °C, 17/17°C, 17/20°C, and 20/20°C, respectively. Air humidity and air velocity were kept at 50-60% and 20 cm/s in both rooms.

Subjects and Clothing

Ten college-aged females served as subjects. The subjects wore standard clothing: shorts, long-sleeved shirts, cardigan sweater, long pants and socks. Total thermal insulation value was 0.75 clo.

This experiment was carried out during November and December. .

Measurements

Tympanic temperature was measured with a radiation thermometer at the beginning and the end of the experiment. Skin temperatures at 8 sites were measured with thermistors every minute. Mean skin temperature was calculated according to the formula of Hardy and DuBois (1). Blood pressure and heart rate were obtained every minute from a continuous blood pressure recorder (KANDS; RBP-100). Thermal sensation and discomfort sensation were asked by using a seven points scale. Acceptability was also asked at the end of exposure.

Procedure

The subjects changed into the standard clothing, and several sensors were attached to their bodies in neutral environment (24°C). They stayed in there for 20 min, thereafter they were exposed to each environment for 10 min. The subjects rested on a chair during the experiments. All data are presented as mean ± SD. The differences among the thermal conditions were compared using an analysis of variance, and in statistical test a value of $P < 0.05$ was accepted as indicating significance.

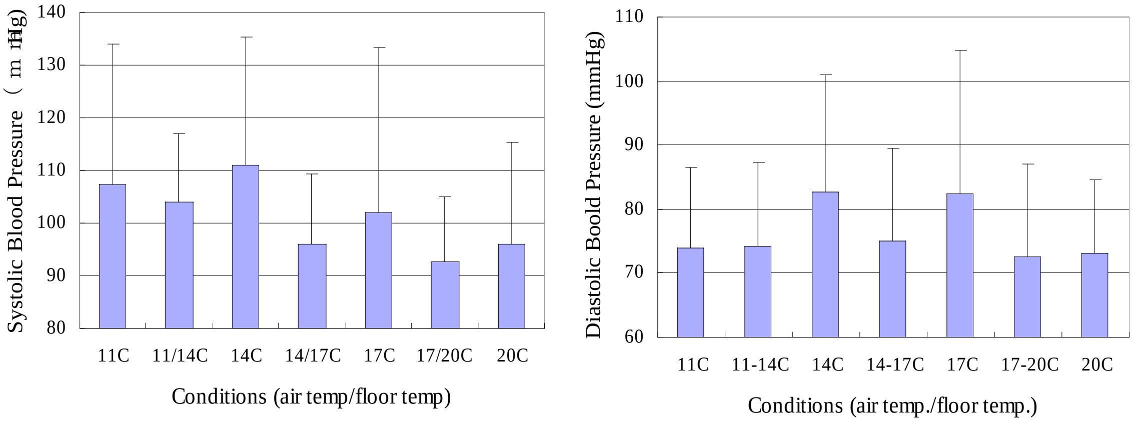


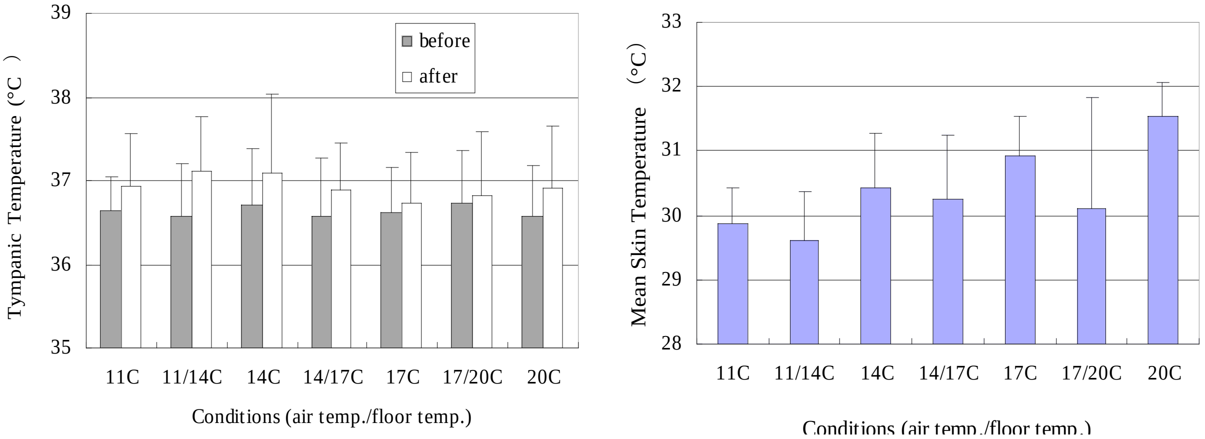
Figure 1. Blood pressures at the end of exposures. (Values are means and SD of 10 subjects)

Results

Blood pressure

Figure 1 showed systolic blood pressure (SBP) and diastolic blood pressure (DBP) at the end of exposures. SBP in the air temperatures at 11 and 14 °C were higher than those at 17 or 20 °C. There were 5-10 mmHg reductions in the conditions with floor-heating, and a significant difference between in 14 and 14/17°C conditions ($t=2.35$; $P<0.05$). DBP in the conditions at 11 and 14 °C air temperatures were somewhat higher than those at 17 or 20 °C, and 5-10 mmHg reductions of DBP with floor heating, especially in the conditions at 14 and 17 °C.

Tympanic and skin temperatures



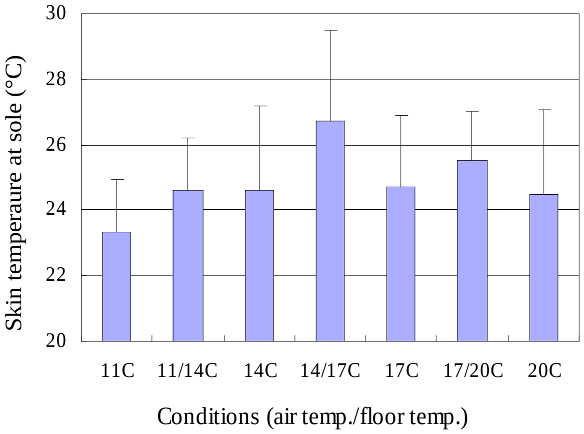


Figure2. Tympanic temperatures before and before and after exposures (upper left), mean skin temperatures (upper right) skin temperatures at sole (left) at the end of exposures. (Values are means and SD of 10 subjects)

Figure 2 showed tympanic temperatures before and after the exposures. Tympanic temperatures did not differ in all conditions. Figure 2 also showed the mean skin temperatures and skin temperatures at sole at the end of exposures. Although, there were significant differences of mean skin temperature among the conditions, no significant differences were found between with and without floor heating. There were significant differences of skin temperature at sole among the conditions. The significant higher skin temperatures at sole were found in the conditions with floor heating.

Thermal and comfort sensations

Figure 3 showed the changes in whole body thermal sensations in all conditions. Although subjects voted as cooler in the lower air temperature conditions, there were no significant differences of thermal sensation between with and without floor heating in the same air temperature conditions.

Figure 4 showed the changes in thermal sensations at sole in all conditions. There were significant differences in thermal sensations at sole among the conditions. Subjects voted as warmer in the conditions with floor heating than without one in the same air temperature conditions.

Figure 5 showed the changes in acceptable rate in all conditions. The conditions at 17 and 20 °C of air temperatures were accepted as thermal conditions of non-heated spaces in houses by more than 70 % of subjects. On the other hand, the conditions at 14 and 11 °C of air temperatures were accepted by less than 50 % of subjects even with floor heating.

Conclusions

1. Blood pressures increased in the conditions of 11, 14, 17 °C of air temperatures, however, the rise of blood pressures declined by 5 – 10 mmHg in the each heated floor condition.
2. Mean skin temperature in the heated floor conditions decreased on a large scale than in the non-heated floor conditions.
3. Although thermal sensations at sole were improved with heated floor in all conditions, no improvements in whole body thermal sensations were found.
4. Subjects permitted 17 and 20 °C of air temperature conditions as a non-heated living spaces in houses, such as corridor, hall etc.

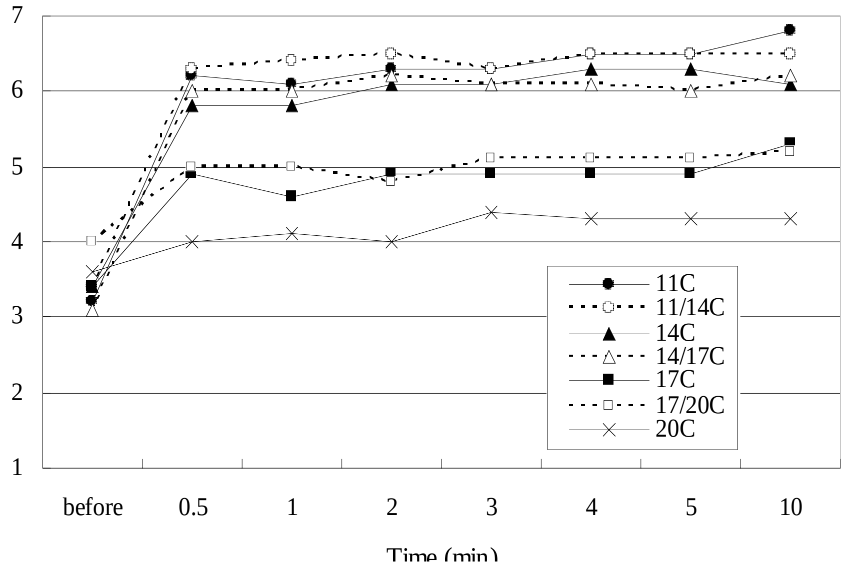


Figure 3. Changes in whole body thermal sensations in all conditions.

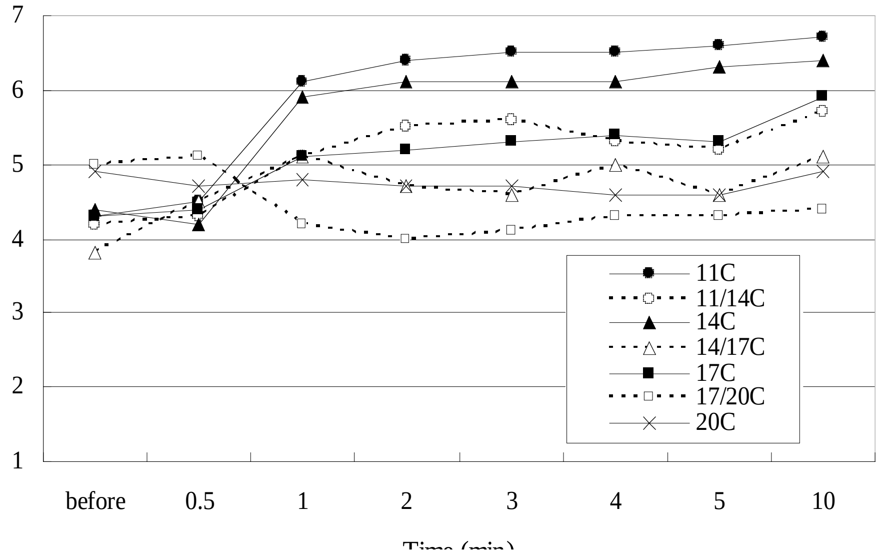


Figure 4.

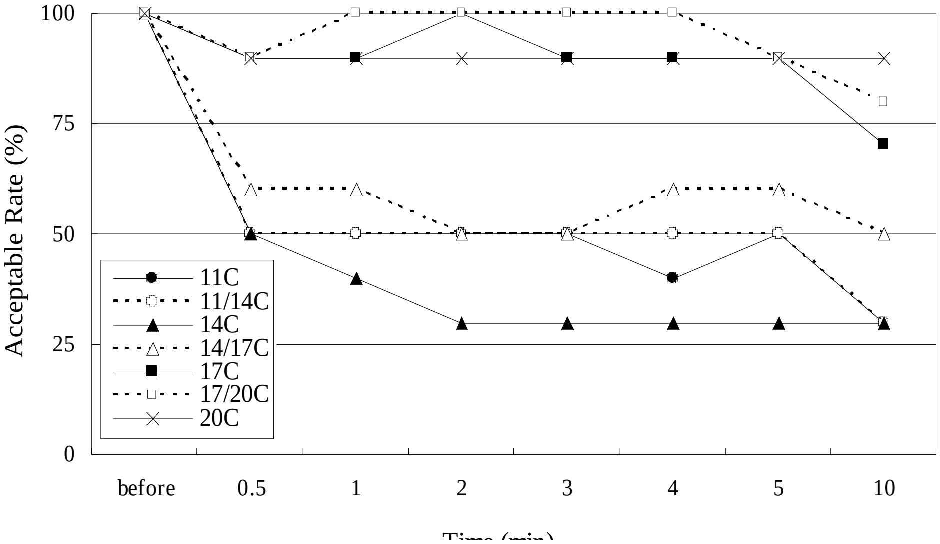


Figure 5. Changes in acceptable rates in all conditions

Acknowledgements

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EXPOSURE TO LONG-TERM AIR-CONDITIONED ENVIRONMENT AFFECTS THE DIURNAL CORTISOL RHYTHM

Tomoko Ueno and Tadakatsu Ohnaka

Department of Living Environmental Science, Fukuoka Women's University
* corresponding author ueno@fwu.ac.jp

Introduction

The human gained biological rhythms, such as body temperature, sleep and awakening, and hormone secretion, for adapting to natural environment. However, in the present days when artificial environment progresses, the human's lifestyle and life pattern have changed variously. By the use of electricity, we spend most of our time under the constant situation all the year round. This environment can consider a possibility of having some influence on human circadian rhythm.

Cortisol that has a circadian rhythm, the principal hormonal product of the hypothalamic-pituitary-adrenal (HPA) axis, is found to be a sensitive maker of heat stress (1). Several workers measured cortisol to study the influence of extreme hot environment (1, 2). However, there are no data concerning the long-term thermal stress under exposure to usual artificial environment. The purpose of this study is to investigate the influence of long-term air-conditioner use in summer on human cortisol rhythm by measuring salivary cortisol.

Methods

Seventeen Japanese female students (aged 20 to 23 years) participated in the present study. The experiments were conducted in the middle of July and in the middle of September. Ambient temperature and humidity surrounding subjects were measured for three days. The saliva samples were then collected by salivettes every 2 hours from 8:00 to 22:00 for one day in each month for cortisol analysis. A questionnaire was also taken on the same day. The common questionnaire items were air-conditioner use time, sleep time, waking time and quality of sleep (ranging from 1, slept well, to 5, couldn’t slept at all). In addition, age, height and body weight were asked in the questionnaire in July, and the air-conditioner use time in August was asked in September.

The saliva samples were stored at -20℃ until required for assay. The amount of cortisol secretion was measured using ELISA method.

Two-way analysis of variance (ANOVA) used to examine the difference of ambient temperature, humidity and cortisol between the times and groups, and two-way repeated measures ANOVA used to them between the times and months. The comparisons of the values between the groups were made Student’s t-test. Statistical significance was accepted at $p<0.05$. Data are presented as means ± SE.

Results and discussion

Age, physical characteristics and results of sleep questionnaire by group

Based on the results of questionnaire, subjects were divided into two groups; those who used air-conditioners in summer less than 4 hours a day (n=8, short-time [S] group) and those who used more than 6 hours (n=9, long-time [L] group). Table 1 summarises the results of questionnaire. The groups did not differ in all variables except air-conditioner use time. Concerning air-conditioner use time, there were significant differences between groups in each month ($p<0.05$), i.e. the L group was using the air-conditioner for a longer time than S group. L group had significantly different use time between July and September (paired t-test, $p<0.01$), and August and September (paired t-test, $p<0.01$). It was shown that sleep rhythm and the quality of sleep not were influenced by the season in spite of the difference in air-conditioner use time.

Ambient temperature and humidity surrounding subjects

The average of ambient temperature was higher in S group (30.8 ± 0.4˚C in July, 28.0 ± 0.3˚C in September) than L group (28.0 ± 0.4˚C in July, 27.3 ± 0.3˚C in September) in both months ($p<0.01$). Figure 1 shows ambient temperature and relative humidity surrounding subjects against time of a day. ANOVA of ambient temperature revealed the following results: significant differences between months in S group ($p<0.01$), between the groups in July ($p<0.01$), and significant interaction between the times and groups in July ($p<0.05$). The average of relative humidity had no difference between S group (56.9 ± 1.9% in July, 63.5 ± 1.7% in September) and L group (52.7 ± 1.8% in July, 61.7 ± 1.8% in September). However, there were differences between months in each group ($p<0.01$). ANOVA of relative humidity revealed the following results: significant differences between the months in each group (S group; $p<0.05$, L group; $p<0.01$), and significant interaction between the times and months in L group ($p<0.01$).

Table 1. Age, physical characteristics and results of sleep questionnaire by group.

	S group (n=8)	**L group (n=9)**
Age	21.0 ± 0.3 yr	21.4 ± 0.3 yr
Height	156.1 ± 2.0 cm	158.9 ± 1.5 cm
Body weight	47.8 ± 0.7 kg	49.1 ± 1.1 kg
BMI	19.7 ± 0.6	19.5 ± 0.4
July		
Air-conditioner use time for last one week **	2.1 ± 0.3 h/day	11.4 ± 1.5 h/day
Sleep time	1:06 ± 30 min	1:11 ± 21 min
Waking time	7:19 ± 9 min	7:15 ± 12 min
Hours slept	6.0 ± 0.5 h	6.3 ± 0.2 h
Quality of sleep	2.1 ± 0.4	1.8 ± 0.3
September		
Air-conditioner use time for August **	1.7 ± 0.4 h/day	14.0 ± 1.8 h/day
Air-conditioner use time for last one week *	1.3 ± 0.5 h/day	4.3 ± 1.1 h/day
Sleep time	12:49 ± 23 min	1:00 ± 16 min
Waking time	7:14 ± 15 min	7:37 ± 13 min
Hours slept	6.4 ± 0.3 h	6.6 ± 0.2 h
Quality of sleep	2.0 ± 0.3	1.7 ± 0.3

Values are means ± SE. $^{**}p<0.01$, $^{*}p<0.05$, respectively, Student's t-test, comparing values for between S and L group.

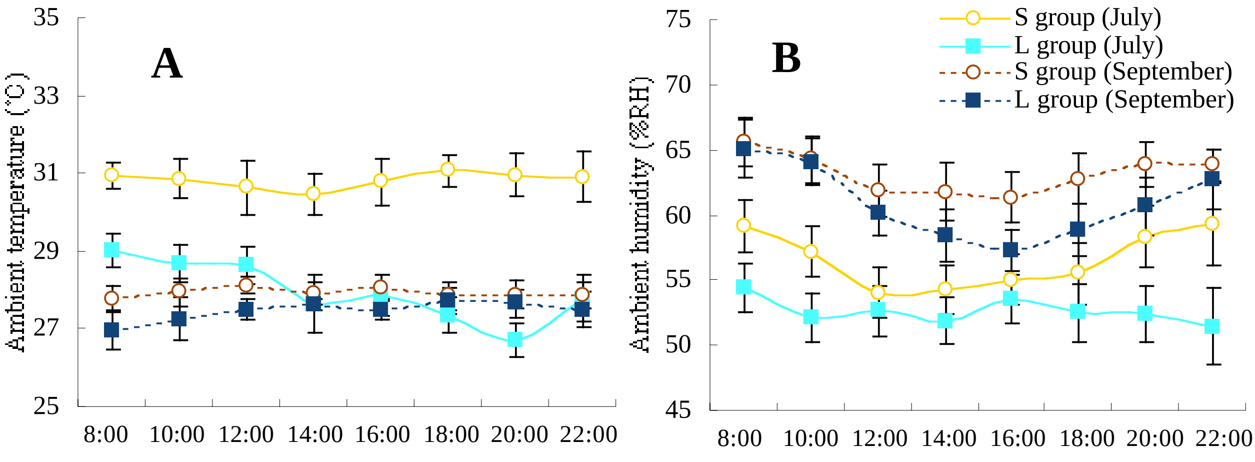

Figure 1. Ambient temperature (A), relative humidity (B) surrounding subjects in July and September in each group. Values are means ± SE.

Rhythms and levels of salivary cortisol secretion

Figure 2 shows the results of salivary cortisol analysis. Cortisol has a well-documented circadian pattern, and is also an established marker of stress responses. In most humans, there is a brisk increase of cortisol following waking, and achieve the peak level at about 30 min(3, 4). In absence of external stimuli, cortisol levels typically decrease throughout the day(5). In the present study, S group had the similar and typical rhythms in both July and September; cortisol levels were highest at 8:00 and decreased thereafter. In July, there were no significant differences between the groups, however, S group observed higher cortisol levels at 8:00 than that of L group. ANOVA of cortisol levels revealed the following results: significant interaction between the times and groups in September ($p<0.05$). Cortisol levels of L group were significantly lower at 8:00 ($p<0.05$) and higher at 10:00 ($p<0.05$) than that of S group. These differences might be due to result from the unstable cortisol rhythm that L group showed in September. There were two peaks at 10:00 and 18:00. It should be noted that the unstable rhythms of L group were observed especially in morning, although sleep time, waking time, hours slept and quality of sleep did not have significant differences between the groups. These results suggest that L group have the weak or slow cortisol awakening response.

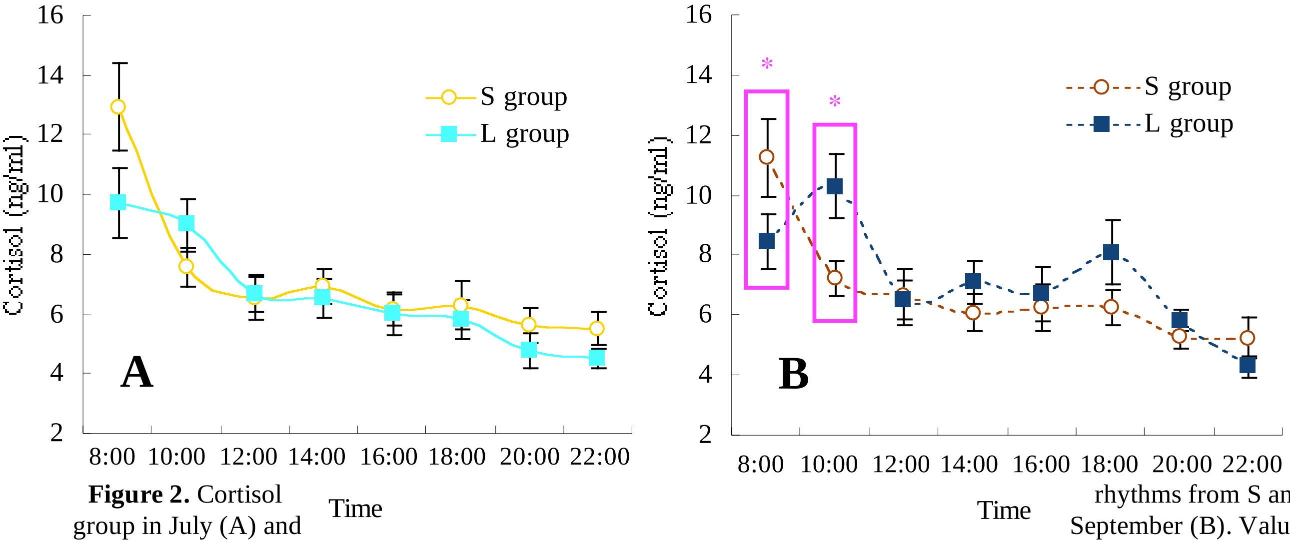

Figure 2. Cortisol rhythms from S and L group in July (A) and September (B). Values are means ± SE. $^{*}p<0.05$, Student's t-test, comparing values for between S and L group.

Conclusions

In the present study, the influence of long-term air-conditioner use in summer was examined by cortisol rhythm of subjects, between the air-conditioner short-time [S] and long-time [L] users group. The S and L group differ in air-conditioner use time, mean ambient temperature and cortisol levels. There were no differences in age, physical characteristics, mean relative humidity, sleep time, waking time, hours slept and quality of sleep between groups. Diurnal patterns of salivary cortisol rhythm of S group were similar in July and September, but L group had unstable rhythm in September. This result suggests that long-term air conditioning use might affect the human cortisol rhythm.

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EFFECTS OF SETTING UP HUMIDIFIERS ON THERMAL CONDITIONS AND SUBJECTIVE RESPONSES OF PATIENTS AND STAFF IN A HOSPITAL DURING WINTER

*Nobuko Hashiguchi[1] *, Megumi Hirakawa[2], Yutaka Tochihara[1], Yumi Kaji[3], Chitake Karaki[4]*

[1] Department of Ergonomics Faculty of Design, Kyushu University , Fukuoka, Japan
[2] PS MFG Co., Ltd., Fukuoka, Japan
[3] Yame Rehabilitation Hospital, Yame, Japan
[4] Techno Ryowa Ltd., Tokyo, Japan
* corresponding author n-hashi@rms.kyushu-id.ac.jp

Introduction

During winter, extreme low humidity is caused by the heating system in various institutions, including offices, hotels, hospitals and nursing homes. Prolonged exposure to such an environment causes dryness of the lips and soreness of the throat. Enomoto et al. (1) indicated that air humidity reached less than 20% in a factory, and many workers complained of dry air and static electricity. Matsui (2) investigated that the thermal environment in a hospital throughout a year, and showed that air humidity therein was less than 30% in winter. A low humidity environment in a hospital during winter was also confirmed in other studies (3-4). In addition, it has been suggested in a previous study that low humidity promotes the spread of influenza viruses (5). Many people who are elderly and have little resistance to infection stay in hospitals compared to other general facilities. It is possible that low humidity in winter caused in the hospital, and the influence of these environments upon patients and staff members' health conditions is greater. However, few studies evaluated the effects of the thermal environment in a hospital during winter on patients and staff members. Hence, we measured the thermal environment in a hospital during winter, and investigated the subjective responses of patients and staff members via a questionnaire. Moreover, we introduced humidifiers into several sickrooms and nurse stations as one measure for improvement of the humidity environment, and evaluated the effects on the thermal conditions in a hospital during winter.

Methods

This survey was conducted at a hospital in the southern part of Fukuoka, Japan. The hospital was 5 stories high, and we investigated the thermal environment on west-side wards on the 2nd and 3rd floors, and an east side ward on the 4th floor. The survey was carried out from the 30th of November to the 22nd of February; a total of 12 weeks. Some humidifiers were introduced on the 25th of January, 8 weeks after starting this survey (Fig.1). Portable and steam humidifiers were used in this survey (HV-77F, SHARP). Data from the latter eight weeks; 4weeks before and 4 weeks after setting up the humidifiers was used for analysis.

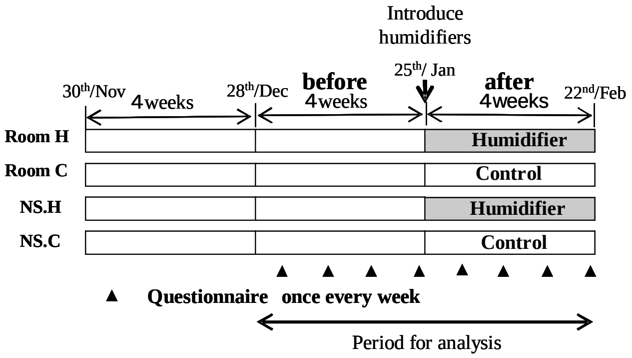


Figure 1. Survey period.

Temperature and relative humidity in 20 sickrooms and at the nurse stations on each of the three floors were measured every 30 minutes by data loggers (Thermo Recorder RS-10, RS-11 Tabai Espec Co. Ltd.). The humidifiers were set up in 9 sickrooms and at a nurse station on the 2nd floor. Sickrooms with and without the humidifiers are represented as "room H" and "room C", respectively in the following text and figures. And nurse stations with and without humidifiers were also represented as "NS.H" and "NS.C", respectively. The total number of measurement points was 37 (sickroom, 34 points; nurse station, 3 points). The data loggers in the sickrooms and at nurse stations were set at 60 cm and 110 cm from the floor, respectively. The subjects of the survey were 36 patients and 45 staff members (nurses or nurses' aides) in the hospital. The mean age of subjects and the main diseases of the patients are shown in Table.1. Patients were in hospital for rehabilitation of several physical functions. The number of patients who stayed in sick rooms with humidifiers was 14. They are represented as "patient H" and patients who stayed in sickrooms without humidifiers are represented as "patient C". And the number of staff who worked at a nurse station with a humidifier was 15. Staff who worked at nurse stations with and without humidifiers are represented as "staff H" and "staff C", respectively. Interviews with the patients and staff members concerning symptoms of their health conditions (e.g., dry and itchy skin, thirst) and evaluation of the thermal environments (e.g., thermal comfort, thermal sensation, and humidity sensation) were carried out once a week.

	N	Age（mean±SD）
Patients	36 (male,10; female,26) *27, over 65 years old	71.0±13.6
Staff	45 (male;7, female;38)	38.7±11.5
Main complaints of patients		
	stroke etc.	66%
	bone fracture etc.	28%
	other	6%

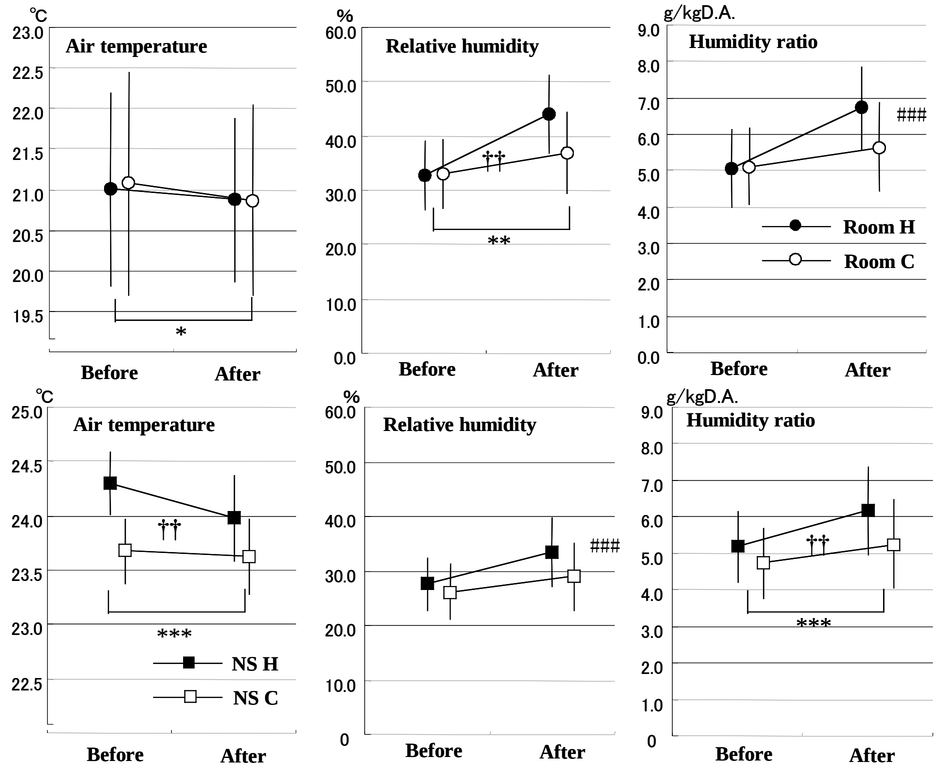
Table 1 Subjects of the survey.

Results and discussion

Changes in air temperature and humidity before and after setting up humidifiers

Fig.2 shows the means of air temperature and humidity in sickrooms and nurse stations before and after setting up humidifiers. The means of air temperature in room H before and after were 21.0℃ and 20.9℃, respectively. And the change in the means of air temperature in room H was similar to that in room C. The air temperatures in sickrooms were controlled within the optimum air temperature range for the elderly that was indicated in a previous study (6). Relative humidity in room H before and after was 33% and 44%, respectively, and the increase was larger than that in room C. The humidity ratio in room H increased from 5.2 g/kgD.A. to 6.2 g/kgD.A through introducing humidifiers, and the increase in the humidity ratio of room H was significantly larger than that of room C ($p<0.001$). The relative humidity in sickrooms before setting up humidifiers was remarkably lower than the optimum range; 40-50%, suggested by the Hospital Engineering Association of Japan (HEAJ (7)). Moreover the humidity reached a low level known to promote the spread of influenza viruses before setting up humidifiers (3).

humidity at



Values are mean±SD *;p<0.05, **;p<0.01, ***;p<0.001, Significant main effect (time) with ANOVA,††;p<0.01, †††;p<0.001, Significant main effect (condition) with ANOVA,###; 0.001, Significant interaction (time×condition) with ANOVA

Fig. 2 Changes in air temperature and humidity before and after setting up humidifiers

Differences in subjective responses before and after setting up humidifiers

There was no significant difference in thermal sensations between before and after setting up humidifiers in both patients and staff members. However, the percentages of staff who complained of being“warm”or “hot”were larger than those of patients.

As shown in Fig.3, a significant difference in thermal comfort before and after setting up humidifiers was not confirmed in patient groups. The percentage of staff who felt comfortable increased greatly and reached over 80% in staff H group after setting up humidifiers. There was a significant difference in thermal comfort in Staff H group between before and after setting up humidifiers (p<0.05).

There was practically no difference in the humidity sensation of patient in both groups (Fig.4).

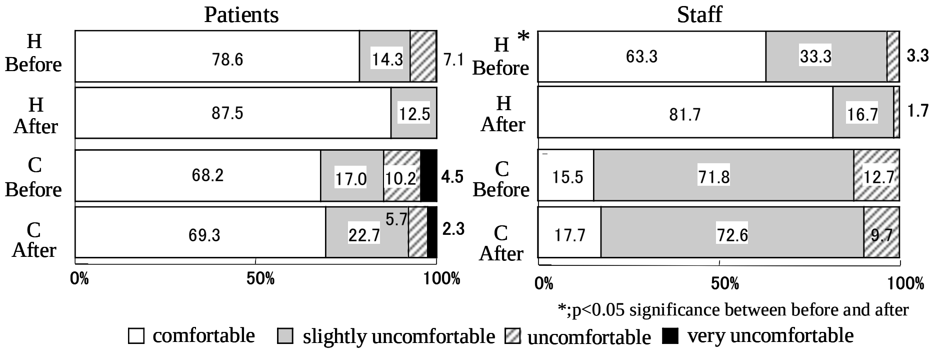


Fig.3 Thermal comfort of patients (left) and staff (right)

Regarding staff members, contrasting results were observed between staff H group and staff C group. 61.7% of staff felt that the air was dry in staff H group before setting up humidifiers, but the percentage decreased by 25%, after set-up. A significant difference in humidity sensation was showed between before and after set-up in staff H group ($p<0.05$). However, there was no distinct difference in the humidity sensation of staff C group between before and after set-up.

There was no significant difference in votes on dry and itchy skin, and thirst between before and after set-up humidifiers in the all 4 groups.

These subjective responses suggested that introducing humidifiers in a hospital during winter is one of the effective methods to relieve staff members' discomfort.

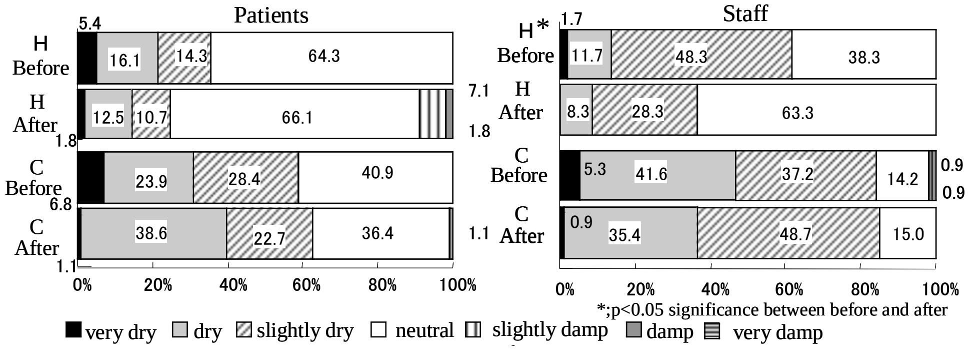


Fig. 4 Humidity sensation of patients (left) and staff (right).

Conclusions

The existence of a low humidity environment in a hospital during winter was confirmed before setting up humidifiers, and the levels of low humidity reached those known to promote the spread of influenza viruses. After introducing humidifiers, air humidity in sickrooms generally increased to within the optimum range. Moreover, the staff members' complaints of thermal discomfort and dryness of air decreased after set-up, though a significant difference in patients' subjective responses between before and after set-up was not indicated. These results suggested that introducing humidifiers in a hospital during winter is one of the effective methods to restrain spread of influenza viruses and relieve staff members' discomfort. However, it was difficult for the portable humidifiers to increase air humidity at nurse stations sufficiently. It will be necessary to improve humidity environments in open spaces like nurse stations.

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AIR TEMPERATURE DISTRIBUTION IN HONG KONG OFFICE BUILDING

Daniel W.T. Chan[1], *Emma S.H. Leung*[1]*

[1] Indoor Environmental Quality Laboratory, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, The People Republic of China
* corresponding author emma.s.h.leung@polyu.edu.hk

Introduction

Hong Kong is in the sub-tropics area and in summer time where intensive cooling is requited. The outdoor humidity also is quite high. The mean temperature in summer reaches 28.8°C. [1] Due to economics and simplicity reason, only the air temperature alone is controlled and the relative humidity is allowed to float. For most of the engineers, the indoor thermal comfort design criteria are simply 24°C. Actually the setting is only a safe choice within the summer thermal comfort zone according to the ASHRAE Standard 55[2]. However, all of the engineers know that there is a distribution of temperature and relative humidity within the air conditioned area, even a single zone. In this paper, the distribution functions of the key parameters (air temperature, relative humidity and radiant temperature) were found. It helps to set up the thermal comfort control algorithm.

Methods

A large scale of thermal comfort survey was conducted in selected Hong Kong office buildings. This includes 1158 workstation covering 30,000m^2. Both the physical and psychological parameters are measured by physical measurement and questionnaire. The selected building detail and the type of the air conditioning systems served are shown in Table 1. Two identical mobile carts were built, each equipped with three arrays of sensors to measure the air temperature, globe temperature, relative humidity and the air velocity. The sensors of the measurement system as listed in Table 2.

In this paper the probability distribution of the air temperature, relative humidity and radiant temperature were found. Different statistical tests were applied to find the distribution function of the probability distribution. Correlation coefficient, constant variance test (Levene's test) Durbin-Waston statistics and the normality test (for error analysis). [3]

Table 1. Summary of the 11 office buildings surveyed

Building code	Type of tenant	Number of Questionnaires	Air conditioning type	Floor plan layout
1	private	59	FCU	Open plan
2	private	206	FCU	Open plan
3	private	30	FCU	Mixed
4	private	363	FCU	Open plan
5	private	96	FCU	Mixed
6	civil	67	CAV+VAV	Mixed
7	private	43	VAV	Open plan
8	civil	139	VAV	Open plan
9	private	95	VAV	Open plan
10	private	92	CAV+FCU	Mixed
11	private	8	FCU	Mixed

Key: CAV: Constant air volume
VAV: Variable air volume
FCU: Fan coil unit

Results and discussion

The descriptive statistical results are presented in the Table 3. When compared the result of a field measurement carried out in Kalgoorlie-Boulder, Australia [4], while the mean air temperature, mean radiant temperature and mean relative humidity were 23.4^{o}C, 24.0^{o}C and 41.5% as also showed in Table 3. It shows that the variation for the 3 parameters in Hong Kong case is smaller then that of Kalgoorlie-Boulder. Except the mean air temperature of Hong Kong is lower, all the others parameter average is higher then that of Australia.

Table 2. Summary of sensors on the measurement system of the mobile cart

Quantity	Sensor		Accuracy
	Description	Position	Calibrated
Air temperature	Shielded thermistor	0.1m,0.6m, 1.1m	±0.1^{o}C over range 17^{o}C to 26^{o}C
Globe temperature	Thermistor	0.1m,0.6m, 1.1	±0.1^{o}C (M) for thermistor
Relative humidity	Digital psychrometer	0.6m	±1% RH (M) for range 0 to 100%
Air speed	Omni-directional constant temperature anemometer	0.1m,0.6m, 1.1	±5%,0.005m/s (M)

* M: Manufacturer calibrated and checked by inter-comparison

Table 3. The descriptive statistical result of the survey in Hong Kong and Kalgoorlie-Boulder

	No. of sample	Range	Minimum	Maximum	Mean	Std. deviation	Variance
Air temperature	1158	8.44	17.6 (19.1)	26.05 (30.5)	21.74 (23.4)	0.97 (1.4)	9.33
Radiant temperature	1158	7.97	20.34 (20.2)	28.31 (32.8)	23.27 (24.0)	1.10 (1.4)	1.216
Relative humidity	1158	33.8	37.9 (24.5)	71.7 (66.1)	55.0 (41.5)	4.95 (8.8)	24.52

( ) is the result of the Kalgoorlie-Boulder

The distribution functions of the three parameters were found out. As all of the engineers know that there exits a distribution of the thermal comfort parameters even a zone is designed to be a single one with a uniform performance across the space. Different statistical tests were applied in order to find out a suitable distribution function for the there thermal comfort parameters. The results are showed in the Table 4. The result of the probability distribution of the survey data are showed in the Table 5. Points represent the real data of the survey and the lines are the probability distribution models for each of the parameters.

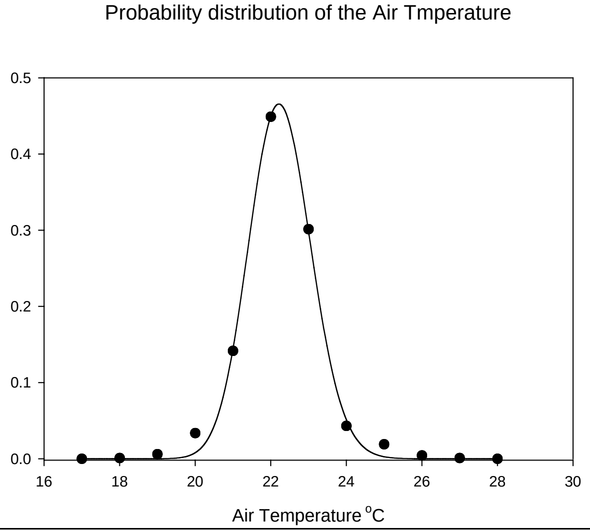
Table 4. The result of the statistical test of the mean air temperature, mean radiant temperature and relative humidity.

Parameter	PDF	R	R sqr	Adj Rsqr	PRESS	Durbin-Waston	Normality test	Constant variance test
Air temperature	Log-normal	0.99	0.99	0.99	0.0022	1.9831	0.3148,0.1498	Passed (P=0.1807)
Radiant temperature	Modified Gaussian	0.99	0.99	0.99	0.0021	1.9360	0.3053, 0.1746	Passes (P=0.3894)
Relative humidity	Lorentzian	0.98	0.97	0.96	0.048	1.9767	0.3232, 0.2488	Passed (P=0.1863)

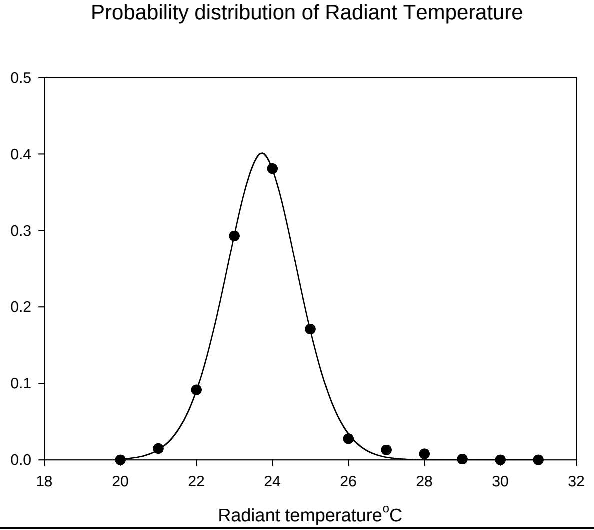
Conclusion

A large scale thermal comfort survey was carried out in Hong Kong office buildings and the results for the three important parameters were presented, air temperature, radiant temperature and relative humidity. When compared the result of Hong Kong to that of Kalgoorlie-Boulder, Western Australia, it is known that the variation of the thermal comfort parameters is smaller. The distribution function of the there parameters were also found out. It represents the real situation of Hong Kong office building thermal environment. Other then assuming a single zone to be a perfect uniform, but everyone knows that it is never happened, it is better to know the distribution of them. By understanding this, it helps to set up the control algorithm of air conditioning system to deliver a better indoor environmental quality to our building occupants.

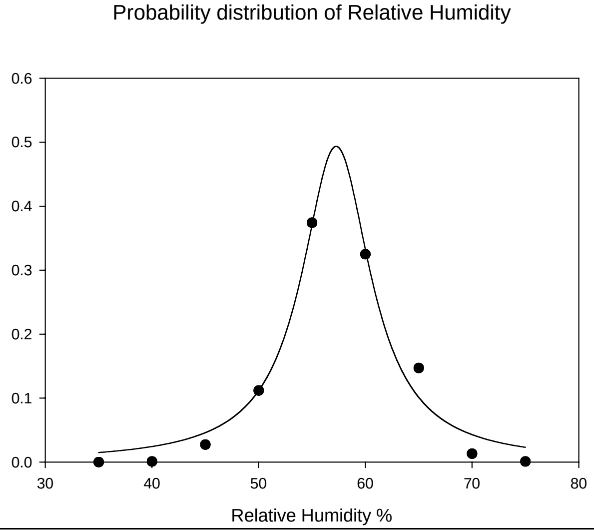
Table 5. Result of the probability distribution function curve and equation



$$P(Ta) = 0.4657e^{\left[-0.5\left[\frac{\ln\left(\frac{Ta}{22.2167}\right)}{0.038}\right]^{2}\right]}$$



$$P(Tr) = 0.4013e^{-0.5\left(\frac{|Tr-23.7263|}{0.9433}\right)^{1.8122}}$$



$$P(RH) = \frac{0.4937}{1+\left(\frac{RH-57.2669}{3.9284}\right)^2}$$

● The probability distribution of the survey data
— The probability function

Acknowledgement

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FACTORS IN THE USE OF CAR SEAT VENTILATION

Peter Bröde and Barbara Griefahn*

Institut für Arbeitsphysiologie an der Universität Dortmund (IfADo), Dortmund, Germany
* corresponding author broede@ifado.de

Introduction

During summertime thermal radiation provokes increased sweat production even inside air conditioned vehicle cabins, that may lead to an accumulation of heat and moisture at the seat-person interface and consecutively cause thermal discomfort (1;3;5). Seat ventilation systems using electrical fans mounted inside the seat and backrest have proven to locally increase the heat loss in the contact area between the body and the seat and to maintain unchanged thermal sensation while ambient temperature is increased up to 2 °C (2;3). However, little is known about the efficiency of ventilated car seats under radiant heat stress and about human and environmental factors like noise emitted by the fans that may interact with thermal sensation (4) and thus also affect the use of the seat ventilation system.

Therefore, the influence of age, gender and environmental perception on physiological, psychological and behavioural responses during the use of ventilated car seats under heat radiation stress was studied in the laboratory.

Methods

Three series, with in total 144 experiments, were carried out in a climatic chamber at 25 °C air temperature, 0.95 kPa water vapour pressure and 0.5 m/s air velocity. In each series 24 subjects, equally divided into younger (18-27 years) and older (40-63 years) females and males, participated in two sessions sitting on two different types of ventilated seats for 90 minutes clothed with jeans and T-shirt (0.6 clo). The parameters varying between the three series were mean radiant temperature (t_r), that was 50 °C in study (A) and 40 °C in (B) and (C) (Table 1), and seat ventilation intensity, that was fixed to maximum possible fan speed in (A) and (B), and could be adjusted at three levels or switched off by the subject in (C). Prior to the first session in (C) the subjects were familiarised to the regulation of ventilation intensity by an extra training session.

Table 1. Mean radiant temperature (t_r) and seat ventilation of the 3 experiments.

Study	**t_r (°C)**	Seat ventilation	No. of sessions
(A)	50	fixed (max. fan speed)	48 = 24 subj. * 2 seats
(B)	40	fixed (max. fan speed)	48 = 24 subj. * 2 seats
(C)	40	adjustable	48 = 24 subj. * 2 seats (+1 training)

Before entering the chamber, the subjects were pre-exposed to thermal radiation with t_r=70 °C for 10 minutes, as were the seats with non-operating ventilation. Then mean radiant temperature in the chamber was set according to Table 1, the subjects were fastened to the seats using 4-point belts to restrict body movement and the ventilation was switched on with maximum fan speed.

Sweat production was measured by weighing the subjects and their clothing before and after the experiment. Heart rates were continuously recorded, as were temperature and humidity of the seat-person microclimate at 4 locations, 2 at the cushion and 2 at the backrest. Corresponding skin temperatures were recorded in the seat-body contact area (upper and lower back and thigh) and at other body parts.

Thermal sensation at various body parts was registered every 5 minutes applying a 7-point scale (-3='cold', -2='cool', -1='slightly cool', 0='neutral', 1='slightly warm', 2='warm', 3='hot') as was moisture sensation using a 5-point scale (1='dry', 2='slightly moist', 3='moist', 4='wet', 5='very wet'). After the experiment subjects reported the perception of heat, cold, draught, noise and vibration caused by the seat ventilation and its impact on the subject's regulation behaviour.

Values of vapour pressure and temperature in the seat microclimate and of contact area skin temperature and thermal and moisture sensation were spatially and temporally (over the last 20 minutes of exposure time) averaged, and the study, age and gender effects on these final values were analysed applying mixed effects ANOVA for repeated measurements treating the seat effect as random.

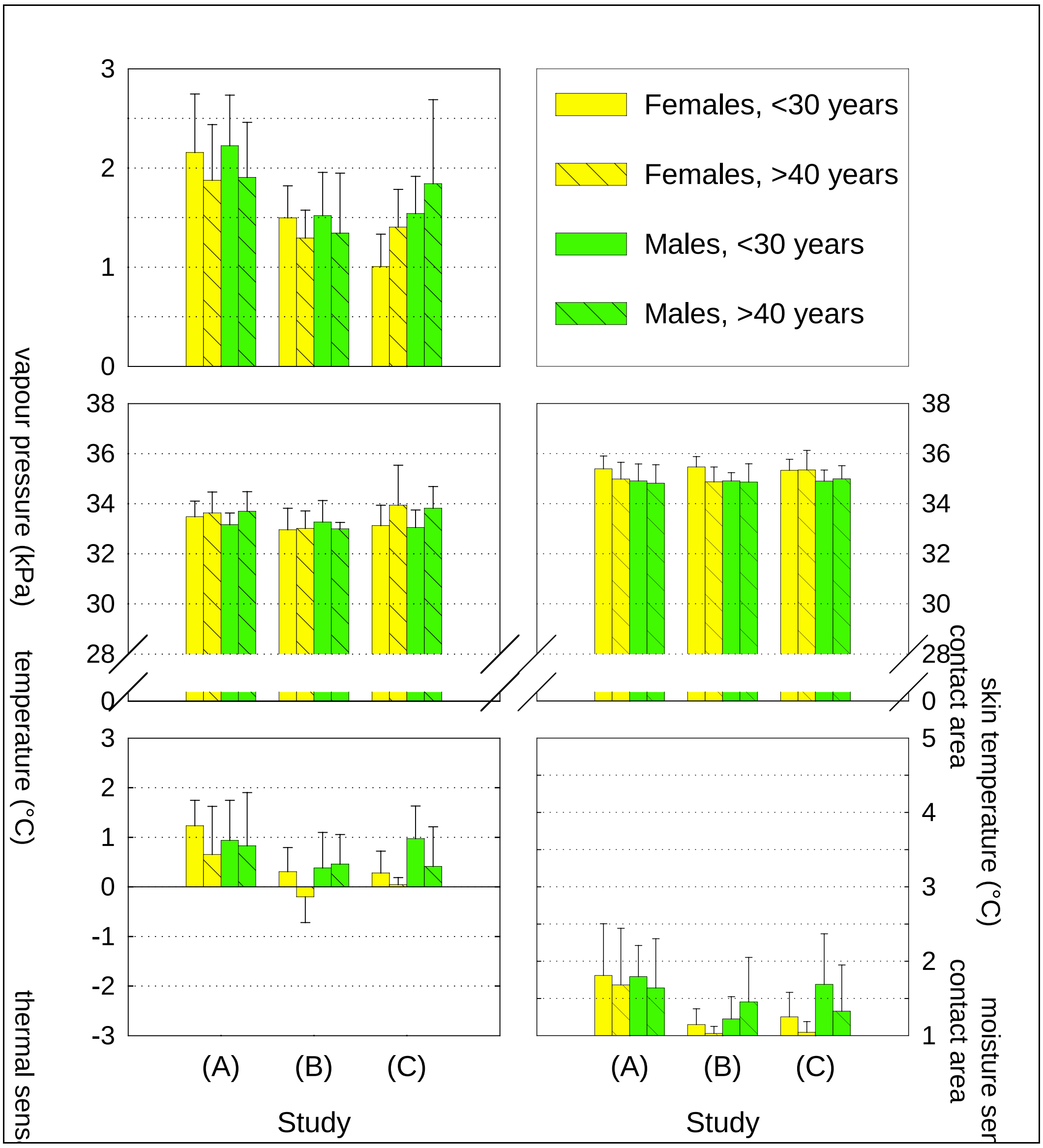

Figure 1. Means and standard deviations for the final values of vapour pressure and temperature in the seat-person microclimate, contact area skin temperature and thermal and moisture sensation for younger and older females and males in each of the 3 studies.

Results and discussion

Microclimate, skin temperature and subjective responses at seat-person interface

Figure 1 presents the means and SD of the responses located in the area with contact between body and seat for the 3 studies and 4 study groups.

Microclimate water vapour pressure for all subjects was kept below 3.5 kPa at t_r=50 °C and below 2 kPa at t_r=40 °C, with mean values of 2 and 1.4 kPa, respectively (Figure 1). This constitutes a considerable reduction in humidity compared to average values of 6 kPa that were observed in an earlier study with conventional seats at t_r=60 °C (1). The study effect was statistically significant with higher humidity for (A) compared to (B) and (C) ($p<0.01$) and males attained 0.2 kPa greater values than females ($p<0.05$). The age effect was significant in (C) ($p<0.01$), but the overall age effect was not ($p>0.05$).

Microclimate temperature was lower in study (B) compared to (A) and (C) (33.1 vs. 33.5 °C, $p<0.05$) and for younger persons (33.2 vs. 33.5 °C, $p<0.05$).

Averaged 'neutral' thermal as well as 'dry' moisture sensation votes were obtained at t_r=40 °C , that increased at t_r=50 °C to 'slightly warm' and 'slightly moist', respectively ($p<0.01$). No significant effects of age or gender on thermal and moisture sensation were observed.

With adjustable ventilation in study (C), females reported neutral thermal sensations whereas young males felt slightly warm (and adjusted to higher fan speeds, see below), but these differences were not significant. Again no age effect was observed.

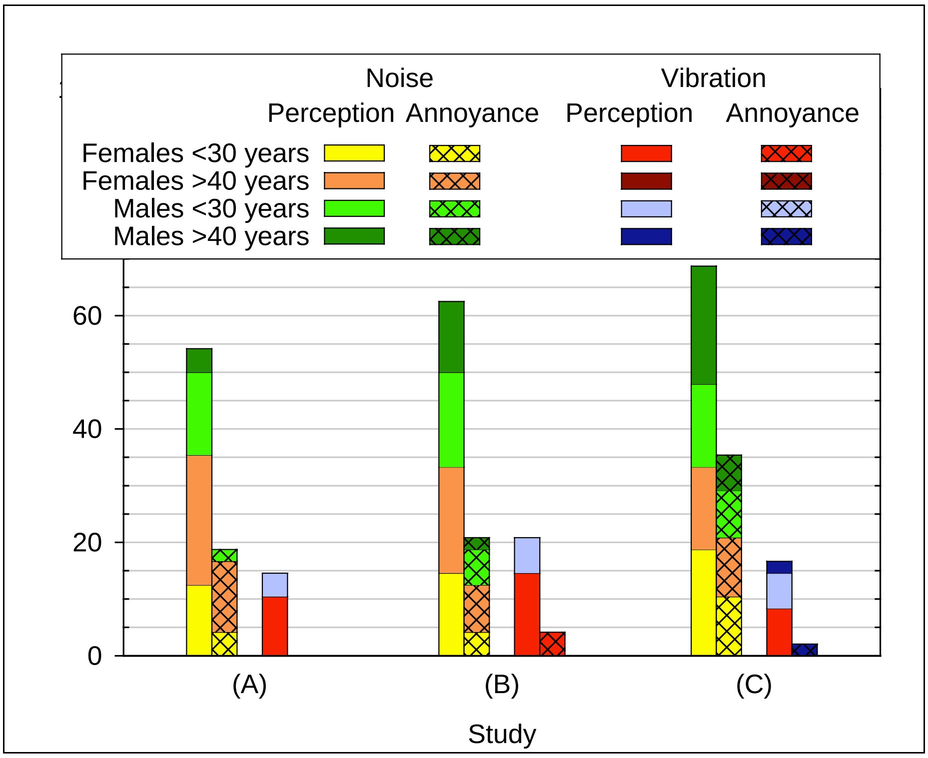

Figure 2. Perception of and annoyance due to ventilation noise and vibration for the 3 studies. Data are presented as percentage of trials with affirmative votes for younger and older females and males.

Fan emitted noise and vibration

As shown in Figure 2, vibration was almost exclusively perceived by younger subjects ($p<0.01$), but did not cause much annoyance.

In contrast, a great proportion of persons perceived and were annoyed by noise emitted from the ventilation. This proportion increased with decreasing heat radiation intensity and was highest with adjustable ventilation. But this trend was not statistically significant ($p>0.05$). However, females were more often annoyed by noise than males ($p<0.05$).

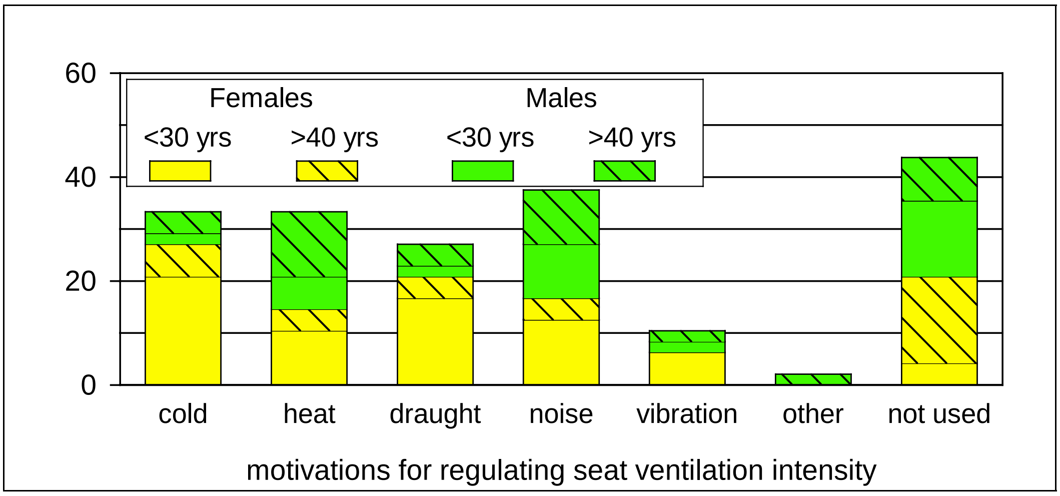

Figure 3. Motivations for regulating ventilation intensity in study (C) for the 4 study groups. Data are presented as percentage of trials with affirmative votes, multiple selections were possible.

Motivations for regulating ventilation intensity in study (C)

The adjusted final fan speed level in (C), with 0 corresponding to non-operating fans and 3 to maximum fan speed, was on average 2.7 for younger males and 2.1 for the other study groups. However, this difference was not statistically significant.

The perception of noise was reported to be an equally important cause for ventilation adjustment as the perception of heat, cold or draught, the latter two were more important to females (Figure 3). This is in accordance with a study (4) suggesting that for females thermal comfort is dominant when considering the simultaneous exposure to noise.

Vibration perception was less important. In nearly half of the trials the regulation was not used (Figure 3), in reports after the experiment especially males requested for higher ventilation intensity, this has also been observed elsewhere (3).

Conclusions

In conclusion, car seat ventilation turned out to effectively maintain the local thermal comfort under moderate heat radiation by enhancing the transport of heat and moisture.

Besides the perception of the thermal environment, noise emitted by the seat ventilation influences the use of the system, whereas vibration and age and gender have only minor impact.

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PHYSIOLOGICAL AND SUBJECTIVE RESPONSES WHILE TOUCHING FEET ON COOLING FLOORS

Junko Takeshita[1], Miwako Matsuo[2], Tadakatsu Ohnaka [2] ,Yutaka Tochihara[3]*

[1] Department of Ergonomics, Kyushu Institute of Design, Fukuoka, Japan
[2] Department of Living Environmental Science, Fukuoka Women's University, Fukuoka, Japan
Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka, Japan
* corresponding author j-take@rms.kyushu-id.ac.jp

Introduction

A floor heating system is widely used in Japan and provides more comfortable thermal conditions compared to a convective air conditioning system because of its smaller air temperature differences from floor to ceiling and comparative lack of air current. A "floor cooling system" might produce comfortable thermal conditions in hot or warm conditions due to similar thermal characteristics of a floor heating system. However, there are few studies on physiological or subjective responses to conditions using a floor cooling system.

The aim of this study is to investigate physiological and subjective responses of humans while touching their feet on cooling floors in warm conditions, and to discuss the possibility of using a floor cooling system as a practical cooling method.

Methods

This study was conducted in July 2004. Twelve healthy female students participated in the experiment. The subjects wore a short sleeved shirt and long sweat trousers in the test room. They were sitting on barefoot with their feet in contact with the floor all the time. They were exposed in a sitting posture for 90 minutes under the 4 conditions (A: air temperature 30°C + floor temperature 28 °C, B: air temperature 28 °C + floor temperature 26 °C, C: air temperature 26 °C + floor temperature 24 °C, D: air temperature 30 °C + floor temperature 26 °C, air humidity 60 %). In this study, tympanic temperature, mean skin temperature, blood pressure, heart rate variability and subjective evaluation of environments (thermal sensation, comfort sensation, sensation of dryness and air current sensations) were measured. The subjects answered a questionnaire before the experiment(1).

Results and discussion

Skin temperatures and Tympanic temperature

Figure 1 shows mean values of skin temperatures at 15 regions and mean skin temperature for the last 10 minutes in the test room. Skin temperatures at forehead and palm were higher in order of A, D, B, C and there were significant ($p<0.05$) differences between conditions A and C and between conditions C and D. Skin temperatures of the back of the hand, shin, instep and sole were higher in order of A, D, B, C and there were significant ($p<0.05$) differences between conditions A and C, between B and C and between C and D. There were significant ($p<0.05$) differences in skin temperatures at chest and back between conditions A and C, between B and D and between C and D. There were significant ($p<0.05$) differences in skin temperatures at buttock and calf between conditions A and C. There were significant ($p<0.05$) differences in skin temperature at forearm and mean skin temperature between conditions A and B, between A and C, between B and C, between B and D and between C and D.

Mean skin temperatures (Tsk) were 34.8 °C, 34.6 °C, 34.2 °C and 33.5 °C in conditions A, D, B, C respectively, and those in condition C were significantly lower than in other conditions. But Tsk of condition C lies in the range of 33~34 °C that is said to be thermally comfortable(2). Tsk rose in condition A by about 0.32 °C during the exposure, but decreased in conditions C and D by about 0.19 °C and 0.14 °C, respectively. No significant changes of Tsk were found in condition B. Table 1 shows that there were significant ($p<0.05$) differences in skin temperatures at regions and Tsk among the environmental condition for the last 10 minutes in the test room. There were significant ($p<0.05$) differences in Tsk and skin temperatures at 15 regions except abdomen, ilium, anterior thigh and posterior thigh between conditions A and C. But there were no significant differences in Tsk and skin temperatures at 15 regions between conditions A and D, despite a 2 °C higher floor temperature in condition A. This shows that skin temperatures might be influenced more by air temperature than floor temperature. Although tympanic temperatures in condition C were somewhat lower than other conditions, there were no significant differences in tympanic temperature among the 4 conditions.

Blood pressure and Heart rate variability

The systolic blood pressure (SBP) decreases with the passage of time independent of air temperatures and floor temperatures. The decrease of SBP in condition A was grater than other conditions, but there were no significant differences among the environmental conditions.

The diastolic blood pressure (DBP) was significantly ($p<0.05$) affected by the interaction of condition and time. DBP in condition A decreased, but those in other conditions increased. However, there were no significant differences among the environmental conditions.

There were significant ($p<0.05$) differences in heart rate (HR) between condition B and C and between C and D. HR in condition C was lower than other conditions.

There were no differences in heart rate variability among the environmental condition.

Thermal sensation

Figure 2 shows mean values of thermal sensation at the sole of the foot and for the whole body at 10 minutes and 90 minutes of exposure. There were significant ($p<0.05$) differences among conditions, and more subjects voted “neutral” under conditions B and C than under conditions A and D. Thermal sensation was significantly ($p<0.05$) affected by the interaction of condition and time. The whole body thermal sensation changes with time, but not sole.

Comfort sensation

Figure 3 shows mean values of thermal comfort sensations of the foot and for the whole body at 10 minutes and 90 minutes of exposure. More subjects voted “uncomfortable” for the whole body under condition A than under the other conditions. Subjects voted “comfortable” with time under condition D, but not under the other conditions. Uncomfortable sensations at the sole of the foot were found more under condition A compare with under the other conditions. Subjects voted “comfortable” at the sole of the foot with time under condition B, but not the other conditions. Conditions B or C were more comfortable for most subjects than conditions A or D.

Significant relationships between the comfort sensation of sole of foot and skin temperature of chest or instep were found, but not between comfort sensation for the whole body and skin temperature of chest or instep. Thermal comfort sensations might be more affected by the conditions of peripheral sites than those of central sites.

Subjective responses

More subjects voted “comfortable” or “neutral” under conditions B and C than under conditions A and D. This shows that the conditions of air temperatures at 28 or 26 °C with 2 °C lower floor temperatures were comfortable and raised smaller physiological strains for most subjects. However, large individual variations in comfort sensation were observed.

Table 1. Mark shows significant ($p<0.05$) differences in skin temperatures among the environmental conditions. Values are means for all 12 subjects. There were significant ($p<0.05$) differences in Tsk and skin temperatures at 15 gions except abdomen, ilium, anterior thigh and posterior thigh between conditions A and C. There were no differences between conditions A and D.

	Forehead	Chest	Back	Forearm	B. hand	Palm	Buttock	Shin	Calf	Instep	Sole	Tsk
AvsB				●								●
AvsC	●	●	●	●	●	●	●	●	●	●	●	●
AvsD												
BvsC				●	●			●		●	●	●
BvsD		●	●	●								●
CvsD	●	●	●	●	●	●		●		●	●	●

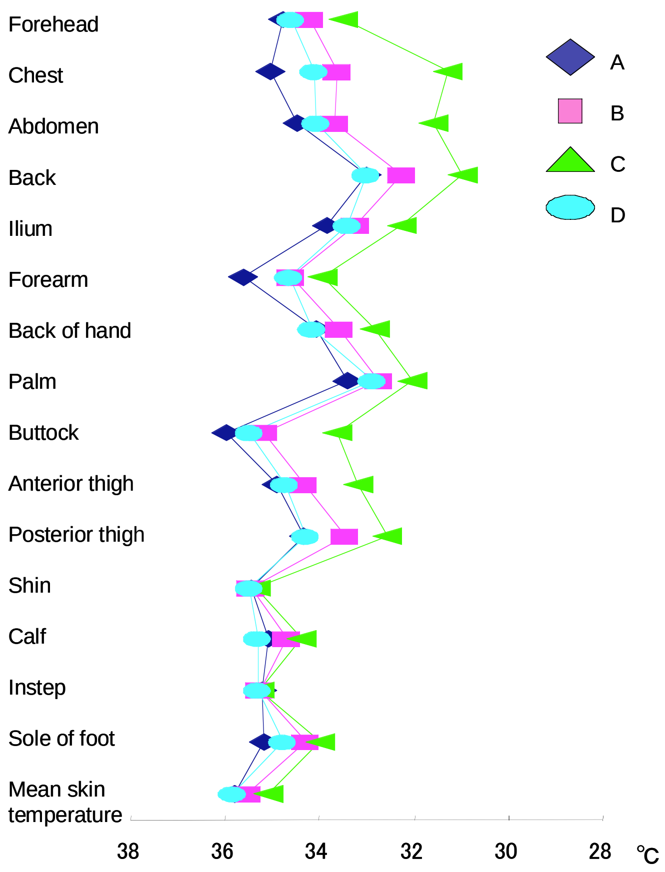

Figure 1. Mean values of skin temperature for the last 10 min. Values are means for all 12 subjects.

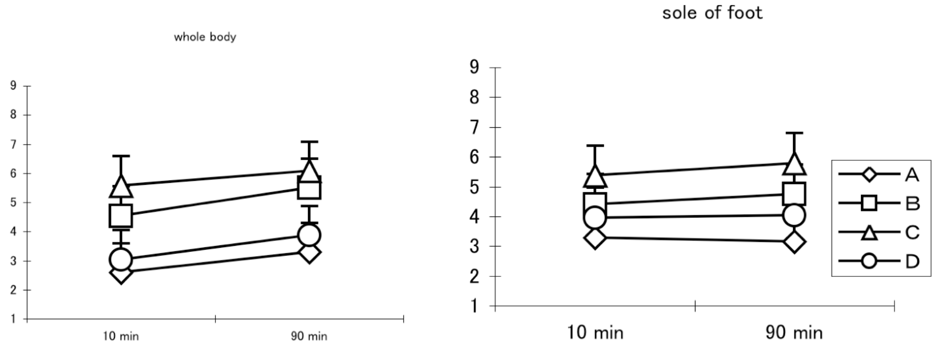

Figure 2. Changes in thermal sensation for sole of foot and for the whole body Values are means for all 12

Condition* time $p<0.05$ Condition $p<0.05$

subjects. (1”very hot”,, 2:”hot” 3”warm”, 4”slightly warm”,5: “neutral”, 6”slightly cool”, 7”cool”, 8:”cold”, 9”very cold”)

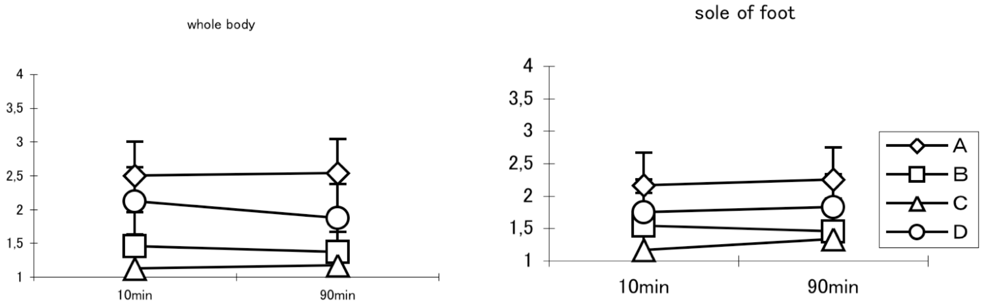

Figure 3. Changes in thermal comfort for sole of foot and for the whole body. Values are means for all 12 subjects. Rating 1: “comfortable”, 4:”very uncomfortable”

Conclusions

The physiological and subjective responses of humans were investigated while touching their feet on cooling floors. There were significant differences in skin temperature at body sites and mean skin temperature among the 4 conditions. Skin temperatures at sole of foot were influenced not only by air temperature but by floor temperature as well. This suggests the comfortable “floor cooling” conditions should be examined as a combination of air temperature and floor temperature. The great individual variations in the thermal and comfort sensations suggested a necessity to examine characteristics of the subjects for comfortable “floor cooling” conditions.

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THE CONTRIBUTIONS OF THERMAL FACTORS TO THERMAL SENSATION AND COMFORT IN VEHICLES

Kazuaki Yamashita [1]*, *Katsuki Yamaguchi* [2], *Yutaka Tochihara* [1], *Hajime Oi* [3], *Youichiro Kondo* [3], *Hiroki Nagayama* [3]

[1] Faculty of Design, Kyushu University, Fukuoka, Japan
[2] Department of Ergonomics, Kyushu Institute of Design, Fukuoka, Japan
[3] Nissan Motor Co. ltd., Kanagawa, Japan
* corresponding author yam@design.kyushu-u.ac.jp

Introduction

It is a complicated task to evaluate thermal comfort in vehicles, since many thermal factors can affect passengers' thermal sensation and comfort. The main thermal factors in vehicles can be categorized into ambient temperature (Ta), radiant temperature (Tr) and seat temperature (Ts). It is well known that Ta and Tr have significant effect on thermal sensation and comfort. On the other hand, Brooks and Parsons (1) reported that a heated seat relieved thermal discomfort under cold thermal conditions (Ta: 5–15ºC). Also, Yamashita et al. (2) demonstrated that a cooled seat could make a slight contribution to the relief of thermal discomfort even in extreme hot environments (Ta: 33–49ºC). However, there are currently few studies which evaluate quantitatively the contribution of these thermal factors to thermal sensation and comfort. Therefore, the present study investigates the contribution of Ta, Tr and Ts to thermal sensation and comfort by controlling each thermal factor independently. Furthermore, we propose a simple index of the thermally comfortable area in vehicles based on the prediction of overall thermal sensation by thermal factors.

Methods

Eight healthy male students participated as the subjects in this study. Each of them received a detailed explanation about the purpose, procedure and possible risks before the experiments, and signed a consent form. Two climatic chambers (chamber No.3 and No.4) were prepared for the experiments. The thermal condition of chamber No.3 was maintained at 25ºC and 50%, and the conditions of chamber No.4 were constructed with a combination of Ta, Tr and Ts. The conditions of Ta were 22ºC, 26ºC and 30ºC. In order to control Tr and Ts, a silicon heater and a temperature–controlled passenger's seat were located respectively in chamber No.4. The silicon heater was used at three setting: off, 80ºC and 120ºC. The passenger's seat was controlled at 31ºC, 34ºC and 37ºC. Ta and Ts were monitored successively during the experiments. Tr was measured using a radiation–measurement instrument after the experiment.

Table 1. Details of the experimental conditions

Ta	Ts	SH	Group	Ta	Ts	SH	Group	Ta	Ts	SH	Group
22				26	31	off	A, B	30	31	off	A, B
						80	A			80	A, B
						120	B			120	A, B
	34	off	B		34	off	A, B		34	off	B
		80	A			80	A, B			80	B
		120	A			120	A, B			120	A
	37	off	A, B		37	off	A, B				
		80	A, B			80	A				
		120	A, B			120	B				

Ta: ambient temperature (^{o}C), Ts: seat temperature (^{o}C), SH: silicon heater (^{o}C)

The subjects were divided into two groups (Groups A and B), and each group was exposed to 11 discrete and 5 common thermal conditions. The details of the experimental conditions are shown in Table 1. First, the subjects stayed in chamber No.3 for at least 30 minutes. Thereafter they moved to chamber No.4 and sat on the passenger's seat for 30 minutes. They evaluated their local (head and back) and overall thermal sensation and thermal comfort while sitting on the passenger's seat every 5 minutes. Each subjective vote was evaluated on the scale from –3 (cold) to +3 (hot) in thermal sensation, and from 0 (neutral) to 3 (very uncomfortable) in thermal comfort, respectively. The clo value of the experimental clothing was 0.48clo.

Results

In order to estimate the contribution ratio of Ta, Tr and Ts to thermal sensation and thermal comfort, we performed multiple regression analysis using each subjective vote as a dependence variable and thermal factors as independent variables. Because Tr can change following the change in Ta, change in Tr (*d*Tr) from when the silicon heater was turned off under each Ta condition was applied as an independent variable instead of Tr. Figure1 shows the time course of the standardized partial regression coefficient (SPRC) of each thermal factor to each subjective vote. Ta had the highest SPRC to thermal comfort and overall thermal sensation through the exposure. Although Tr had an obviously higher SPRC to thermal comfort than Ts, the SPRCs of both Tr and Ts were lower in overall thermal sensation. On the other hand, the SPRC of Tr was as approximately equal to that of Ta in head thermal sensation. Also, Ts had the highest SPRC to back thermal sensation through the exposure. However, the SPRC of Ts showed a slight decrease with time, while that of Ta showed a gradual increase simultaneously.

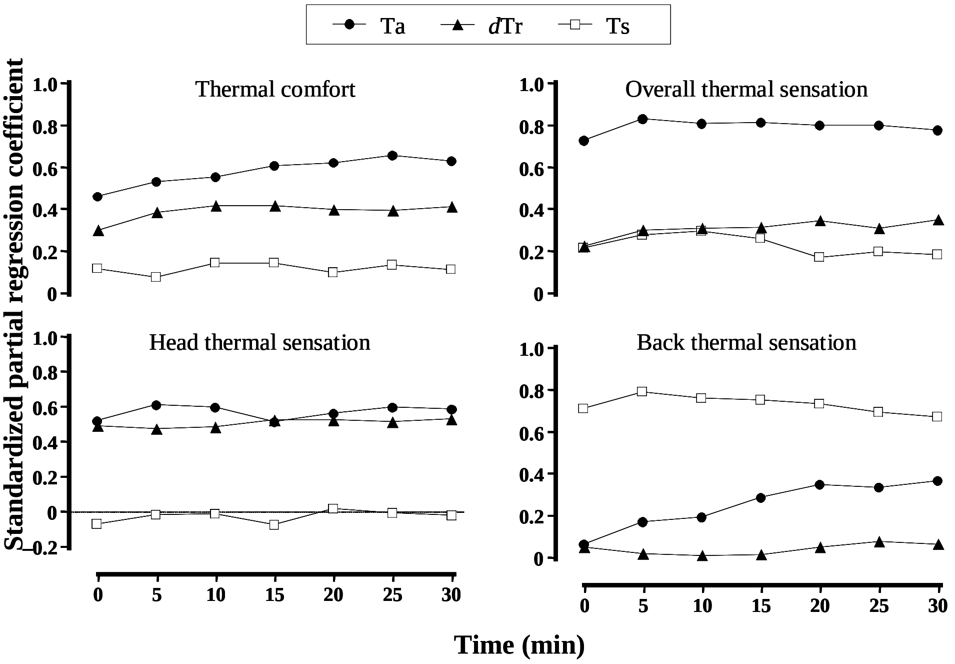

Fig.1 Time course of standardized partial regression coefficients of ambient temperature (Ta), change in radiant temperature (*d*Tr) and seat temperature (Ts) to thermal comfort and overall, head and back thermal sensation during the exposure.

By multiple regression analysis, the following equation (1) was obtained.

$S = aX + bY + cZ + d$ (1)
S: subjective vote; X: Ta; Y: *d*Tr; Z: Ts;
a, b, c: partial regression coefficients; d: intercept

By transforming the equation (1), the following equation (2) was obtained.

$aX + bY + cZ + (d - S) = 0$ (2)

The equation (2) indicates an equation of a flat plane constructed with X (Ta), Y (dTr) and Z (Ts). By inputting a certain S into equation (2), the condition ofeach thermal factor where a subjective vote is of a certain value can be represented as a flat plane. As the result of the analysis, a significant regression was observed between overall thermal sensation and the three thermal factors (R^{*2}=0.56). Figure 2 illustrates the planes when overall thermal sensation was 0 and +1, respectively. Since thermal comfort was within the range from 0 (comfortable) to 1 (slightly uncomfortable) when overall thermal sensation was voted from 0 (neutral) to +1 (slightly warm), the area between the planes could be considered to indicate a thermally comfortable area. By plotting actual data into the space, we can determine easily whether the thermal condition is comfortable or not. Even if the thermal condition is out of the comfortable thermal area, this index will provide information on how much each thermal factor should be changed in order to improve the thermal condition.

Discussion

The present results revealed that Ta made a considerable contribution to overall thermal sensation compared with dTr and Ts. On the other hand, dTr and Ts showed significant contribution to head and back thermal sensation, respectively. These results would indicate that radiant temperature and seat temperature could not exert a significant influence on overall thermal sensation, but on local thermal sensation of the exposed body parts. However, the SPRC of Ts showed a slight decrease in back thermal sensation (Fig.1), and a similar tendency was observed in overall thermal sensation. This result may indicate that the contribution of seat temperature to thermal sensation could be impaired gradually with time after passengers sit on a seat. dTr showed a relatively higher contribution to thermal comfort compared with overall thermal sensation. Also, the SPRC of dTr was approximately equal to that of Ta in head thermal sensation. These results may indicate that radiant temperature is an important factor for thermal comfort rather than for overall thermal sensation. Furthermore, head thermal sensation may make a considerable contribution to thermal comfort. Since the head is usually exposed to solar radiation, it might be an important task to decrease radiation, in particular, to the head in order to relieve thermal discomfort in a vehicle. Further study will be necessary regarding the direction of radiation and solar radiation, since the present study discusses only frontal radiation and infrared radiation from the silicon heater.

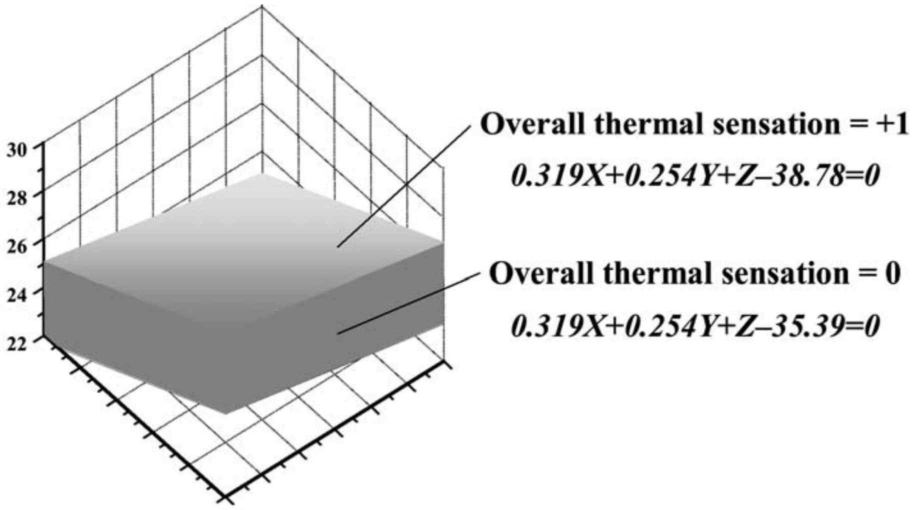

Fig.2 Flat planes constructed with ambient temperature (Ta), change in radiant temperature (dTr) and seat temperature (Ts), and these equations. Each plane indicates the condition of each thermal factor when overall thermal sensation is 0 (neutral; below) and +1 (slightly warm; above), respectively. The shaded area indicates the thermally comfortable area

The present study proposed a simple index constructed with Ta, *d*Tr and Ts. This index will be useful to estimate comfortable temperature of Ta, *d*Tr and Ts simply. Although the idea of this index is quite simple, it would provide useful information when designing thermal conditions in vehicles. However, we would have to discuss in more detail effects of ambient, radiation and seat temperature by utilizing a wider range of each thermal factor in order to create a more informative index. In addition, effects of seasonal variation, clothing, local airflow from an air–conditioner and gender and/or age differences should be discussed in the future.

Conclusions

The present study showed that ambient temperature makes a considerable contribution to both overall thermal sensation and thermal comfort compared with radiant temperature and seat temperature. On the other hand, radiant temperature may be an important thermal factor for thermal comfort, although seat temperature seems to make little contribution to either overall thermal sensation or thermal comfort.

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TEE (THERMAL ENVIRONMENT ASSESSMENT): A FRIENDLY TOOL FOR THERMAL ENVIRONMENT EVALUATION

Francesca Romana d'Ambrosio Alfano[1*], *Boris Igor Palella*[2], *Giuseppe Riccio*[2]

[1]DIMEC - Dipartimento di Ingegneria Meccanica, Università di Salerno, Fisciano, Italy
Via Ponte Don Melillo, 1 – 84084 Fisciano (Salerno) Italy
[2]DETEC - Dipartimento di Energetica, Termofluidodinamica Applicata e Condizionamenti Ambientali, Università degli Studi di Napoli Federico II, Naples, Italy
*corresponding author fdambrosio@unisa.it

Introduction

Beginning from the twentieth century the thermal sensation evaluation and the characterisation of thermal comfort conditions on a rational basis were plane out for leading only in its second part to the definition of comfort (1, 2) and stress indexes (3) up till now used. For such reason, depending on the nature of microclimate it became necessary classifying thermal environments in "moderate" and "severe". In moderate environments the main designer goal is assuring the thermal comfort for the occupants while, in severe ones, protecting the health of workers.

The rational approach for the thermal environment assessment requires:

a. an in-depth physiologic analysis of the human body behaviour in order to predict the subject response to the thermal environment;
b. a detailed analysis of the heat-exchange mechanisms regulating the energy balance of the human body.

In both cases, the right thermal environment assessment needs the implementation of mathematical models often hard to solve, for the experts also. Thus the evaluation of a comfort or stress index also may become a serious problem without a suitable software able to give a fast and clear answer to both the ergonomic specialist and the not skilled technicians.

Methods

In the early nineties our research group presented the TEE - Thermal Environment Evaluation - MS-DOS® software (4) able to evaluate both sensation indexes for the moderate environments evaluation (PMV and ET*) and stress indexes for severe ones (WBGT, SW_{req}, IREQ). In the last fifteen years the enhancement of the know-how of the heat exchange mechanisms and the formulation of new physiologic models allowing the prediction of the human body behaviour in unsteady conditions also (5, 6), resulted in more and more complex models making necessary an often hard regulation update. As a consequence, the original version of TEE was completely redesigned taking into account not only the working out of new regulations, but especially the need to supply the ergonomic beginner with an evaluation tool as more as possible friendly.

Results and discussion

The new version of TEE allows the thermal environment assessment according to the regulations actually in force. More in detail:

- moderate environments: ISO 7730 (7);
- cold severe thermal environments: ISO TR 11079 (8);
- hot severe thermal environments: ISO 7243 (9) and ISO 7933 (10);
- metabolic rate: ISO 8996 (11);
- clothing properties: ISO 9920 (12);
- vocabulary and symbols: ISO 13731 (13).

It is noteworthy to bring out that ISO TR 11079, ISO 7730 and ISO 9920 standards, under revision today, are very close to the final passage. A software upgrade is therefore expected within the end of 2005.

The computer program uses as input data the standard parameters on which the thermal energy balance of the human body depends (3). Such variables are related to the environment (grouped in microclimatic parameters) and the subject (grouped in subjective parameters). The program user interface which appears at the program start-up is showed in fig. 1.

The main window shows two sections:

Data input section: devoted to the characterisation of both the microclimate and the subject behaviour. When some of such variables is not directly available (this could be the case of mean radiant temperature, t_r) or unknown, the value can be calculated according to ISO 7726 standard (14) or read on an adequate database designed according to the regulation in force.

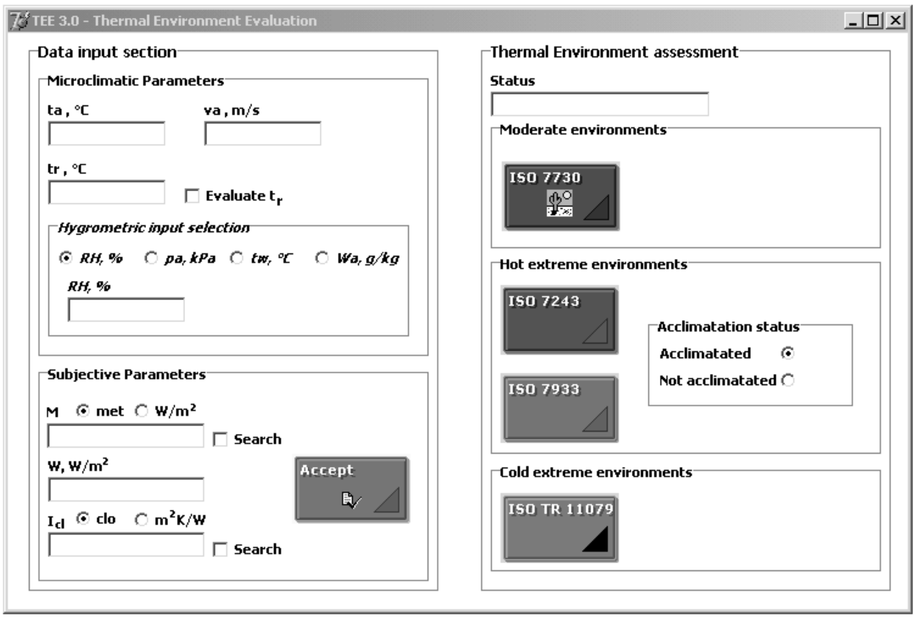


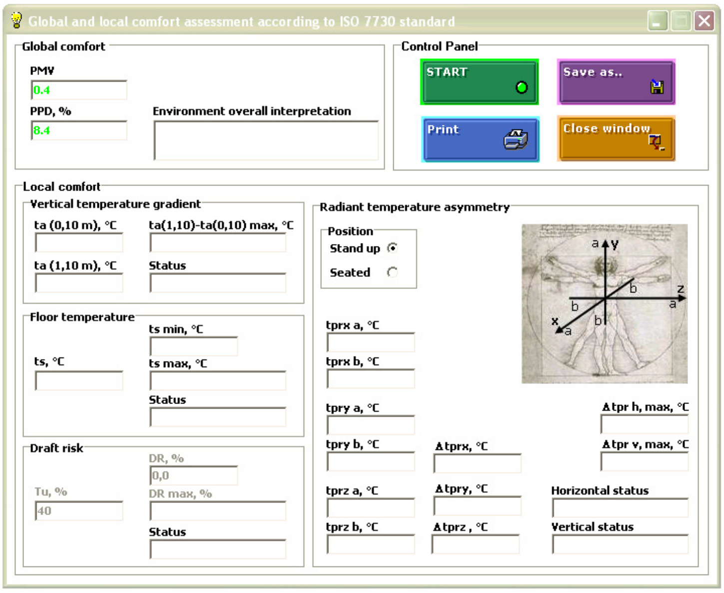
Figure 1. Main TEE program interface.

Thermal environment assessment section: devoted to the thermal environment assessment. In order to start with the environment evaluation the calculation of the PMV index according to ISO 7730 (7) is required. Therefore both hot and cold severe environments assessment buttons (see fig. 1) are not available before this preliminary operation since only when PMV value is known the environment can be assumed moderate or severe. It is noteworthy to highlight that as limit-values between moderate and severe environments +1 (slightly hot) and -1 (slightly cold) have been respectively selected. Such choice agrees with PMV comfort range [-0,50 ; 0,50] whereas ±1,0 correspond to discomfort situations.

Clicking on the respective button the thermal comfort assessment (global and local) window appears (fig. 2).

The window hosts three main boxes:

1. Global comfort: predicted mean vote (PMV) and the percentage of dissatisfied (PPD) values (calculated according to the data input of fig. 1) here are reported. Moreover a memo-box reporting the environment interpretation here is housed.
2. Local comfort: the user has to put further data related to the causes of local discomfort as vertical temperature gradient, floor temperature, draft risk and radiant temperature asymmetry.
3. Control panel: is provided with four operation buttons allowing respectively the local comfort assessment (Go), results saving (Save as), printing (Print) and coming back to the main window (Exit) for the severe (or a new) environment assessment.



Global and local comfort assessment according to ISO 7730 standard

PMV: 0.4

PPD, %: 8.4

Position: Stand up ● Seated ○

DR, %: 0,0

Tu, %: 40

Figure 2. **Moderate environment interface (ISO 7730).**

Hot severe environments

In case of hot severe environment (PMV>1), TEE allows two different assessment procedures according to the regulation in force:
Figure 1 wet bulb globe temperature (WBGT) inspiring 7243 standard (9) only for a raw assessment; predicted heat strain (PHS) on which 7933 standard (10) is based. The reference window shows three main boxes with a similar philosophy above quoted.
Additional subjective variables. Additional information about the subject position, the walking features and the clothing additional properties as the static vapour permeability index (i_m) and the clothing reflection coefficients (F_r) are required. When such parameters are unknown, user can read their typical value on a built-in database.
Control panel. It is provided with five operation buttons according to above quoted. It is noteworthy to highlight the presence of an additional button which allows an in-depth analysis for ergonomic specialists.
Assessment results. TEE returns the whole of final variables as the water loss, the final rectal temperature, t_{re} and the maximum allowable exposure time. In order to make easier the results reading for beginners also, in the interpretation memo-box a sentence-remark on the working condition appears.

Cold severe environments

Concerning the assessment of cold severe environments any additional variable is required. After clicking on “ISO TR 11079” button a new window appears (fig. 3) where TEE automatically returns minimum and neutral required insulation values ($IREQ_{min}$ and $IREQ_{neutral}$ respectively), the corresponding clothing insulation values ($I_{clr,min}$ and $I_{clr,neutral}$), the duration limits exposure ($D_{lim,min}$ and $D_{lim,neutral}$), and, finally the values of wind chill index (WCI) and the chill temperature, t_{ch}, required for the convective cooling. Similarly to others assessment windows the interpretation memo-boxes contain a sentence-remark on the working condition.

Conclusions

The old TEE software running under MS-DOS® has been completely redesigned taking into account the working out of the ergonomic know-how occurred during the last fifteen years. The new graphic interface full of buttons and hints easy to understand supplies both the ergonomic specialist and the beginner with an evaluation tool very friendly to use. The flexibility of its design we will allow in the next future its fast upgrade to the new standard now in discussion. Another version designed for Linux® platforms is under construction also.

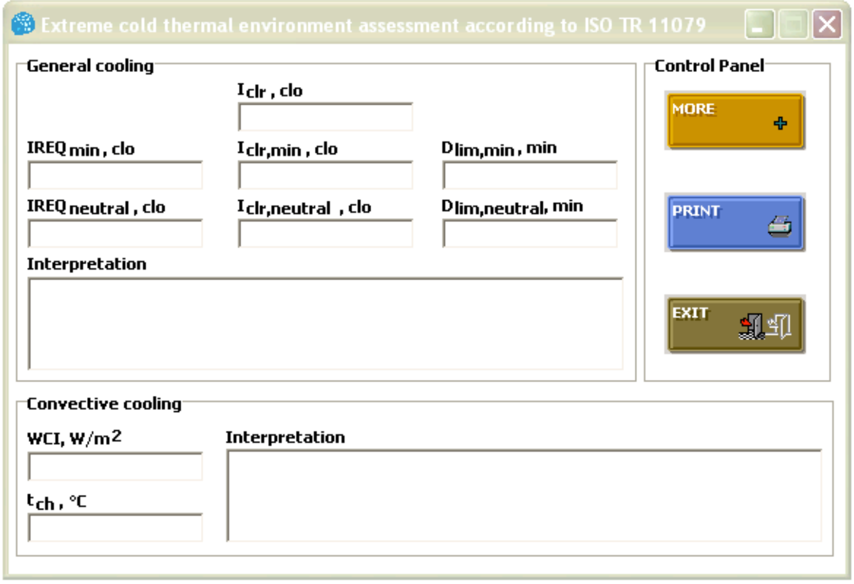


Figure 3. **Cold severe environments interface (ISO TR 11079).**

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DUST IN BUILDINGS – A METHOD FOR IDENTIFYING PARTICLE SOURCES

A. Gudmundsson, J Löndahl and M Bohgard*

Division of ergonomics and aerosol technology, Lund Institute of Technology,
SE-221 00, PO Box 118, Lund, Sweden

Introduction

There are many sources to airborne particles in indoor environments. In addition to infiltrations from the outdoor, there are various indoor sources to both coarse and fine particles. Combustion sources as smoking, incense and kerosene heaters are common for fine particles. Various activities causing disintegration and resuspension are sources to coarse dust. Sometimes there are reports from inhabitants experiencing unusually high dust levels. Growing concern about airborne particles in indoor environments requires fast source identification in order to apply remedial actions.

The aim of this work was to develop and apply a method for fast identification of sources of indoor airborne dust.

Method

The method applied for identifying sources consists of three stages. 1) Visual inspection of interior surfaces in an attempt to identify deposited particles. 2) Performing technical measurements of airborne particles in different parts of the building with simultaneous logging of activities. 3) Isolate suspected activities/particle sources in an experimental room, initially free from particles, for experimental characterizations of the particles generated.

The technical instruments used are: An aerodynamic particle sizer, APS (Model 3321, TSI Inc., US), and three optical particle counters, OPC (Remote 5010, Lighthouse Worldwide Solutions, US). The APS detects particles in the size interval 0.5-20 µm, giving a detailed particle size distribution in this range. The OPC classes the detected particles into two size classes, ≥ 0.3 µm and ≥ 5 µm.

The third step, simulating activities in laboratory, was performed in an airtight experiment chamber (volume 20 m^3, walls of stainless steel, temperature 20 °C, RH 10%, ventilation 40 m^3h^{-1} with a background particle concentration <0.01 cm^{-3} of 0.5-20 µm particles).

These steps were applied for three houses in the same area from two of which there had been reports of dust problems; House 1 (dust problems, four persons, 130 m^2), House 2 (dust problems, two persons, 132 m^2) and House 3 (no dust problems, four persons, 135 m^2). The three neighboring houses were built 2001 and hey were situated in a small town of southern Sweden.

Results

For the two houses with dust problems, deposited particles evenly distributed over the interior surfaces could be visually observed. Microscope and element analysis, conducted by the building contractor, showed that the deposited dust did not arise from the insulating material of the house.

Figure 1 show an example of results from the three OPC-instruments, situated in bedroom, living room/kitchen and study, respectively. Figure 2 shows results from the APS –instrument situated in the laundry room. The instruments had been measuring continuously for three days and nights in each house meanwhile the families noted different activities as cooking, washing, cleaning and sleeping times.

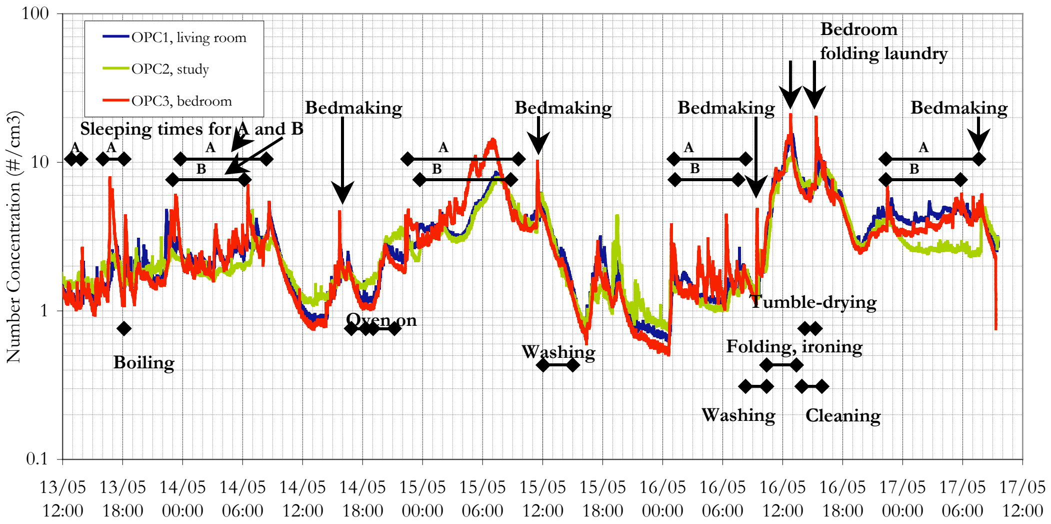


Figure 1. *The number concentration (≥0.3 µm) in a house during three days and nights measured using three OPC-instruments. Different activities logged by the members in the family are inserted in the diagram.*

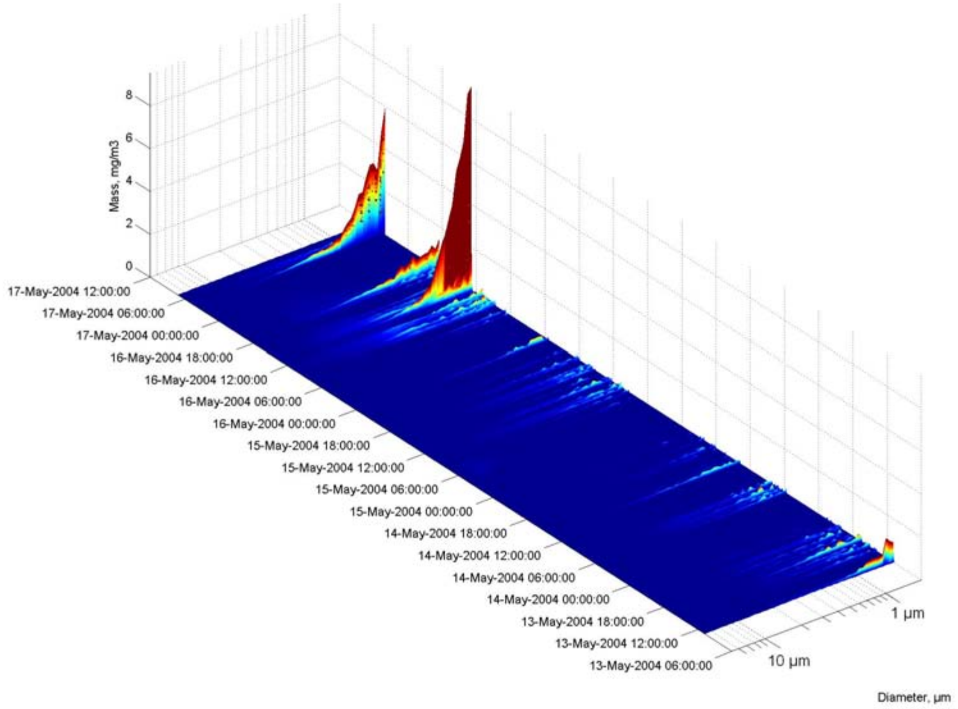
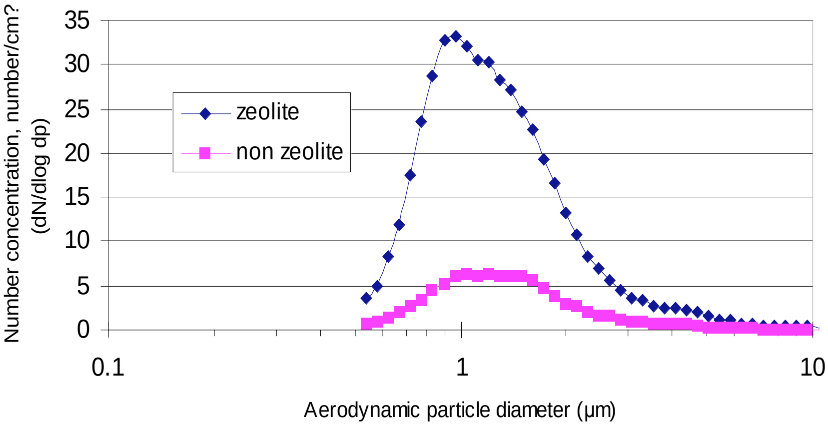


Figure 2. *The particle mass distribution in laundry room of the house during three days and nights measured using an Aerodynamic particle sizer. Temporary high mass concentrations above 1 mg/m^3 in the size interval 1- 5 µm occurred during the washing procedure.*

The following observations can be made from the measurements in the houses; 1) concentration varies largely with time, 2) some peaks can be seen almost simultaneously in the whole house, indicating the mixing is rather rapid, 3) handling of textiles generates particles, 4) all the peaks are not possible to explain by observed activities, 5) the mass concentration does often reach values corresponding to several mg/m^3 for short time intervals.

As textile handling seemed to be a major source and as exceptional high mass concentration appeared in the laundry room at tumble-drying, textile handling was further studied in laboratory. The families with dust problems used detergents consisting of up to 30% insoluble zeolites, the family without problems did not use detergent with zeolites.

A laboratory study was performed to compare textiles washed with and without detergents containing zeolite. The textiles (four pillowcases) were washed and thereafter shaken with, for this experiment, standardized motions by a test person wearing clean room clothes. Figure 3 illustrates the different particle size distributions emitted from the textiles washed with and without zeolite detergent when they were handled in the airtight experiment chamber. The particle concentration in the chamber was 6-7 times higher for the textiles washed with zeolite detergent.



Figur 3 *The number particle concentration in the chamber from textiles washed with detergent containing zeolites and detergents without zeolites, respectively.*

Conclusion and Discussion

No definite conclusion can be drawn that the perceived dust problems are related to the particles measured with the instruments, since no particles larger than 20 µm are detected. However, there are several reasons to assume that the dust originates from textiles containing detergent zeolite residues:

- The households with dust problems did use zeolite detergents; the household without problems did not.
- Activities like tumble-drying and bed making give high particle concentrations.
- The dust is spread on all surfaces in the whole house, which implies that it arises from relatively small particles.
- The particle concentration is often high for sizes between 1-5 µm – about the same sizes are reported for zeolite particles in detergents.
- Studies have shown that zeolites remain in clothes after washing and The Swedish Consumer Agency (2004) has reported that modern washing machines have an insufficient rinse, which results in significant amounts of detergent residues in the washed textiles.
- The preliminary study in the chamber clearly demonstrates the large amount of particles suspended from textiles washed by a detergent containing zeolite.

Zeolites have increasingly been replacing phosphates as softening agent during the last two decades and about one million tons of zeolites are used worldwide every year in power laundry detergents (Kemezis, 1999). Zeolites are not soluble in water.

The methodology applied was able to identify one probable major particle source and will be applied in future investigations in buildings from, which dust problems are reported.

Knowledge on differences in concentrations between different rooms, real-time measurements comparisons with activity reports from the inhabitants, detailed information on particle size distribution and simulating the activities in laboratory, facilitates the identification of sources to particle emissions.

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USE OF HUMIDEX TO SET THERMAL WORK LIMITS FOR EMERGENCY WORKERS IN PROTECTIVE CLOTHING

William R. Santee and Robert F. Wallace*

U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760, USA
*corresponding author william.santee@na.amedd.army.mil

Introduction

Humidex (HD) is a temperature-humidity index (1) developed and used primarily in Canada. HD and other heat indices, usually obtained from weather services, are widely disseminated by media outlets to provide general guidance to the public concerning comfort and potential heat hazards (2). Although usually not specified, guidance for using heat indices is presumably based on normal activities and clothing. Unfortunately police, military and other emergency personnel, responding to security threats, overt violence, or nuclear, biological, or chemical (NBC) contamination, including accidents, must wear either protective body armor or NBC protective clothing which can impose a greater heat burden than most normal clothing. Although thermal models (3) provide more precise guidance, at present the public does not have ready access to those models, nor the requisite inputs for novel applications. Given the wide availability via the media and simplicity of heat indices, it would be useful to adapt civilian indices to emergency conditions.

In a prior study (3), we compared HD to the Heat Index (HI), the U.S. National Weather Service index for heat exposure, by using body core temperatures predicted with our Institute's Heat Stress Decision Aid (HSDA). Input limits, including a minimum value for T_a of 26.7°C, were based on guidance for HI. In that study, HI and HD were considered equivalent, but HD was preferred as it used dew-point temperature rather than relative humidity. An additional advantage of HD is that it is not limited by the 26.7°C threshold imposed on HI. Our proposal was to use HD to provide short-term (30-120 min) heat exposure guidance for emergency workers wearing specialized clothing.

Methods

HSDA (3) was used to calculate core temperatures (T_{core}) for different combinations of air temperature and relative humidity (RH). Corresponding HD values were calculated by estimating T_{dp} from T_a and RH, then using a simplified equation (4) to calculate HD from T_a and T_{dp}. Constant values were selected for other model inputs. Activity levels used were light (139 $W \cdot m^{-2}$), medium (236 $W \cdot m^{-2}$) and heavy (333 $W \cdot m^{-2}$). When simulating body armor, insulation (R_c) and water vapor permeability (R_e) values were 0.27 $m^2 \cdot K \cdot W^{-1}$ and 0.43 $m^2 \cdot Pa \cdot W^{-1}$. For fully encapsulated NBC clothing (Level A PPE), $R_c = 0.27\ m^2 \cdot K \cdot W^{-1}$ and $R_e = 0.41\ m^2 \cdot Pa \cdot W^{-1}$. Other constants used in the simulation were subject height 180 cm, weight 80 kg, wind 2.5 $m \cdot s^{-1}$ and no solar radiation. A second dataset was generated for an indoor wind speed of 0.1 m/s. Second order polynomial equations were then calculated for the relationship between T_{core} and HD. To set an upper thermal limit for the derivation of the equations, the maximum value included in the data sets was $T_{core} \leq 42$. For our evaluation, 2861 sets of activities and environmental conditions were used.

Results

The mean R^2 value for all forty-eight polynomial equations comparing the HSDA simulations and the HD index was 0.97. Equations for 60 min model simulations are presented in Table 1. To evaluate the utility of these polynomial predictions, the difference between T_{core} predicted by the equation and the model was calculated. The upper limit for this evaluation was set at 41°C – when most individuals would be experiencing significant heat injuries. The average maximum difference was 0.36°C. As environmental conditions became more extreme, with a corresponding increase in thermal strain, the predicted T_{core} values become less precise due to increased variability in the model output (Figure 1), with predicted values in the upper range exceed ±0.25°C. The data can be used to set HD thresholds for a given level of thermal strain (T_{core}) and activity. When predicted T_{core} approach 41°C, an under prediction of 0.25°C would not be acceptable. If the maximum T_{core} value is ≥ 39.5°C values, the deviation between the values predicted with the second order equations and the HSDA values are minimized. At 39.5°C most individuals will be heat casualties. Figure 2 compares T_{core} values calculated for the two wind conditions.

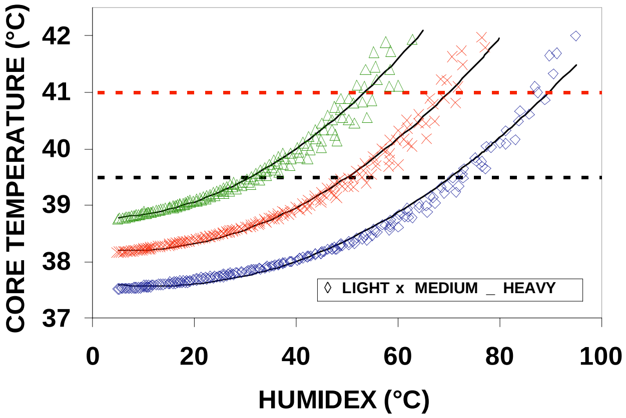

Figure 1. HSDA predicted core temperature at 60 min, wind=2.5 $m \cdot s^{-1}$ versus Humidex at 3 work intensities, Light =139 $W \bullet m^{-2}$ (◊), Medium = 236 $W \bullet m^{-2}$ (X) and Heavy = 333 $W \bullet m^{-2}$(Δ), in Chemical Protective (CP) clothing. Solid lines represent second order linear fit to HSDA values. Dashed lines at 39.5°C and 41°C represent critical T_{core} values for heat casualties.

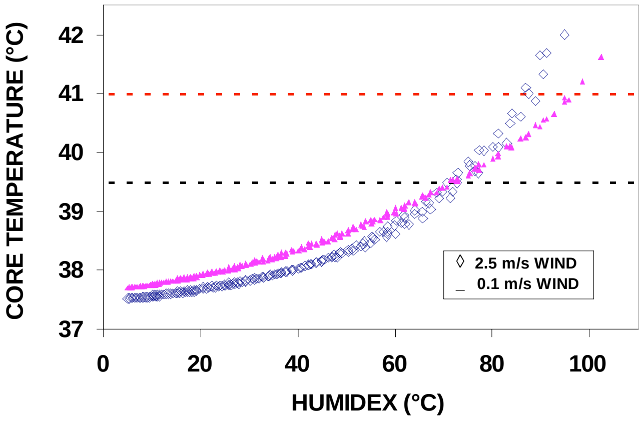

Figure 2. HSDA predicted core temperature at 60 min, wind=0.1 $m \cdot s^{-1}$ versus Humidex for Light (139 $W \bullet m^{-2}$) work in Chemical Protective (CP) clothing. Dashed lines at 39.5°C and 41°C represent critical T_{core} values for heat casualties.

Discussion

During an emergency operation, the maximum continuous exposure limit that can be sustained without incurring permanent thermal injury – or which allows a sustained work-rest cycle – is of critical importance. A complete discussion of those limits is beyond the scope of this paper. When the predicted T_{core} values approach critical upper thermal thresholds, there is less tolerance for variability. Deviations from T_{core} values predicted by the equations tend to increase in the upper, more extreme, ranges of HD, T_{core} and activity levels. When these upper limits (T_{core} ≥41°C) are approached, the importance of evaporative cooling, and thus humidity, in determining core temperatures, increases. When T_a is greater than skin temperature, greater clothing insulation, normally a disadvantage, may now afford protection from convective heat gain. The crossover of T_{core} values for 2.5 and 0.1 $m \cdot s^{-1}$ wind speeds in Figure 2 indicates that the direction of convective heat transfer has been reversed. Simple heat indices, which are based on a constant relationship between T_a and humidity, fail to adequately reflect the increasing importance of humidity. There is a distinct preference by government agencies and private industry to present thermal guidance in look-up or survival tables, but the necessity of generating multiple tables to compensate for each significant difference in parameters eventually becomes too unwieldy. Figure 1 clearly illustrates the problem of using HD or other heat indices during emergencies, when personnel may be pushed to perform beyond normal thermal limits.

Table 1. Predictive Equations for core temperature [T_{core} = ß$_0$ + ß$_1$•HD + ß$_2$.•HD^2 (°C)] from Humidex (HD) for Body Armor (BA) and Chemical Protective (CP) Clothing for 2 wind speeds

GARMENT	**WIND** $m \bullet s^{-1}$	**TIME MIN**	**ACTIVITY** $W \bullet m^{-2}$	**ß$_0$ ND**	**ß$_1$ ND**	**ß$_2$ ND**	**R^2 ND**
BA	2.5	60	139	37.67303	-0.02627	0.00075003	0.96
CP	2.5	60	139	37.64962	-0.01398	0.00057254	0.98
BA	2.5	60	236	38.19958	-0.02448	0.00088363	0.96
CP	2.5	60	236	38.23653	-0.01035	0.00071054	0.98
BA	2.5	60	333	38.69937	-0.02056	0.00096736	0.94
CP	2.5	60	333	38.77277	-0.00191	0.00081473	0.97
BA	0.1	60	139	37.75628	-0.00360	0.00041062	0.99
CP	0.1	60	139	37.73435	0.00268	0.0003148	0.99
BA	0.1	60	236	38.41555	-0.01711	0.00083443	0.99
CP	0.1	60	236	38.34544	0.00269	0.00054633	0.99
BA	0.1	60	333	38.87185	-0.01407	0.0010400	0.98
CP	0.1	60	333	38.95729	0.00682	0.00078602	0.99

Conclusion

There was a clear relationship between HD and predicted thermal strain. For less extreme thermal limits (T_{core} ≤39.5°C), the polynomial equations relating HD to T_{core} may be useful. However, at the upper limit for human tolerance (T_{core} ≥41°C) under extreme conditions, differences between the HSDA model and HD predictions for the polynomial equations are too large to provide adequate guidance for personnel management during emergency situations.

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NONINVASIVE WARNING INDICATOR OF THE “RED ZONE” OF POTENTIAL THERMAL INJURY AND PERFORMANCE IMPAIRMENT: A PILOT STUDY.

Miyo Yokota[1*]*, Daniel Moran*[2]*, Larry Berglund*[1]*, Lou Stephenson*[1]*, Margaret Kolka*[1]*.*

[1]U.S. Army Research Institute of Environmental Medicine (USARIEM), Natick, MA, USA..
[2]Heller Institute of Medical Research, Sheba Medical Center, Tel Hashomer, Israel.
* corresponding author: Miyo.Yokota@na.amedd.army.mil

INTRODUCTION

Guidelines for assessing workers’ level of heat strain to prevent thermal injury and performance impairment have been widely adopted by private industries to promote workers’ health and safety. Internal body temperature (T_{core}) is the common physiological parameter for heat strain assessment as it reliably indicates impending injury (1,2). Laboratory studies as well as occupational guidelines for civilian workforces (e.g., metal and glass workers, fire fighters) and military personnel, all suggest regulating workers’ operational or environment conditions when T_{core} is 38.0°C (100.4°F) - 38.5°C (101.3°F) (1,2) or there is less than 1°C difference between T_{core} and skin temperature (T_{skin}) (3). However, measuring T_{core} may be invasive and impractical for real time monitoring of worker’s health status or Soldiers engaged in long hours of various multiple and unpredictable tasks in hot environments.

T_{skin} and heart rate (HR) are non-invasive, easily measured physiological parameters that are also indicators of the thermo-vascular status of workers exposed to thermal stress. Skin blood flows and sweating are active primary control mechanisms for T_{core} (4). If the T_{core} rises above its set point (~37°C), blood flow to the skin increases. Normal blood flow to the skin for a comfortable sedentary person is about 6 $L{\bullet}h^{-1}{\bullet}m^{-2}$ but can increase to 90 $L{\bullet}h^{-1}{\bullet}m^{-2}$ or higher, when a person becomes overheated (4). T_{skin} rises as a result of the warm blood flow to the skin. Under the conditions of excessive body heat, T_{skin} approaches T_{core}, and thermoregulatory insufficiency may occur due to the minimal heat transfer.

HR increases as oxygen consumption increases during work (4). The worker’s age adjusted maximum HR should not exceed a value of 220 – age (5). Despite the documentation that these physiological non-invasive measures increase with T_{core} under excessive heat exposure (4,6), the combination of HR and skin temperature are rarely utilized for occupational performance advisories or guidance.

This paper presents a preliminary investigation of the impeding heat strain warning system called Red Zone (RZ), which is based on non-invasive measures of HR and T_{skin} combined with Body Mass Index (BMI). Individual differences characterized by BMI relate to differences in physiological responses to heat exposure (7,8) and improve the accuracy of the RZ warning system for individuals.

MATERIALS AND METHODS

Individual data from four USARIEM datasets (Age = 25 ± 6 yrs, BMI = 23.9 ± 3.1, N = 19) and a heat tolerance study (Age = 19 ± 1yrs, BMI = 24.5 ± 3.2, N = 24) were used to formulate the Red Zone. Table 1 depicts the summary of five study conditions. Thigh or chest skin temperatures were examined in these data because they were less variable than T_{skin} taken from arm or calf regions. Because T_{skin} for USARIEM study4 were not monitored, T_{skin} of these subjects were estimated by SCENARIO, a USARIEM thermoregulatory mathematical model (9). In all studies, subjects discontinued a test when T_{core} reached 39.5°C. In addition, testing was stopped when subjects reached 95% of age-estimated HR_{max} or remained at 90-94% of age-estimated HR_{max} for 5 minutes.

The final measurements of T_{skin} and HR for all tests and BMI were compared. BMI is relatively convenient to measure and is beneficial to describe associations with body fat, age, and gender. BMI, calculated by (weight, kg)/(height^2, m^2), was the only consistently measured individual parameter available between the datasets. When a BMI was unavailable (Heat tolerance study), it was randomly generated for the individual subject from the mean and standard deviation of published BMI data. Subjects were categorized into three BMI groups: a) low <= 20; b) 20 <medium <25; c) high >= 25. The RZ was also classified into three conditions: a) good/safe; b) experiencing heat/warning; and c) critical/overheated. The individual subject data labeled with these Red Zone categories based on their physiological responses were compared to their individual T_{core}, using Fisher's exact test.

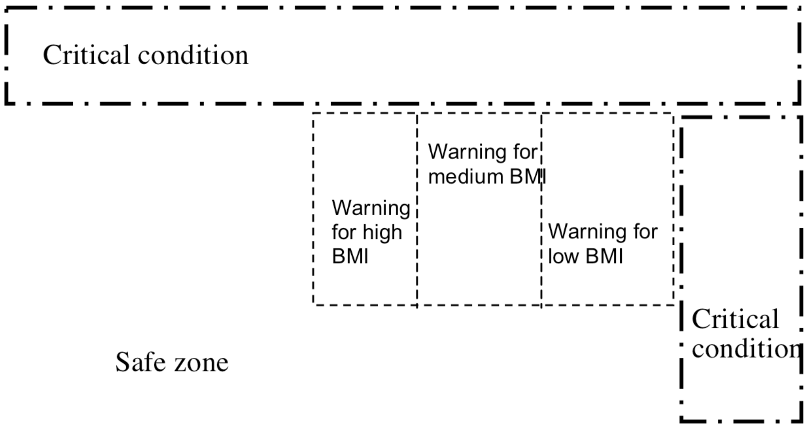
Table 1. Summary of five study conditions used in this study.

Database (reference)	N	Lab vs Field	Weather (mean)	Main activity	Clothing	Duration
USARIEM study1 (10)	5	Lab	38°C, 30%RH	walk (2 mph, 0% grade)	CP	240 min
USARIEM study2 (11)	5	Lab	30°C, 30%RH	walk (1.46 ms^{-1}, 2% grade)	CP	80 min
USARIEM study3 (12)	7	Lab	30°C, 38%RH	walk (3 mph, 2% grade)	CP	45-90 min
USARIEM study4*	2	Field	34°C, 44%RH	walk (altitude up to 350m)	BDU	all day
Heat tolerance study (6)	24	Lab	40°C, 40%RH	walk (5 km.h^{-1}, 2% grade)	Shorts, T-shirt	120 min

Database: * indicates an unpublished study
Clothing: CP = Chemical Protective Garment; BDU = Battle Dress Uniform

RESULTS

The combinations of final T_{skin} and HR from the 5 different studies are summarized by BMI in Figure 1. T_{skin} above 38°C is likely to indicate potential heat injury irrespective of HR regardless of BMI values (upper area in Figure 1). When T_{skin} is above 36°C and HR above the subject's HR warning threshold adjusted by BMI categories, there is an increasing probability of impeding hyperthermia, heat injury and performance decrements. When T_{skin} ranges between 36°C and 38°C, the HR warning threshold increases with decreasing BMI (three dotted BMI boxes in Figure 1). For instance, when an individual's HR and T_{skin} are 150 bpm and 37°C, respectively, the RZ is classified as "safe" if the BMI is low, "warning" if the BMI is medium or "critical" if the BMI is high. When an individual's BMI is high (>= 25), he/she is likely to experience hyperthermia and heat stress at a lower HR than medium/light BMI individuals. Low BMI individuals (<= 20) are less likely to experience potential heat injury until HR limits reach to around 160-175 bpm (Figure 1).



— · - indicates critical/warning conditions
------- indicates warning conditions for addressed BMI.
BMI: L = low; M = medium; H = high

Figure 1. Red Zone model based on heart rate (HR, bpm), skin temperature (T_{skin}, °C) and three BMI categories (low, medium, high) applied for 5 studies.

Table 2 demonstrates the relationships of termination points between T_{core} classified by a standard heat guidelines (T_{core} = 38.5°C as a threshold) (1,2) and T_{skin} categorized by the RZ model. The accuracy in the RZ warning that T_{core} is greater than 38.5 °C is around 60%. Similarly, T_{core} below 38.5°C was classified as no warning by RZ with ~60% accuracy. The false positive rate (T_{skin} was classified as a safe condition, although T_{core} was recorded above 38.5°C) was around 20%. The data points classified by the three RZ categories showed relatively good agreement with T_{core} (Fisher's exact, $p < 0.05$).

Table 2. The assessment of relationship between categorical Red Zone classifications and core temperature, obtained from 5 different studies

Core Temperature	*Red Zone*			*Total*
	Safe	Warning	Critical	
Safe (< 38.5 °C)	13 (59.1%)	5 (22.7%)	4 (18.2%)	22 (100.0%)
Critical (>= 38.5 °C)	5 (23.8%)	4 (19.1%)	12 (57.1%)	21 (100.0%)
Total	18 (41.9%)	9 (20.9%)	16 (37.2%)	43 (100.0%)

CONCLUSIONS

The RZ is an encouraging approach to warn occupational workers that they are approaching or/under excessive thermal physiological strain. This preliminary study suggests that there was a 60% – 80% probability that T_{core} is above 38.5°C when T_{skin} and HR of individuals fell into RZ classifications of "experiencing heat or critical conditions." Some of the RZ false positive results might be related to a person's heat acclimation state because heat tolerant individuals may be able to maintain lower T_{skin} in compensable environments than heat intolerant individuals despite their high T_{core}. The RZ function, derived from non-invasive T_{skin} and HR measurements, utilizing BMI is useful to warn of likely excessive T_{core} and thermoregulatory distress as it occurs. Further field measurements including various environmental, clothing, and operational conditions will be important to refine this warning method, increase confidence intervals, and improve applications to diversified military populations.

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RAPID ACCLIMATIZATION TO HEAT - IS IT ATTAINABLE?

Y Epstein, DS Moran, Y Shapiro*

Heller Institute of Medical Research, Sheba Medical Center, Tel Hashomer and the Sackler Faculty of Medicine,
Tel Aviv University, Israel

Acclimatization to heat is a physiological adaptive mechanism that results with an enhanced endurance of heat stress. Effective acclimatization is achieved following several weeks of free-living under warm climatic conditions. This process can be accelerated under controlled environmental conditions - acclimation - and usually can be attained within 8-10 days of a determined exercise-heat stress protocol. Operational requirements to deploy military troops from one climatic condition to another with short notice force the development of an acclimation procedure, which can be effective in less than 5 days. The present study is a preliminary trial to achieve this goal. Two groups of young (22±2 yrs) male subjects, matched for physical fitness and anthropometrical parameters, participated in a 5 day acclimation procedure. Group A (n=8), dressed in shorts and tennis shoes, was exposed to hot/dry climatic conditions (40oC; 40% rh). Group B (n=9), dressed with impermeable protective garments, was exposed to temperate climatic conditions (20oC; 50% rh). Daily exposure lasted 120 min while walking on a treadmill at a pace of 5km/h and 2% inclination. Rectal temperature, skin temperature and heart rate were monitored at 5 min intervals. Physiological strain was assessed by the PSI according to Moran et al (AJP 275:R129, 1998). In group A PSI was reduced from 5.2±0.8 units (mean±SE) at day 1 to 4.1±0.4 units on day 3 with no further reduction on day 5. In Group B PSI decreased from 5.2±0.6 units on day 1 to 3.9±0.6 on day 3 and 3.4±0.3 on day 5. From these preliminary results it can be concluded that impermeable protective clothing, worn under temperate climatic conditions, imposes a physiological strain that is comparable to exposure to warm climate. Thus, a rapid procedure of acclimation can possibly be based on an exposure of 5 days to temperate climate while wearing impermeable clothing.

THE VALIDATION OF HEAT STRESS INDICES IN MOBARAKE STEEL COMPLEX

Ardeshir Kalantari[1] , *Mohammad Reza Sadeghi*[2]

1 - Isfahan University of Medical Sciences, faculty of Health ,Dpt of occupational and environmental Health, 81745, IRAN.
2 - Isfahan University of Medical Sciences . MSc in occupational health.

Introduction

For evaluation of the heat load , that workers exposed with it, some indices have been already introduced and comparison. In the present study validity of some of these indices have been evaluated.

Material and Methods

Conventional thermometer, kata thermometer, WBGT instrument, Globe temperature instrument and Hygrometer were used for assessing indices and environmental parameters. Firstly, the unit of foundry was divided to 15station and these parameters were measured and data were collected. Special equations were applied for calculating of heat stress indices. In this study 90 healthy and acclimatized men were chosen and then mouth, core and skin temperatures of these men were measured and recorded . The results analyzed by SPSS program and correlation coefficient (r), Mean and standard deviation for each of factors were obtained.

Results

In this study, mean , minimum, maximum and SD for environmental factors and desirable indices were calculated. Then relation between personal factors (mouth, core and skin temperatures) with environmental factors and indices were assessed. There relationship between heat stress and environmental factors was not significant ($P>0.05$). Heat stress index, P4SR ($P= 0.005$) had the most relationship, whereas other indices showed no significant relationships.

Discussion

In this study, a meaningful relationship was found between P4SR and all of other variables. Therefore in this research P4SR index was selected as the valid index. A strong and meaningful relationship between desirable measured parameters have been seen. It is recommended that in separate study, not acclimatized persons be evaluated against the same conditions used in this study. Also other indices could be measured in other industries. (hot - humid or hot dry).

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HABITUATION TO A COMPLEX WORKING TASK IN THE HEAT: MINE RESCUE TRAINING

Bernhard Kampmann [1]*, *Georg Bresser* [2]

[1] Division of Applied Physiology, Occupational Medicine & Infectiology, Department of Safety Engineering, Bergische Universität Wuppertal, Wuppertal, Germany
[2] Central Mine Rescue Station, Deutsche Steinkohle AG, Herne, Germany
* corresponding author kampmann@uni-wuppertal.de

Introduction

During regular training of brigadesmen high values of physiological strain have been reported (1, 2, 3, 4). Most mine rescue brigadesmen estimate their first training in a training gallery – using a self contained breathing apparatus and wearing flame protective clothing – as the most strenuous training of their career. The aim of our study was to determine whether this subjective impression corresponds to strain parameters as heart rate and body temperature, and – if so – what practical conclusions could be drawn from these results. Especially the time scale on which a habituation takes place is of interest for the arrangement of mine rescue training for beginners.

Material and methods

For a beginner who entered the mine rescue service (at an age of 36 years) heart rate and body temperature were recorded continuously by means of a portable device during all his trainings. Within the first seven years of his membership a total of 39 trainings could be made full use of, comprising different types of training. As well the continuous recordings as statistical parameters of heart rate and rectal temperature during all the trainings were available for evaluation.

Results

There were four different types of mine rescue training performed within the training facilities of the Central Mine Rescue Station in Essen (1). The time course of rectal temperature showed that for no type of training a thermoregulatory equilibrium was established due to the chosen stress parameters *Temperature within the gallery*, *Equipment* (Flame protecting clothing, Self Contained Breathing Apparatus BG 174 (Dräger Inc.)) and *Work load* (way within the training gallery, duration of the training, additional climatic stress in a separate climatic chamber).

As the body temperature only was recorded and not monitored, we were surprised by the high physiological strain after looking onto the first results; it turned out that the strain reduced during the following trainings and that other brigadesmen had strain of similar magnitude.

Figure 1 shows the results for a *standard training with climatic stress* (i.e. added to walking, climbing and crouching in the training gallery were 10 minutes of walking on a treadmill (3.5 km/h at an inclination of 5°) in a climatic chamber at $t_a = 40$ °C; $t_{wb} = 31$°C) with a scheduled total duration of 100 minutes. As the different types of training show different physiological strain, rectal temperatures are given for the first six trainings just of this type of training. Rectal temperature shows a distinct reduction up to the third repetition.

In order to assess the habituation to the mine rescue training, two types of training – causing physiological strain of similar magnitude (*standard training* and *standard training with climatic stress*) – are depicted in Figure 2. The physiological strain obviously was higher during the *standard trainings with climatic stress* compared to the *standard training*. As the duration of the training was not fixed exactly (the velocity of a brigade usually is set by the leader in consent with the brigadesmen) the data show an additional variation. Nevertheless the strain shows a decrease during the first 15 months after the first training that may be approximated linearly.

The 95th percentile of heart rate (the 95th percentile of heart rate is more stable – with respect to artefacts that cannot always be avoided – compared to the maximum value of heat rate) reduced – within a linear regression – for about 20 min^{-1} during the first year of training ($r = 0{,}91$; $p < 0{,}02$); the rectal temperature at the end of the training reduced for 1.4°C during the first year of mine rescue training ($r = 0{,}93$; $p < 0{,}01$).

After 1 ½ years the strain shows no further decrease. Our data allow an analysis of different intervening parameters during the adjacent time interval. Only the standard training (being the type of training with the highest frequency) will be shown. Within the time interval between 1.5 and 7 years after the first training 17 standard trainings took place.

Although the training took place at the late morning or early afternoon body temperature at the begin of the training showed variations from 36.8°C up to 37.6°C (mean value: 37.3°C). Figure 3 shows in the upper part the maximum of rectal temperature during the training depending on the value at the start: a linear regression ($r = 0{,}67$; $p < 0{,}005$) results in a slope of 0.985, i.e. if rectal temperature is increased at the beginning of the training, the maximum temperature at the end of the training will be elevated correspondingly. The mean increase of rectal temperature during a standard training is 1.7°C.

For a standard training with a target time for duration of 120 minutes a faster pace – reducing the duration of the training for 10 minutes – corresponded to an increase of rectal temperature towards the end of the training of 0.3°C (linear regression: $r = 0{,}68$: $p < 0{,}005$).

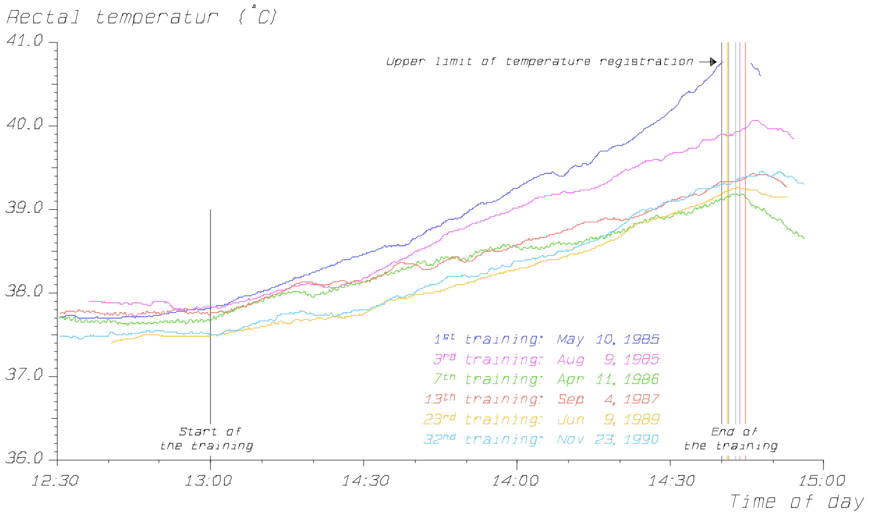

Figure 1. Rectal temperature during *standard trainings with climatic stress* for 6 trainings of this type during five years (the sequence of training elements was changed sometimes, so the inclination of the slope varies respectively). For the sake of clarity the begin of the training was adjusted to 13:00 in the plot.

Discussion

The subjective impression of very high strain during the first mine rescue training corresponded with high values of heart rates and especially high body temperatures. Both parameters decreased strongly in the following trainings.

The physical fitness of the subject did not change much during the investigation. As the participation in about five mine rescue trainings per year will not increase physical training status, we hypothesize that habituation to the mine rescue training (use of the Self Contained Breathing Apparatus, wearing of flame protection clothing, and elements of the training like climbing and crouching within the training facility or work at the weight pulling device) leads as well to a reduction of energy expenditure as to reduced psychological stress. – A reduction of energy expenditure due to better coordination of movements has been described even for much more simple activities – compared to mine rescue training – like walking on a treadmill or for a step-test (6). – As no thermoregulatory equilibrium will be established during the training (cf. Figure 1), the mechanisms for regulating body temperature will only be operative to a minor extent: this may explain the direct dependence of the maximal rectal temperature from the initial value of rectal temperature.

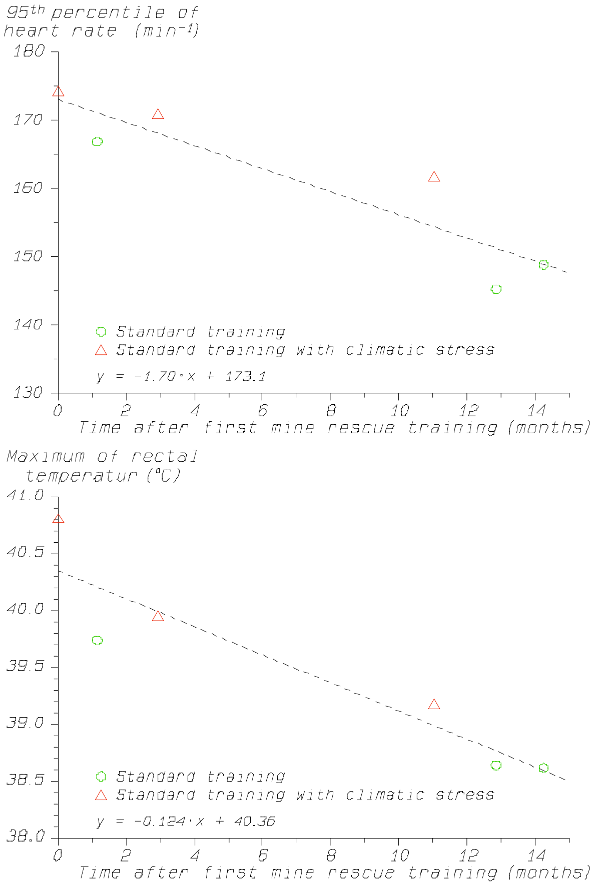

Figure 2. Change of physiological strain (95th percentile of heart rate and maximum of rectal temperature) during 15 months following the first training (*standard training* and *standard training with climatic stress.*)

Conclusions

As a consequence of our results it was decided that the first two trainings of each mine rescue brigadesman shall be limited to one hour of duration – until then a shortening of the training was left to the judgement of the supervisor of the training. We assume that a reduction of physiological strain after habituation to the mine rescue training also will be existing during missions of the mine rescue service underground.

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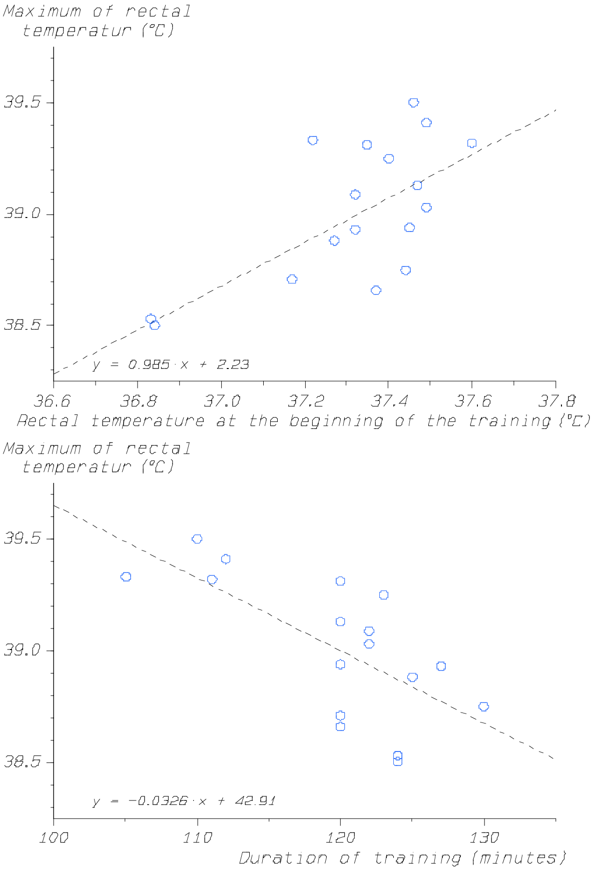

Figure 3. Influence of intervening parameters on the maximal rectal temperature during a *standard training*: rectal temperature at the begin of the training and duration of the training (data from 17 standard trainings from the time interval between 1.5 years and 7 years after the first mine rescue training).

PHYSIOLOGICAL INVESTIGATION FOR THE DESIGN OF WORK-REST CYCLES DURING WORK IN THE HEAT

Bernhard Kampmannn, Hansjürgen Gebhardt*

Institute ASER e.V. at the University of Wuppertal, Wuppertal; Germany
* corresponding author kampmann@uni-wuppertal.de

Introduction

A lot of investigations have been made concerning physiological strain at hot working places. For most studies in the laboratory as well constant climatic conditions as constant working conditions were looked at and the question of work-rest-cycles was set aside. As resting phases are needed at hot working places when the combination of workload and heat stress exceeds a thermoregulatory steady-state, Pangert et al. (5) made up a pragmatic proposal for work-rest cycles based on a literature review and a questionnaire within German companies with respect to resting phases at work in the heat (Figure 1). Their proposal introduces a scheme for work-rest ratios at air temperatures above 35°C. The frame for rest and work was set to one hour in total for reasons of practicability; the duration of the resting phases within this frame depends on the degree of heat stress. During the resting phase light work is assumed to be performed as to meet industrial practice.

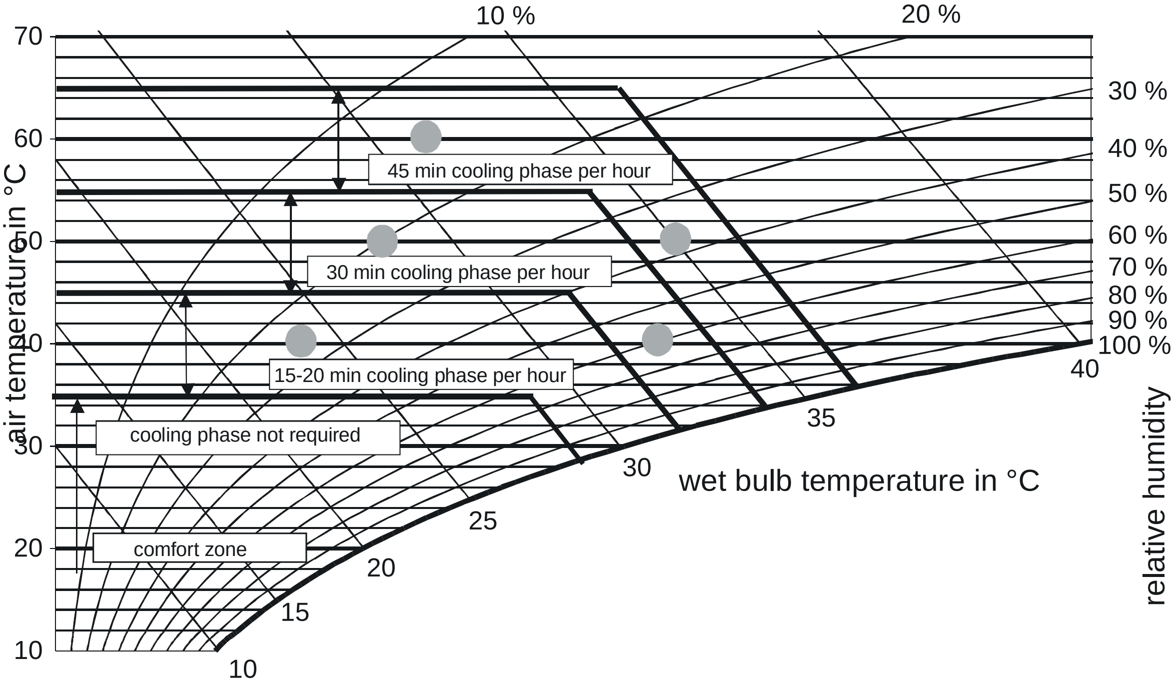

Figure 1. Proposal by Pangert et al. (5) for work-rest cycles in hot climate and the combinations of air temperature and relative humidity chosen for the investigation presented here. The combinations chosen are in the mid of the different regimes; the two combination defined at the right hand side shall test the break off of the boundery lines with increasing humidity.

The aim of our study is to first validate the proposal of Pangert et al. (5) and afterwards to test climatic indices like PHS (Malchaire et al. (3), ISO 7933, (2)) with respect to the prognosis of the predicted values of body temperature and sweat loss later on. For that a research project (funded by the Federal Institute for Occupational Safety and Health, Dortmund, Germany; F 1860) was started using standardized climatic and working conditions in climatic chambers.

Material and Methods

In order to reduce the multiple possible variations of the experimental setting it was decided to test the proposal (5)

for a frame of one hour (total duration of a working and a resting phase) that is repeated at least 4 times to simulate half a working day.

for five combinations of air temperature and relative humidity (40 °C; 20 % relative humidity (45/15)), (40 °C; 60 % rel. hum. (30/30)), (50 °C; 20 % rel. hum. (30/30)), (50 °C; 40 % rel. hum. (15/45)) und (60 °C; 20 % rel. hum. (15/45)) representing hot-dry as well as warm-humid climatic conditions. These combinations are plotted in figure 1. The proposed durations of work and rest according to (5) are given in brackets.

work load was chosen relatively high as to simulate hard working conditions in the field: walking on a treadmill at 4.0 km/h at an inclination of 5°.

“cooling phases” took place in a second climatic chamber at a comfortable air temperature of 23 °C; as workers in the field will not do nothing during the cool-down times, a light work intensity was chosen (20 W external work at a bicycle ergometer) to meet the working conditions in the field.

clothing was chosen according to actual clothing of workers at hot working conditions with an insulation of I_{cl} = 0.8 clo. Clothing was not changed at the beginning of the cooling phase, even if it was quite wet.

During the exposure heart rate and body temperature (rectal temperature) were recorded and monitored outside the climatic chambers. Body mass and the weight of beverages were measured before the working phase started and after it was finished.

The experiments started with the subject resting for 20 minutes at an air temperature of 23 °C (no work). After that the climatic exposure started. The exposure ended either at the time according to Figure 1, or at any time before due to the will of the subject or when withdrawal criteria were met. The withdrawal criteria were chosen for heart rate to be “200 – age” and for body temperature as 38.5 °C. If the withdrawal criteria were met the rest of the hour was spent at light work in the second chamber at 23 °C. Before the series of exposures started the subject had a medical checkup according to (1) as any worker in hot conditions in Germany has to pass.

In case that the ratio of work and cooling time did not cause heart rate or body temperature to increase to the criteria for withdrawal, the ratio of work and cooling time was chosen higher for a next exposure and vice versa.

In order to estimate the influence of a “lunch hour” at noon, for some exposures a 30 minutes break was added in the comfortable climate (no work, time to eat, read and relax), followed by another hour of climatic exposure with the chosen ratio of work in the heat and cooling.

The investigation started with one subject (age 54 years, body height 1,87 m; body mass 103 kg; PWC 150 = 298 W corresponding to 138 % of the required value (in (1)) of 2.1 W/kg body mass) in order to get experiences at the different combinations of work-rest cycles and climatic stresses.

Results

The most important results of the investigation so far are given in Table 1. In case a physiological limit was exceeded, the moment of withdrawal of the subject is given.

Our results are in line with the proposals in Figure 1 to an acceptable extent with respect to the proposed ratio of working and cooling times at the chosen physiological limit criteria. It turned out as an important feature that the clothing – mostly wet from sweat after the heat exposure – was not changed at the beginning of the cooling phase. So evaporation cooling could continue during this phase, sometimes leading even to chill of the subject. Moreover it showed that an exposure time of two hours cannot be used to predict the result of longer exposure times, as the wetting of the clothing increases in most cases during the second hour of exposure; after the second hour of exposure the wetting does not increase strongly and therefore the evaporation cooling in the cooling phases shows a smaller increase compared to an extrapolation from the first and second hour.

Discussion

The results in Table 1 in general confirm the proposal of Pangert et al. (5) given in Figure 1 for the climatic exposure and workload chosen in our set-up. In case of air temperatures of 50 °C and 60 °C the limit criteria were met only at the end of the 3rd resp. 4th hour of exposure for an increased work-rest ratio. So in this part of Figure 1 the boundary line between the (30/30) and the (15/45) regimes seems to be somewhat low for our subject.

At an air temperature of 40 °C and 27 % relative humidity the combined stress of work and heat did not exceed a thermoregulatory steady-state for our subject. – At 40 °C and 60 % relative humidity the limit criteria for heart rate and body temperature are just missed during an exposure of four hours for the work-rest ratio of (30/30) minutes. Here the boundary line for a work-rest ratio of (30/30) is situated a bit too high in Figure 1 for the subject in our test, as the climatic stress was chosen to be in the middle of the (30/30) regime.

In international standards heat stress often is limited as to keep body temperature below 38.0 °C in case that body temperature is not monitored (based on WHO (6); cf. e.g. WBGT or Malchaire et al. (4)). For our study this limiting criterion for body temperature would result in the same classification of work-rest ratios for the exposures at 50 °C and 60 °C according to Table 1: at the proposed work-rest ratio the limit criteria were not met; at an increased work-rest ratio the limit value of 38.0 °C of course would have been met earlier than 38.5 °C. – At 40 °C and 27 % relative humidity the result would correspond to Figure 1 also for a limit value for body temperature of 38.0 °C. – For 40 °C and a relative humidity of 60 % a body temperature of 38.0 °C would have been definitely exceeded also in case of a work-rest ratio of (30/30): in this case the boundary line would have to be lowered.

In a next step the individual variation of physiological strain shall be taken into account by testing more subjects.

Table 1: Maximum values of heart rate and body temperature registrated during four hours of exposure with predefined work-rest cycles (according to Figure 1); work in different climates, cooling at light work in comfortable climate (23 °C).

Climatic conditions during work	Duration of work in climate [minutes]	Duration of rest [minutes]	Maximum of heart rate [min-1]	Maximum of body temperature*[° C]	Criterium for withdrawal from work reached
40 °C 27 % rel. hum.	40	20	114	37.9	Ø
	60	0	122	38.1	Ø
40 °C 60 % rel. hum.	30	30	144	38.5	Ø
	45	15	142	38.5	1st hour of exposure; 42. minute
50 °C 20 % rel. hum.	30	30	127	38.0	Ø
	45	15	145	38.5	3rd hour of exposure; 42. minute
50 °C 37 % rel. hum.	15	45	122	37.9	Ø
	30	30	147	38.5	2nd hour of exposure; 26. minute
60 °C 16 % rel. hum.	15	45	112	37.4	Ø
	30	30	142	38.5	4th hour of exposure; 24. minute

* at the end of work exposure

Conclusions

The first results of our study correspond remarkably to the proposals of Pangert et al. (5) for the set-up we have chosen.

The data will serve as a basis to test the climatic index Predicted Heat Strain (PHS, Malchaire et al. (3); ISO 7933 (2)) with respect to the prediction of physiological data (sweat rate and body temperature) for working situations beyond the steady-state limit of thermoregulation, where resting phases have to be introduced within industrial work.

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MODELLING SWEAT RATE EFFICIENCY WITHIN PHS AND VALIDATION ON EXPERIMENTAL DATA

Bernhard Kampmann [1]*, *Jacques Malchaire* [2]

[1] Division of Applied Physiology, Occupational Medicine & Infectiology, Department of Safety Engineering, Bergische Universität Wuppertal, Wuppertal, Germany
[2] Unité Hygiène et Physiologie du Travail UCL–HYTR, ESP - Clos Chapelle aux Champs, Bruxelles, Belgium
* corresponding author kampmann@uni-wuppertal. de

Introduction

In warm-humid climatic conditions, sweat will not always evaporate completely from the skin but will drip off. Therefore, when modelling the thermal balance of a subject, the evaporative efficiency of sweating (η) needs to be described as a function of skin wettedness (w). In the first version of ISO 7933 (SW_{req}, 1989 (1)), the evaporation efficiency was assumed to decrease to 0.5, when the wettedness of the skin approached 1.0 and to remain equal to 0.5 when the wettedness increased further. Then, in very humid conditions, the model was assuming a maximum evaporation rate and a predicted sweat rate that decreased with increasing humidity. This was clearly contradicted by data from Kohler (1976 (4)) and Zintl (1979 (7)) (3).

In order to avoid this misleading result, it is assumed that the thickness of the water layer on the skin can increase even if the skin is 100% wet and therefore that the evaporative efficiency continues to decrease for w > 1.0. In the new version of ISO 7933 (Predicted Heat Strain; 2004 (2)), the relationship is then described by:

$\eta = 1 - w^2/2$ for $w \le 1$
$\eta = (2 - w)^2/2$ for $1 < w \le 1.7$
$\eta = 0.05$ for $w > 1.7$ (6)

and plotted in Figure 1:

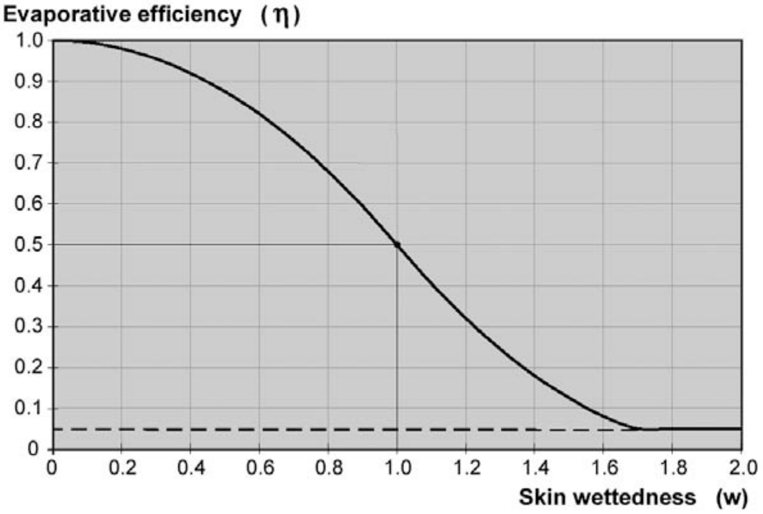

Figure 1. Proposed relationship between skin wettedness and evaporation efficiency (6).

Material and methods

The data from Zintl concerned a acclimated subject resting (seated) for 4 hours at 10 occasions in environments where the air temperature was always 38. 2°C, but the relative humidity increased up to 87 %. Kohler's data concerned 2 sets of experiments with 5 exposures each at t_a = 38.2°C and 43.1°C and relative humidity increasing up to 80 % respectively 56 %.

As the data of Kohler and Zintl have not been used during modelling PHS, they may now be taken for validation of the model at very high humidities.

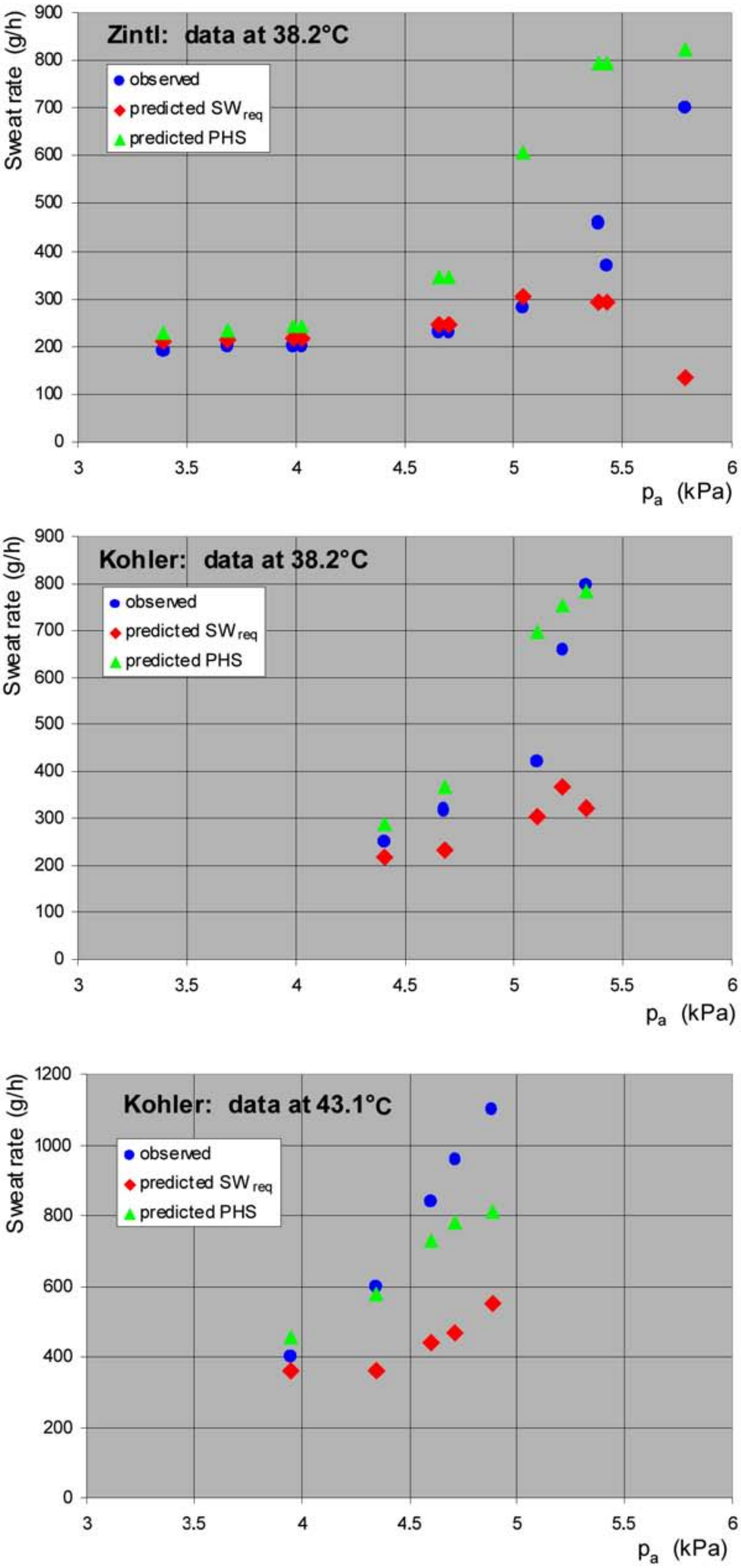

Figure 2. Increase of sweat rate with increasing water vapour pressure as observed by Kohler (4) & Zintl (7), and predicted by ISO 7933 (1986) “SW$_{req}$” (1) and ISO 7933 2004 “PHS” (2). (The data from Zintl’s exposures at 4.01, 4.68 and 5.41 kPa are plotted slightly horizontally displaced as to enable the distinction of data points.)

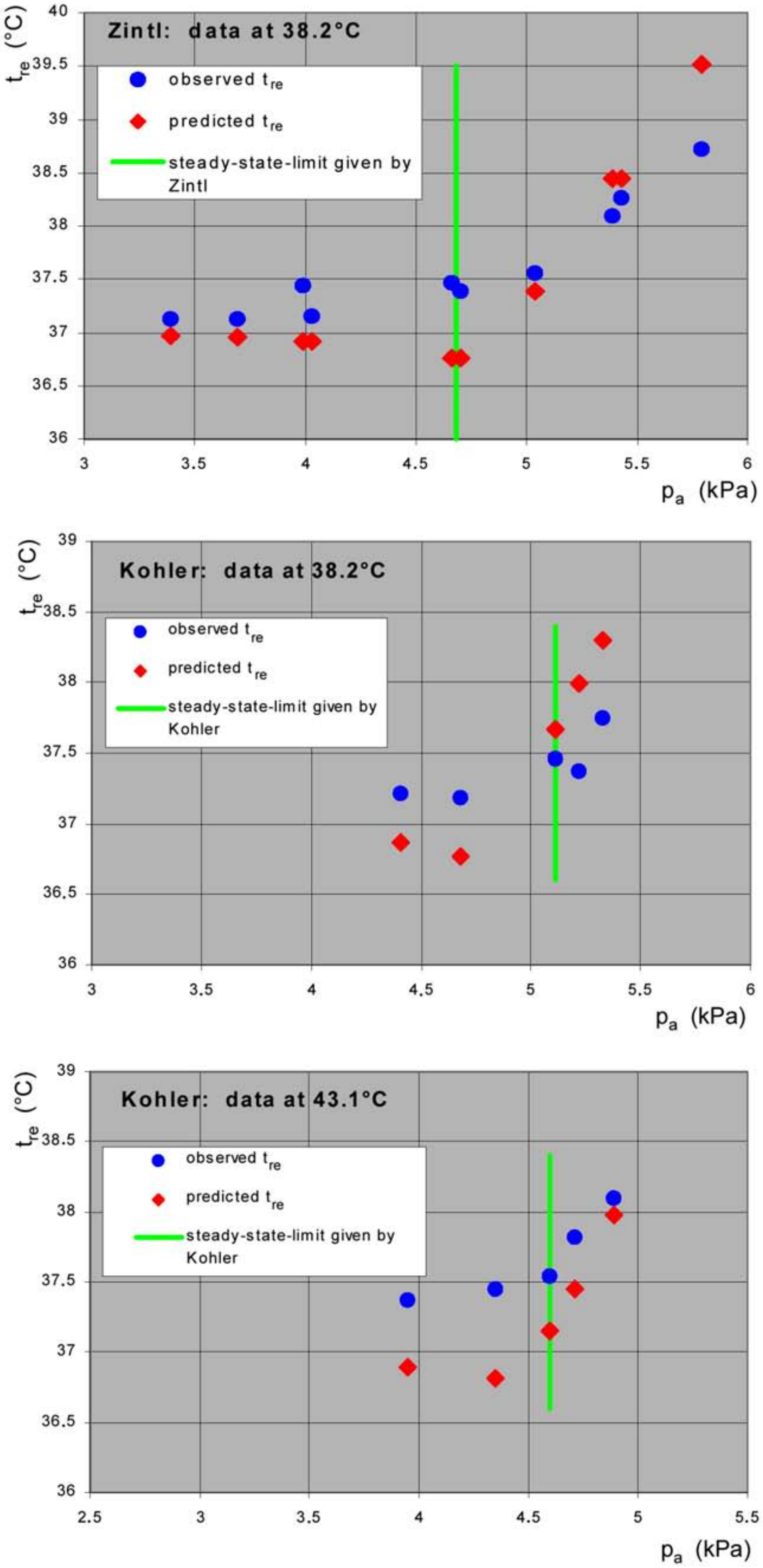

Figure 3. Increase of body temperature with increasing water vapour pressure as observed by Kohler (4) & Zintl (7), and predicted by ISO 7933 2004 "PHS" (2). Steady-state limits estimated by Kohler and Zintl from

the series of exposures are marked. (The data from Zintl's exposures at 4.01, 4.68 and 5.41 kPa are plotted slightly horizontally displaced as to enable the distinction of data points.)

Results

Predicted sweat rates were calculated by means of as well SW_{req} as of the PHS index which makes it also possible to predict the rectal temperature after three hours of exposure. Figure 2 shows the prediction of sweat rates. Figure 3 gives the calculation of rectal temperature (mean value for the third hour of exposure) by PHS.

Discussion

The prediction of sweat rates using the new algorithm within the PHS model is by far better than when using the previous SW_{req} model. Figure 2 demonstrates that, especially at very high humidity, the sweat rates predicted by PHS increase as do the observed sweat rates, while, on the contrary, SW_{req} predicted a decrease in sweat rate that is not at all found in the studies of Kohler and Zintl. The deviation of observed values from PHS predictions seems to be of the order of interindividual differences, as at 38. 2°C the prognosis for Kohler's data is quite good whereas for Zintl's subject there is an overestimation.

The rectal temperatures predicted by PHS show good agreement with observed data for high humidities. The increase of rectal temperature with increasing humidity shows good agreement with the observed data as well as with the steady-state limits found by Zintl and Kohler. As the steady-state limit represents the border of the "prescriptive zone" (Lind (5)), the prediction of this border perhaps is even more important than the prediction of the absolute value of rectal temperature that is influenced e. g. by circadian rhythm.

Conclusions

The modelling of evaporation efficiency within PHS seems quite acceptable, at least until more comprehensive data for the evaporation efficiency of sweat become available.

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THE EFFECT OF ACCESSIBLE COOL WATER ON HYDRATION STATUS DURING ARMOURED VEHICLE ACTIVITIES IN HOT ENVIRONMENTS

Mark J Patterson[1], Warren S Roberts[1], James P Finn[2], David Barton[3]*

[1] Chemical, Biological, Radiological and Nuclear Defence Centre, Defence Science and Technology Organisation, Melbourne, Australia
[2] School of Science and Primary Industries, Charles Darwin University, Darwin, Australia
[3] Land Systems Division, Defence Materiel Organisation, Melbourne, Australia
* corresponding author mark.patterson@dsto.defence.gov.au

Introduction

Dehydration is frequently reported when working in hot climates and is typically associated with inadequate fluid intake. Drinking water temperature (1) and the water delivery system (2) have been both identified to affect fluid intake. We sought to determine the combined effect of cool drinking water and a water bladder system for improved water accessibility, during armoured vehicle field activities in a hot environment on crew hydration status and the subsequent effect on physiological strain.

Methods

The Australian main battle tank was the vehicle employed during these field exercises. This vehicle consists of a four-man crew, being a crew commander, loader, gunner and driver. Three crews conducted two 9-hr (08:00-17:00) trials separated by at least two days. Work activities were the same in both trials and included a road run, a hide with erection of cam nets, force-on-force and offensive and defensive operations. The two trials differed in that the crew either drank water from 2 litre water containers at temperatures from 30°C to 45°C (control) or were supplied 10°C water in a 2 litre bladder system worn on their backs (cool water). For most crewmen to drink from the 2 litre water containers required the vehicle to cease activities.

Subjects were advised to drink 15 ml/kg of water before retiring for bed on the night prior to the trial and eat a meal high in carbohydrate. A further 10 ml/kg of fluid was advised upon waking with a high carbohydrate breakfast. Subjects were also asked to refine from alcohol in the 24-hr period prior to the trial and caffeine and tobacco in the 12-hr period prior to the trial. No caffeine or tobacco consumption was permitted during the 9-hr trial. Subjects brought their own food snacks and were provided with hotbox lunches, these were standardised between days.

Environmental conditions (wet bulb globe temperature; WBGT) were monitored continuously at 1-min intervals in the field, external to the vehicle and within the vehicle at the loader's, gunner's and driver's positions. Body core temperature was recorded at 1- min intervals using a gastrointestinal radio-pill. Heart rate was recorded at 5-sec intervals using the Polar Team System. Hydration status was estimated by changes in pre- and post-trial semi-nude body mass (gravimetrically; ±50 g) and urine specific gravity (USG; refractometer). All fluid and food intake were gravimetrically determined, as were urine losses (±50 g).

Results and discussion

The mean external-vehicle environmental conditions were similar between days, with a mean WBGT 31.6°C (range: 27.9 – 34.5°C). The subsequent mean internal-vehicle WBGT was 31.5°C (range: 28.2 - 35.8°C). Sweat loss was equivalent between trials (5.3 ± 1.0 L vs. 5.4 ± 1.2 L; control vs. cool water, respectively; $P > 0.05$), whereas fluid intake was significantly greater when drinking the more accessible cooler water (3.7 ± 1.1 L vs. 5.0 ± 1.4 L; $P < 0.05$; Figure 1). Consequently, the percentage body mass loss was greater for the standard water supply system (1.5 ± 0.6 % vs. 0.8 ± 1.0 %; $P < 0.05$). The post-trial USG also indicated that the level of dehydration was lower in the cool water trial (1.026 ± 0.006 vs. 1.019 ± 0.010; $P < 0.05$). The greater fluid intake in the cool water trial also resulted in a greater urine production (0.38 ± 0.31 L vs. 0.93 ± 0.58 L; $P < 0.05$). Consequently while on average an extra 1.3 L was consumed in the cool water, ~40% of this volume was excreted as urine.

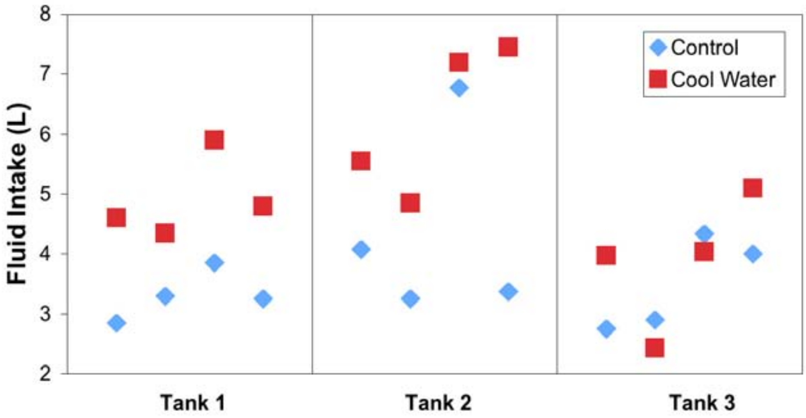

Figure 1. Individual fluid intake in control and cool water trials.

While the magnitude of dehydration was reduced in the cool water condition this did not affect the mean body core temperature (37.5 ± 0.2°C vs. 37.4 ± 0.1°C; control vs. cool water, respectively; $P > 0.05$) or the mean heart rate (90 ± 8 beats/min vs. 91 ± 8 beats/min; control vs. cool water, respectively; $P > 0.05$) over the 9-hr trial.

Conclusions

It is clear that more water was consumed when accessible cool water was provided, and consequently the magnitude of dehydration was reduced. This lower level of dehydration did not impact on the overall physiological strain induced by the armoured vehicle activities. Further work is required to ascertain whether or not accessible cool water can reduced physiological strain and improve work performance during more prolonged field exercises

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SIMULATION OF INDIVIDUAL THERMOREGULATORY RESPONSES TO PARTIAL COLD WATER IMMERSION AND EXERCISE

Xiaojiang Xu[*], *John W. Castellani, William Santee, Margaret Kolka*

US Army Research Institute of Environmental Medicine, Natick, MA, USA
[*]Corresponding author: xiaojiang.xu@us.army.mil

Introduction

During emergencies, adventure racing or military operations, individuals may be partially submerged in cold water, thereby at risk for rapid heat loss and hypothermia. By modeling the effects of water immersion, this hazard may be better understood, and more active preventive measures can be implemented or public warnings issued. The purpose of this study was to determine whether a previously validated cold thermoregulatory model (CTM) (1,2) for predicting temperature responses in sedentary people during whole-body immersion was applicable to partial immersion in cold water during exercise (treadmill walking).

Methods

CTM is a six cylinder mathematical model representing the head, trunk, arms, legs, hands, and feet. Each segment is further concentrically divided into compartments representing the core, muscle, fat, and skin. The integrated thermal signal to the thermoregulatory controller is composed of the weighted thermal input from thermal receptors at various sites distributed throughout the body. The difference between this signal and its threshold activates several thermoregulatory actions including vasomotor changes, sweat production and metabolic heat production. The shivering thermogenesis function (i.e. part of metabolic heat production) includes shivering exhaustion, intensity control, maximal capability, and inhibition due to a low core temperature.

Two subjects, whose physical characteristic are listed in Table 1, were immersed in 10 and 15°C water at both the chest (CH) and waist level (WA). They wore a standard US military uniform (BDU) for all trials and walked at 0.44 $m \cdot s^{-1}$ until their rectal temperature (T_{re}) fell to 35.5°C or they requested to stop. A CTM simulation was run for each of the 8 individual trials (abbreviated as CH15, CH10, WA15, and WA10).

Table 1 Individual physical characteristics for two subjects

Subject	age (year)	height (m)	weight (kg)	fat percentage (%)	VO^2 max (ml/min kg)
A	20	1.75	69.0	17.0	42.5
B	18	1.73	68.0	15.0	47.8

The CTM inputs were the individual characteristics listed in Table 1 plus environmental parameters (i.e. temperature, humidity and wind velocity) and clothing parameters (clo, Im) for each of the six cylinders. Since only a portion of the torso was submersed in CH and WA, the environmental and clothing parameters for the torso were modified. It was assumed that 20% of the torso was exposed to air while 80% was immersed during CH, whereas during WA, 80% of the torso was exposed to air while 20% was immersed. In addition, measured heat transfer coefficients for trials, instead of model default values, were used to make the simulation more realistic. The measured core temperature (T_c, esophageal temperature T_{es}, and rectal temperature) and mean skin temperature (T_{sk}, 7 sites) were compared with the predicted T_c and the T_{sk}, respectively, using root mean square deviations (RMSD) (3,4). RMSD was calculated between the observed and predicted temperatures with a 5 min interval.

Results and Discussion

Calculated RMSD indicates that the measured T_c agreed with predicted T_c for both subjects (Table 2). However, the predicted T_{sk} was close to the measured T_{sk} for Subject A, but not for Subject B, as shown by relatively high RMSDs. The differences are due to initial T_{sk} values; predicted T_{sk} started always at a thermal neutral temperature of 33°C while the measured T_{sk} began at ~24-26°C. Figure 1 shows the predicted and measured T_c for Subject A and B during CH15, CH10, WA15 and WA10. While predicted T_c agree with measured T_c during CH15 and CH10, predicted T_c are higher than measured T_c during WA. The clothing covering the torso was getting wet during WA, the water in the fabric evaporated and then enhanced evaporative heat loss to the environments. This extra heat loss was not taken into account in the simulation. Physiological responses to partial immersion were also complicated. As shown in Fig.1 for subject A, differences between the measured T_c at the end of CH10 and WA10 trials were minimal. Given that the prediction was run for an individual response rather than a group response, CTM was able to simulate T_c in non-uniform environments (partial immersion, walking) with reasonable accuracy.

Table 2 RMSD of the core and mean skin temperatures for subjects A and B

	Subject A		Subject B	
	T_c	T_{sk}	T_c	T_{sk}
CH10	0.25	1.10	0.15	2.37
CH15	0.26	0.82	0.09	1.45
WA10	0.21	1.40	0.17	2.39
WA15	0.13	1.05	0.23	2.66

Partial immersion represents a relatively complex set of experimental conditions. Although CTM allows each of the six cylinders to have its own environmental and clothing parameters, in this experiment, one cylinder (e.g., torso) is only partially immersed. To adapt the model for partial immersion, adjustments based on the percentage of the cylinder that was immersed as well as using the actual convective heat coefficient were made to the inputs for the torso section. Results from this study indicate that adjustments (i.e. parameters for the torso section) to the model based on best available information are necessary to ensure that the inputs and predictions more accurately represent actual conditions.

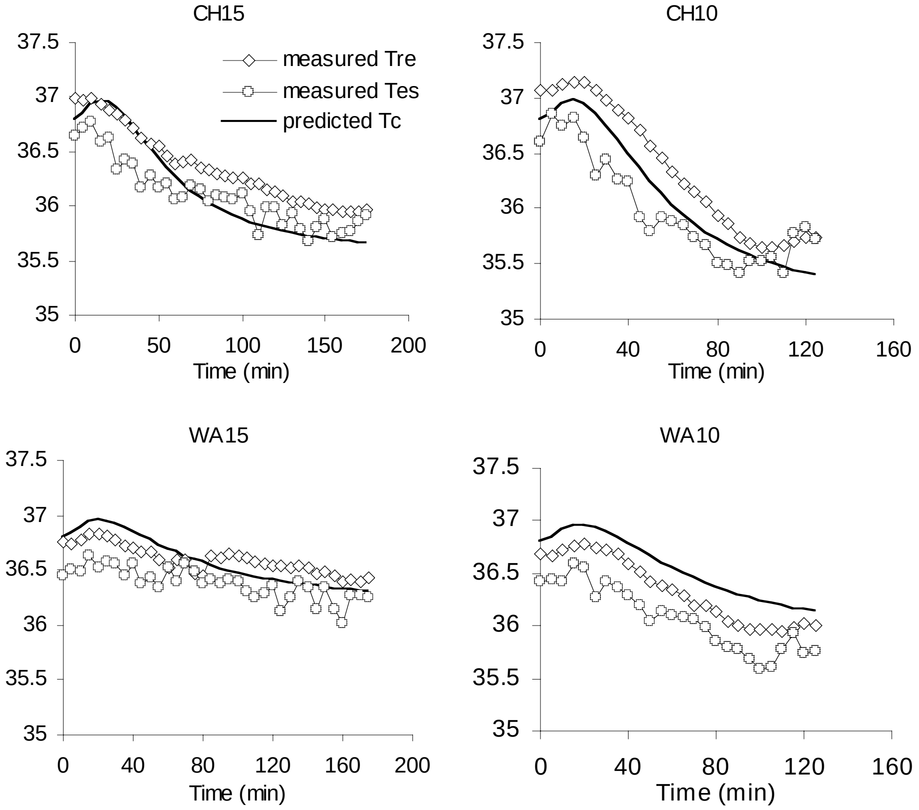

Figure 1 Subject A, measured and predicted T_c during CH15, CH10, WA15, and WA10

When CTM is used to predict thermal responses in the field, it is important to use the best available parameters as inputs. To ensure that the inputs are realistic, rigorous evaluation to identify all possible scenarios is required. To provide the most accurate predictions, it may be necessary to have real-time monitoring of the conditions so that input parameters can be adjusted accordingly. When the information available is limited, it might be necessary to run thermal response simulations for the worst and best cases. If applied appropriately, models such as CTM could help to plan operations, organize rescue activities, assist post mortem investigations, etc.

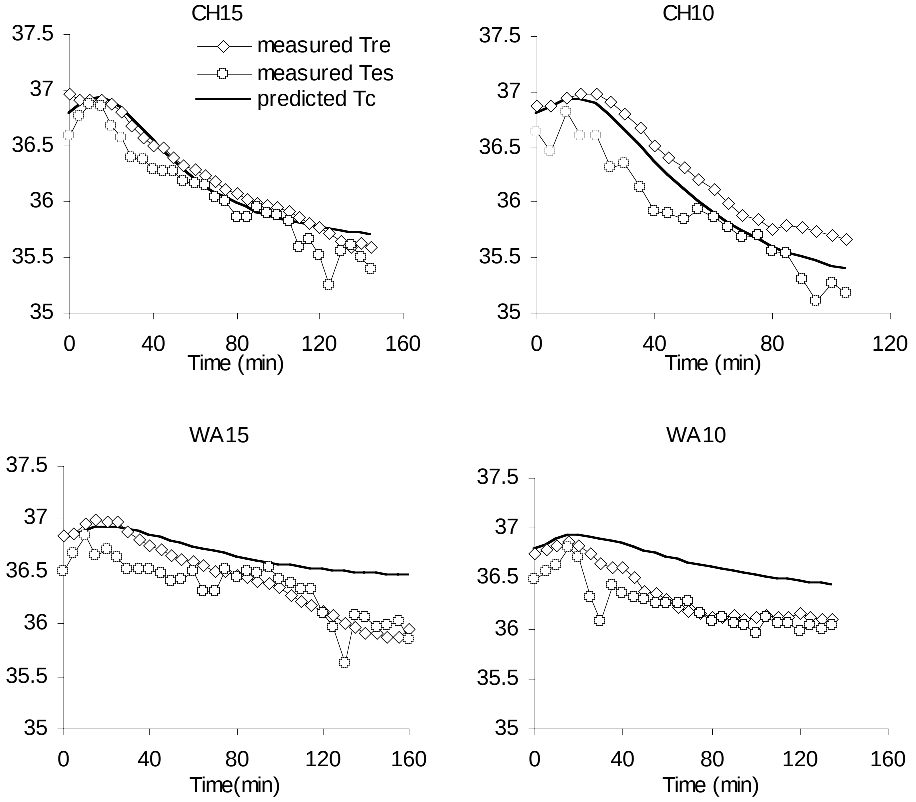

Figure 2 Subject B, measured and predicted Tc during CH15, CH10, WA15, and WA10

Conclusions

These results demonstrate that the CTM can reasonably simulate core temperature responses to partial water immersion during exercise. However, to obtain more accurate core and skin temperature predictions, it is critical to determine the appropriate parameter inputs for each body segment before running the simulation.

Disclaimer

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MODELING A MICROCLIMATE COOLING SYSTEM IN PROTECTIVE CLOTHING

Irena Yermakova[1], *Victor Candas*[2], *Julia Tadejeva*[1] .

1) International Center for Information Technologies and Systems UNESCO, Kiev, Ukraine.
2) Centre d'Etudes de Physiologie Appliquée (CNRS), Strasbourg, France.

Introduction

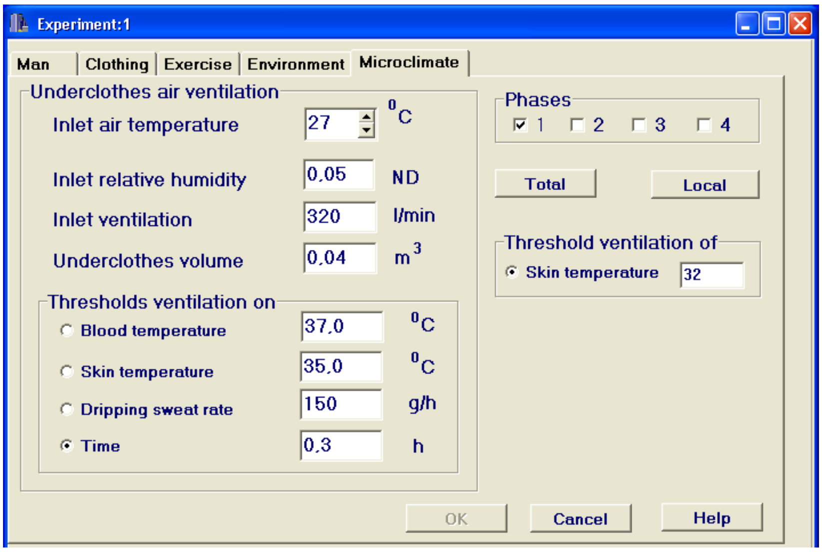
Various solutions have been proposed to reduce heat stress or to provide thermal comfort for man wearing impermeable protective clothing during his work in hostile environments. Air cooling by air ventilation systems is used in special cases (1). The ventilation renews the trapped air in the underclothes, it allows to remove some extra heat and this cooling effect is often considered for safety reasons. The ventilation with dry air has the main advantage to facilitate the sweat evaporation, a very powerful phenomenon : practically, the method can be applied on the whole body or only on some body parts, considering their importance in terms of "heat sink" capacity : surface, their vasomotor and/or sweating capacity (2,3).

Methods

The aim of this present work was to simulate, by using a computer including a human thermoregulatory model, a microclimate cooling system (MCS) impermeable protective clothing worn by human subjects exposed to hot environments.

In reality, the cooling effect depends on many parameters and it is not easy to predict its physiological consequences. The reason why it is interesting to use the model approach is that it can take into account many factors and it makes possible to get preliminary ideas of the effect of the cooling system for a given man, clothing and environment. Modeling of MCS is performed here using Computer Simulator for prediction of Human state in different environments, this computer program has been developed from existing adapted human temperature regulation program to which was added the clothing layers and their characteristics (4).

Main menu for modeling of Microclimate Cooling System is showed in fig.1 below.



Underclothes air ventilation

Inlet air temperature 27 ^{0}C

Inlet relative humidity 0,05 ND

Inlet ventilation 320 l/min

Underclothes volume 0,04 m^3

Thresholds ventilation on

○ Blood temperature 37,0 ^{0}C

○ Skin temperature 35,0 ^{0}C

○ Dripping sweat rate 150 g/h

● Time 0,3 h

Phases

☑ 1 ☐ 2 ☐ 3 ☐ 4

Threshold ventilation of

● Skin temperature 32

Figure.1 Modeling of MCS

To simulate MCS effect, it is necessary to select and choose all parameters related to MAN, CLOTHING, EXERCISE, and ENVIRONMENT and of course MCS. All these points are described in the companion paper in this book (5).It is enough to recall here that MAN gives the possibility to choose body approximation. CLOTHING requires knowledge of thermal insulation and evaporative resistance of protective clothing. EXERCISE relates to work power and body movements. ENVIRONMENT is characterized by environmental temperatures, humidity and air velocity.

MCS simulations are performed through various possibilities, the first one being the way of cooling: If whole body cooling is considered, TOTAL is selected but if only parts of the body are concerned, we select LOCAL followed by choice of body parts: torso, head and/or others. Then it is necessary to input the conditions which characterize the MCS. These are : ventilation, temperature and humidity of inlet air, underclothes volume. Our model allows to perform experiments under different conditions of MCS “ON” or MCS “OFF”. Fig 1 shows the possibility of four thresholds for triggering MCS.’ON”. They are : blood temperature, mean skin temperature, dripping sweat rate or exposure time. Here, for MCS “OFF”, mean skin temperature is validated.

Results and discussion

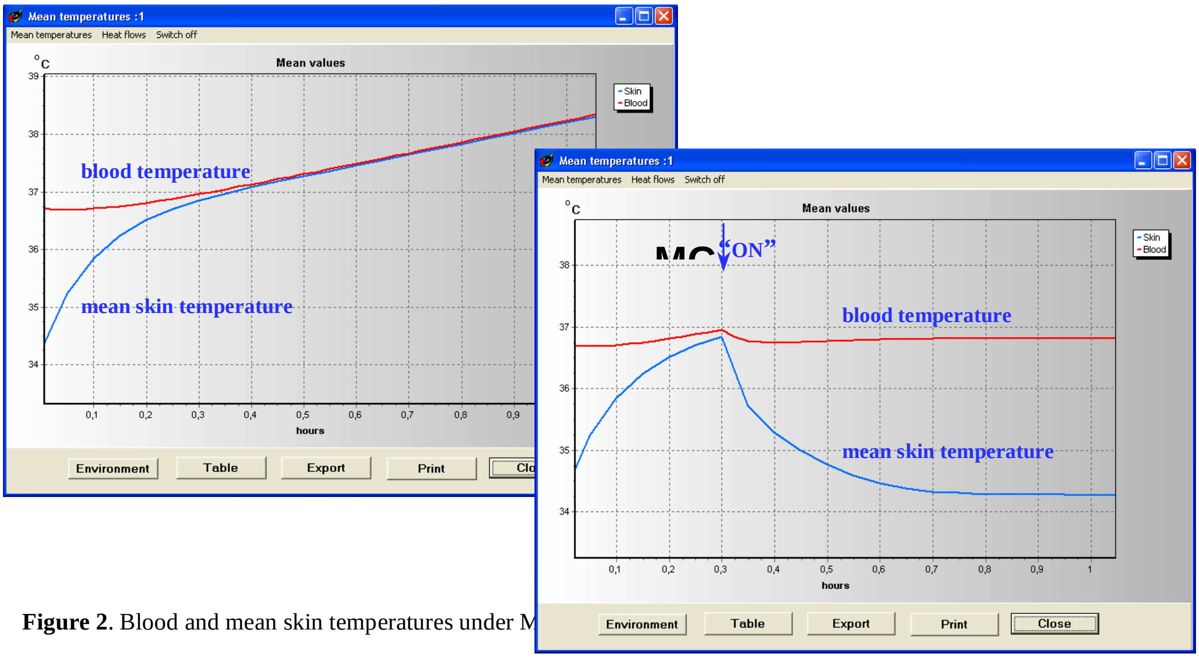


Figure 2. Blood and mean skin temperatures under M

We have performed many computer simulations taking into consideration different combinations of MCS characteristics, some of them giving available results from the literature.

Samples of modeling results for one experiment are showed in Fig.2 and Fig.3. They correspond to simulated case when MAN is wearing impermeable protective clothing, 100% PVC, position 73 of reference 6 : thermal insulation is 0.016 m^2 $^{\circ}$C/W, evaporative resistance is 0.3489 m^2 kPa/W; ambient environment: air temperature is 40 ^{0}C, relative humidity 50%, air velocity is 0.1 m/s. Metabolic heat production is 150W.

Characteristics of MCS is seen on MCS sheet (fig.1). Inlet air temperature is 27 ^{0}C, inlet air humidity 5%, ventilation is 320 l/min. Value of underclothes volume is 0.04 m^3. Volume was assessed on the basis of Daanen's and others' work (7).

In this experiment switching “ON” MCS was set at threshold time equal to 0.3 h. It corresponds to case when man wears impermeable protective clothing and works in a hot environment during 0.3 hour without MCS, at this moment MCS is switched "ON" and the simulation in this case demonstrates the efficiency of MCS. Figure 2 illustrates the dynamic changes of blood and mean skin temperatures in the two cases : constantly “OFF” and “ON” MCS after 0.3 hour respectively . The first case (left part of the figure) shows large increases in core and skin temperatures as there is no possible heat loss by evaporation. Sweat dripping at the end of this experiment reached 980 g/h . In the second part of the figure (right), MCS being “ON”, absence of hyperthermia is shown. Considerable improvement of the situation has been possible thanks to efficient heat removal via convection and evaporation heat flows (fig.3).

Computer simulations can illustrate the dynamic changes of local and global heat fluxes and body temperatures, sweat wettedness and sweat efficiency, evaporative and dripping sweat rates, body water losses, heart rate, cardiac output, and other quantitative parameters which have to be considered for the assessments of the cooling effect of the microclimate system.

Conclusions

Obviously, computer simulations are always theoretical and give nice results which can be sometimes criticized or may be even irrelevant. In case of a well established model based on physical and physiological laws, the results expected are supposed trustworthy as long as no reasoning or mathematical errors are included. Whatever the accuracy of the model in case of human being wearing clothes, the results are always somehow approximate since many complicated mechanisms cannot be controlled : here for instance, the dilution phenomenon, the porosity of the clothing layers, the pumping effects …. Nevertheless the results obtained are generally useful for predictions of health hazards because they anticipate the actual exposure and can avoid undesired hazards. When the environmental and working conditions are adverse to the human safety of well-being, the use of computer simulation appears convenient for testing solutions that may reduce the heat strain. This is particularly true in case of designing the microclimate systems.

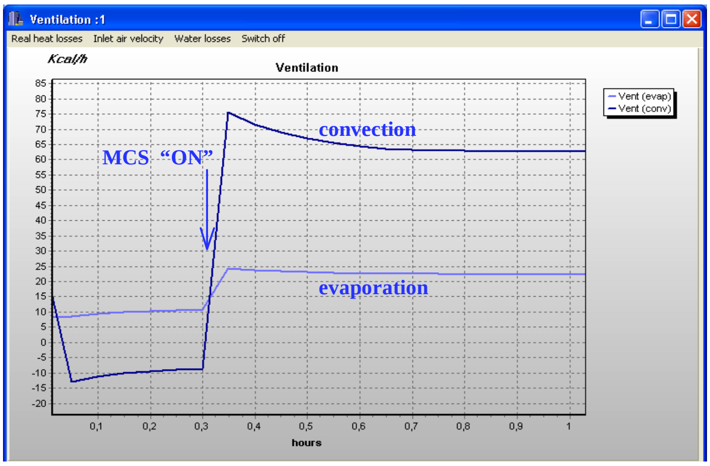


Figure 3. Result of heat flows of a Microclimate Cooling Example.

Acknowledgements

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AN INVESTIGATION OF THE ABILITY TO ADMINISTER CARDIO-PULMONARY RESUCITATION (CPR) AFLOAT

Michael Tipton[1*], *Geoff David* [2], *C. Eglin*[1] *& F. Golden*[1]

[1]Institute of Biomedical & Biomolecular Sciences, Dept. of Sport & Exercise Science, University of Portsmouth, Portsmouth, Hampshire, UK.
[2]Robens Centre for Health Ergonomics, EIHMS, University of Surrey, Guildford, Surrey, UK.
* Corresponding author: michael.tipton@port.ac.uk

Introduction

Current Prevention of Fire and Explosion, and Emergency Response regulations require operators of UK North Sea offshore oil and gas installations to produce plans which provide all personnel with a 'good prospect of being recovered, rescued and taken to a place of safety' following an incident. Increasingly, the recovery and rescue roles have been undertaken by Daughter Craft (DC), which are specialised fast rescue craft. Debate continues concerning whether a DC can be defined as a 'place of safety' and thus fulfil the regulatory safety requirements. The primary function of a DC is to provide close support and, in the event of an emergency, to assist in either the recovery of people from the water/survival craft, or in the evacuation of an offshore installation. Most DC are 9-12m in length with a cabin, and are supposed to be able to carry 12-15 persons.

Oil industry guidelines[6] state that it should be possible to provide basic lifesaving first aid to casualties while a DC is on passage. This ability is likely to be related to a wide range of factors, including: sea state, speed and course of a DC (ship motion), design of the DC (ergonomic issues), number/condition of survivors, usefulness/usability of equipment available to assist, physical state and training/experience of rescuers. However, no data exist to help determine if DC crew are able to meet the demands and expectations placed upon them. The present investigation addressed this issue[5], with particular reference to the feasibility of performing effective cardiopulmonary resuscitation (CPR) whilst afloat.

Methods

The study was undertaken in the southern North Sea using the crew and facilities of Boston Putford Offshore Safety Limited. Ethical approval was obtained from the University of Portsmouth ethics committee.

Nine DC crew volunteered for the study. Their average (SD) personal data were: age 31 (6) years of age; stature 181 (9)cm; mass 79 (14)kg; experience on a DC 9.8 (6) years. All crew had achieved at least basic, certified first aid training and were given additional refresher training in CPR immediately prior to participation in the study, using a Resusci-Annie (Laerdal, UK) 'Skill Reporter' resuscitation manikin.

Both the respiratory component (expired air ventilation [EAV]) and cardiac component (external cardiac massage [ECM]) of CPR were examined. The compression:ventilation ratio was set at 15:2, with the requirement of an average ventilatory volume of 490mL and rate of 7 breaths per minute. The average depth of chest compression was required to be 45mm. The output of the manikin gave details of the ventilations performed (average volume; average number per minute; minute volume; total number; number correct; % correct; number that had too much or too little volume; number that were too fast) and compressions performed (average depth; average number per minute; average compression rate; total number; number correct; % correct; number too deep; number too shallow; number with wrong hand position; number with hand position too low; number with incomplete release). The comments made by subjects about the performance of CPR in the different conditions were also recorded.

Following establishment of baseline data on an Emergency Response & Rescue Vessel (ERRV, large [67m] stabilised support vessel), the DC crew attempted 3 minutes of CPR with the resuscitation manikin in a range of conditions at sea. Tests were undertaken offshore aboard 9.1m, 10m and 11.6m DC on 18 occasions over a 12-month period. On each occasion the three crewmen were tested every 30 minutes during the deployments, which last between 30-216 minutes (mean 112.3 minutes). Arm, hand and chest temperatures (Grants Instruments thermistors & logger), grip strength (Takei, Japan, hand grip dynamometer), hand dexterity (nut & bolt test) and heart rate (Polar® heart rate monitors) were also measured during the exposures. Back and leg strength were measured on the ERRV immediately before and after exposures on the DC.

Results and Discussion

Tests were undertaken in sea states ranging from 0.5 to 6m (15cm to 4m wave height). Wind speeds ranged between 0-35knots and ambient temperature between 5-15°C. Cabin temperature ranged between 10-20°C.

No consistent alterations were observed in grip strength, leg and back strength or manual dexterity as a result of time aboard the DC. None of the cabin or skin temperatures gave cause for concern. Across all conditions the average (SD) skin temperatures were: hand 23.7 (4.3)°C; forearm 31.6 (1.5)°C; chest 34.4 (1)°C. The availability of the cabin and air conditioning on the DC enabled crewmembers to remain comfortable. The majority of subjects reported being neutral to warm in the DC, even during the winter months when most of the measurements were taken.

Significant increases in heart rate occurred while performing CPR. All subjects reported finding this a difficult and tiring test. Average (SD) heart rates during CPR were 112 (11)bts.min^{-1} compared to 75 (11)bts.min^{-1} when inactive on the DC. All of the subjects questioned thought that they would find extended periods (>5minutes) of CPR physically challenging. The difficulty associated with this task was due, in part, to the postures that the crewmembers had to adopt during CPR (Figure 1).

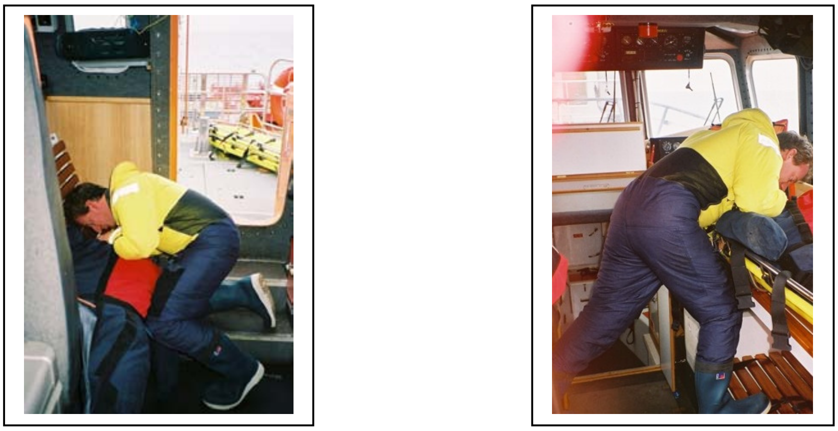

Figure 1. Postures required whilst performing CPR on the largest (11.6m) DC.

During CPR, the average (SD) ventilatory volume on the ERRV was 521 (52)mL. The corresponding values for minute volume were 3125 (468)mL. On the DC (all conditions) average (SD) ventilatory volume was 569 (80)mL and minute volume was 3604 (411)mL.

Table 1. Expired air ventilation results (%) obtained on the ERRV and DC (all conditions)

EAV Variable	**ERRV**	**DC**
“Correct”	62.0%	43.0%
Over-inflation	21.0%	36.0%
Under-inflation	8.5%	9.7%
EAV conducted too quickly	14.5%	30.7%

The average (SD) depth of compression on the ERRV was 43.1 (2.5)mm with an average (SD) compression rate of 91.5 (15.4) per minute. The corresponding figures on the DC were 38.8 (3.8)mm for depth of compression, and 99.6 (15.6) per minute for rate of compression.

Table 2. External cardiac massage results (%) obtained on the ERRV and DC (all conditions)

ECM Variable	**ERRV**	**DC**
“Correct”	82.8%	50.7%
Compressions too deep	2.0%	0.5%
Compressions too shallow	9.0%	39.5%
Hand position too low	3.2%	6.0%
Incomplete release of compression	2.7%	6.6%

More “incorrect” EAV and ECM were recorded on the DC than the ERRV due, primarily, to a tendency to both over-inflate during EAV and perform EAV too quickly, and under-compress during ECM (Tables 1 & 2). It is important to note that the Skill Reporter’ resuscitation manikin classifies both small and large deviations from the ideal as “incorrect”, hence some of the “incorrect” EAV and ECM are unlikely to have had any practical consequences for a casualty, and simply reflect the decline in ability to undertake CPR accurately on a moving compared to stable platform. The exception to this is the tendency for compressions to be too shallow during ECM; this can have significant implications for perfusion and thus tissue oxygenation.

Aside from the manikin results, on the 9.1m and 10m DC, CPR became impossible when wave heights exceeded 0.5m, or when the craft were underway due to motion-induced interruptions. The worst CPR performance figures were obtained on the 9.1m DC in 0.6-0.9m waves, where the number of correct EAV averaged 65% of that seen on the ERRV, the number of correct ECM averaged 35% of that seen on the ERRV. Performance was better maintained on the 11.6m DC, but deteriorated when progressing at any speed in a 3m sea. The reduction in performance was greater when travelling ‘into’ compared to ‘with’ the prevailing conditions. In this context, it is worth noting that the average wave heights recorded at one northern North Sea offshore installation (latitude 60°N) exceeded 0.5m for 98% of the year, and 3m for 35% of the year[3].

These results are in general agreement with the perception of the DC crew that CPR could be performed proficiently on one casualty in flat calm, but would become increasingly difficult with worsening sea states. Also, when CPR was undertaken, the needs of the boat would leave only one crewmember available to treat the casualty. Thus, a multiple casualty scenario would represent a particular problem. In the present study, the crew found performing CPR for three minutes at sea tiring. However, during a real emergency CPR may be required to be performed continuously for up to one hour following the heavy physical demand of casualty recovery, and before rendezvous and transfer to the ERRV. Thus, even with intermittent crew substitution, the prospect of a successful outcome must be considered.

The most important criterion for successful CPR would appear to be early intervention. A Swedish hospital study[2] reported that 33% of those receiving CPR in less than 1min recovered, the comparable figure for those in whom CPR was delayed for more than 1min was only 14%. A large “out of hospital” survey has been undertaken in Copenhagen, in which teams of trained paramedics, assisted by anaesthetists, manned special cardiac arrest mobile teams in the city[4]. Of the 764 cases in which CPR was attempted, initial resuscitation was successful in all witnessed arrests (464), but in none of those that were not witnessed. Of those initially resuscitated, 68 (14.6%) survived to leave hospital alive and 54 (11.7%) were still alive a year later.

Whilst it is possible that DC crew may observe the cardiac arrest of a survivor, commence effective CPR within a minute and, with crew rotation, maintain it for up to the hour required to reach the ERRV, it is considered unlikely to be effective. As a consequence it is concluded that the expectation of the level of medical care that can be provided by DC crew may far outweigh the reality, and DC should be regarded as a rescue and recovery craft rather than a ‘place of safety’. DC play an important role in the survival chain, but successful resuscitation and life support should not be expected in all cases. The difficulty of diagnosing cardiac arrest in a small unstable boat in a hostile environment, and consequent danger of precipitating ventricular fibrillation by performing ECM on hypothermic individuals in slow sinus rhythm, coupled with the difficulty in performing effective ECM, lead us to conclude that the current recommendation[1] that DC crew should not commence ECM, remains extant.

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EFFECTS OF THERMAL SWIMSUIT ON THERMOREGULATORY RESPONSES DURING LIGHT TO MODERATE INTENSITY EXERCISE AT COOL WATER ENVIRONMENT

Hitoshi Wakabayashi[1] ** Atsuko Hanai*[2]*, Koichi Kaneda*[1]*, Shintaro Yokoyama*[3]*, Takeo Nomura*[1]

[1] University of Tsukuba, Ibaraki, Japan [2] Hokkaido Asai Gakuen College, Hokkaido, Japan [3] Hokkaido University, Hokkaido, Japan * corresponding author s015219@ipe.tsukuba.ac.jp

Introduction

During water immersion body heat is rapidly conducted away from the skin to the water, because of the higher thermal conductance of water. Water immersion changes the body temperature and thermal comfort depending on water temperature, exercise intensity and physical characteristics. For these reasons, thermal swimsuit (TS), which partially cover the skin, has been developed to prevent the body heat loss and to reduce the thermal discomfort during water exercise, while few studies have examined the effect of TS.

We had evaluated the effect of TS during water immersion (26°C) at rest, and we clarified that wearing TS maintained body temperature, kept down the shivering thermo genesis and reduced thermal discomfort compared to normal swimsuit. However, few studies examined the effect of TS during water exercise. The purpose of present study was to evaluate the effects of TS on physiological and psychological parameters during light to moderate exercise at cool (26°C) water environment.

Methods

Subjects and Thermal Swimsuit

Three healthy male subjects volunteered in this study (Table 1). % body fat was measured by bioelectrical impedance analysis (BC-118, TANITA, Japan) and skinfold thickness was measured at six sites (subscapula, umbilicus, lateral waist, triceps, thigh and calf) using a skinfold caliper. Body surface area (SA) was estimated by using DuBois equation ($SA = 0.007184 \cdot weight^{0.425} \cdot height^{0.725}$) (2). The TS used in this study was made of nylon faced neoprene (2mm thickness), consisted of jacket (front zip) and pants, covered trunk, upper arms, thighs and neck (206776-09, Footmark, Japan). Thermal conductivity of wetted texture, measured by hot plate method, was $0.1065\ W \cdot m^{-1} \cdot K^{-1}$.

Procedure and Measurements

Subjects sat in room air (28.7 - 31.1 °C) for 5 min, after that they immersed in water (26.3 - 26.4 °C) up to the neck level, then pedalled underwater ergometer for 30 min at 60 rpm pedalling rate. Each subject carried out the protocol with TS at two submaximal (light and moderate) exercise intensities.

Esophagus temperature (T_{es}), rectal temperature (T_{re}), 10 points of skin temperatures (T_{sk}), heart rate (HR), rating of perceived exertion, RPE (1), thermal sensation and thermal comfort were measured during experiments. Mean skin temperature (mean T_{sk}) were calculated using the following equation based on Hardy (3) and DuBois (2).

$$\text{mean } T_{sk} = 0.07\, T_{head} + 0.35\, (T_{chest} + T_{abdominal} + T_{back})/3 + 0.14\, (T_{upperarm} + T_{forearm})/2 + 0.05\, T_{hand} + 0.19\, T_{thigh} + 0.13\, T_{calf} + 0.07\, T_{foot}$$

The scale of thermal sensation and thermal comfort were shown in Figure 1.

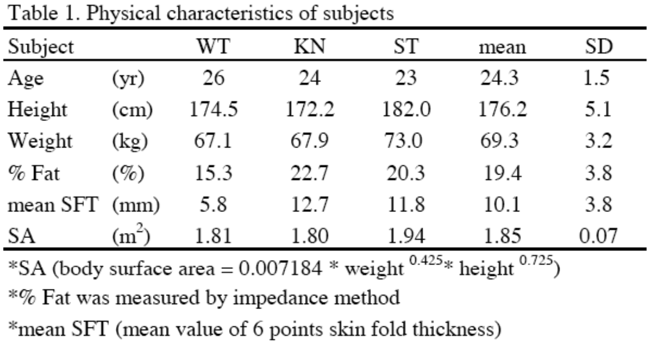


Table 1. Physical characteristics of subjects

Subject		WT	KN	ST	mean	SD
Age	(yr)	26	24	23	24.3	1.5
Height	(cm)	174.5	172.2	182.0	176.2	5.1
Weight	(kg)	67.1	67.9	73.0	69.3	3.2
% Fat	(%)	15.3	22.7	20.3	19.4	3.8
mean SFT	(mm)	5.8	12.7	11.8	10.1	3.8
SA	(m^2)	1.81	1.80	1.94	1.85	0.07

*SA (body surface area = 0.007184 * weight $^{0.425}$* height $^{0.725}$)

*% Fat was measured by impedance method

*mean SFT (mean value of 6 points skin fold thickness)

Results and discussion

Water exercise intensity

Table 2 shows the mean value of HR and RPE during water exercise at two exercise intensities. HR and RPE were averaged from 5 min after onset of exercise to the end. Light exercise was “very light” RPE level (9.7 ± 0.5) and moderate exercise was “somewhat hard” level (13.5 ± 0.3).

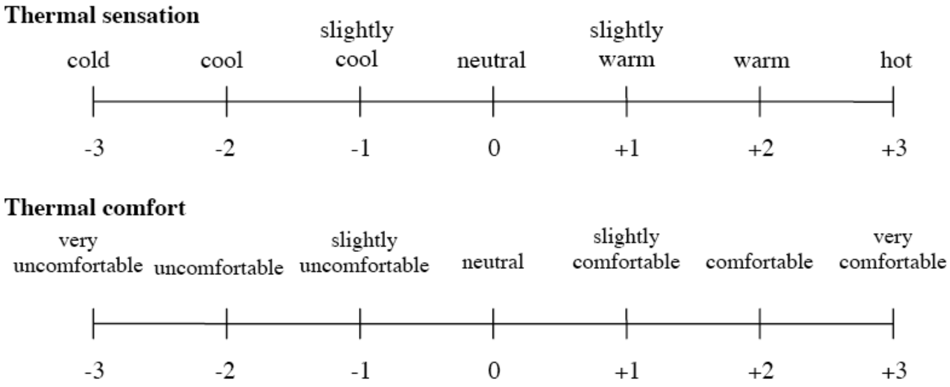


Figure 1. Scale of thermal sensation and thermal comfort

Body temperatures and Thermal sensations

The changes in T_{es} and mean T_{sk} during water exercise at both intensities are shown in Figure 2, 3. After onset of water exercise T_{es} increased gradually to the end of water exercise for both intensities. T_{es} during exercise at moderate intensity increased significantly than light intensity exercise. Immediately after immersion mean T_{sk} decreased quickly at both conditions. After onset of water exercise light exercise decreased mean T_{sk} gradually to the end of water exercise, while moderate exercise decreased mean T_{sk} for about 10 min then increased gradually to the end of water exercise. The increment of mean T_{sk} during moderate water exercise was mainly caused by the increment of regional T_{sk} where were clothed in TS.

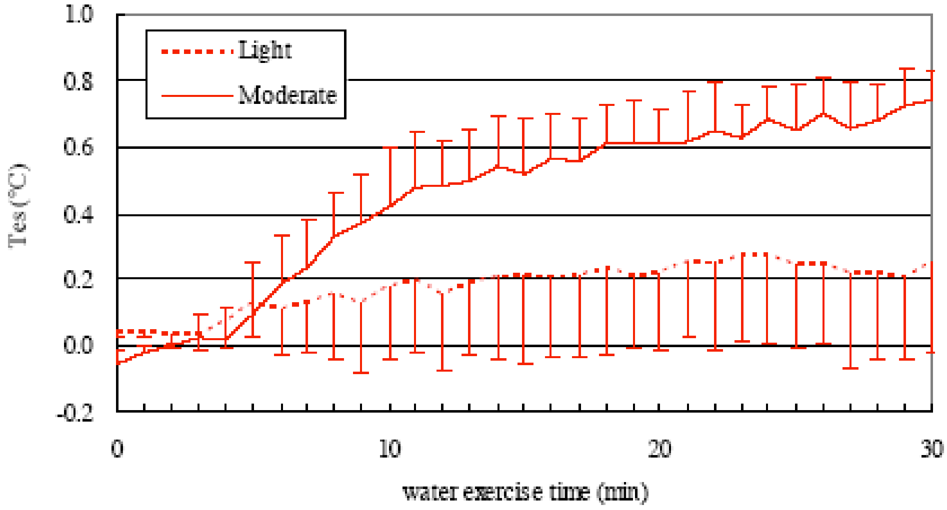


Figure 2. Change in esophagus temperature (mean ± SE)

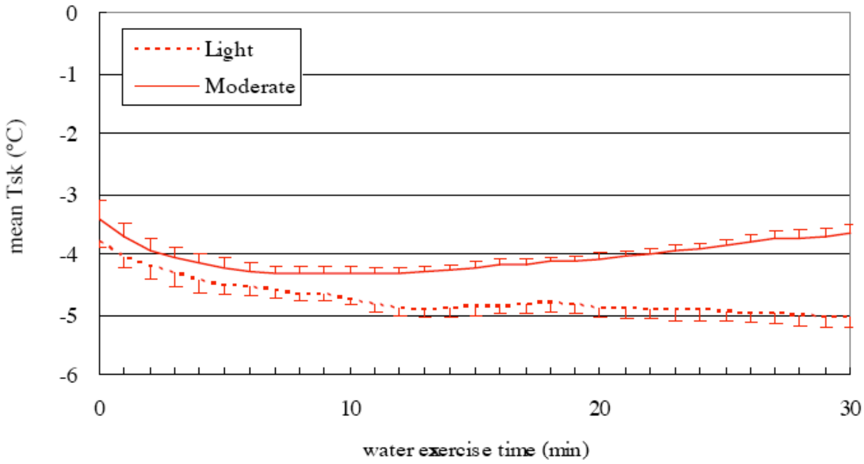
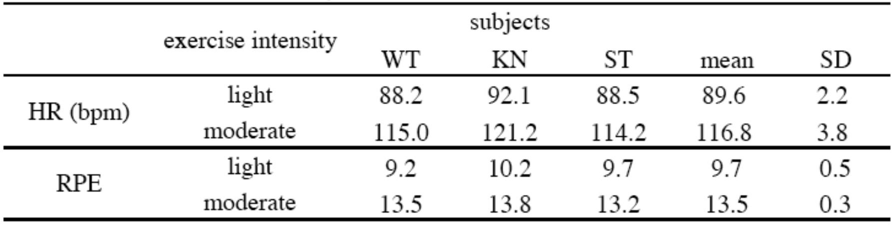


Figure 3. Change in mean skin temperature (mean ± SE)

Table 3 shows body temperatures, thermal sensation and thermal comfort of each subject at the end of 30 min water exercise. After the light exercise, T_{es} of subject WT decreased 0.28 °C from base line, while T_{es} of the other subjects increased 0.41, 0.61°C. As the results of T_{es}, WT felt “cold” and “slightly uncomfortable”, while others felt “neutral” or “slightly comfortable”. It might be caused by the lower % fat and skinfold thickness of subject WT. During light intensity water exercise metabolic heat production was lower level and movement of legs increased heat loss from the skin through the forced convection. So subject WT who had poor tissue insulation could not keep T_{es}.

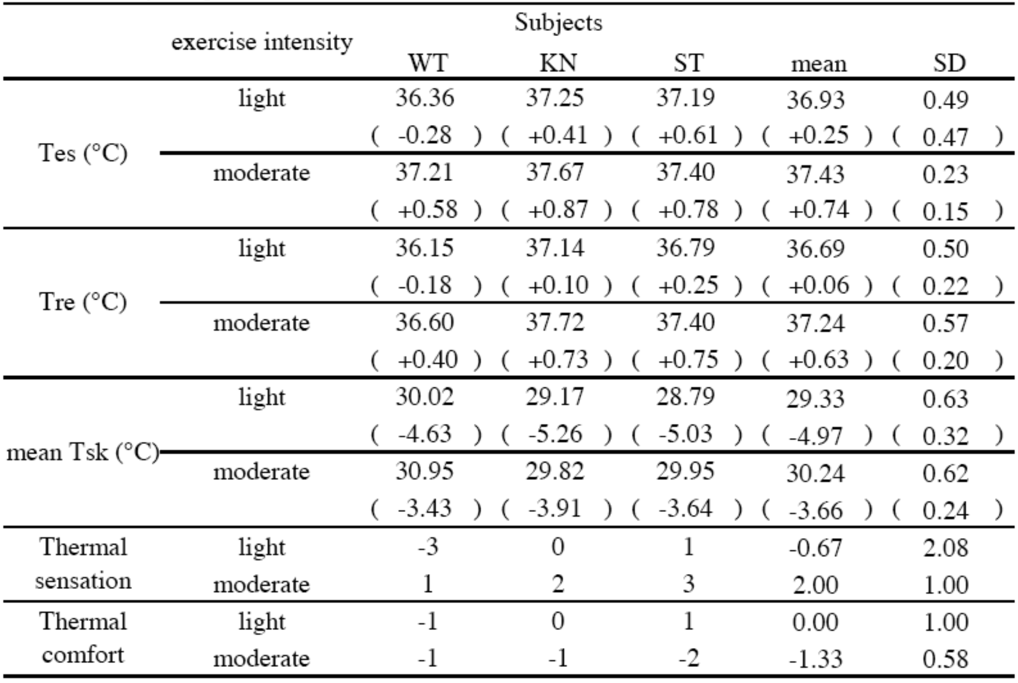
On the other hand, during moderate exercise, every subject increased T_{es}, felt “slightly warm” to “hot” and “uncomfortable” because of the heat sensation. So during moderate water exercise at 26 °C, the insulation of TS was higher than required value to maintain body temperature and wearing TS had adverse effect increasing thermal discomfort.

Table 2. Water exercise intensity



	exercise intensity	WT	KN	ST	mean	SD
		subjects				
HR (bpm)	light	88.2	92.1	88.5	89.6	2.2
	moderate	115.0	121.2	114.2	116.8	3.8
RPE	light	9.2	10.2	9.7	9.7	0.5
	moderate	13.5	13.8	13.2	13.5	0.3

Table 3. Body temperatures and thermal sensation at the end of water exercise



	exercise intensity	WT	KN	ST	mean	SD
		Subjects				
Tes (°C)	light	36.36	37.25	37.19	36.93	0.49
		(-0.28)	(+0.41)	(+0.61)	(+0.25)	(0.47)
	moderate	37.21	37.67	37.40	37.43	0.23
		(+0.58)	(+0.87)	(+0.78)	(+0.74)	(0.15)
Tre (°C)	light	36.15	37.14	36.79	36.69	0.50
		(-0.18)	(+0.10)	(+0.25)	(+0.06)	(0.22)
	moderate	36.60	37.72	37.40	37.24	0.57
		(+0.40)	(+0.73)	(+0.75)	(+0.63)	(0.20)
mean Tsk (°C)	light	30.02	29.17	28.79	29.33	0.63
		(-4.63)	(-5.26)	(-5.03)	(-4.97)	(0.32)
	moderate	30.95	29.82	29.95	30.24	0.62
		(-3.43)	(-3.91)	(-3.64)	(-3.66)	(0.24)
Thermal sensation	light	-3	0	1	-0.67	2.08
	moderate	1	2	3	2.00	1.00
Thermal comfort	light	-1	0	1	0.00	1.00
	moderate	-1	-1	-2	-1.33	0.58

*(temperature difference between base line value)

Conclusions

According to the results of present study, during light exercise at cool (26 °C) water environment, wearing TS can maintain core temperature and thermal comfort. However we should take care about individual difference such as % fat and skin fold thickness. Furthermore during moderate water exercise, the insulation of TS was higher than required value to maintain body temperature and wearing TS had adverse effect increasing thermal discomfort. So we clarified that it was not necessary to wear TS during moderate exercise at 26 °C water environment from the object of maintaining body temperature. Further researches were required to clarify the effects of TS during water exercise which was affected by water temperature, exercise intensity and physical characteristics.

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PREDICTING INDIVIDUALS’ ABILITIES TO SELF-BOARD A LIFE RAFT

Peter Tikuisis, Allan A. Keefe*

Simulation, Modelling, Acquisition, Rehearsal, & Training Section
Defence Research & Development Canada – Toronto
* Peter.Tikuisis@drdc-rddc.gc.ca

Introduction

Advances in Search and Rescue (SAR) technologies allow for a more rapid response to casualties immersed in water. Yet, an outstanding concern of SAR planners is the ability of casualties to self-board a life raft, which is still a formidable task for many individuals (1). To address this concern, experimental data were collected to formulate an algorithm for predicting the time to failure for self-boarding a life raft as a function of the time spent in cold water.

Methods

Details on the experimental procedure can be found in Ref. 2; a brief description follows. 24 men and 24 women (see Table 1) were first tested on their upper body strength. This involved separate series of three repeated measurements of maximum voluntary contractions using strength testing apparatus of the hands (grip strength via grip dynamometer), arms (biceps flexion), and upper back (latissimus dorsi pull-down). The arithmetic average of the right and left hand grip strengths, arm strength, and one-half of upper back strength, normalized by body mass, represented the overall strength. To account for the advantage of reach, the arbitrary factor $(\text{height}/170)^3$ was applied as a non-linear multiplier to the overall normalized strength to obtain a height-adjusted value. This value was used to predict each subject’s ability, on a 5-point scale, to board the life raft. Adjusted values in the ranges of < 0.35, 0.35 to < 0.5, 0.5 to < 0.65, 0.65 to < 0.8, and ≥ 0.8 were assigned categories (CAT) from 1 to 5, respectively.

Table 1. Mean ± SD (and range) of anthropometric values of the study participants. * indicates a significant gender difference.

Variable	**Men**	**Women**
Age (yr)	35.0 ± 9.4 (21 – 52)	34.5 ± 10.0 (18 – 52)
Height (cm)	176 ± 5 (165 – 185)*	168 ± 7 (153 – 178)
Body Mass (kg)	80.4 ± 9.7 (61.5 – 99.0)*	65.2 ± 8.0 (53.2 – 85.5)
BMI (kg/m^2)	25.9 ± 3.0 (21.0 – 32.6)*	23.3 ± 2.8 (19.8 – 30.3)
BF (%)	16.4 ± 5.1 (7.0 – 29.4)*	21.9 ± 5.7 (14.0 – 34.0)

Subjects entered the swimming pool area wearing a bathing suit and t-shirt. After donning a SOLAS-compliant lifejacket, the subject entered the pool under warm (~27°C) and calm conditions. Cold and turbulent water was purposely avoided so that baseline data could be obtained on boarding the life raft (double-tube 6-man capacity) without the additional stress of cold or excess movement, as explained below. Subjects that successfully boarded the life raft over the side without any aids were then burdened with additional weight for up to three further attempts. Starting weights ranged from 2 to 10 kg depending on the predicted ability of the subject to self-board (i.e., = 2 x CAT); these weights were evenly distributed about the subject’s mid-lower torso level. The weights were adjusted as follows: weight on 2nd attempt = 1 x CAT or 3 x CAT if the 1st attempt failed or succeeded, respectively. Similarly, weight on 3rd attempt = 0.5 x CAT or 1.5 x CAT if the 2nd attempt using 1 x CAT failed or succeeded, or weight on 3rd attempt = 2.5 x CAT or 3.5 x CAT if the 2nd attempt using 3 x CAT failed or succeeded.

The maximum boarding weight was then assumed to represent the subject’s reserve capacity. It is hypothesized that this capacity will diminish with muscle cooling due to time spent in cold water. Hence, it should be possible to predict when an individual has lost their reserve capacity using a model of body cooling (3, 4) coinciding with the individual’s threshold of just being able to self-board.

Results

23 men and 18 women successfully boarded the life raft without aids or weight; their boarding times and efforts are provided in Table 2. Of these subjects, one less in each gender group failed to board with additional weight. The boarding times and efforts were less for the men vs. the women during the unweighted attempts. This was not the case during the weighted attempts when maximum weights were carried. However, the reserve capacities of the men were higher compared to the women.

Table 2. Mean ± SD (and range) of subjective and objective measures of successful life raft boardings. WT/BM represents the reserve capacity whereby WT is the maximum weight burdened by the subjects and BM is their body mass. * indicates a significant gender difference.

Variable		Men	Women
Unweighted	n	23	18
Boarding time (s)		176 ± 5 (165 – 185)*	30.1 ± 10.2 (15 – 51)
effort		6.2 ± 2.5 (2 – 10)*	8.1 ± 2.0 (3 – 10)
Weighted	n	22	17
Boarding time (s)		23.8 ± 15.9 (3 – 60)	30.5 ± 11.9 (19 – 58)
effort		7.8 ± 2.1 (4 – 10)	8.4 ± 1.6 (4 – 10)
WT/BM (%)		14.2 ± 5.8 (1.6 – 23.1)*	10.1 ± 6.0 (1.5 – 21.1)

Stratification of the data by age suggests that the failure to self-board a life raft can be approximated as follows: 25% for men > 40 yr old, 25% for women ≤ 40 yr old, and 50% for women > 40 yr old. Additional considerations of excessive body mass and wet clothing, which detracts from one’s reserve capacity, have been taken into account to estimate the initial failure rate to self-board a life raft (details of the algorithm are found in Ref. 5). The time to failure of individuals that can initially board the life raft is assumed to occur when the individual’s reserve capacity is diminished due to muscle cooling, as follows.

The decrease in muscle strength due to immersion in cold water is predicted using:

$$\text{strength} = \text{strength}_{\text{max}} \cdot Q_{10}^{\Delta T/10} \qquad \text{Eq. 1}$$

where Q_{10} defines the factor of change in muscle strength for each 10°C change in mean muscle temperature, herein assumed to be 1.4 (4), and $\text{strength}_{\text{max}}$ is based on the reserve capacity given by:

$$\text{strength}_{\text{max}}(\%) = 100 + \text{reserve}(\%) \qquad \text{Eq. 2}$$

The failure to self-board threshold occurs when strength reaches 100% (i.e., the individual’s capacity to self-board only their own body weight). After substituting Eq. 2 into Eq. 1 with strength = 100%, the decrease in the mean muscle temperature of the arm corresponding to the failure threshold is given by:

$$\Delta T = 10 \cdot \ln\left[100/(100 + \text{reserve})\right]/\ln\left(Q_{10}\right) \qquad \text{Eq. 3}$$

Body cooling models can be used to predict when the above change in muscle temperature occurs. Using the model described in Ref. 4 leads to the prediction shown in Fig. 1. In this example, 4 out of 10 casualties are predicted to successfully self-board the life raft upon immersion. Thereafter, 3, 2, and 1 out of 10 casualties are predicted to retain self-boarding ability after 20, 30, and 40 min of immersion, respectively.

Discussion

Approximately 20% of our total subject population, the majority owing to the women, was unable to board the life raft with any additional weight. It is reasonable, however, to expect that the failure percentage of individuals from the population at large, which would include less healthy individuals than we used, would be higher than we found, and markedly so for an older, injured, or heavier population.

The present findings pertain to a single design life raft under warm, calm conditions. The success rate of self-boarding attempts would likely benefit from an ergonomically-wise redesign of the life raft, but can still be expected to worsen with challenging sea states (1). While aids such as ramps and ladders have been found to increase the likelihood of self-boarding, they do not guarantee 100% success (2).

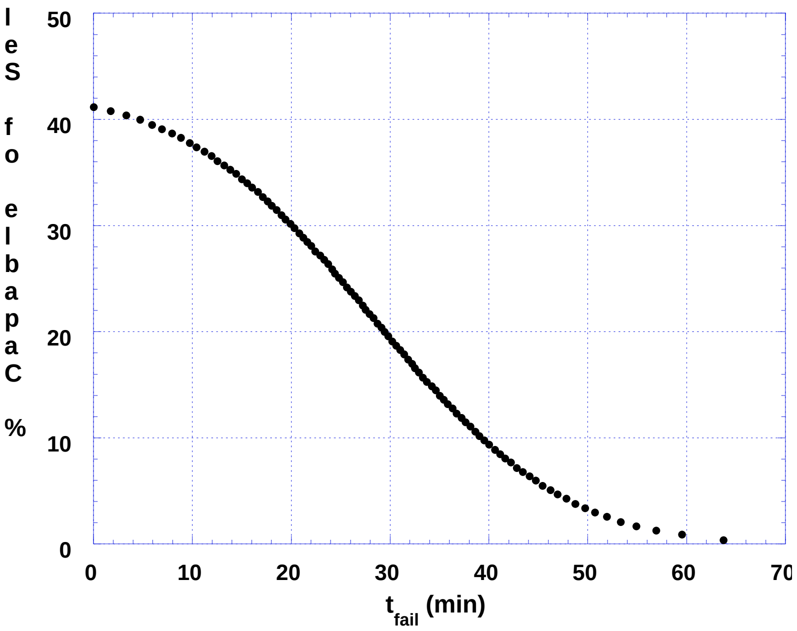

Figure 1. Predicted distribution of life raft self-boarding time limits for males neck-immersed in 10°C heavy seas and wearing a long-sleeved shirt, light sweater, and jacket.

The limited reserve capacity found in this study suggests that water-immersed casualties face a considerable challenge when attempting to self-board a life raft. Indeed, the added weight of wet clothing might easily overcome an individual's reserve capacity. Further, time spent in cold water will reduce an individual's reserve capacity via loss of muscle strength to a point where self-boarding will not be possible, as depicted in Fig. 1. Additional experimental trials should be conducted in cold water to verify these predictions.

Acknowledgements

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SELF-RESCUE STRATEGIES DURING ACCIDENTAL COLD WATER IMMERSION: PERFORMANCE AND THERMAL CONSIDERATIONS

David Lounsbury[1], *Michel B. Ducharme*[2, 1*]

[1]University of Toronto, Toronto, Canada
[2]Defence R&D Canada - Toronto, Toronto, Canada
*corresponding author michel.ducharme@drdc-rddc.gc.ca

Introduction

What should a person do after accidental immersion in cold water, in a situation where safety is in sight some distance away? Well-recognized aquatics safety organizations and government agencies state that swimming should not be attempted, even when a personal flotation device (PFD) is worn (1, 2, 3). These recommendations are based on the idea that delaying hypothermia should be the goal of the immersion victim.

While it is true that exercise in cold water makes the human body more thermally susceptible to cooling, this fact alone cannot rule out self-rescue via swimming as a viable survival strategy. One recent study in a cold Canadian lake (14 ºC) found that the average PFD-equipped test subject could cover 889 m before becoming incapacitated by cold and fatigue after about 45 minutes (4). It remains quantitatively unclear to what degree self-paced swimming, performed until exhaustion, would be thermally detrimental in a cold water situation when compared to the Heat Escape Lessening Posture (HELP). There is probably some reasonably attainable distance from shore from which the average immersion victim would have the best chance of survival by swimming to land rather than waiting for rescue.

The purpose of this study was to compare the effects of two different survival strategies (i.e. "waiting for rescue" vs. "swimming for it") on thermal status during immersion in cold water.

Methods

Fifteen healthy subjects (8 males, 7 females; age (mean ± SD) 31.3 ± 10.1 years; height 173 ± 1 cm; mass 72.1 ± 15.3 kg; body fat 16.2 ± 6.1 %) volunteered for this study. The experimental protocol was approved by the Defence R&D Canada - Toronto and University of Toronto Human Research Ethic Committees.

Two experimental trials were conducted in a swimming flume with water temperature maintained at 10.0 ± 0.1 ºC. Before immersion into the flume, subjects were instrumented and dressed. Subjects self-inserted a rectal probe 15 cm beyond the anal sphincter to monitor rectal temperature (T_{re}). A heart rate (HR) monitor was strapped across the chest just below the pectoralis major muscles. A 12-point skin temperature (T_{sk}) and heat flux (HF) harness was applied to subjects with weighting factors assigned as previously determined by Hardy and Dubois (5).

After instrumentation was completed, subjects donned standardized clothing (meant to represent reasonable Canadian seasonal clothing during times when inland water bodies would likely have temperatures around 10 ºC). The clothing ensemble included: underclothing (pants for both genders, and bra for females), a pair of long cotton sweat pants and a T-shirt, a long-sleeved sweat shirt, and socks, running shoes, and a personal flotation device (PFD). Clothing and footwear products were generic.

There were two types of experimental trials, experienced by each subject in random order. The first type of trial, called passive cooling (PC), was designed to simulate a "sit and wait" scenario, in which a person decides that it is best to wait for rescue. The second type of trial, called free swimming (FS), represents a situation in which a person has decided that a "swim for it" strategy would give the greatest chance for survival. After becoming exhausted from swimming and failing to reach shore (a worst case scenario), a person would then have no choice but to passively wait in water for rescue. Therefore, there were two phases (swimming and waiting) in FS trials.

In the PC trials, subjected maintained the HELP during and following the three-minute cold shock. Subjects maintained this posture to the best of their ability until one of the following stop criteria occurred: T_{re} decrease to 34 ˚C, or elapse of 120 minutes of immersion. In the FS trials, subjects were instructed to start swimming following the three-minute cold shock period in the HELP. Subjects were asked to choose an "endurance pace" of swimming that they could maintain for a long time. Since swimming occurred in a flume, the swimming velocity of the subjects could be directly manipulated as required. Practical considerations dictated that subjects choose either the front crawl or the breast stroke technique, because swimming sideways or backwards would have caused tangling of data leads attached to the subjects bodies. A previous study (4) showed that the subjects prefer those swimming techniques. Also, subjects were instructed to keep their heads out of the water during swimming. Subjects continued to swim until one of the following occurred: T_{re} decrease to 35 ˚C (transition to HELP), subject exhibits swimming failure (transition to HELP), or elapse of 120 minutes of immersion. For the rest of the trial, these subjects were asked to hold the HELP. They continued this until one of the following conditions was met: T_{re} decrease to 34 ˚C, or elapse of 120 minutes of immersion.

Statistical analyses were run with Statistica software. For the continuously measured variables (e.g. rectal temperature) two way, repeated measures ANOVA’s (condition x time) were used. For variables that represented an entire experimental trial (e.g. cooling rate), one-way, repeated measures ANOVA’s (condition) were used. When statistical significance was determined for main or interaction effects, a Tukey’s HSD post hoc analysis was performed. For all statistical analyses described, significance was said to exist when $p < 0.05$.

Results

Table 1A presents the rectal temperature cooling rate over the entire immersion period for the two trial (dT/dt, in °C·min^{-1}). A main effect of condition is observed. The cooling rate for PC (0.037 ± 0.006 °C·min^{-1}) was less marked than the cooling rate for FS (0.047 ± 0.007 °C·min^{-1}) ($p<0.001$).

Table 1. Overall core cooling rate, steady-state skin temperature and heat loss during passive cooling (PC) and free swimming (FS) in 10°C water. *** -denotes a significant difference between PC and FS ($p<0.001$). n = 15.

A	**Core cooling rate (°C·min^{-1})**	
	PC	FS
Mean	0.037***	0.047
SEM	0.006	0.007
B	**Skin temperature (°C)**	
	PC	FS
Mean	16.4***	13.9
SEM	0.2	0.2
C	**Heat loss (W·m^{-2})**	
	PC	FS
Mean	234.88***	268.41
SEM	21.57	14.83

The mean values for skin temperature (T_{sk}, in °C) at steady-state across the two experimental trials are presented in Table 1B. Within 10 minutes, there was a marked drop in T_{sk} in both trials (PC and FS) of about 15°C. A main effect of time was first observed at 5 minutes, when T_{sk} first became significantly less than baseline ($p<0.001$). T_{sk} for FS (13.9 ± 0.2°C) was lower than PC (16.4 ± 0.2°C) from 10 minutes to 70 minutes ($p<0.001$ for t=10 to t=65, $p<0.01$ for t=70).

The mean steady-state values for heat flow (HF, in W·m^{-2}) across both experimental trials are presented in Table 1C. A main effect of time was first observed at 5 minutes, when both HF first became significantly greater than baseline ($p<0.001$). A main effect is seen for activity, with FS exceeding PC (268.41 vs. 234.88 W·m^{-2}, $p<0.001$).

Mean total immersion times (in min) for each experimental condition are presented in Figure 1. PC had the longest mean total immersion time (75.5 ± 7.5 min), which was significantly greater than the mean total immersion time in FS (61.5 ± 7.0 min, $p<0.001$). The average swimming period during FS was 41.5 ± 4.8 min. During that time, the subjects were able to swim on average 1119.8 ± 142.2 m at an average swimming speed of 0.44 ± 0.13 m/s.

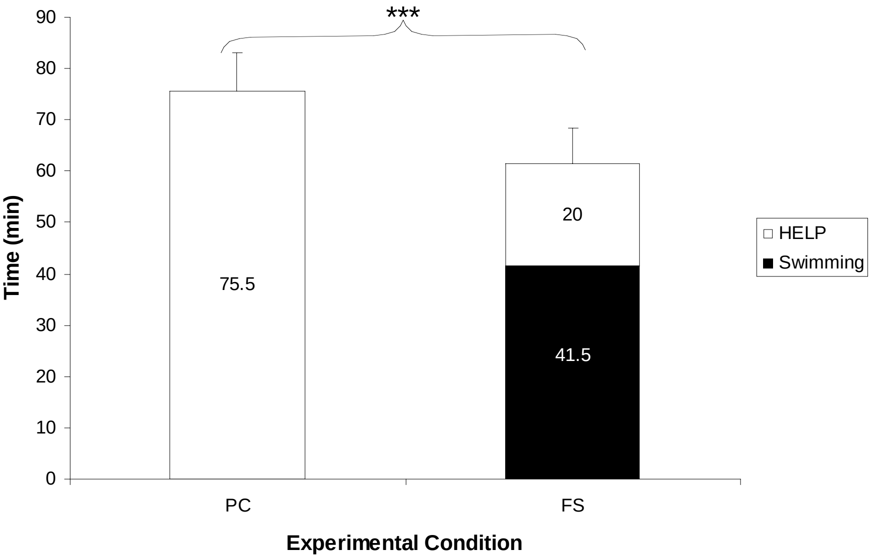

Figure 1. Total bar heights represent group mean (± SEM) for immersion time. To preserve clarity, no error bars were drawn for HELP or Swimming sub-bars. *** - denotes a significant difference between PC and FS ($p<0.001$).

Discussion

The PC and FS conditions represent opposite behavioural responses to the scenario of accidental immersion in cold water. During PC, subjects conserved their energy and heat by holding the HELP and floating in their PFD's. In FS, subjects swam freely at their own pace, in an effort to cover as much distance as possible before succumbing to the effects of fatigue and/or cold stress and reaching end points of either swimming failure or experimental hypothermia.

The steady state heat flow data are quantitatively in agreement with the T_{re} cooling rates, with the 17 % greater cooling rate being largely accounted for by the 13 % greater steady state HF during swimming activity. From the discussion above, it can be understood that the "swim for it" approach is thermally disadvantageous. The pertinent question that remains is whether the 17 % faster decline in T_{re} and the 13 % greater steady state HF associated with swimming is detrimental enough to abandon this survival option. Based on the thermal data, it is reasonable to assume that the PC condition would have increased the time to hypothermia versus FS. This reasoning is validated by the greater immersion time (Figure 1) in PC (75.5 ± 7.5 min) as compared with FS (61.5 ± 7.0 min) ($p<0.01$). This represents an approximately 23 % increase in "functional time" if it is assumed that subjects treated the trials like "real life" and stayed in the water as long as possible. The exit temperatures indicate that subjects did put forth very stoic efforts. Of the 30 immersions (15 subjects x 2 trials per subject), 20 ended with a T_{re} of 34.0 - 35.0 °C. Of these 20 trials 10 ended between 34.3 and 34.0 °C (achieving the "target" hypothermia of the experiment).

The ultimate survival objective during accidental cold water immersion should not be to preserve heat in the short term, but to remove the thermal stress by leaving the water as soon as possible. In most cases, traveling about 1000 m (toward shore) is more likely to result in egress from the water than waiting for rescue for 14 minutes longer. If an immersion victim adopts the strategy "swim for it" but could not reach shore, what would be the impact of this choice on Survival Time (ST; time to reach a Tre of 28°C; 6)? Will the ST be significantly shorter than if the victim "waits for rescue" from the start of the accidental immersion? If we assume that the victim would adopt HELP to minimize body heat loss following a 41.5 min of swimming activity (average swimming duration, see Fig. 1), it is estimated using the cooling rates observed from this study for PC and FS, that swimming and failing to reach shore will decrease ST by only 7.7% (~20 min) compared to holding still in water for the full immersion (ST of 253 min compared to 233 min when swimming).

Conclusions

For subjects dressed in light clothing and equipped with a PFD, survival swimming is thermally disadvantageous versus resting in the HELP. The level of thermal disadvantage observed in this study was not profound, however, and the greater rates of heat loss during swimming were abolished after a short period (about 10 minutes) after cessation of swimming. The relative benefits and detriments of the two basic survival strategies must be weighed by each immersion victim during the early phase of the accidental immersion and would depend on factors such as: probability of rescue, distance to shore, swimming ability and physical fitness.

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FLOTATION POSTURE IN THE DESIGN OF PERSONAL FLOTATION DEVICES: THE EFFECTS OF COOLING THE BACK OF THE HEAD ON CORE TEMPERATURE AND MENTAL PERFORMANCE

Gordon Giesbrecht[1], Tamara Lockhard[1], Gerald Bristow[1],Chris Jamieson[1],Allan Steinman[1, 2]*

[1] Laboratory for Exercise and Environmental Medicine, University of Manitoba, Winnipeg, Canada
[2] U.S. Pyblic Health Service/U.S. Coast Guart (ret)
* corresponding author giesbrec@ms.umanitoba.ca

Introduction

PFD effectiveness is influenced by both total buoyancy and flotation posture. PFDs which float a survivor more horizontally might decrease the number of mouth immersions; but the horizontal flotation posture might also position the back of the head in the water, potentially increasing a survivor's rate of cooling and adversely affecting mental performance. Both hypothermia and impaired cognitive performance have negative consequences for survival (7).

The purpose of this study was to measure the specific effects of dorsal head cooling on the rate of onset of hypothermia and on mental performance. Two different types of PFDs were evaluated: PFD#1 (Type I, SOLAS Reference Vest (USCG Model 2000)) maintained the subject in a semi-recumbent flotation posture with the head totally out of the water; PFD#2 (a Type V, User-Assisted Inflatable PFD) maintained the subject in a horizontal flotation posture with the dorsal head (i.e., back of the head) immersed. A control garment, consisting of an insulated dry suit and hood, was used for comparison. Four test conditions were thus possible: head-out, body-in (PFD#1); head-in, body-in (PFD#2); head-out, body-insulated (dry suit with hood); head-in, body-insulated (dry suit without hood).

The study was conducted in two parts: Part 1) evaluation of the effect of dorsal head immersion on core temperature and cognitive performance in shivering human subjects immersed in 10 °C water in a laboratory tank; Part 2) evaluation of the effect of dorsal head immersion on core temperature in non-shivering human subjects (simulating the effects of severe hypothermia) in 12 °C water in a laboratory tank.

Methods (Part 1)

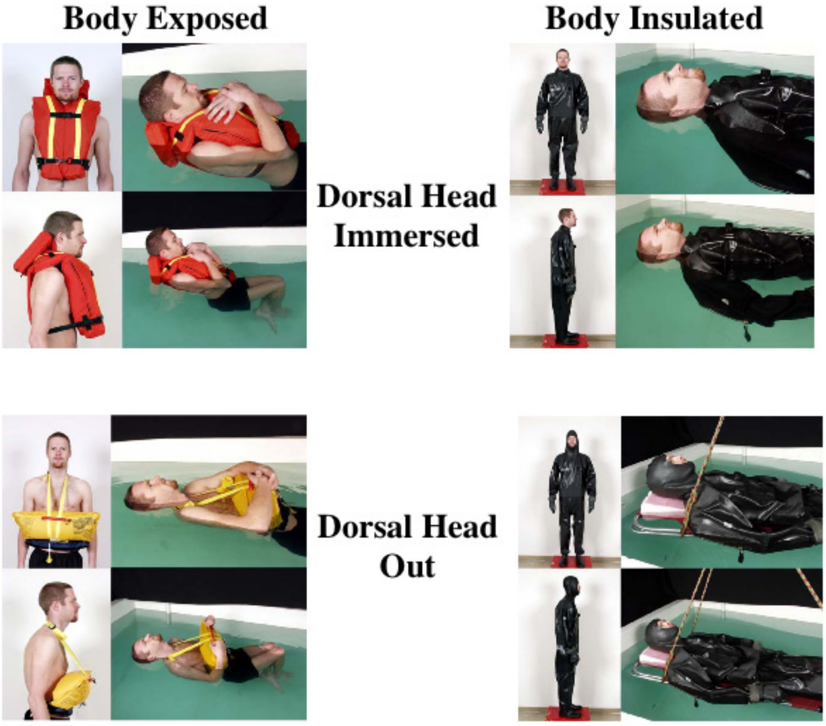
In Part 1, six healthy male volunteers (mean age = 26.8 yr; mean height = 184 cm; mean weight = 81 kg; mean body-fat = 20%) were immersed for a maximum of 65 minutes, or until core temperature < 34 °C. Core temperature was measured in the esophagus at the level of the heart. Heart rate and oxygen consumption were also measured. Mental performance tests included: logic reasoning test (1); Stroop word-color test (5); digit symbol coding; backward digit span, and paced auditory serial addition test (4). Three test conditions were evaluated: head-in, body-insulated (dry suit without hood); head-out, body-in (PFD#1); head-in, body-in (PFD#2).

Results (Part 1)

The results showed that the core temperature cooling rate was significantly faster for PFD#2 (2.8 ± 1.6 °C/hr) than for PFD#1 (1.5 ± 0.7 °C/hr) or for the dry suit (0.4 ± 0.2 °C/hr). Oxygen consumption (a measure of shivering) rose significantly during the immersions for both PFDs, but not for the drysuit. Although no statistically significant effects on cognitive performance were noted for the individual PFDs and dry suit, when analyzed as a group, four of the tests of cognitive performance (Stroop word-color, digit symbol coding, backward digit span, and PASAT) showed significant correlations between decreasing core temperature and diminished cognitive performance.

Methods (Part 2)

In Part 2, six healthy male volunteers (mean age = 27.0 yr; mean height = 184.5 cm; mean weight = 79.1 kg; mean body-fat = 19.6%) were immersed for a maximum of 60 minutes, or until core temperature = 34 °C. Shivering was inhibited, via intravenous administration of meperidine, to simulate the condition of severe hypothermia (2,3). Cutaneous heat flux, skin temperature from thirteen sites, oxygen consumption, and heart rate were also measured; respiratory and body segmental heat losses as well as total energy production were calculated from the above variables (6). Four test conditions were evaluated: head-in, body-insulated (dry suit without hood); head-out, body-insulated, (dry suit with hood); head-out, body-in (PFD#1); head-in, body-in (PFD#2).



Results (Part 2)

The results showed that meperidine nearly completely eliminated shivering thermogenesis during the first 30 minutes of immersion. As in Part 1 of this study, core temperature (after 30 minutes of immersion) was significantly lower in PFD#2 (34.6 ± 0.6 °C) compared to PFD#1 (35.3± 0.6 °C), and both were significantly lower than the body-insulated, head-out (36.6 ± 0.2 °C) and body-insulated, head-in (36.4 ± 0.3 °C) conditions. Over the first 30 minutes of immersion, the mean cooling rate was 5.0 °C/hr for PFD#2 compared to 3.6 °C/hr for PFD#1. For both PFD#1 and PFD#2, the inhibition of shivering thermogenesis thus resulted in significantly faster cooling rates than seen for the shivering subjects in Part 1 of this study.

Discussion

Total body heat loss was about 2.8 times greater in the PFD#1 and PFD#2 conditions than in either of the body-insulated conditions. The negative energy balance during immersion was significantly higher in PFD#2 and PFD#1 (-951 kJ and -810 kJ, respectively) than in the body-insulated conditions (-262 kJ and -171 kJ for head-in and head-out, respectively). Furthermore, heat loss from the head accounted for only about 5% of total body heat loss in the PFD#2 condition. This was approximately proportional to the *immersed* surface area of the dorsal head and neck compared to the total *immersed* surface area of the whole body. Thus, this study found that the head did not contribute disproportionately (i.e., beyond the dorsal head's percentage of total body surface area) to total body heat loss when immersed in cold water.

In addition, the differences found in core cooling and heat loss between PFD#1 and PFD#2 resulted both from truncal immersion and from head immersion. PFD#2, with a flotation posture that immersed the upper chest (as well as the dorsal head), showed a 5% greater truncal heat loss than did PFD#1. This is approximately equal to the surface area of the upper chest compared to that of the whole body. Finally, the differences found in core cooling and heat loss between the two PFD's also likely resulted from a greater decrease in peripheral blood flow in PFD#2 compared to PFD#1, through both cutaneous vasoconstriction and decreased muscle blood flow. This effect is secondary to a combination of increased exposed surface area and a greater amount of core temperature decline.

In both Part 1 and Part 2, isolated head cooling in the dry suit (head-in, body-insulated) condition resulted in only a small drop in core temperature, while the addition of head cooling to body cooling (e.g. PFD#2 vs. PFD#1) resulted in a large increase in cooling rate and a large difference in core temperature decline. These results likely stem from the difference in perfused tissue mass of the body in the three conditions (Chris Jamieson[18]). In the drysuit condition, the extremities would be vasodilated and perfused. Any cooled blood from the head would quickly be dissipated throughout the large volume of perfused tissue so the net cooling effect from this blood would be negligible. In the PFD #2 condition, however, the extremities are not being perfused to any great degree as they are maximally vasoconstricted. This means that only a small volume of core tissue is being well perfused. Therefore, cooled blood from the head would be distributed into a much smaller tissue volume and the net cooling effect would be much greater. This would result in a much greater drop in core temperature.

The results of this study show that subjects wearing PFD#2 are at a critical disadvantage in a cold-water survival situation compared to those wearing PFD#1. PFD#2 not only exposes the dorsal head and neck to immersion, but it also increases the total truncal surface area exposed to cold-water. The additional 10% of total body surface area immersed in PFD#2 (i.e., 5% from dorsal head and neck plus 5% from upper chest) compared to PFD#1 increases core cooling rate and decreases potential survival time. As shown in Part 1 of this study, head cooling is also associated with cognitive decrements, which would likely increase in severity with decreasing core temperatures.

Conclusions

1) Dorsal head immersion in cold water is associated with a statistically significant increase in heat loss and a substantial increase in core temperature cooling rate.
2) For the two PFD designs evaluated in this study, total heat loss is in direct proportion to the total surface area of the body exposed to cold water. The differences between PFD#1 and PFD#2 are primarily the result of differences in flotation posture, i.e., immersion of the dorsal head and upper chest. The head is not an area of unusually high relative or absolute heat loss beyond its contribution to the total immersed body surface area.
3) Dorsal head immersion in cold water is associated with decrements in cognitive performance. These decrements would likely increase in severity with continued cooling beyond the limiting core temperature (34 °C) used in this study. Such decrements would likely be of significance for survivors immersed in cold water.
4) PFD designs should attempt to minimize exposure of the dorsal head and neck to cold-water immersion, both to maintain cognitive function and to minimize the total surface area of the body exposed to cold.
5) Meperidine is effective in inhibiting shivering thermogenesis in human subjects in the moderately cold water temperature used in this study. This drug is thus useful in creating a human model of severe hypothermia (wherein shivering ceases) for studying the human physiologic response to cold in a laboratory setting.

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EFFECTIVENESS OF CYCLE ERGOMETRY FOR INCREASING FINGER TEMPERATURE IN MILDLY HYPOTHERMIC SUBJECTS

C. O'Brien, I.V. Sils, M.L. Reese and J.W. Castellani*

U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760-5007
* corresponding author kate.obrien@us.army.mil

Introduction

A practical approach often used to maintain finger skin temperature during cold exposure is to increase metabolic activity through exercise (1,2). By maintaining warmer body temperatures, cold-induced vasoconstriction is reduced. The resulting increase in finger temperature can increase thermal comfort, reduce risk of cold injury, and improve manual performance in the cold.

A reduction in core temperature is known to increase vasoconstriction in the extremities and can blunt the cold-induced vasodilation response even more than lowered skin temperature alone (3,4). In comparison to normothermia, using exercise to increase extremity temperatures in subjects who are mildly hypothermic may be ineffective until core temperature has increased and the central stimulus for sympathetic vasoconstriction has been reduced. The purpose of this study was to examine the finger temperature response to cycle ergometry in subjects exposed to cold while normothermic and again while mildly hypothermic.

Methodology

Seven males (height 180±8 cm; mass 73±7 kg; body fat 15±4%; maximal oxygen uptake 46±4 ml/kg/min) walked on an underwater treadmill while immersed to their chest (arms not immersed) in 15ºC water (hypothermic trial (HYP)) until their rectal temperature (Tre) reached 35.5ºC (3 subjects) or they requested to stop the test (4 subjects; average Tre 36.3ºC). After donning dry shorts, shoes and socks, they proceeded to a cold air (10ºC) chamber where they completed a computer task for ~20 min, followed by ~10 min of performance tasks (e.g., dexterity, marksmanship, grip strength) before beginning a cycle ergometer task (EX) of 3 kJ per kg body weight. Subjects self-selected their work rate during EX, but were instructed to complete EX as quickly as possible. On a separate occasion they completed a control trial (CON) during which they sat at room temperature (~19ºC) dressed in BDU (0.85 clo) with no cold water immersion or treadmill walking, then completed the cold air exposure descibed above. Mean weighted skin temperature (Tsk) measured using thermistors, was determined according to the following formula: 0.07 * (forearm + triceps + hand) + 0.14 * (chest + back) + 0.06 * foot + 0.28 * thigh + 0.17 * calf. Middle finger skin temperature (Tf) was measured on the dorsal aspect of the middle phalange.

Repeated measures analysis of variance (trial x time) was used to determine whether there were any significant ($P<0.05$) main or interactive effects between trials, and Tukey's HSD post-hoc analysis was applied when significant differences were found. Data are presented as mean ± standard deviation.

Results

EX was completed in 22.5±3.1 min during CON and 24.0±3.3 min during HYP (P<0.05), indicating that subjects chose a lower (P<0.05) average work load during HYP (155±20 Watts) than during CON (165±22). Temperature responses are shown in Figure 1. Initial temperatures were all lower (P<0.05) during HYP than CON. Tre increased (P<0.05) during EX similarly on CON (36.8±0.3ºC to 37.5±0.4ºC) and HYP (36.0±0.7ºC to 36.9±0.5ºC). Tsk increased (P<0.05) during exercise similarly during CON (27.5±1.0ºC to 28.4±1.4ºC) and HYP (26.1±1.1ºC to 26.8±1.2ºC). Tf increased (P<0.05) during exercise on both trials, but with a greater increase during CON (16.1±1.7ºC to 25.9±6.0ºC) than during HYP (15.5±1.3ºC to 20.7±2.9ºC). One subject had no increase in Tf with exercise on either trial.

Discussion

The present study demonstrates the effectiveness of exercise for increasing Tf during cold air exposure even under conditions of mild hypothermia. During cold exposure, sympathetic vasoconstriction results in reduced finger temperatures and a blunted cold-induced vasodilation response (3,4), and this is independently influenced by both lowered skin and core temperatures (4). In the present study, Tsk decreased upon cold exposure on both trials, while Tre was lower only on HYP. EX was effective at increasing Tf under both conditions, although Tf at the end of exercise was still lower during HYP than CON. A typical response of Tre and Tf during cold air exposure is shown in Figure 2 for a representative subject.

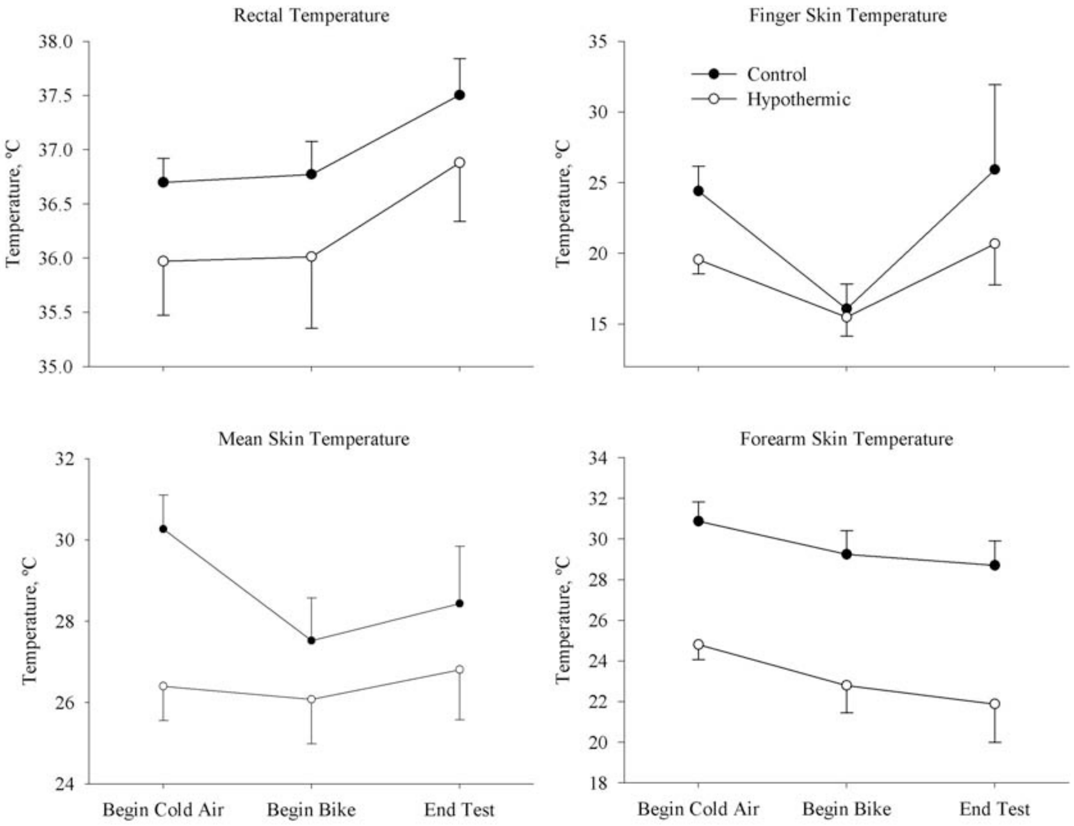

Figure 1. Mean temperature responses (mean ± standard deviation) during control and hypothermic trials.

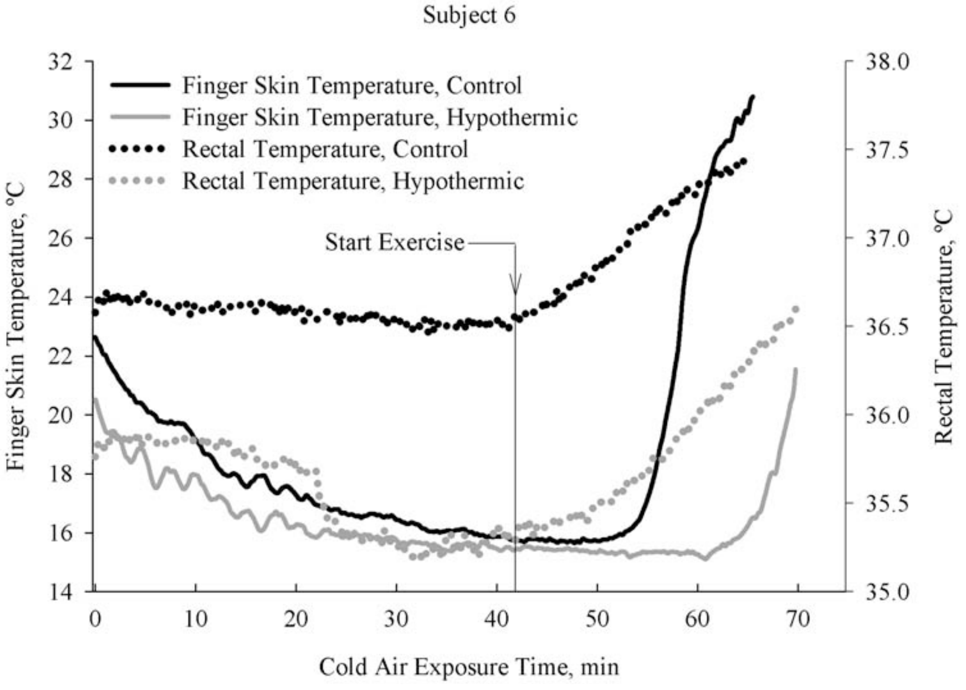

Figure 2. Finger skin (left axis) and rectal (right axis) temperature responses on control and hypothermic trials. Vertical line indicates start of cycle ergometer exercise.

Importantly, even during HYP, the Tf that was achieved with exercise, 20.7ºC, was above the skin temperature (20ºC) typically associated with increasing thermal discomfort (5) and reduced manual dexterity (6). The subjects in the present study exercised at a work load of ~160 Watts. Hellstrøm et al. (2) demonstrated that only exercise of 100 W or greater was able to increase finger temperature during 10ºC cold exposure, a work load that also increased Tre in their normothermic subjects. Furthermore, data from Walsh and Graham (7) suggest that exercise must be continuous, because temperature increases are only transient with intermittent exercise.

As Tf increased with exercise, there was a corresponding fall in forearm skin temperature. It seems likely that this reflects the cooler venous return from the hand. Although forearm blood flow is typically reduced upon onset of exercise under normothermic conditions, the cold exposure in the present study already provides a strong drive for vasoconstriction. Indeed, Nakayama et al. (8) showed no further vasoconstriction with exercise at 13ºC when skin temperature was already low, whereas blood flow to inactive tissues was reduced during exercise at 20ºC and 27ºC. The increase in Tf during exercise despite reduced Tre and Tsk on HYP suggest a role for nonthermoregulatory factors associated with exercise, such as changes in baroreceptor activation (9).

Conclusions

Exercise is effective at increasing finger temperatures during cold air exposure even in mildly hypothermic individuals.

Disclaimer

The opinions or assertions contained herein are the private views of the authors and are not be construed as official or reflecting the views of the U.S. Army or the Department of Defense. The investigators have adhered to the policies for the protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46. This study was approved by the U.S. Army Research Institute of Environmental Medicine Scientific and Human Use Review Committees. Human subjects participated in these studies after giving their free and informed voluntary consent. Approved for public release: distribution is unlimited.

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Thermophysiology and self-perceived sensations During Cold exposure of the Hands:

THERMOPHYSIOLOGY AND SELF-PERCEIVED SENSATIONS DURING COLD EXPOSURE OF THE HANDS: DATA FOR A BIOPHYSICAL DEVICE

Karl Jochen Glitz[1*], *Uwe Seibel*[1], *Bernhard Kurz*[2], *Wolfgang H. Uedelhoven*[3], *Dieter Leyk*[1]

[1]Central Institute of the Bundeswehr Medical Service Koblenz, Germany
[2]Institute for Applied Ergonomics, Munich, Germany
[3]Bundeswehr Research Institute for Materials, Explosives, Fuels and Lubricants, Erding, Germany
[*]corresponding author karljochenglitz@bundeswehr.org

INTRODUCTION

The human-physiological simulation device “CYBOR“ (Cybernetic Body Regulation) is used for predictions about the climatic wearing comfort of shoes and gloves (7, 12). It is intended to implement a new feature into the system in order to compute and predict the thermal range, in which gloves can comfortably be worn during cold exposure of the hands.
Thus, as a requirement for this implementation, it was the aim of the present study to determine valid basis data concerning thermophysiology as well as the self-perceived thermal sensations of the hands.

METHODS

Ten male volunteers participated in the study. They sat in a climatic chamber (t_a 20 °C, RH 50 %, v_{air} < 0.1 $m \cdot s^{-1}$) and held their bare hands into a climatic box, based on the CYBOR-technique with climatic control provided by adjusting the temperature and humidity of the air. The hands were exposed up to 150 min to decreasing temperatures (from 27.4 ± 1.6 °C to 9.7 ± 0.8 °C, M ± SD) and RH of at first 53 ± 9 %. After 90 min the air was humidified thus increasing RH up to 81 ± 10 %.
Heart rate, temperatures [tympanic membrane, mean body skin (9), finger and hand skin] and perfusion of fingers (laser-doppler-technique) were measured. The participants self-perceived sensations were ascertained by bipolar adjectival scales [ex.: from - 3 (cold) to + 3 (warm)] every 10 min. Statistical analysis was conducted by the software SPSS.

RESULTS

Heart rate decreased only very slightly (HR = - 0.02 min + 73) and not significantly. Tympanic membrane temperature (M ± SD) was reduced from 36.6 ± 0.3 °C to 35.9 ± 0.5 °C ($p < 0.05$).

Figure 1 shows the temperatures of the skin and in the CYBOR-box: Mean body skin temperature dropped from 33.0 ± 0.9 °C to 32.4 ± 1.5 °C ($p < 0.05$). All hand skin temperatures decreased continuously (minimum at the little fingers 12.3 ± 2.6 °C) and statistically significant ($p < 0.001$). Four tests were stopped prematurely after 76, 116, 120, 145 min respectively because the volunteers hands had become too cold.

Figure 2 shows the coherence between mean finger skin temperature and the perfusion of fingers. For mean finger skin temperature 15 – 31 °C the variability of perfusion was 1 : 2.5.

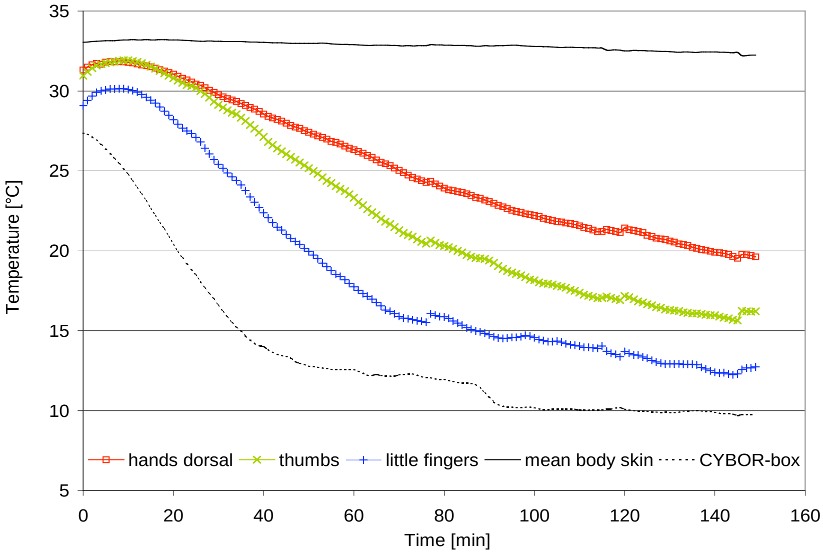

Figure 1. Temperatures (skin and CYBOR-box, values are means)

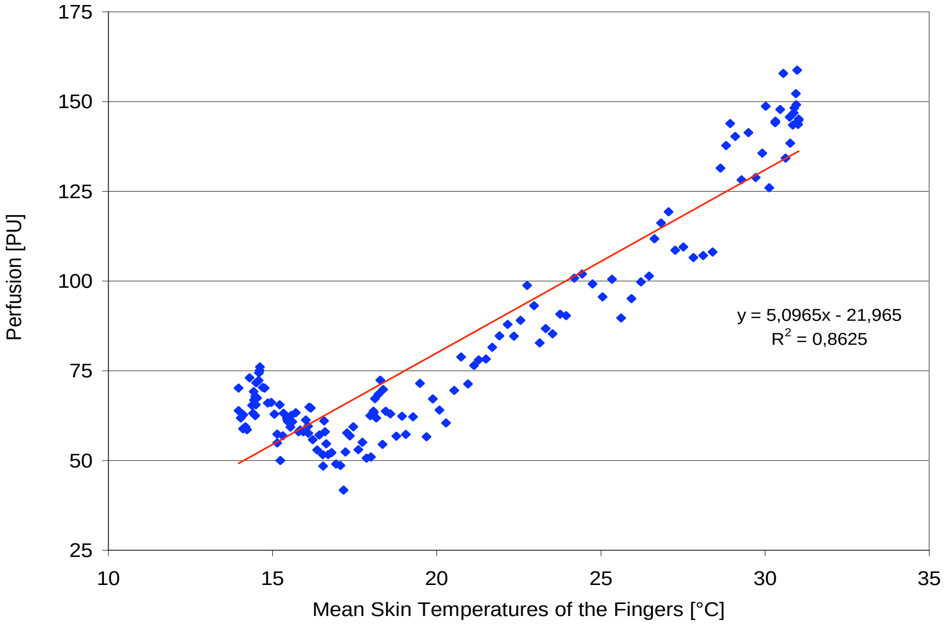

Figure 2. Perfusion of the fingers (laser-doppler-technique) vs. mean skin temperature of the fingers

The self perceived thermal sensations of the body decreased not statistically significant from + 0.6 ± 1.2 at the beginning to 0.0 ± 1.6 at the end of the cold exposure. The self perceived thermal sensations of the hands were more specific; they changed from + 1.3 ± 1.1 to –2.2 ± 0.9 ($p < 0.05$). This wide variation could best be described by a fourth-degree polynomial equation (144 couples, $R^2 = 0.62$) with a thermal neutral zone of 27 °C for mean hand skin temperature.

There were no sweat sensations, neither for the body nor for the hands in the climates of the chamber and the CYBOR-box.

DISCUSSION

At the beginning of the test the self perceived thermal sensation of the body was slightly warmer than neutral and the temperature of the CYBOR-box was within the thermal neutral zone of the hands. Thus the ambient climate of the climatic chamber seems to be well adapted for the low metabolic heat production of the volunteers. Due to the progressive cold exposure in the CYBOR-box the heat loss of the hands resulted in decreasing temperatures (tympanic membrane, mean body skin, finger and hand skin), reduction of the perfusion of fingers and increasing thermal discomfort. So a known hand skin temperature graduation (3) from the back of the hands (higher level) to the thumbs and to the little fingers (lowest level) was obtained.

To determine the variability of perfusion, a mean finger skin temperature of 15 °C was chosen according to the limits of a sufficient manual skill (6). – The result of 1 : 2.5 does not show the much higher variability of blood flow as known from former studies with extremer conditions: Differences of 1 : 600 for the fingers and 1 : 30 for the hands were reported (1, 2, 11). It is also reviewed (4) that the perfusion of the fingers can vary 100 times and more between complete vasodilatation and complete vasoconstriction (10).

With comparable methods (convective cooling with 19 °C) palm blood flow (laser-doppler-technique) can be reduced to 53 % (8). This result correlates well with the present study, because blood flow of the palms is greater than of the fingers and higher temperatures than those in the CYBOR-box were used.

The wide variation of self perceived thermal sensations of the hands is similar to the results known for the feet or the complete body. The thermal neutral zone of 27 °C for mean hand skin temperature, however, is nearly the same which was found for the dorsal side of the hand while touching cold materials with the contact side (5).

A significant association of the relative humidity in the CYBOR-box with the sweat sensation was not found. This might be caused by several facts:
The naked hands had no mechanical contact to gloves; so humidity cannot be felt “indirectly“ either.
The maximum relative humidity of 81 ± 10 % in the CYBOR-box could have been too low or the relative humidity was possibly increased at too low temperatures in the CYBOR-box.

CONCLUSIONS

The obtained results have been successfully implemented in CYBOR´s control software so the dynamic adjustment of heat flow into the hand model as a function of model ”skin” temperature is possible. The main advantage consists of the improved transfer from simulations to self-perceived sensations which has been demonstrated in the tests of different handwear.

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EFFECTS OF ICE ON CONTACT COOLING

Sirkka Rissanen, Hannu Rintamäki*

Oulu Regional Institute of Occupational Health, Oulu, Finland
* corresponding author sirkka.rissanen@ttl.fi

Introduction

Contacting cold surfaces with bare hand or finger decreases skin temperature and may cause frostbite. Some safe time limits of hand/finger contact with various cold surfaces (metals, plastic, stone and wood) are introduced in a draft proposal document for a CEN standard[1]. In cold and humid conditions the cold surfaces may be covered by water, snow or ice, but their effects on contact cooling are not well documented. Furthermore, sticking of wet skin on cold metal is well known phenomenon in practice, but further knowledge about the surface temperature and the conditions at which the sticking occurs has been lacking. The aim of this study was to determine 1) the effect of moisture and ice on contact cooling and 2) the surface temperature at which the skin sticking starts.

Methods

Three voluntary subjects participated in the contact cooling measurements. Gripping materials were an ice bar (diameter 40 mm), a nylon bar (diameter 40 mm) and a nylon bar covered by thin (ca 1 mm) layer of ice. Duration of the gripping was for maximum of 120 s. The measurements were done in a climatic chamber at -15 °C. The bars were stabilised in the same temperature at least for 4 hours before the measurements. Contact skin temperatures were measured on the volar side of the distal phalanx of the little finger and on three sites of the palm (near index finger, thumb and little finger) by thermocouples (K-type, diameter 0.3 mm). Thermocouple was attached by a small piece of surgical tape (Blenderm, 3M) while the tip of the thermocouple was left uncovered.

In the sticking experiments one voluntary man served as a subject. The sticking was studied with the bare finger as well as with the finger and the hand covered by a latex surgeon's glove. The finger (bare or covered) and covered hand was dry or wetted by water. Wetting of the finger or glove was performed by immersing the finger/hand into water. The metal bar was hanging from a hand grip dynamometer (Newtest, Finland) in a vertical position. Peak forces during the drawing of finger or hand from the bar were measured. The temperatures of the bars were between -5 and -20 °C.

The metal bar (aluminium or steel) was touched for 2 s with the volar side of the finger with a pressure of ca. 50 g, and the finger was pulled downwards until the release happened. In the handgrip experiments the metal bar was gripped (with a pressure comparable to lift 500 g) for 2 s by a dominant hand covered by a surgeon's glove. After that the gripping was released, and hand was pulled downwards until the release of glove from the bar. In each session, 3 - 4 trials were done. Sticking was also tested when cold metal bars were covered by a thin layer of ice due to a rapid condensation of moisture.

Results

With bare nylon bar the contact temperature of finger ($T_{cfinger}$) decreased to ca. 18 °C (Figure 1). When the ice-covered bar was gripped, $T_{cfinger}$ dropped to 13 °C in 4 seconds after which $T_{cfinger}$ increased and stabilized to ca 17 °C. During ice bar gripping $T_{cfinger}$ reached 3 °C in 6 seconds after which it stabilized. Contact temperatures of palm decreased as well rapidly being appr. at the same level as $T_{cfinger}$ at the end of the gripping.

The tests with dry finger did not show any sticking response when dry or ice-covered cold metal was touched. Sticking of wet skin or glove started to develop when the temperature of aluminium or steel decreased below -5 °C and -7 °C, respectively. The sticking force increased steeply until the metal surface temperature decreased to –10 °C both with bare finger (Figure 2) and covered hand (Figure 3). Between -10 and -20 °C the change in the sticking force was small. The results with bare finger and covered finger did not differ markedly. The maximal sticking force was ca. 1.5 kg and 8 kg for finger and hand, respectively at -20 °C.

Discussion and conclusions

Gripping of ice bar resulted in rapid cooling of fingers and palm as could be seen during gripping of a cold metal[2]. Contact skin temperature did not decrease below 0 °C. Ice-cover on the cold nylon bar increased contact cooling rate until its melting point after which rewarming occurred to a slightly lower level than in the case of dry nylon bar.

The results showed that dry skin do not stick on metal, even if the metal is covered by a thin layer of ice. Wet skin started to stick on metal surface when its temperature decreased below –5 °C. The differences between the sticking forces with aluminium and steel were not marked except during the contact with bare finger, when the force was higher with steel. Sticking force was maximally ca. 0.4 and 0.08 kg/cm² for the fingertip and hand gripping contacts, respectively.

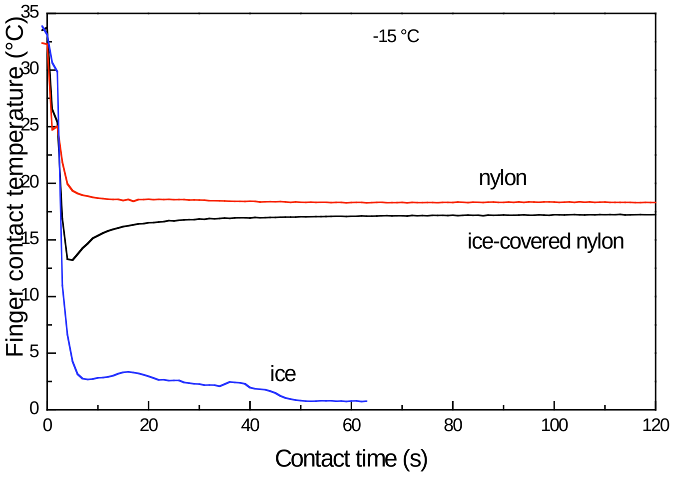

Figure 1. Finger contact temperature while gripping of nylon, ice-covered nylon and ice bars at –15 °C. Results are from one subject.

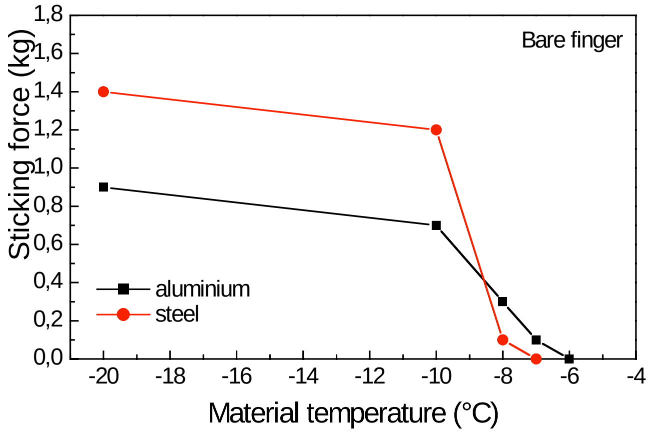

Figure 2. Sticking force (kg) with a bare wetted finger at different metal surface temperatures. Values are means of 3 - 4 measurements.

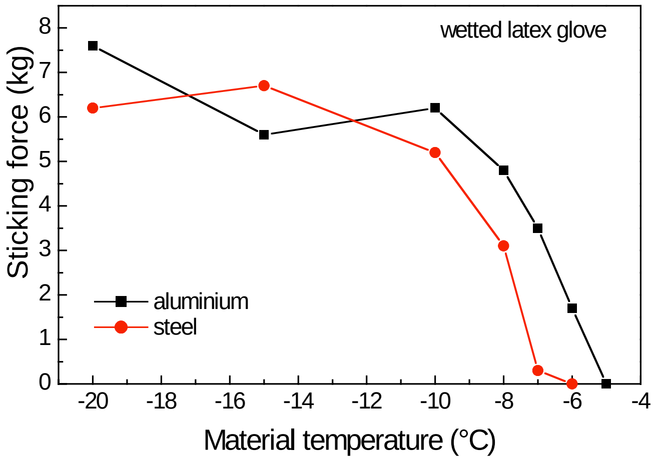

Figure 3. Sticking force (kg) with a hand covered by wetted latex glove at different metal surface temperatures. Values are means of 3 - 4 measurements.

The sticking force of a bare finger can be quite reliably simulated with a finger covered by a latex surgeon's glove, because the direction of the pulling is downwards. In the case of the sticking force of covered hand, the direction of the hand movement is parallel with the metal bar after the initial release of the gripping. Furthermore, the surgeon's glove is stretched which does not really simulate the behaviour of skin and may overestimate the sticking force.

In conclusion, the pattern of contact cooling is similar with ice and cold metal bars. However, melting of ice resulted in stabilization of contact skin temperature above 0 °C. Thin layer of ice on the nylon bar increased contact cooling rate until the melting point of the ice. Dry skin does not stick on cold metal. Wet skin started to stick on metal surface when its temperature decreased below –5 °C. The maximal sticking force was ca. 1.5 kg and 8 kg for finger and hand, respectively at -20 °C.

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EFFECTS OF AN ARCTIC OCEAN SKI TRAVERSE ON THE PROTECTIVE CAPABILITIES OF EXPEDITION FOOTWEAR

Thomas Endrusick[1], Peter Frykman[1], Catherine O'Brien[1], Joseph Giblo[2]*

[1] U.S. Army Research Institute of Environmental Medicine, Natick, MA USA
[2] U.S. Navy Clothing and Textile Research Facility, Natick, MA USA
*corresponding author thomas.endrusick@na.amedd.army.mil

Introduction

From 16 February to 3 June 2000, two 28-year-old Norwegian Navy SEALs traversed the Arctic Ocean via the geographic North Pole from Cape Arctichesky, Siberia to Ward Hunt Island, Canada during a 1,940-km ski expedition. The expedition was completely self-supported with no resupply from outside sources during the entire trek. Each member began the expedition carrying a 20-kg backpack while pulling two 80- to 100-kg sleds in tandem. After 18 days each member dropped one of the sleds and at 88 days the remaining sleds were dropped leaving each carrying a 40- to 45-kg backpack. Both members wore the same clothing system consisting of a multilayered, extreme cold weather ensemble along with multicomponent headgear, handwear and footwear.

There is limited information on the effects of continuous wear on cold weather personal protective equipment. This expedition provided a unique opportunity to assess the impact of an extreme cold environment on the insulating capabilities of the specialized footwear system (FS) actually worn by one of the expedition members.

Methods

A thermal foot model (TFM, Figure 1) was used to measure the thermal resistance of the footwear worn by one of the participants in both new, pre-expedition and used, post-expedition conditions (Figure 2). The left-side boot from both the new and used FS was tested in this study due to the left-footed TFM.

The TFM is a copper, life-sized model of the human foot that measures both total and regional thermal resistance, R ($m^2 \cdot K \cdot W^{-1}$). Power input and the calculation of insulation values for the total TFM and its 29 individual sections are controlled by an automated computer system. In this study, the copper surface of the TFM was controlled at 30°C while the climatic chamber housing the TFM was controlled at 20°C and 50% RH. Sectional thermal resistance to heat exchange was calculated using

$$\mathbf{R = A \cdot T / P}$$

where

A = area of each individual regional segment, m^2,
T = temperature gradient between the TFM surface and ambient air temperature, °C, and
P = regional power input, W.

Ideally, three separate samples of the same test item(s) are evaluated to minimize differences due to manufacture processes. R values can be converted to the more familiar clo unit (1 clo = 0.155 $m^2 \cdot K \cdot W^{-1}$). TFM data is routinely used to compare standard and prototype footwear, identifying advances in materials, design and manufacturing as part of a final selection process for military procurement purposes. Similar examples of the TFM used in this study are employed worldwide in the evaluation of protective footwear in military, academic, and industrial laboratories.

Additional TFM testing was conducted on only the used FS to simulate the effects of environmental exposure and foot sweating typically experienced during the expedition. This included externally immersing the used FS in shallow water, internally wetting the FS, and periodically spraying the FS with water. Personal communication with the wearer of the FS tested in this study assisted in designing the simulated wetting tests.

The FS consisted of a two-layer sock, a vapor barrier sock, a removable woolen inner boot, a 75 mm norm leather/synthetic ski boot, and a waterproof gaiter. All R values reported are the average result of three separate TFM tests.

Figure 1. Diagram showing regional sections of the TFM (left) and photographs showing the TFM bare (center) and during typical military footwear testing (right).

Figure 2. Photographs showing the FS in a new, unused condition (left) and after the 109 day Arctic Ocean ski trek (center and right).

Results

Table 1 shows TFM R values and weights of a new, pre-expedition FS and a used, post-expedition FS when dry and during wear conditions typically encountered during the ski trek. When comparing initial total R of both FS with all components dry, the used FS showed an increase of 10%. Modifications were made to the outer ski boot by the wearer during the course of the trek, including cutting the leather along the D-ring lacing closure and elimination of most of the boot lacing and two of the supportive leather Velcro™ ankle straps. These changes, combined with the undamaged woolen insulation boot, provided the wearer with more boot volume and presumably more foot comfort during use. Dry R values at the toe sections and sole were not different between both FS when dry.

Table 1. TFM resistance values (R, $m^2 \cdot K \cdot W^{-1}$) and total weights (kg) of a new, pre-expedition FS and a used, post-expedition FS when dry and during simulated wear conditions. Only the left-side boot of the FS was tested. All R values reported are the average result of three separate TFM tests.

	New FS-dry	**Used FS-dry**	**Used FS-externally wetted**[a]	**Used FS-internally wetted**[b]
R, total TFM	0.248	0.276	0.183	0.143
R, toe sections[c]	0.310	0.318	0.104	0.095
R, sole section	0.391	0.390	0.115	0.132
FS weight	1.64	1.62	2.40	2.56

[a] External wetting consisted of immersing the entire welt of the boot in 8 cm of water for 18 hr.
[b] Internal wetting consisted of soaking the two-sock layer in water for 1 hr followed by hand-wringing of excess liquid.
[c] Average R value of the 3 TFM toe sections.

Exposure of the used FS to both external and internal moisture caused large reductions in both total and regional R. External immersion of the entire welt of the boot in 8 cm of water for 18 hrs reduced the initial R by 34%. Simulated internal sweat-wetting of the two socks caused a 41% reduction from initial R with similar losses at the toes and sole regions of the TFM.

Periodic external spraying of the outer gaiter combined with wet socks resulted in a 46% reduction from initial R. After being allowed to dry for 96 hrs, the used FS regained only 72% of initial total dry R, indicating a large amount of moisture remained within the various insulating layers.

Discussion

The slight increase in total R of the used FS compared to the new FS was an unexpected result. The physical appearance of the used FS would suggest the opposite result with extensive wear damage to the upper, front outsole and front welt of the test boot. This increase in R is probably the result of the absence of any permanent damage and compression of the custom-made woolen felt inner boot, which represented the greatest insulating component of the FS.

Moisture accumulation within protective footwear from the environment and foot perspiration is unavoidable even during a short duration of wear. A previous TFM evaluation (1) showed similar insulation losses as seen in this study in U.S. military boots utilizing Gore-Tex™ and Thinsulate™ when evaluated during simulated, sustained cold-wet conditions.

The above R losses and the corresponding increases in boot weight when subjected to wetting indicate that the FS probably retained a substantial amount of moisture during the entire expedition. Both expedition members did sustain a moderate case of trench foot while continuously wearing the vapor barrier socks during the early part of the expedition (2).

The U.S. Army invests in a substantial research and development effort to procure protective footwear that provides optimum levels of comfort and protection. As footwear design, materials, and manufacturing processes improve, the TFM test method described here will be instrumental in identifying those that are most effective. A recent inter-laboratory test of the same footwear on 8 different TFM found R value differences mainly related to test climatic conditions, TFM design, and operating procedure (3). Further standardization of TFM design and test procedures would allow for a more universal approach to the development of improved protective footwear.

The U.S. military is concerned about the impact of extremity cooling on soldier performance in cold-wet and cold-dry environments. A physiological cold strain index has been modified to assess peripheral cold stress using measured core and toe temperature (4). Results were found to be consistent with subject behavior and measured toe temperature. Future TFM data combined with physiological responses to cold exposure is expected to enhance these predictive efforts.

Conclusions

Although the used FS had extensive physical wear to the outsole, insole, upper and gaiter as well as numerous wearer modifications, it did not show a reduction in total R when dry as a result of the expedition when compared to a similar, new FS. In fact, long-term use and modifications of this FS resulted in a small increase in total R while toe and sole values were unchanged. Despite the wear damage, the structural integrity of the outer boot and the insulating inner boot was not affected. Wetting of the various footwear layers of the used FS caused marked reductions in both total and regional R, while retaining moisture that could cause cold injury to the feet during prolonged use.

This specialized footwear system appeared to be well chosen by the expedition members as it provided sufficient thermal insulation during continuous, severe use in one of the world’s most inhospitable climates.

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PHYSIOLOGICAL RESPONSES TO EXTREME COLD OF SHORT DURATION (WHOLE-BODY CRYOTHERAPY AND WINTER SWIMMING)

Juhani Smolander[1], Tarja Westerlund[2], Juhani Leppäluoto[3], Arja Uusitalo[4], Juha Oksa[5], Pirkko Huttunen[6], Riina Nieminen[7], Eeva Moilanen[7], Benoit Dugue[8], Marja Mikkelsson[2]*

[1] Orton Research Institute, Orton Orthopaedic Hospital, Helsinki, Finland
[2] Rheumatism Foundation Hospital, Heinola, Finland
[3] Department of Physiology, University of Oulu, Oulu, Finland
[4] Department of Biology of Physical Activity, University of Jyvaskyla, Jyvaskyla, Finland.
[5] Oulu Regional Institute of Occupational Health, Oulu, Finland
[6] Department of Forensic Medicine, University of Oulu, Oulu, Finland
[7] The Immunopharmacological Research Group, University of Tampere, Tampere, Finland
[8] Faculty of Sport Sciences, University of Poitiers, Poitiers, France, and Minerva Foundation Institute for Medical Research, Helsinki, Finland
* corresponding author juhani.smolander@invalidisaatio.fi

Introduction

In whole-body cryotherapy (WBC) patients are exposed to very cold air (-110°C) for 1 to 3 min in minimal clothing. It is mainly used to alleviate inflammation and pain in, for example, arthritis (1), osteoarthritis (2), and fibromyalgia (3). Winter swimming (WS), ie swimming or immersion in ice-cold water, is practised in northern countries, where seas, lakes, and rivers freeze during the wintertime. The reported reasons for WS include improved general well-being, and self-treatment or body hardening against respiratory tract infections and musculoskeletal pains (4). Despite possible health benefits of these forms of cryotherapy, very little scientific information has been available in the literature. This review highlights some recent findings from our research on WBC and WS on healthy subjects. The studies on WBC were undertaken to ensure the safety of WBC for patients and personnel.

Methodology

The WBC group had three 2 min exposures per week for 3 months at -110°C in a specially built, temperature-controlled unit (Zimmer, Elektromedizin, www.zimmer.de). The unit has three chambers, where the subject passes through the first room (-10°C) and the second room (-60°C) before coming into the therapy room. During WBC, the subjects wore a bathing suit, surgical mask, cap, gloves, socks, and shoes. In the therapy chamber, the subjects were instructed to slightly move their fingers and legs. The WS group had three exposures per week for 3 months (February, March, April) in a small pond in the hospital area. The WS was done without sauna bath. The subjects were instructed to stay still in the water for ca 20 s immersed to the neck ('head-out immersion'). The study protocols were approved by the ethical committee of the local hospital district. All subjects were healthy, and moderately active in their leisure time.

Results and Discussion

Body temperatures during the WBC

In this study 10 healthy subjects were recruited (5). The WBC did not change significantly rectal temperature during the exposure. As expected, there was a fast decrease in local skin temperatures. The lowest skin temperatures were measured on forearm (5.2°C), and calf (5.3°C). During WBC, the decrease in skin temperatures is about the same as with 10 min ice-cube massage or 30 min ice-pack treatment.

When skin temperature drops below 20°C, the production of acetylcholine, and the nerve conduction velocity are decreased. Thus, the WBC lowers most of the local skin temperatures to an analgetic level. However, the recovery of skin temperatures after WBC is fast, indicating that this effect only occurs during a limited period after the exposure. WBC involves no risk for frostbites. Similar temperature data are not available for WS as for WBC, but it can be assumed that even colder values exist when the skin contacts ice-water directly.

Thermal sensation and comfort

Twenty healthy women were divided into 2 groups: a WBC and a WS group (6). Thermal sensation and comfort were asked before and after the exposures with standard scales. In general, WBC was voted as a colder exposure compared to WS. Most of the votes after both exposures did not reveal any major cold discomfort. A habituation response was observed at the early stages of both exposures, which may be related to a decrease in synaptic transmission in the limbic system.

Circulatory and respiratory effects

A concern has been raised about the safety of WBC, when patients with cardiac and/or respiratory risk factors or diseases are treated. The blood pressure responses to the WBC were measured before and after the WBC in 32 healthy subjects (7). Acute WBC increased both systolic and diastolic blood pressure temporarily, and no adaptive changes were observed during the 3 month intervention. The magnitude of the blood pressure increase was supposed, however, to be safe for healthy persons. Limited data exist on blood pressure response to WS. The few studies indicate that the rise in blood pressure may be relatively high, probably because the hydrostatic effect of water immersion is added to the effect of cold water temperature.

Lung function was measured before and after WBC in 25 healthy and non-smoking subjects (Smolander et al, unpublished observations). Each subject performed maximal forced exhalations before and after the WBC. Peak expiratory flow rate, forced expiratory volume in one second, and forced vital capacity were determined from the flow-volume recordings. The WBC caused minor reductions (< 5%) in airflow parameters indicating slight airway narrowing in individuals with healthy lungs. The observed bronchoconstriction may be the result of both face and airway cooling, but its magnitude was less than previously reported in healthy subjects. Therefore, the face mask covering the cheeks and airways during the WBC may have an important protective effect. Respiratory data are not available for WS.

Though the blood pressure and lung function results did not reveal any major risk to health with WBC, caution should exercised with sensitive individuals, and their exposures should be individually tailored.

Antioxidant capacity

Adaptation to cold stress, especially the WS, has been postulated as a mechanism resulting in increased resistance to diseases, but very little evidence exist. We measured the total peroxyl radical trapping antioxidant capacity of plasma (TRAP) in the WS group (n = 10), and in the WBC group (n=10) (8). TRAP reflects the global combined antioxidant capacity of all individual antioxidants in blood. The changes in TRAP values due to WBC and WS were rather minor (< 5%), and no long-term effects were observed. However, the results do not exclude minor changes in single antioxidants. From a safety point of view the WBC and WS three times per week for 12 weeks do not not seem harmful as far as antioxidative capacity is concerned.

Conclusions

Our results indicate that the WBC is safe and well-tolerated by healthy subjects. The utility and effectiveness of WBC in the rehabilitation of patients with rheumatic diseases are currently studied at the Rheumatism Foundation Hospital in Heinola, Finland. WS is used as a recreational hobby, but many patients also use it as a self-treatment. Our results indicate that similar kind of physiological effects are achieved by WS and WBC, but WS is carried out in variable, and less-controlled outdoor conditions and without medical surveillance.

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FINGER PERFORMANCE AND PROTECTION DURING MILKING IN COLD ENVIRONMENT

Qiuqing Geng[1]**, *Olle Norén*[1], *Ingvar Holmér*[2]

[1] JTI - Swedish Institute of Agricultural and Environmental Engineering, Uppsala, Sweden
[2] Thermal Environment Laboratory, Department of Design, Lund University, Lund, Sweden
* Corresponding author: qiuqing.geng@jti.slu.se

Introduction

During recent years, an increasing number of non-insulated loose housing dairy farms have been built in Sweden. Therefore, the milking tasks must be performed in cold-milking parlors during winter. A previous survey (2) showed that unacceptable low finger temperatures often appeared during milking in the cold environment. Finger cooling and manual performance reduction become main problems for the farmers because of such cold exposures. It is known that hand/finger cooling reduces the manual performance, which can degrade the quality of work and can even cause accident or injury (7,5,6,1,3). In a recent field study (4), surface temperatures of wet tissues and teat cups down to 2 °C were observed in the cold milking parlors. It has been supposed that the main causes to the low finger temperature would be inappropriate gloves and hand/finger contact with cold objects (cold wet tissues and cold teat cups). Various attempts to solve the problems, however, have not yet been investigated. A further investigation of essential factors on the effect of cold climate on finger temperature would be needed to provide better knowledge to understand the problem and provide better basis for adequate actions to preserve warm fingers during milking.

The aim of this study is to analyze causes to problems during milking in the cold, and to recommend actions that will improve working conditions. The hypothesis is that the problem of finger cooling could be minimized with relatively small changes in the working environment, in protection and/or in working method.

Methods

The study was carried out with human subjects in a climate chamber where a working station was constructed to simulate a cold-milking parlor. Ambient temperature in the climatic chamber was controlled at 3 °C and air velocity was 0,3 m/s. Different actions that affect finger temperature were investigated. A two-level factorial design was utilized for the experiments and statistical data analysis. The three factors studied sere 1) hand-wear (with/without gloves), 2) surface material of teat cup (metallic/plastic) and 3) wet tissue temperature (3 °C/ 22 °C). The subject was asked to perform the simulated milking tasks. They went down into the milking parlor with hands gripping the metallic handrail of the stair, cleared up the udder with wet tissue before the milking and put the teat cups to the udders. Finger skin temperatures were measured continuously during the cold exposure for 40 minutes. Finger tactile sensitivity and dexterity were examined before and after milking for each condition.

Eight healthy subjects (4 males and 4 females) with average age of 24±3 years, weight of 71±11 kg, and height of 177±9 cm gave their free informed consent to participate in the experiments. All the subjects were right handed and none of them had any history of cold injury or peripheral vascular disease. One of the subjects used to smoke about 4 cigarettes per day. The characteristics and anthropometric data for the subjects' right hand are shown in Table 1.

Milking gloves made of rubber with different sizes were used (Nitril, prepowdered, DeLaval, 988250-12-3). A milking organ with four metallic teat cups was used, the surface on two of them were covered by plastic tape. Two thermocouples of t-type with 1 mm diameter connected to a data logger were utilized (Test 175 –T3) for the measurements of middle fingers skin temperatures. Semmes-Weinstein filaments (SWF) were used to touch right middle finger pad for the finger pressure tactile sensitivity test. The filament's number 2,36 that represents a press force of 15 mg was used as lightest force in the tests (Tomancik, 1987). O'Connor model 32021 for dexterity tests was used. In the dexterity tests, the subjects were asked to fill the holes with three pins per hole as quickly as she/he could for duration of one minute.

Results and discussion

Finger temperature

Mean values of finger skin temperature under different combined test conditions are shown in Table 2. The results revealed that the mean finger temperatures became notably low during milking with bare hand, especially under test condition: BCM. Without gloves the temperatures became lower than 15 °C, except test condition BWP, while warm wet tissue and plastic teat cups were used. Observably, the combinations of GCP and GWP had higher finger temperatures. The best condition is GWP for the milking.

Table 1. Characteristics and anthropometric data on the right hand of the subjects

Subject	Age (year)	Weight (kg)	Height (cm)	Finger* length (cm)	Hand length (cm)	Hand width (cm)	Hand circumference (cm)
F1	24	60	160	7,5	17,0	8,5	19,0
F2	26	63	170	8,0	18,0	8,0	19,0
F3	24	70	178	9,0	19,5	8,5	20,0
F4	24	64	179	8,5	18,5	8,0	19,0
M1	28	94	185	8,5	20,0	9,5	24,0
M2	26	77	177	8,5	19,5	9,0	21,5
M3	20	65	181	8,5	19,0	9,0	21,0
M4	19	75	188	8,0	19,0	8,0	21,0
Mean	24	71	177	8,3	18,8	8,6	20,6
SD	3	11	9	0,5	1,0	0,6	1,7

*Middle finger

Table 2. Mean finger temperatures of all subjects under different test combinations

Test condition	Combination of factors	Mean finger temperature			
		middle finger		little finger	
		right	left	right	left
BCM	Bare hand + cold tissue + metallic cup	9,67	11,40	10,90	11,49
BCP	Bare hand + cold tissue + plastic cup	11,20	13,48	10,39	11,95
BWM	Bare hand + warm tissue + metallic cup	12,88	13,75	12,16	13,53
BWP	Bare hand + warm tissue + plastic cup	13,93	15,97	15,03	15,96
GCM	Gloved hand + cold tissue + metallic cup	15,90	16,48	14,62	16,27
GCP	Gloved hand + cold tissue + plastic cup	17,23	20,23	15,70	16,42
GWM	Gloved hand + warm tissue + metallic cup	16,03	17,33	14,15	15,85
GWP	Gloved hand + warm tissue + plastic cup	17,20	19,53	16,06	16,53

Effects of factors

Figure 1 illustrates the plots of three factors for right and left middle finger skin temperature. It is expected that all the factors could affect the finger skin temperature. The mean values of the skin temperatures with gloved hands (G) were significantly higher (more than 4 °C) compared to the bare hands (B). The milking glove is recommended to use for milking. It was noticed that an improvement of the glove design to prevent water is needed. Wearing milking glove in combination with wristlets or arm muffs may be an efficient way to avoid wet hand. The surface temperature of wet tissue and the surface material of the teat cup had effects on the protection against finger cooling. It is suggested that warmer wet tissues and better, insulating material on the metallic teat cups be used for further improvement of finger protection during milking in the cold climate.

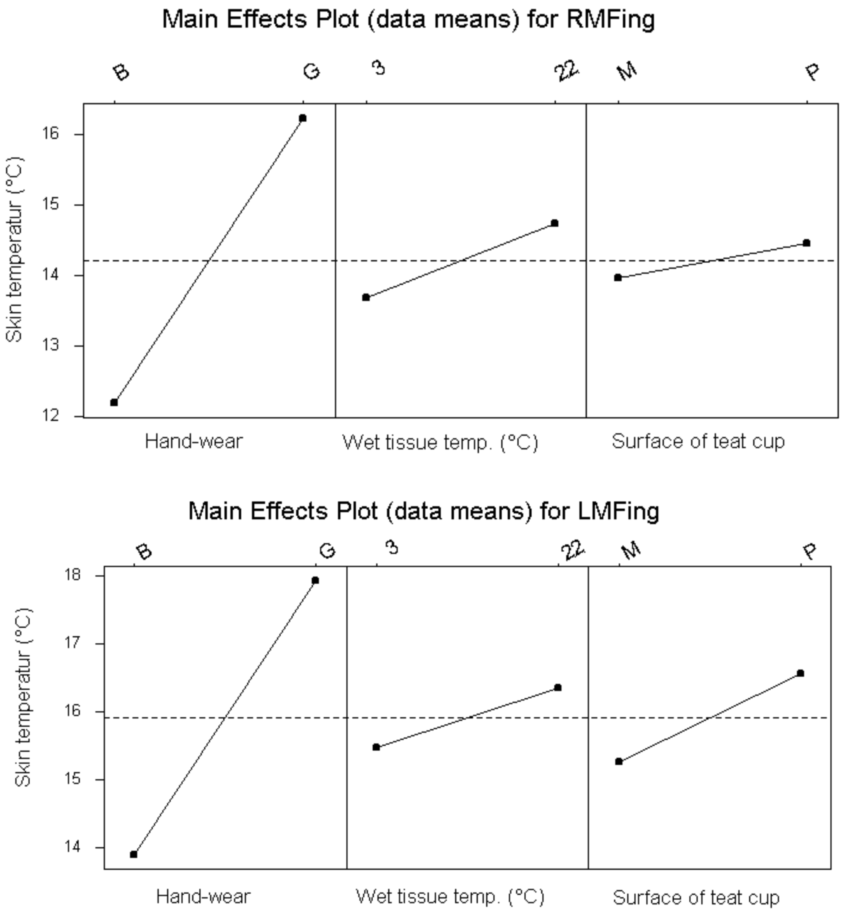

Figure 1. Main effect plots for right and left middle finger temperatures (RMFing = Right middle finger, LMFing = left middle finger B = Bare hand, G = Gloved hand, M = Metallic, P = Plastic).

Finger performance

Statistical comparison of finger performance before and after cold exposure was made. The box plots of SWF and Oconnor tests at 95% confidence are shown in Figure 2. There is a statistically significant difference between the means of SWF pressure for finger tactile sensitivity before and after the finger cooling (P-value: 0,048). Also, the finger dexterity test showed that the completion of total filled holes after finger cooling is significantly less than that before finger cooling (P-value: 0,050).

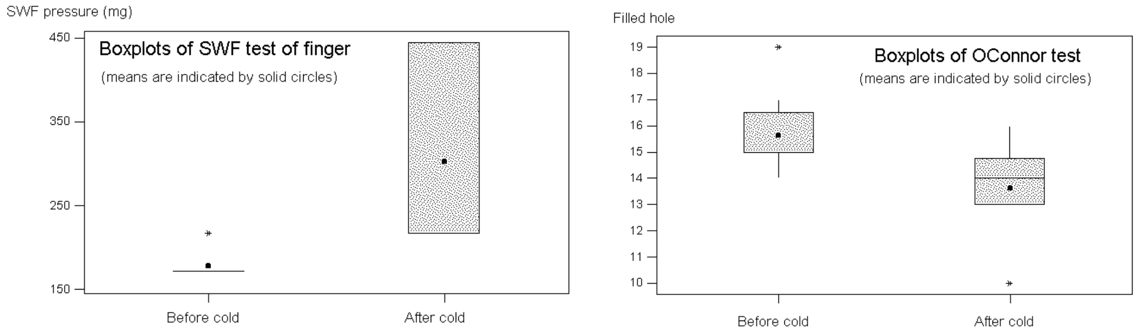

Figure 2. Comparisons of finger tactile sensitivity SWF pressure and finger dexterity Oconnor tests before and after exposures in the cold.

Conclusions

The finger skin temperature reduced significantly after working in the cold milking parlor with bare hands. The significant finger cooling caused a significant decrease in finger performance (tactile sensitivity/dexterity). The most efficient way to prevent both cold and wet is to wear appropriate milking gloves in combination with wristlets or arm muffs. Other important actions to be taken are heating wet tissues to about 35 °C, isolate metallic surfaces that are touched frequently and to use teat cups with a plastic surface.

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COLD STRESS IN PORTUGAL: EVALUATION OF WORKING THERMAL ENVIRONMENTS USING THE REQUIRED CLOTHING INSULATION INDEX (IREQ)

A. Virgílio M. Oliveira[1]**, Adélio R. Gaspar*[2]*, Divo A. Quintela*[2]

[1] Departamento de Engenharia Mecânica, Instituto Superior de Engenharia de Coimbra, Instituto Politécnico de Coimbra, Rua Pedro Nunes - Quinta da Nora, 3030 – 199 Coimbra, Portugal
[2] Departamento de Engenharia Mecânica, Universidade de Coimbra, Pólo II, 3030 – 201 Coimbra, Portugal
* avfmo@mail.isec.pt

Introduction

The development of automation and robotics over the last decades has clearly contributed to the reduction of human presence close to industrial processes. In the case of thermal exposure, there are still many activities where the human direct intervention is irreplaceable, which means that workers can be exposed to extreme temperatures during periods sometimes significant. As a consequence, heat and cold stress situations are frequent and one of the major problems that workers have to deal with. However, in Portugal, at this time there is no specific regulation that addresses these matters.

The absence of systematic studies concerning working conditions in cold environments has thus motivated the development of a field study, which is aimed to characterise the actual reality within the food industry and distribution units. In order to characterise the level of cold exposure, the method proposed by ISO/TR 11079 based on the evaluation of the required clothing insulation to maintain the thermal balance of the body was adopted.

Among all the activities where cold stress conditions may appear, in moderate and hot climates, the food industry is one of the most relevant. Fish, meat and milk-food production, conservation and distribution are examples of sectors that are being analysed. In this work, the results of a set of measurements undertaken at 26 workplaces in 5 food distribution industries are presented and discussed. The results demonstrate that a significant percentage of the workers are repeatedly exposed to extreme conditions with insufficient clothing insulation. The low temperatures found in refrigerating and in freezing chambers, associated with prolonged exposures, clearly suggest the need for changes in the work/rest regimes, particularly when the time needed to complete the required tasks exceeds the recommended duration limit exposure (*DLE*).

Methods

Adopted by ISO as a Technical Report, the Required Clothing Insulation Index (*IREQ*), developed by Holmér (1984), provides a method to assess the thermal stress associated with exposure to cold environments. It integrates the physical parameters air and mean radiant temperatures (t_a and t_r), air velocity (v_a) and humidity (*rh*) and two individual parameters the metabolic rate and the thermal insulation of clothing. It applies to continuous, intermittent and occasional exposure and in both indoor and outdoor work. Two levels of physiological strain, defined in terms of mean skin temperature, skin wettedness and change in body heat content are proposed: $IREQ_{neutral}$ and $IREQ_{min}$.

Based on the human heat balance equation, the thermal insulation of clothing required to maintain thermal equilibrium ($IREQ_{min}$) and thermal comfort ($IREQ_{neutral}$) are calculated. If the actual clothing insulation is less than $IREQ_{min}$, there is a risk of progressive body cooling. In contrast, if the workers wear an ensemble with insulation greater than $IREQ_{neutral}$, there will be an increasing feeling of warmth and overheating may occur. The interval between $IREQ_{min}$ and $IREQ_{neutral}$ can be regarded as the clothing regulatory zone, in which each individual chooses the appropriate protection level.

Experiment

The visits to the 5 food distribution industries took place from January to March. The measurements were carried out according to ISO 7726 (1998). The globe temperature was measured using a 50 mm globe, which has a faster response time than the standard 150 mm globe. The mean radiant temperature was then estimated according to ISO 7726 (1998). Sensors from Testo were used for the t_a, t_g, v_a and *rh* measurements.

The activity levels, M, were estimated according to ISO 8996 (1990), applying the level II procedure, i.e., considering for each single activity, the posture, type of work, motion, work speed and the basal metabolic rate. Whenever we got authorization from the workers, the metabolic rate estimation was based on heart rate measurements. For this purpose, a chest electrode belt with a telemetric heart rate transmitter (Sigma Sport PC 1600) was placed on the subject. The observation period for the description of the activity lasted for one hour.The clothing insulation, I_{cl}, for the clothing ensemble was calculated by adding the values corresponding to each individual garment. Based on a questionnaire with a set of figures representing different types of garments, the workers were asked to identify the garments worn. With this information, the thermal insulation of clothing was estimated following ISO 9920 (1995). In order to consider the reduction of insulation due to body movements, I_{cl} was reduced 20 and 10% for activities with M higher or lower than 100 W/m^2, respectively.

Results and discussion

Figures 1 to 4 show the results of the measured physical parameters, t_a, t_g, rh and v_a.

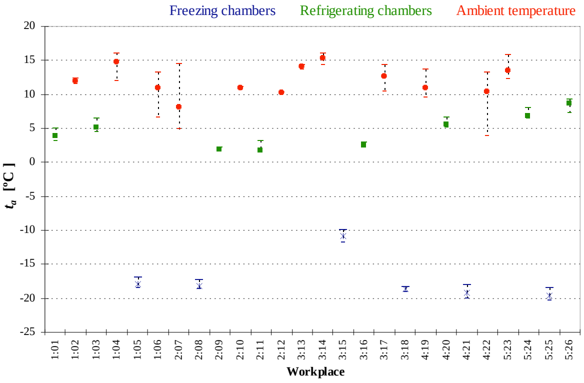

Figure 1. Maximum, mean and minimum values of t_a

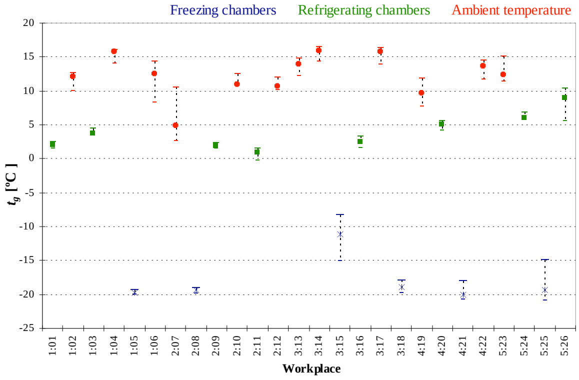

Figure 2. Maximum, mean and minimum values of t_g

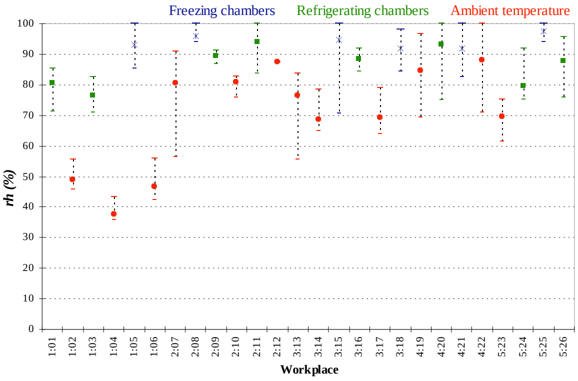

Figure 3. Maximum, mean and minimum values of rh

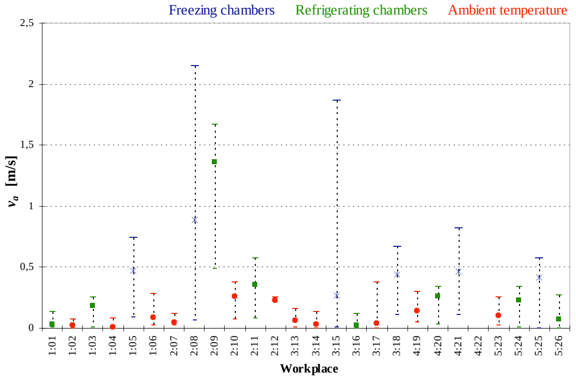

Figure 4. Maximum, mean and minimum values of v_a

From Figure 1 we can identify 3 types of workplaces, associated to different environmental conditions. The freezing chambers are the most severe, with air temperatures around –18ºC. In the refrigerating chambers, the temperatures range from 0 and 7ºC. Finally, in the workplaces next to public attendance zones the air temperature is usually between 10 and 15ºC. The globe temperatures (Figure 2) are similar to the previous, therefore the three mentioned temperature intervals can be easily identified. As shown in Figure 3, in all cold chambers, rh varies from 76,4 *(1:03)* up to 97,4% *(5:25)* with a mean value greater than 75%. The public attendance zones have typically lower values. Figure 4 shows that, in general, the mean value of v_a is lower than 0,5 m/s, with two exceptions *(2:08 and 2:09)*.

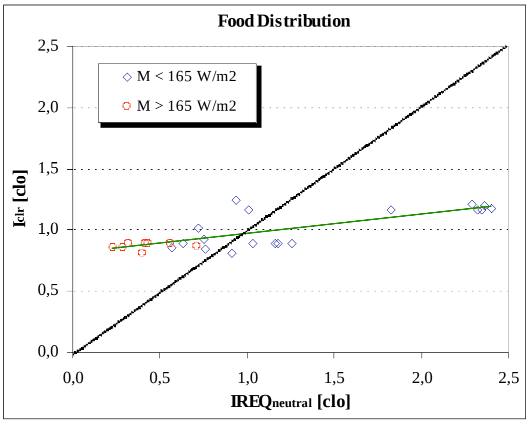

Figure 5. Resultant insulation, I_{clr} *vs* $IREQ_{neutral}$

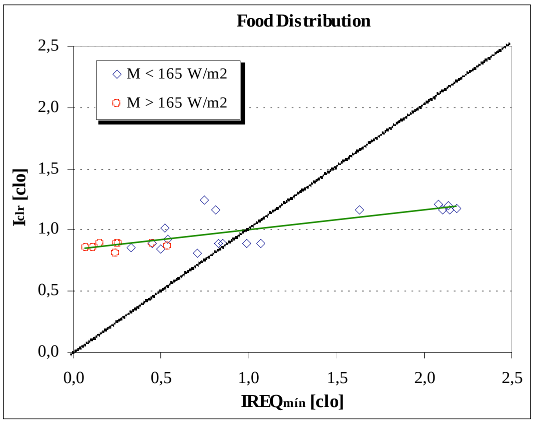

Figure 6. Resultant insulation, I_{clr} *vs* $IREQ_{min}$

The relationships between the resultant clothing insulation, I_{clr}, and *IREQ* for both neutral and minimum criteria are shown on Figures 5 and 6. If the selected clothing ensemble provides sufficient insulation, the points that characterize this condition are located close or over the diagonal line. This situation occurs whenever $IREQ_{mín} \leq I_{clr} \leq IREQ_{neutral}$. If the actual clothing insulation is higher or lower than required, the points are above or below the diagonal line, respectively. In the area below, the growing distance to the diagonal line represents an increasing risk of hypothermia with progressive exposure, while in the area above, the higher the distance the larger the risk of overheating and excessive sweating.

Among the 26 workplaces under analysis, 18 correspond to activities with M<165 W/m^2, while in the remaining 8 the workloads were higher than 165 W/m^2. Below the diagonal line, there are only activities with M<165 W/m^2. In contrast, all the activities with M higher than 165 W/m^2 are above this diagonal line. The figures show a slight tendency for the increase of the actual clothing insulation with the required insulation, and the correlation based on all data demonstrates this fact. However, this trend is far from the ideal situation, i.e., the diagonal line, which indicates that further attention must be given to these matters and to adapt the clothing to the work environment. Indeed, not only the clothing insulation is sometimes clearly insufficient, but also the opposite scenario is true, since frequently the selected ensembles provide more than sufficient insulation.

The majority of cases correspond to the situation where the selected clothing insulation provides more than sufficient insulation ($I_{clr} > IREQ_{neutral}$ - 61,5 %). Still, in 30,8 % of the situations, the clothing ensemble worn by the workers doesn't provide enough protection ($I_{clr} < IREQ_{mín}$). The condition $IREQ_{mín} \leq I_{clr} \leq IREQ_{neutral}$, represents only 7,7 % of the cases.

As a final remark, it should be emphasized that the most critical workplaces correspond to the cold chambers. In these situations, particular care should be addressed to the time of exposure whenever it exceeds the *DLE*. During the visits to the industries, the authors realised that those periods vary considerably. As a rule, the bigger the industrial unit and/or cold chamber, the larger the exposure time. Typically, the time needed to perform the required tasks within the chambers doesn't exceed 1 hour and only exceptionally is extended to 2 or 3 hours.

Finally, as the metabolic rates and clothing insulations are based upon estimations, the associated errors can have some influence on the results. Regarding the metabolism, the Standard states for the two methods applied here an accuracy of ± 15%. When the estimation was based on the heart rate measurements the comparison with the other method shows differences lower than 20%. The estimation of the insulation is also important since the evaluation of the condition for heat balance is based on the comparison between *IREQ* and I_{clr}. In addition, the calculation of *DLE* requires I_{clr}. The summation method proposed by ISO standard gives acceptable accuracy for typical indoor clothing. The main source of inaccuracy lies on the estimation of individual garments being the overall accuracies on the order of ± 25% if the tables are used carefully (ASHRAE, 2001). The comparison with some measurements (Oliveira *et al*, 2005) shows that the estimated values for typical indoor garments are usually overestimated, however the differences weren't significant. For the cold protective clothes, the measured values were in average 0,35 *clo* above the estimated.

The foregoing highlights the need for a wide agreement about the adoption of a common method for the measurement of clothing insulation. Therefore, the authors believe that a correct labelling of protective clothing will reduce the errors related to the estimation methods.

Conclusions

The characterization of working conditions in cold environments in the Portuguese food distribution sector was the aim of this paper. The present evaluations show that a significant percentage of workers are repeatedly exposed to extreme conditions with insufficient clothing insulation. The low temperatures found in refrigerating and in freezing chambers, associated with prolonged exposures, clearly suggest the need for changes in the work/rest regimes, particularly when the time needed to complete the required tasks exceeds the recommended duration limit exposure. The most critical workplaces correspond, as should be expected, to the cold chambers, especially the freezing ones since in all of them the selected clothing ensemble doesn't provide enough insulation ($I_{clr}<IREQ_{mín}$). In contrast, outside the cold chambers, i. e., the workplaces where people are exposed to controlled positive temperatures, the actual clothing insulation is more than sufficient. As far as the refrigerating chambers are concerned, this work situation leads typically, to an $IREQ_{mín} \leq I_{clr} \leq IREQ_{neutral}$ condition.

Finally, the authors believe that this kind of field evaluations play an important role in the efforts to decrease the negative effects and risks associated with the work in cold environments. Therefore, the studies about the assessment of working conditions should be promoted, with the aim of collecting more representative data of the Portuguese reality.

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COLD-INDUCED VASOACTIVE RESPONSES IN THE PATIENTS WITH ISCHEMIC HEART DISEASE

Voronova I.P.[1*], *Bulatetskaja L.M.*[2], *Okouneva G.N.*[2]

[1]Institute of Physiology RAMS, Novosibirsk, Russia
[2]The Blood Circulation Pathology Research Institute, Novosibirsk, Russia
*corresponding author kozyreva@iph.ma.nsc.ru

Introduction

The appearance frequency of cardio-vascular diseases is high in many countries of the world, including Russia, where these diseases are the causes of human's death in 53,5% of all the cases (2,9). In accordance with death-rate caused by ischemic heart disease and by cerebral stroke Russia takes one of the first places in the Europe (2). It is known that, both ischemic heart disease and cerebral stroke, evolve from abnormal vascular reactivity (3,4). Sympatho-adrenal system plays an important role in the regulation of the vascular tone. The activation of sympatho-adrenal system occurs both as a response to psycho-emotional stress (6) and at the cooling conditions (5,12,20). Cold is an inherent element of the Siberian climate. It is impossible to avoid its influence, because even short local cooling produces expressed thermoregulatory responses (11,13,15), accompanied by the excretion of norepinephrine - the mediator of sympathetic nervous system (16). Thus, since cold can provoke a rise of blood pressure and represents a risk-factor for people with cardio-vascular diseases, the investigation of vasomotor responses of such patients remains one of the actual medical problems.

Cold pressor test is one of noninvasive and widely spread maneuver for investigation the reactivity of man's cardiovascular system. Valsalva maneuver is closed to the loads, regularly occurring during the defecation, cough, weak muscle efforts, vormiting (7). It is used enough widely for the investigation of the blood circulation state (1). In the manifestation of the hole complexes of the responses, observed during Valsalva manoeuvre, in particular in the vasoconstriction development, sympathetic nervous system is mostly important (14). Taking into account, that cooling activates sympatho-adrenal system, the carrying out a Valsalva manoeuvre in combination with cold pressor test may turn out enough informative for estimation the cardiovascular system's state.

The task of our investigation was to estimate the state of the peripheral blood flow in the patients with ischemic heart disease during Valsalva manoeuvre and cold pressor test.

Methods

Our studies were performed in 13 patients (mean age 48±3 years) with the diagnosis "ischemic heart disease, stable angina (NYHA II-III)". During all the procedures patients sat in a resting state in an armchair. The investigation began after 20 min of patient resting. The ambient temperature was 24-26°C. Cold pressor test was performed as a local cooling of a hand in the ice-bath during 1 minute. As a Valsalva manoeuvre, existing in different modifications (14), we used a breathing delay for 15 seconds at the highest point of inspiration. Breathing delay was carried out twice: before and 14 minute after cooling. Blood vessel responses were estimated with the laser-Doppler flowmeter ALF-21 (Transonic Systems Inc.) at the left index finger pulp using the R-type sensor. According to the instrument calibration the value of a peripheral blood flow was measured as ml/min·100g tissue.

The level of the arterial blood pressure was registered before all the testing procedures and was monitored each minutes during the cold pressor test and during the period of recovery.

Results and discussion

It was found that all patients could be divided in two groups according to their initial level of peripheral blood flow: first group with low (12-22 ml/min·100g; N=8) and second group with high (28-35 ml/min·100g; N=5) level of peripheral blood flow. Subsequent analysis of the physiological reactions confirmed the correctness of this division (Fig.1). During the Valsalva manoeuvre the peripheral blood flow in the patients of both two groups reduced significantly and the minimal its levels registered during the first breathing delay were almost the same. However, in the patients of the second group the peripheral blood flow recovered in1 minute to initial level, but in the patients of the first group it remained decreased (16.9±1.22ml/min·100g and 12.3±0.75 ml/min·100g; before and after Valsalva manoeuvre respectively, $P<0.05$). Cold pressor test led to reduction of the peripheral blood flow during the cooling. The value of blood flow measured during 1minite in the patients of the second group was higher then it was in the patients of the first group (6.3±1.7 and 2.2±0.7 ml/min·100g; respectively, P<0.05). The recovery of the peripheral blood flow after cooling occurred also in different ways: in the patients of the second group the peripheral blood flow recovered completely in 14 minutes; while the peripheral blood flow in the patients of the first group in the same time recovered only to 94% of the level before cooling.

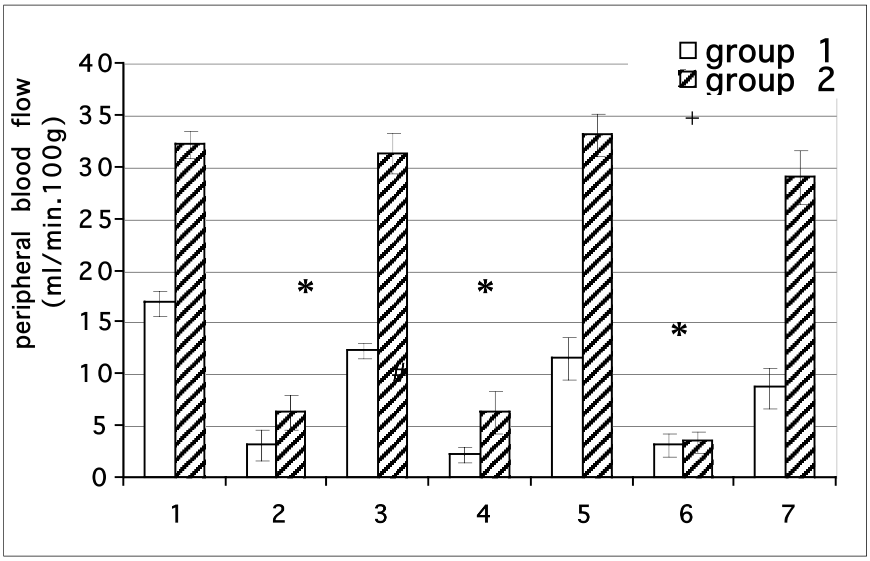

Figure 1. Chaneges of the peripheral blood flow at the different periods of investigation in the patients of two groups: 1 - baseline at the rest before all the procedures; 2 - minimal level of the peripheral blood flow registered during the first breathing delay; 3 – recovery: peripheral blood flow registered during 1min after the end of breathing delay; 4 - peripheral blood flow registered during 1min of cooling; 5 - peripheral blood flow registered during 14thmin of the recovery period after cooling; 6 - minimal level of the peripheral blood flow registered during the second breathing delay; 7 - recovery: peripheral blood flow registered during 1min after the end of breathing delay. * - P<0.05 compared to the initial level; # - P<0.05 the difference between two groups; + - P<0.05 compared to previous recovery.

It seems, that cold exposure changed a capacity of vessels to recover blood flow after its fall caused by breathing delay: before cooling the peripheral blood flow in the patients of the second group recovered completely in 1 minute after the breathing delay, after cooling it was lower by 4.2±1.1 ml/min·100g (P<0.05). The patients of the first group demonstrated the lowering capacity to recover blood flow after breathing delay even before cooling. It is necessary to note that in the last case the significance of the observed differences in the patients of the second group are a result of a light overdrawing the initial level of the peripheral blood flow by blood flow recovering after cooling. In comparing the level of the peripheral blood flow after second Valsalva manoeuvre with the initial level the significance of the difference is absent.

Observed differences of the peripheral blood flow in the patients of the two marked out groups are not the result of a difference of their arterial blood pressure levels, because the magnitude of the arterial blood pressure in the rest before all testing procedures as well as the dynamics of its changes during cold pressor test and during the process of recovery were identical in the patients of these groups (Table1).

Table1. Arterial blood pressure in the patients of the two groups.

		arterial blood pressure (mm Hg)					
		initial level		**during cooling**		**14thmin of recovery**	
group	**n**	**systolic**	**dyastolic**	**systolic**	**dyastolic**	**systolic**	**dyastolic**
I	8	116±3.7	80±2.5	136±4.8	94±2.8	114±4.4	79±2.1
II	5	118±2.3	78±2.4	138±7.2	88±5.0	116±5.0	76±4.2

It appears, that the observed differences in the initial level of a peripheral blood flow according to which our patients were divided in two groups and the differences in the responses to the used tests are determined by the own properties of the blood vessels. And it is possible, that various sensibility to the activation of the sympathetic nervous system plays an important role in the origin of these differences.

Indeed, our patients were studied under the conditions, when three, one after the other, procedures activated the sympathetic nervous system. Each activation of the sympathetic nervous system led to a significant vasoconstriction. In spite of that, the peripheral blood flow in the patients of the second group recovered quickly and completely. On the contrary, in the patients of the first group each following maneuver led to the opposite phenomenon: the level of the blood flow recovered worse and worse. Let compare the blood flow levels: initial - 16.9±1.22 ml/min·100g: after first Valsalva maneuver - 12.3±0.75 ml/min·100g; after cold pressor test - 11.5±2.03 ml/min·100g and after second Valsalva maneuver - 8.7±1.95 ml/min·100g.

Thus, following one after the other events activating the sympathetic nervous system can provoke in some human the changes, which could cause a stable spasm of the blood vessels.

The mechanisms, which are involved in increasing the sensibility to sympathetic stimulation in human with heart and cardio-vascular disease is not studied enough. .But as for animals it’s well known, that prolong cold exposure (adaptation to cold according to Hart(8)) or repeated cold exposure (adaptation to cold according to LeBlanc(13)) change the sensibility of the organism to sympathetic stimulation (10,17,18). Certainly, not only the cold can provoke such hypersensibility, but as for the cold, it is an inherent element of the climate, its influence on the sympathetic nervous system is inevitable, and it may by a background for cardio-vascular diseases.

It is necessary to note that stable spasm of the blood vessels caused by the sympathetic nervous system activating may take place not only at skin, but also in heart. There are the data, showing the existence of correlation between the level of peripheral microcirculation and status of a heart (19). More over among the wide multiplicity of the ischemic heart diseases there is a so called vasospastic type. This type is not accompanied by morphological disorders and it’s difficult to establish the correct diagnosis. Probably, it’s the physiological testing of the peripheral blood flow that will help to solve this problem.

Conclusion

Thus, two groups of patients distinguished by their various level of peripheral blood flow had the different blood vessels capacity to recover. The methods used for these studies could be the adequate tests to determine the ischemic heart disease patients for which cold is a risk-factor.

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A METHOD FOR DETECTION OF PREVIOUS COLD INJURIES

Anders Linné

Swedish Armed Forces Winter Unit
Boden, Sweden
anders.linne@mil.se

Introduction

A certain amount of various cold injuries among the soldiers in the Swedish Defence Force is reported every year. Cold injuries lead to great costs for the Swedish Defence Force, as responsible for the origin of the injury. A cold injured soldier gets a lower fighting effectiveness, which also increases costs. Finally, a cold injury means a handicap for the affected person.

In a study made by Tony Hagman (FSC) , of reported cold injuries in the Swedish Defence Force the winter 1995-99 690 cold injuries were reported.

For 2000-2003 293 cold injuries were reported.

The most commonly affected body parts were:

Toes	243	(left 179, right 64)
Fingers	248	(left 178, right 70)
Face	116	(head, not in face 29)

Method

Since 1986 one practice in the winter training at I 19 have been to learn how to warm up a cold foot. The soldier should make a short barefooted run in snow and after that warm his foot upon a companion’s chest. During the winter training 1996 this practice by coincidence lead to the detection of one previous cold injury. The soldier told that he always got a white toe after being outdoors wintertime. In the final winter exercise, “Snowstorm” March 1999 600 soldiers from the south of Sweden were examined by this method. The detected previous cold injuries were reported to the platoon commanders. Not a single new cold injury was reported from the final exercise the winter 1998-1999.

The autumn 1999, one month after their insertion, 333 soldiers at MekBrigad 19 in Boden answered an inquiry about previous cold injuries, especially in the face and on toes and fingers. In the inquiry 130 previous cold injuries of different degrees were reported. One person could report several injuries. In the late-vinter 2000, one day before they left the unit and went home, only one new minor frostnipe/frostbite were reported in the same group.

Conclusion

Two simple methods can be used for early detection of previous cold injuries on feet. One is a short exposure to cold snow and the other is an inquiry where the soldier describes his injuries, as far as he is conscious of them. The detected injuries can be compared to the answers in the inquiry. There seams to be a great correspondence between the results of the snow test and the answers in the inquiry.

Detection of previous cold injuries leads to a better adaptation of the education of the soldier as well as of the equipment. It also leads to better leadership from the officers. The officer is better aware of the special needs of management in cold environment. The responsible officer gets an honest chance to take care of the soldier, to prevent and reduce further cold injuries. And finally the reduction of new injuries reduces the cost for the Swedish Defence Force.

PRINCIPLES OF REANIMATION AFTER DEEP HYPOTHERMIA AND RESTORATION OF PHYSIOLOGICAL FUNCTIONS WITHOUT REWARMING

K. P. Ivanov

I.P.Pavlov institute of physiology, Russian Academy of Sciences, St.Petersburg, 199034, Russia

Introduction

Scientific and applied studies of the development of deep hypothermia in humans on accidents are going on for more than 100 years. Nevertheless up to now there is no sufficiently reliable scientific data on the reasons for the emergence of cold paralyses of autonomic nervous centers (respiration, thermoregulation), and also on the mechanisms of abrupt oppression and complete arrest of the heart activity. There is still no consensus about the best methods of reanimating an organism after deep hypothermia. Paton (1) contends that the reanimation of the victims of accidental hypothermia is possible only with the help of rewarming their bodies. However, rewarming the body after sea catastrophes, for example, is well known to result often in the death of an overcooled organism. The reasons of the death during rewarming are not examined adequately. Hence it is difficult to explain the danger of one or other method of rewarming. Our long-standing studies on animals and examination of published data led us to the conclusion that the result of rewarming the victim of deep hypothermia depends essentially on two factors: first, on the rate of rewarming and second, on the duration of the period of deep cooling (2). The retention of deep lung ventilation, of adequate pulse frequency, of arterial blood pressure on the level of 100-110 mm Hg allows the victim of the medium depth hypothermia to withstand rapid rewarming and restores the temperature homeostasis. The problems of the intensity of rewarming arise when the patient body temperature decreases to 28-29°C, when the respiration is depressed, the pulse is rare, and the consciousness is lost. Why do such patients often die during rewarming?

The matter is that a decrease in the temperature of a living tissue by 10°C decreases the energy consumption by the tissue by a factor of 2-3 according to van't-Hoff's coefficient. This rule is especially important for the brain, since a decrease in the energy consumption by the brain arrests its functions. We determined the consumption of O_2 by the whole brain of rats in vivo during normothermia or hypothermia. After decreasing the brain temperature from 36-37 to 20°C the O_2 consumption by the brain decreased from 58±3 to 10±2 µl/g·min, i.e. by a factor of 5. The blood flow through the brain (measured in vivo) decreased from 0.71±0.03 to 0.25±0.03 ml/g·min, i.e. by a factor of 3. The methods were described earlier **(3)**. The simplicity of the problem and also clear-cut results of the measurements make possible the data obtained on the rat brain to be used for physiological analysis of the deep brain hypothermia in various organisms, including humans. A priori during rewarming the increase in the blood supply of the brain will lag behind the process of increasing the brain tissue demands in O_2. This is the main reason of the energy exchange violations and of the human organism death on rewarming after deep hypothermia. Such a conclusion was supported by the numerical data on studying the whole organism **(2)**. The rats of 260-300 g were cooled to 15-16°C in rectum. We maintained this body temperature in them for an hour. Then the animals were rewarmed with the rate of ~0.2°C/min. During rewarming the rectum temperature (T°C), cardiac output (ml/100 g/min) (V) and oxygen consumption by the whole animal (ml/100 g/min) (Qo_2) were measured. (n=7), (M±m)

T°C	36.9±0.2	15-16	20	25	30	34
V	38.6±2.7$_{(1)}$	9.0±0.6$_{(2)}$	9.4±1.7$_{(3)}$	12.6±3$_{(4)}$.	24.4±6.1$_{(5)}$	28.1±6.1$_{(6)}$
Qo_2	1.94±0.11$_{(7)}$	0.30±0.2$_{(8)}$	0.60±0.05$_{(9)}$	1.16±0.09$_{(10)}$	2.12±0.35$_{(11)}$	1.81±0.27$_{(12)}$

$P_{w\,1-2}<0.0001$; $P_{w\,2-4}>0.1$; $P_{w\,2-5}<0.01$; $P_{w\,1-6}<0.01$; $P_{w\,7-8}<0.0001$; $P_{w\,8-10}<0.001$; $P_{w\,7-11}<0.05$.

These numbers show that during the decrease in the body temperature to 15-16°C the cardiac output decreases by a factor of 4.3 and oxygen consumption – by a factor of 6.5. On increasing the body temperature from 15-16°C to 25°C the oxygen consumption increases by a factor of 3.9 and attains almost

60% from the norm. However the cardiac output does not increase and remains on the level of 23-30% from the starting level during normothermia. On warming the animal body to 30°C the oxygen consumption exceeds the starting value by about 10%, whereas the cardiac output at this temperature is only ~60% from the starting value. We emphasize that during the period of rewarming the animal an increase in the oxygen consumption keeps ahead of an increase in cardiac output, and the organism is in the state of deep hypoxia. The most dangerous situation is at the beginning of rewarming, i.e. as the body temperature is increased from 15-16 to 25°C. By our opinion these numbers distinctly show that a rapid rewarming of deeply cooled organism is very dangerous, since the circulation apparatus of a cooled organism is not capable of sufficiently rapid increasing in its power and providing for increasing demands of an organism in oxygen. In these experiments all the animals (n=7) remained alive, because the period of cooling was relatively short (1 hour), and respiration and circulation systems still retained a sufficiently good functional state. In another series of tests (n=7) the animals had the body temperature of 15-16°C for 3 hours. Corresponding data are given below.

T°C	36.9±0.4	15-16	20	25	30	34
V	32.4±4.1$_{(1)}$	3.3±0.8$_{(2)}$	3.6±1.1$_{(3)}$	5.3±1.7$_{(4)}$	10.0±3.5$_{(5)}$	7.0±2.5$_{(6)}$
Qo_2	1.85±0.15$_{(7)}$	0.28±0.03$_{(8)}$	0.36±0.04$_{(9)}$	0.54±0.08$_{(10)}$	0.96±0.16$_{(11)}$	0.46± 0.15$_{(12)}$

$P_{w\,1\text{-}2}<0.0001$; $P_{w\,2\text{-}4}<0.05$; $P_{w\,2\text{-}4}<0.01$; $P_{w\,2\text{–}5}<0.01$; $P_{w\,5\text{–}6}<0.01$; $P_{w\,7\text{–}8}<0.0001$; $P_{w\,8\text{–}11}<0.01$; $P_{w\,11\text{–}12}<0.01$.

Thus, a more prolonged cooling for 3 h resulted in a very abrupt depression of the circulation apparatus in these animals. The heart of these animals almost lost the ability to restore the starting power of its function. An increase in the body temperature on rewarming demonstrates this dramatic situation. These figures show that on rewarming the animal body from 15-16 to 25°C the cardiac output comprised only 10-12% from the starting value. At the body temperature of 30°C the cardiac output was **16%** from the starting value and at the body temperature of 34°C the cardiac output began to decrease. In agreement with a low cardiac output the oxygen consumption (Qo_2) also had a very low level. Only at the body temperature of 30°C the oxygen consumption was restored almost to 50% from the starting level and then began to decrease. All the animals of this series died during rewarming (the rate of rewarming was 0.2°C per min).

From these experiments we can conclude that the main danger for a cooled organism during reanimation by rewarming consists in a too high rate of rewarming. Too rapid increase in the temperature of the brain tissues results in a rapid increase in the brain demands in oxygen (energy). The restoration of the functions of circulation apparatus occurs much slower. Therefore the brain cells and the whole brain cease functioning owing to the lack of energy and an organism dies. A very slow rewarming of the animals, which were in the state of deep hypothermia for 2-4 hours, allows the physiological functions to be restored providing the lungs are artificially ventilated. However, even in this case we managed to save only a part of animals from immediate death. Our thorough observations of microcirculation in the brain cortex of cooled animals in vivo show that after deep hypothermia the capillary circulation is restored slowly. Our coworker N.Melnikova showed by direct observations in vivo that a mass adhesion of leukocytes to the walls of the venulas from 5-7 to 10-12 μm in diameter occurs in the brain cortex of cooled rats at deep hypothermia. In some microvessels this results in slowing down of the blood flow, in others – their complete occlusion. Consequently, a decrease in the circulation in the brain at hypothermia depends not only on cold weakening of the heart, but also on the violation of the blood flow through the microvessels. This mechanism of the cold death has not been known. The elimination of leukocyte agglomerates in the brain microvessels is a special problem for future studies on reanimation of an overcooled organism.

There is also another important problem of restoring the functions of a deeply cooled organism. Its solution is suggested by nature. Hibernation of some species of homoiothermic organisms can be considered as a natural hypothermia. Such animals can retain the lung ventilation and circulation on cooling up to 2-4°C. The physiological rewarming and restoration of the temperature homeostasis in these animals begin from the enhancement of the lung ventilation and the increase in the frequency of the heart contractions. In such a manner they increase the flow of oxygen and energy carriers to the cooled tissues beforehand. Only after this the process of vigorous increase in the heat production in the organism starts, and the body temperature of hibernators begins to increase slowly.

A thorough study of the published data led us to the conclusion that the primary reason for the cold paralysis of respiration center and of thermoregulation center in the brain of common homoiothermic animals lays in the accumulation of calcium ions in the cytoplasm of corresponding nervous cells. The hibernators have a mechanism making possible a very low concentration of calcium ions, not higher than 10^{-8}M to be maintained in corresponding neurons **(4)**. Therefore they retain their respiration and circulation, though the temperature of their brain is close to the freezing point of water. We tried to facilitate the transfer of the excess of calcium ions from the cytoplasm of the cells into the intercellular medium and the blood in common homoiothermic animals (rats, rabbits) with the help of decreasing the content of calcium ions in the blood. The latter was achieved by introducing disodium salt of ethylenediaminetetraacetic acid (EDTA) into the blood of cooled rats. EDTA forms a complex compound with calcium ions in the blood. The procedure of these experiments was published earlier **(5,6)**. The result of introducing 0.016 mmol of EDTA into the blood of white rats, which decreased the content of Ca^{2+} in the blood by 25-30%, is shown below. T is the brain temperature, °C; F – the frequency of respiration movements; A – the amplitude of respiration movements, % from the starting value at normothermia (n=8).

Measured parameters	Starting values	Cold paralysis of respiration	In 4-7 min after the 1st injection of EDTA	In 15 min after the 2nd injection of EDTA
T	34.8±1.2(1)	17.7±0.8(2)	16.6±0.6(3)	16.2±0.3(4)
F	87±11(5)	0	21±4(6)	28±8(7)
A	100%	0	20±5%(8)	64±10%(9)

$P_{w\,1-2}<0.0001$; $P_{w\,2-3}<0.05$; $P_{w\,5-6}<0.0001$; $P_{w\,6-7}<0.05$; $P_{w\,8-9}<0.001$.

The cold paralysis of respiration center practically means the death from cold, since respiration is not restored on its own. We managed to restore the lung respiration at an absolutely deadly temperature of the brain. This is a fundamental fact from the scientific point of view. It means the widening of the lowest temperature limits of life. From the practical aspect this makes possible the respiration and thermoregulation to be stimulated before the beginning of the external rewarming and the efficiency and safety of reanimation to be increased. Such a preliminary stimulation coincides to some extent with the strategy of restoring the temperature homeostasis in hibernators. Further development of the method showed that the introduction of EDTA immediately into the lateral ventricles of the brain of cooled animals, rather than into the blood, allow a similar effect to be obtained with the dose of the reagent decreased by a factor of 60 **(7)**. However, the most important problem of restoring the physiological functions after cold paralysis of respiration and thermoregulation centers is stimulating the heart activity. It appeared that the introduction of EDTA into the blood and a decrease in the concentration of Ca^{2+} in the blood by about 25-30% does not change the character of linear decrease in the frequency and strength of the heart contractions as the animal body and myocardium are gradually cooled. The heart stops contracting after the temperature of myocardium in the thorax of the animal decreases to 12-13°C. We were able to increase substantially the cold resistance of an isolated heart of rats by decreasing the concentration of K^+ in the perfusate. The Figure shows that when the temperature of the myocardium is 20°C the content of potassium in the perfusate almost does not affect the frequency of the heart contractions. However, during further cooling of the heart the frequency of contractions decreases the slower, the lower is K^+ concentration in the perfusate. As follows from the figure, in the control experiments the isolated heart ceases to work when the myocardium temperature decreases to 12.3±0.6°C (n=12). The hearts perfused with the solution with [K^+] 3.6 mM (n=5) were arrested at the myocardium temperature of 6.7 ± 0.6°C (n = 6) and, given K^+ concentration in the perfusate 2.48 mM (n=6), the heart was arrested at the myocardium temperature of 2.2±0.4°C (n=6). The differences between the average values are statistically significant ($P_w<0.01$).

Conclusions.

The data presented touch fundamental problems of biology, since they show the possibility to decrease the lowest limit of life for homoiothermic organisms by changing the ion composition of the blood. These data make it possible also to elucidate particular biological and physiological reasons for cold paralyses of physiological functions and put forward the methods of their restoration without rewarming.

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THE METABOLIC RESPONSE OF GURKHAS TO COOLING

Phil Newton[1], Igor Mekjavic[1,2], Carol House[3], Mike Tipton[1]*

[1] Department Sport & Exercise Science, Institute of Biomedical and Biomolecular Sciences, University of Portsmouth, Hampshire, PO1 2DT, U.K
[2] Josef Stefan Institute, Ljubljana, Slovenia.
[3] Environmental Medicine Division, Institute of Naval Medicine, Gosport, Hampshire, PO12 2DL, U.K.
* Corresponding author phil.newton@port.ac.uk

Introduction

Thermoregulatory studies have predominantly been conducted on Caucasian populations; consequently, little information exists regarding the influence of ethnicity on temperature regulation. Adams and Covino(1) reported that African Americans when exposed to the cold, fail to increase heat production as soon as, or as high as Caucasians or Eskimos. One of the few studies examining ethnicity and whole body thermal responses, Glickman et al 2001 (6) compared the metabolic response of Caucasians with African Americans during immersion in water at 20°C. They found similar metabolic responses between the two groups, and a slightly greater reduction in the oesophageal temperature of African Americans.

The present investigation assessed the thermoregulatory metabolic responses of six British Army Gurkhas, 6 days before they set out on a 7-week unsupported expedition, and reassessed their physiological responses 2 days after their return. The strenuous expedition had three phases: Phase 1: completing 6 marathons in 6 days enduring the heat (38°C) of the Ascension islands; Phase 2: competing in the Devizes to Westminster canoe race; Phase 3: unsupported trans-Greenland icecap crossing in extremely cold (-35°C) conditions. The thermoregulatory responses of the Gurkhas were compared with empirical data obtained from Caucasians undertaking an equivalent protocol.

We hypothesize that the Gurkhas would have a different metabolic response to cooling than Caucasians, and pre and post expedition.

Methods

Ethical approval was obtained from the MOD(N) Personnel Research Ethical Committee. Six male Gurkhas volunteered for the study and all were deemed healthy after independent medical consultation and with a normal resting 12 lead ECG.

The physical characteristics of the group are presented in Table 1. Stature, body mass and skinfolds were measured using a stadiometer (Leighton height measure, Seca, Germany), electronic scales (3000, Seca, Germany) and callipers (John Bull, Harpenden, UK) respectively. Maximal oxygen uptake was determined on a treadmill (ELG, Woodway, Waukesha, USA) using an online metabolic cart (Vmax 29 series, Sensormedics, California, USA). The Gurkha's were compared with nine male Caucasian subjects from the original "null-zone" study by Mekjavic et al (8) (Table 1).

Table 1. Physical characteristics of the Gurkhas (GUR) and Caucasians (CAU).

GUR	*Age* *yr*	*Mass* *kg*	*Ht* *m*	*A_D* *m^2*	*VO_{2max}* *$ml..kg^{-1}.min^{-1}$*	**CAU**	*Age* *yr*	*Mass* *kg*	*Ht* *m*	*A_D* *m^2*	*VO_{2max}* *$ml..kg^{-1}.min^{-1}$*
1	27	65.0	1.62	1.68	50.7	1	31	71.5	1.76	1.87	53.0
2	25	70.0	1.63	1.77	53.4	2	32	65.2	1.78	1.83	55.1
3	23	66.5	1.64	1.74	56.8	3	30	75.0	1.83	1.95	45.7
4	26	67.6	1.67	1.74	57.1	4	27	91.5	1.95	2.25	44.3
5	23	66.8	1.68	1.78	58.1	5	30	73.5	1.77	1.90	53.6
6	21	63.5	1.67	1.69	63.2	6	30	74.0	1.85	1.97	38.7
-	-	-	-	-	-	7	24	90.0	1.90	2.18	50.6
-	-	-	-	-	-	8	25	80.5	1.85	2.04	48.9
-	-	-	-	-	-	9	25	80.0	1.90	2.08	42.5
Mean	**24.2**	**66.6**	**1.65**	**1.73**	**56.6**	**Mean**	**27.5**	**81.7**	**1.86**	**2.07**	**48.7**
SD	**2.2**	**2.2**	**0.025**	**0.04**	**4.3**	**SD**	**3.6**	**9.4**	**0.07**	**0.16**	**4.6**

The volunteers wore swimming costumes and were instrumented with a 5 lead ECG, recorded via telemetry (MIE Medical Research Ltd, Leeds, UK). All temperatures were recorded at 1-minute intervals on a data logger (Squirrel 1250, Grants Instruments Ltd, Cambridge, UK) using calibrated Grant thermistors. Rectal temperature (T_{RE}) was monitored with a rectal probe (U-VL2) self positioned 15cm beyond the anal sphincter; an insulated aural thermistor (U-VLS-0) was positioned in the left ear adjacent to the tympanic membrane. Skin thermistors (U-V52-2) were positioned on the right hand side of the body on the pectoral chest, mid-upper arm, mid-calf and mid-thigh.

Once seated on the cycle ergometer (818e, Monark, Sweden), the participants were secured with quick release straps to aid underwater cycling. An online metabolic cart (Vmax 29 series, Sensormedics, California, USA) measured oxygen consumption, in order to monitor the exercise intensity and shivering response. The mean (SD) temperature of the stirred water was 28 (0.5)°C and the volunteers were immersed on the cycle ergometer to the laryngeal prominence. Once immersed they cycled at an oxygen consumption of 2l.min^{-1} until T_{RE} rose 0.5°C above the level at which sweating was initiated, this took approximately 20 minutes. The volunteer then stopped cycling and remained seated in the water until shivering was initiated and T_{RE} fell to 36°C; this took approximately 100 minutes.

All data had a normal distribution (Kolmogorov-Smirnov Test) and were analysed using a one-way ANOVA where significance was set at $P<0.05$.

Results

The body composition (mass, % body fat), thermal (T_{RE}, T_{SK}) and metabolic ($\dot{V}O_2$) variables of the Gurkhas did not differ significantly pre and post expedition (see Figure 1 for T_{RE} data). During the expedition, two Gurkhas suffered frostbite. The Gurkhas had significantly lower age, mass, height and body surface area (A_D determined from DuBois and DuBois[5]), but higher $\dot{V}O_{2MAX}$ than the Caucasians. (Table 1)

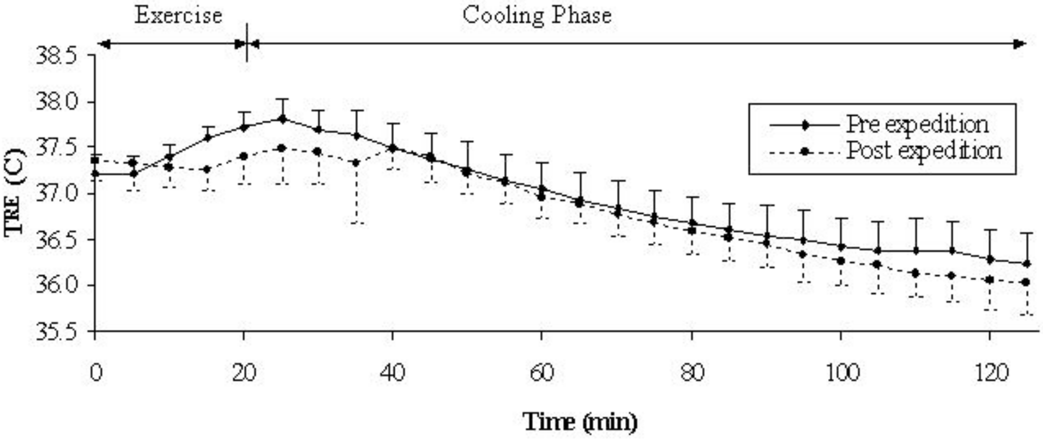

Figure 1: Pre and Post expedition deep body temperatures during the exercise (0-20min) and the static (20-120min) cooling phase. Mean, (SD) (n=6)

The oxygen consumption of 2 l.min^{-1} during exercise fell rapidly upon transition to the static cooling phase and reached a plateau in all volunteers by 25minutes. At this time point T_{RE} had returned to pre exercise values and the metabolic rate at this time was taken as the baseline. This was 0.33(0.034) and 0.32(0.089) l.min^{-1} pre and post expedition respectively. The pre-immersion baseline value for Caucasians was 0.46 (0.09) l.min^{-1}.

The onset of shivering (OS) was defined as a 25% increase in $\dot{V}O_2$ above baseline. The T_{RE} of the nine Caucasians studied by Mekjavic et al[7] fell between 37°C and 36.5°C at a rate of 0.019°C.min^{-1} and averaged 36.8 (0.4)°C at OS. The corresponding data for the Gurkhas in the present study was 0.017°C.min^{-1} and 36.5 (0.4)°C for OS. The increase in $\dot{V}O_2$ as a result of a 1°C drop in T_{RE} (sensitivity of the metabolic response) in Caucasians was approximately 255ml.min^{-1} compared with 134ml.min^{-1} in the Gurkhas (Fig. 2) When expressed relative to body mass, Caucasians increased by 3.12 ml.kg.min^{-1} and the Gurkhas increased by 2.01ml.kg.min^{-1}

Discussion

This investigation examined the shivering response in six male Gurkhas and compared this response with published data obtained from nine Caucasian subjects. The Gurkhas were also studied before and after a strenuous expedition. The results show that there was no significant difference in the variables measured pre and post expedition. Given the close proximity of the pre and post measures to the expedition, this finding suggests that the expedition had little impact on the physiology of the Gurkhas.

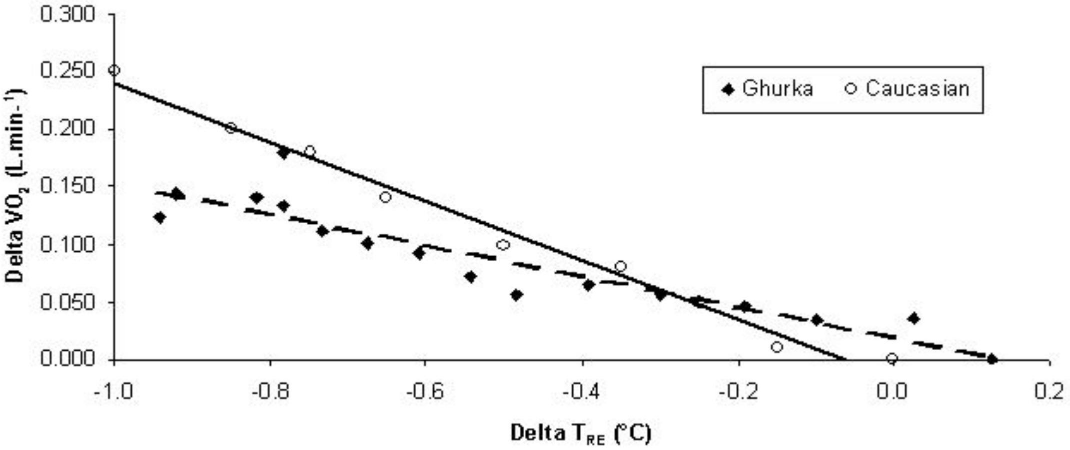

Figure 2. Change in thermoregulatory VO2 with change in Tre (Ghu n=6; Cau n=9).

The Gurkhas had both a similar rectal temperature for the initiation of thermoregulatory metabolism and a similar rate of fall in rectal temperature as the Caucasians. However, once initiated, the sensitivity of the Gurkhas metabolic response was lower as shown in figure 2. The differences in shivering sensitivity between Caucasians and Gurkhas could be due to differences in fitness, cold acclimatisation or ethnicity. Both fitness and cold acclimatisation have been reported to lower the body temperature threshold for the onset of shivering (SO) (2,3,4). However, despite having higher maximal oxygen consumptions and being born and raised in a cold environment, the shivering onset of the Gurkhas was the same as the Caucasians. However, once initiated, the shivering response of the Gurkhas did appear to be less sensitive than that of the Caucasians. Again, this is not typical of the response reported for cold acclimatised individuals, in whom the threshold for the onset of shivering is reduced but the sensitivity remains the same (3,7). We are left with the possibility that the differences in the shivering response of the Gurkhas and that of Caucasians are due to ethnicity.

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WET CLOTHING INCREASES SURFACE HEAT LOSS WITH LOW INSULATION BUT NOT HIGH INSULATION

Thea Pretorius[1] *and Gordon Giesbrecht*[1]*

[1] Laboratory for Exercise and Environmental Medicine, University of Manitoba, Winnipeg, Canada
* corresponding author giesbrec@ms.umanitoba.ca

Introduction

Guidelines for the primary field management of cold wet victims usually recommend removal of wet clothing prior to placing the victim in an insulated, vapor-barrier cocoon. Removal of wet clothing is advised in order to minimize heat loss.[1-3] This advice may be contraindicated in some conditions however. If the patient is severely hypothermic, the act of clothing removal presents a theoretical risk of ventricular fibrillation caused by mechanical stimuli to the cold heart.[4-7]

The insulation value of clothing decreases substantially when it is wet, allowing more heat loss through evaporation, conduction, and convection. [8-10] Thus when the cold patient is encapsulated within low-to-moderate insulation, the decreased insulation of the wet clothing layer would cause increased heat loss. However, if external insulation values were high enough (i.e., approaching infinity), the relative amount of insulation attributed to the clothing would be minimal and it should not matter whether the clothing is wet or not.

The purpose of this study was to confirm that wet clothing increases surface heat loss when low insulation and a vapor barrier are used, and that high insulation eliminates this effect of wet clothing.

Methods

Six volunteer subjects (one female) were studied on four separate occasions at least 24 hours apart but at the same time each day to control for circadian effects. Subjects were insulated and, after 10 minutes of baseline measurements, were placed in a climatic chamber at –20 °C for 60 minutes. In two trials, the subjects were placed in low insulation with clothing either dry or wet (LoDry and LoWet). In the other two trials, the subjects were placed in high insulation with clothing either dry or wet (HiDry and HiWet). The order of conditions for each subject was randomly assigned to achieve a balanced design.

Core temperature was measured by a thermocouple inserted into the aural canal as close to the tympanic membrane as possible (T_{ac}). Heavy ear muffs were worn to prevent thermal contamination of the aural canal from the environment. Single-channel electrocardiogram and heart rate were also monitored for the duration of each trial.

Cutaneous heat flux ($W \cdot m^{-2}$) and skin temperature (°C) were measured from 13 sites using thermal flux transducers (Concept Engineering, Old Saybrook, CT) according to our standard procedures [11].

Oxygen consumption ($\dot{V}O_2$) and the respiratory exchange ratio (RER) were measured with an open-circuit method from measurements of expired minute volume and inspired and mixed expired gas concentrations sampled from a mixing box (V_{max} 229 by Sensormedics).

Clothing consisted of a fleece suit and wool socks and was either dry or wet. In wet conditions clothing was wetted and contained 3 kg of 20°C water (based on change in weight), which was evenly distributed. After instrumentation the subjects laid down on a thin plastic vapor barrier and insulation system. The low insulation consisted of a 3-season Hollofil II sleeping bag (wt. of 2 kg.). In the high insulation condition, the 3-season sleeping bag was placed within a winter-weight down sleeping bag (750+ fill; total wt. of 1.85 kg) and an emergency rescue bag containing Thinsulate insulation (wt. of 4.75 kg).

During all baseline periods, subjects were wrapped in the vapor barrier and the 3 season-sleeping bag. In the high insulation conditions, the outer down and rescue bags were zipped up just prior to entry into the cold chamber; this delay prevented overheating during baseline measurements. The subjects were then wheeled into the environmental chamber (ambient temperature of - 20°C) where they remained for 60 minutes.

Results

Aural canal temperature did not change throughout the experiment and there was no significant difference between the conditions.

During baseline, heat loss was greater in the wet conditions than dry ($p<0.001$) with no difference between insulation conditions. Exposure to the cold chamber did not affect heat loss in either dry condition, however heat loss decreased with high insulation ($p=0.01$). Heat loss decreased with time in both wet conditions ($p<0.001$); reaching a steady state loss of ~80 W/m^2 with low insulation, which was greater than the ~45 W/m^2 with high insulation ($p<0.001$). Once steady state conditions were reached, wet clothing increased heat loss in the low insulation conditions by 38% (22 W/m^2) ($p<0.001$). However, this difference was eliminated in the high insulation conditions.

Heat production was unchanged throughout cold exposure and there were no differences between conditions, except in the final 10 minutes when heat production was slightly, but significantly, lower in the high insulation-wet condition than the low insulation-wet and high insulation-dry conditions ($p<0.01$).

Discussion

Wet clothing increased heat loss by 38% in the low insulation conditions while this effect of wetness was eliminated by high insulation.

Body surface heat loss is dependent on the temperature differential between the skin and the surrounding air, and the insulative barrier to heat loss [8]. The insulation value of the vapor barrier is minimal, however it does eliminate evaporative heat loss from the body and prevents the outer insulation layers from becoming wet and losing some of their insulation value [10].

There was no evidence of an increase in metabolic heat production as a result of shivering or non-shivering thermogenesis in any condition. Increased heat production prevents or attenuates the decrease in core temperature during significant cold stress [12-15]. However, shivering also increases surface heat loss due to the movement caused by shivering, and the increased blood flow to the shivering muscles [13]. Qualitatively similar effects of wet clothing would be expected if the study were conducted on shivering hypothermic subjects, however, it is difficult to predict the magnitude of these differences.

In a mildly hypothermic vigorously shivering patient, there is less danger of initiating ventricular fibrillation from the mechanical stimulation of removing and/or replacing wet clothing [4, 5, 7]. Thus, wet clothing should be removed once the victim is relatively sheltered from ambient cold. Alternatively, a severely hypothermic non-shivering patient is at much higher risk of ventricular fibrillation [7, 15]. In this case, a long-term increase in surface heat loss could significantly affect core temperature. Action must be taken that minimizes both heat loss and the risk of stimulating ventricular fibrillation. Thus, care should be taken when cutting off clothing.

Conclusions

Since it is unlikely that the high insulation values attained in this study, could be attained in the field, the advice to cut off wet clothing (while focusing on gentle treatment of the patient) should be continued.

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ASSESSMENT OF SLIP RESISTANCE OF FOOTWEAR WITH A ROBOT MANIPULATOR

Bogomir Vrhovec[1], Bojan Nemec[1], Ales Jurca[2] and Igor B. Mekjavic[1]*

[1]Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute,
Jamova 39, SI-1000 Ljubljana, Slovenia;
[2]UCS Sistemi d.o.o., Dobracevska ulica 53, SI-4226 Ziri, Slovenia.
*corresponding author: miro.vrhovec@ijs.si

Introduction

Prevention of slip and fall accidents in the home and in public facilities is achieved primarily by appropriately designing the walking surfaces. For field and industrial environments, minimising the risk of slip and fall accidents can only be achieved by designing appropriate soles for footwear. There is, as yet, no conformity in the manner slip resistance is evaluated (1). We describe a device, which enables the objective measurement of slip resistance of footwear on a variety of surfaces. The device measures the coefficient of friction (COF), defined as the ratio between the horizontal force resisting slip, and the vertical force. With this device, we were able to rank five commercially available hiking boots on the basis of slip resistance.

Methods

A three stage Cartesian manipulator was modified to enable the assessment of slip resistance of footwear (Fig. 1). The manipulator is capable of exerting a force of 600 N. Movement along the various axes is achieved with servomotors. The action of the manipulator can be programmed by dedicated software.

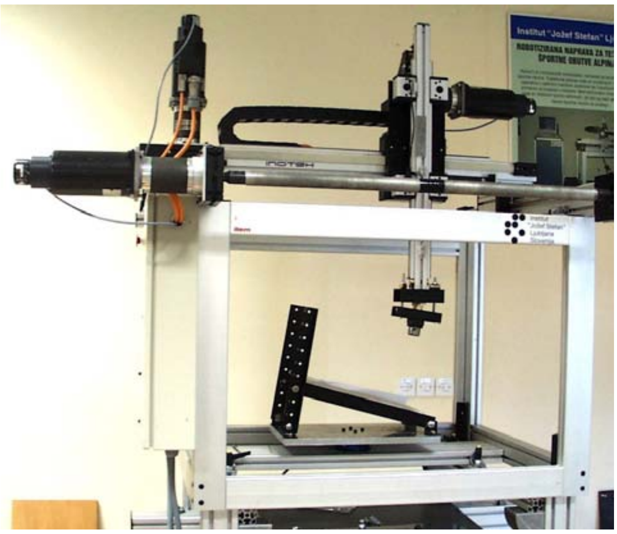

Figure 1: Three stage Cartesian manipulator

Test footwear is donned on a size 42 foot prosthesis, mounted on the last stage of the manipulator. The upper portion of the foot prosthesis is made of epoxy, and the lower part of silicone rubber (Fig. 2). The latter allows for optimal fit, and a better simulation of weight distribution over the weight-bearing surface.

The adjustable frame below the manipulator allows the assessment of slip resistance of footwear for different surface angles, as well as different surface materials (Fig. 3). As can be seen from Fig. 3, different types of surface materials can be placed in the frame, and the angle of the surface also adjusted over a wide range.

The protocol for the assessment of slip resistance requires that the manipulator exerts a vertical force of 200N on the test surface, while simultaneously moving the prosthesis horizontally (forward and backward) at a speed of 10mm.s^{-1}. During the test, force is measured with a 6 axial force transducer.

Figure 2: Foot prosthesis

Slip resistance of test footwear was conducted on dry wooden, rubber and marble surfaces, at surface angles of 0°, 5°, and 10°, both during forward (Fig. 3) and backward (Fig. 4) movement.

Ambient temperature during the tests was maintained at 26°C.

Figure 3: Test of slip resistance of a hiking boot during forward movement, at different surface angles (0^0, 5^0 and 10^0).

Figure 4: Test of slip resistance of a hiking boot during backward movement, at surface angles of 0^0 and 5^0.

Results

We evaluated the slip resistance of 5 prototype hiking boots manufactured by Alpina d.d. (Ziri, Slovenia). The coefficient of friction for the 5 boots was determined for 4 surface angles and 4 materials (Table 1).

	0L	0G	0H	0P	1L	1G	1H	1P	2L	2G	2H	2P	3L	3G	3H	3P	AVG	MAX	MIN
1	0,75	0,99	0,82	0,84	0,62	0,83	0,68	0,72	0,58	0,76	0,56	0,57	0,39	0,60	0,40	0,44	0,66	0,99	0,39
2	0,47	0,97	0,70	0,62	0,60	0,70	0,62	0,41	0,33	0,61	0,47	0,41	0,37	0,60	0,40	0,28	0,54	0,97	0,28
3	0,74	0,99	0,81	0,90	0,58	0,76	0,72	0,65	0,53	0,75	0,56	0,67	0,37	0,67			0,69	0,99	0,37
4	0,88	1,00	0,87	1,00	0,51	0,86	0,73	0,78	0,61	0,76	0,57	0,69	0,52	0,63	0,49	0,55	0,71	1,00	0,49
5	0,45	0,85	0,68	0,54	0,55	0,83	0,58	0,35	0,29	0,72	0,42	0,24	0,24	0,52	0,30	0,15	0,48	0,85	0,15

Table 1: The friction coefficient for different surface angles (0°, 5°, 10°, and 15°) and surface materials (wood, rubber, marble and polished marble).

As evident from Table 4, boot no. 4 had the best slip resistance of the boots tested.

Conclusions

The developed slip resistance test device allows accurate measurement of the coefficient of friction. By placing the device in a climatic chamber, slip resistance on different surfaces can be assessed over a range of ambient temperatures.

Acknowledgements

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EVALUATION OF HYPERBARIC BAGS FOR THE TREATMENT OF ACUTE MOUNTAIN SICKNESS

Igor B. Mekjavic[1], Petra Golja[2], Tomaz Klinar[3], Jurij Gorjanc[4], Polona Jaki Mekjavic[5] and Ola Eiken[6]*

[1]Department of Automation, Biocybernetics and Robotics, Jozef Stefan Insititute,
Jamova 39, SI-1000 Ljubljana, Slovenia;
[2]Polytechnic Nova Gorica, Kostanjeviska cesta 16, Pristava, SI-5000 Nova Gorica, Slovenia;
[3]Department of Surgery, Slovenj Gradec General Hospital, Slovenj Gradec, Slovenia;
[4]Eye Clinic, Clinical Centre Ljubljana, SI-1000 Ljubljana, Slovenia;
[5]Local Health Centre Domzale, Mestni trg 2, SI-1230 Domzale, Slovenia;
[6]Swedish Defence Research Agency, Karolinska Institutet, Berzelius v. 13, S-17177 Stockholm, Sweden
*Corresponding author: igor.mekjavic@ijs.si

Introduction

Hyperbaric bags are used for the emergency field treatment of Acute Mountain Sickness (AMS). Victims of AMS are placed inside the bag and the pressure inside the bag increased with a foot pump. The increasing pressure inside the hyperbaric bag simulates descent to lower altitudes. Once inflated to the desired pressure, pumping must be continued to replenish the air within the hyperbaric bag. A pressure relief valve ensures that the internal pressure remains constant during continuous pumping. The life support system must therefore be designed to offer adequate ventilation of the internal environment, so as to maintain PCO_2 within specified limits (Mekjavic and Morariu, 1991).

The aim of the present study was to evaluate the accumulation of carbon dioxide in two types of hyperbaric bags during simulated treatments. Specifically, we assessed whether the pump-stroke frequency recommended by the manufacturers is sufficient to maintain CO_2 concentration below levels recommended for life support systems.

Methods

We simulated hyperbaric therapy using the Gamow (Chinook Medical Gear, Durango, CO, USA) and Certec (Sourcieux-les-Mines, 69210 L'Arbresle, France) bags. A 75 kg patient's volume was simulated by placing canisters totalling approx. 75 liters in the bag. Expired CO_2 was simulated by adjusting a flow (VCO_2) of 0.3 $L.min^{-1}$ from a CO_2 gas cylinder, which was also placed inside the bag.

The CO_2 concentration inside the bag was measured with a portable CO_2 analyzer (Minigas 01-14, Conrad Elektronik, Germany) located at the site of the head. CO_2 inside the bags was measured at minute intervals. During the simulated treatment, the bags were inflated by 15 strokes per minute (Gamow) and 8 strokes per minute (Certec). The inflation rate was similar for both bags, as the Certec pump has a dual action mechanism.

The Certec bag was also evaluated during field treatment of a climber afflicted with AMS. The climber was a member of a Slovenian Himalayan expedition to Shisha Pangme. He received two treatments with the hyperbaric bag, conducted at base camp at an altitude of 5200m. During the treamtents, CO_2 concentration within the bag was monitored with the same portable CO_2 analyser as in the laboratory evaluation.

Results

Laboratory evaluation

Figure 1 indicates a gradual increase in CO_2 levels inside both bags, attaining equilibrium levels, 2% for the Gamow bag and 2.75% for the Certec bag, by the end of the simulated one hour treatment.

Field evaluation

Two treatments were conducted on the same day (the interval between the treatments was 3 hours), each of one hour duration. During the first treatment, the pressure within the bag was maintained at 220 mbar above the ambient pressure. By the end of the treatment, the CO_2 concentration within the bag reached 2.8%. Upon completion of the treatment, the personnel attending the patient noted that the overpressure valves were blocked by blankets placed inside the bag. This reduced the ventilation of the hyperbaric bag, and consequently caused the substantial increase in CO_2 concentration inside the bag. During the second therapy, the over pressure valves functioned properly. As a result, it was not possible to attain a bag pressure of 220 mbar, as in the first treatment. Also, maintenance of a bag pressure of 200 mbar required substantially more effort on the part of the rescuer maintaining the inflation rate. The CO_2 concentration increased to 2.3% upon completion of the 1 hour treatment.

The field treatment successfully eliminated the symptoms of AMS.

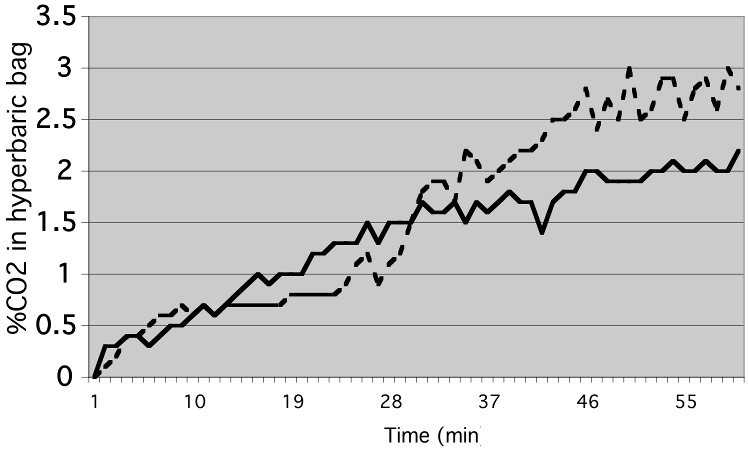

Figure 1: CO_2 accumulation in the Gamow (solid line) and Certec (dashed line) hyperbaric bags tested.

Conclusions

There are no standards regarding the maximum allowable CO_2 levels specifically for hyperbaric bags for treatment of AMS. Considering that a hyperbaric bag is a life support system, then its opreation should conform to the standards for such systems. For manned submersibles, as an example, it is expected that PCO_2 during normal operations will not exceed 0.005 ATA (American Bureau of Shipping, 1990; Germanischer Lloyd, 1987; Lloyd's Register of Shipping, 1987; Norske Veritas, 1982; Norwegian Petroleum Directorate, 1990). In exceptional situations, where survival is in question, life-support systems should maintain PCO_2 below 0.02 (Germanicher Lloyd, 1987) or 0.015 (American Bureau of Shipping, 1987). The results of the present laboratory and field evaluations indicate that the limits of PCO_2 for exceptional survival scenarios (0.02 ATA) are exceeded during a one hour treatment. Thus, the pumping frequency recommended by manufacturers is not adequate. The discrepancy between manufacturers' recommendations and our results may occur, if the volume of a patient is omitted in the determination of CO_2 accumulation. Our results suggest that higher frequency of pump strokes should be used during treatment. The energy demand of such action on the the rescuer should also be investigated. Namely, the work capacity of an individual is limited at altitude, and a higher pump frequency may not be sustainable for the duration of a one hour treatment at all altitudes. A further consideration might also be to include a CO_2 scrubber in the bag, which would be capable of maintaining PCO_2 within appropriate limits (Mekjavic et al., 1992).

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USE OF SKIN TEMPERATURE TO MEASURE MUSCLE TEMPERATURE

Brajkovic, D. [1]*, *Ducharme, M.B.* [1,2], *Webb, P.* [3], *Kenny, G.P.* [2], *and Reardon, F.D.* [2]

[1] DRDC Toronto, Human Protection and Performance Group, Toronto, Ontario, Canada
[2] School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada
[3] Consultant, 370 Orton Road, Yellow Springs, Ohio, USA
* corresponding author: dragan.brajkovic@drdc-rddc.gc.ca

Introduction

Zero-heat-flow probes provide a non-invasive means of measuring core temperature (1-3). A typical ZHF probe has two thermistors separated by an insulating material and an electrical heater positioned at the top of the probe. The temperatures of the two thermistors are compared by a differential amplifier. The error signal is used to control the heater so that there is no temperature gradient across the insulating layer and thus ZHF status is achieved. The ZHF method is based on the principle that heat will flow from the core to the skin surface as long as a temperature gradient exists. If the surface is perfectly insulated, then the temperature gradient between the core and skin will continue to get smaller with time, and as a result, the amount of heat flowing to the surface will decrease and the skin temperature immediately under the insulated area will continue to increase. Eventually, the skin temperature under the ZHF probe will reach the temperature of the warmest region under the insulation. The temperature of the insulated skin alone has been used as an indicator of the core temperature when the ZHF probe is placed on the occipital region of the forehead or the sternum (1-3).

In the past, the ZHF method has been evaluated as a method to estimate bicep muscle temperature between skin and core temperature (1). The study found that a ZHF probe placed on the surface of the bicep closely tracked (0.1±0.08℃ lower on average) the timeline response of intramuscular temperature. Hence, the investigators concluded that the ZHF method may be a practical method of measuring muscle temperature non-invasively during rest and isometric exercise conditions.

However, a more recent study (4) found that the ZHF probe does not provide a correct absolute measurement of thigh muscle temperature up to 2 cm below the skin surface because the probe heats the muscle tissue in the process of measuring muscle temperature.

The present study examined the effect of using the ZHF approach, but without the active heating (using a passive insulation disk) to indirectly measure the intermediate tissue temperature of the thigh during rest in a thermoneutral (28ºC) ambient environment. Unlike Togawa et al.'s (1) study which measured tissue temperature to a depth of 1 cm below the skin, the present study measured tissue temperature up to 2.8±0.2 cm below the skin. Insulation disks were placed on the skin and the skin temperature under each disk was used to estimate muscle temperature below the disk. The working hypothesis was that the insulated skin under each disk would increase to some unknown steady state temperature which could be determined by comparing the steady state skin temperature under the disk with the actual muscle temperatures measured by a control probe which directly measured tissue temperature 0.8±0.2 cm, 1.3±0.2 cm, 1.8±0.2 cm, 2.3±0.2 cm, and 2.8±0.2 cm below the skin surface. Therefore, the temperature of the insulated skin alone could be used as an indicator of the muscle temperature at a specific depth below the skin.

Methods

Eight male subjects with the following characteristics were recruited (mean±SD): age 30.5±5.7 years old, height 177±0.03 cm, weight 80.4±14.0 kg, body surface area 1.97±0.14 m^2, body fat 13.7±3.4 %, and lateral thigh skin and subcutaneous fat thickness of 4.9±1.4 mm. The experimental protocol was approved by the DRDC Toronto Human Research Ethics Committee. Skinfold measurements of the lateral thigh were done 15 cm superior to the patella using skinfold calipers.

The subject arrived to the laboratory at 08:00 h and inserted a rectal probe 15 cm beyond the anal sphincter. Rectal temperature was measured via a thermistor (Pharmaseal 400 series, Baxter, Valencia, CA, USA). The subject then lay down on a stretcher. A sterile control multicouple muscle temperature probe (CMTP) (5) was inserted into the *vastus lateralis* muscle to a depth of 2.5 cm and at a distance of 20.5 cm superior to the patella (see Fig. 1). Prior to insertion, the skin was anaesthetized with 2%

lidocaine (without epinephrine) (2.0 ml). The CMTP was then inserted into the muscle through the lumen of a sterilized 18 gauge needle (inserted ~ 3 cm into the thigh) and then the needle was withdrawn.

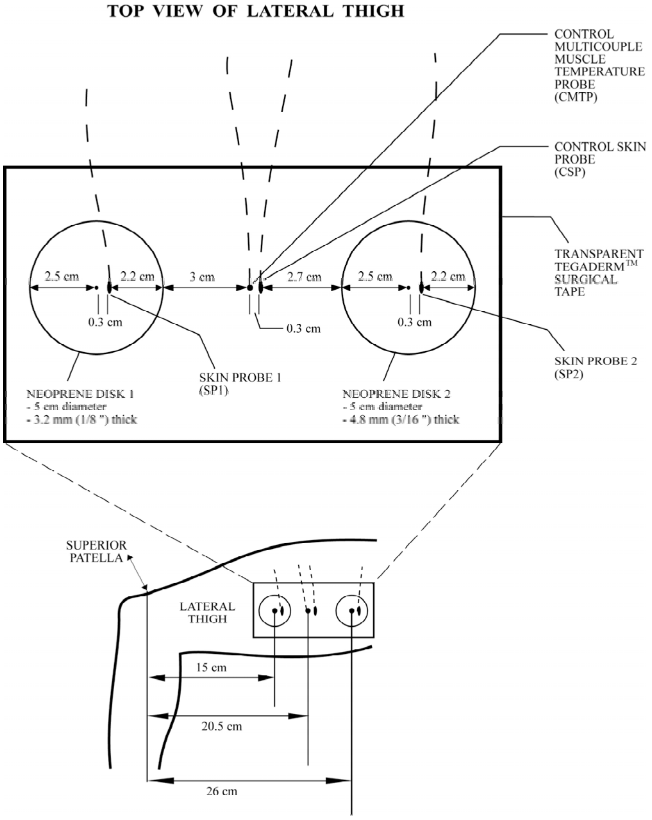

Figure 1. Placement of CMTP, SP1, SP2, and neoprene foam insulation disks on the lateral thigh.

The objective was to insert the probe to a depth of 2.5 cm below the skin, however, the probe was unintentionally pushed slightly deeper (range of 2.6 to 3.0 cm) when Tegaderm™ surgical tape (3M Medical, St. Paul, MN) was applied over the CMTP to hold it in place against the thigh. The probe contained a thermocouple junction at the tip and 0.5 cm, 1 cm, 1.5 cm, 2 cm, and 2.5 cm from the tip. However, because the probes were on average inserted 0.3±0.2 cm beyond the planned 2.5 cm depth, the thermocouple junctions therefore actually measured tissue temperature 0.8±0.2 cm, 1.3±0.2 cm, 1.8±0.2 cm, 2.3±0.2 cm, and 2.8±0.2 cm below skin surface. The Tegaderm™ prevented the CMTP from sliding out of the puncture site. The same piece of Tegaderm™ tape was used to hold three skin thermistors in place on the left lateral thigh. The skin thermistors were located 15.3 cm (Skin Probe 1, designated as SP1), 20.8 cm (Control Skin Probe, designated as CSP), and 26.3 cm (Skin Probe 2, designated as SP2) superior to the patella. A piece of Transpore™ surgical tape was then applied over each sensor and across the thigh to ensure that the CMTP and three skin probes would not come out. After the CMTP and skin probes were in place, the subject entered a climatic chamber (28±1°C air, R.H. 30±5%) and sat in a chair for 180 min. A t-shirt, shorts, socks, and running shoes were worn during the entire exposure. During the first 60 min inside the climatic chamber, SP1 and SP2 were not covered by the neoprene insulation disks. This 60 min period was used as a control period to compare the thigh skin temperatures without being disturbed by the disks. Open cell neoprene foam was chosen as insulating material for the disk because it is a flexible insulating material which conformed well to the curved shape of the body. After 60 min in the climatic chamber, neoprene insulation disk 1 (3.2 mm thick) and disk 2 (4.8 mm thick) were placed directly on top of SP1 and SP2, respectively. Each disk was 5 cm in diameter. The CSP and CMTP were left uncovered for the entire 180 min exposure. Disks 1 and 2 covered SP1 and SP2, respectively, from time 60 to 180 min.

The data from CMTP, SP1, SP2, and CSP were stored every minute using a 75000 Hewlett Packard data acquisition system. The data were analyzed using a repeated measures two-way ANOVA with "insulation disk thickness" and "time" as the independent variables which were used to compare SP1, SP2, and CSP from time 0 to 180 min. A p value (using a Greenhouse Geiser correction) of < 0.05 was considered significant. A Newman-Keuls post-hoc test was used to determine the time at which there was a significant difference between SP1, SP2, and CSP.

Results

Two subjects did not complete the full three-hour session inside the climatic chamber. As a result, there was significant step change in the SP1 and SP2 data at time 120 min. In addition, the ΔT in SP1 and SP2 after time 120 min was very small (only a 0.13ºC and 0.20ºC increase, respectively, by time 180 min). The SP1 and SP2 values at time 120 min were 88% and 87%, respectively, of the final skin temperatures observed at time 180 min. Therefore, the focus of the data reported was from time 0 to 120 min.

On average, SP1, SP2, and CSP remained stable at 32.76±0.27ºC, 32.60±0.25ºC, and 32.67±0.27ºC for the first hour when all three probes were left uncovered. There were no significant differences in skin temperature between the three probes during the first hour. At time 60 min, Disks 1 and 2 were placed on top of SP1 and SP2, respectively. This resulted in a significant increase in SP1 from 32.76±0.27ºC to 33.67±0.20ºC (increase of 1.08±0.20ºC) from time 60 to 120 min. In addition, there was a significant increase in SP2 from 32.44±0.25ºC to 33.94±0.23ºC (increase of 1.50±0.23ºC) from time 60 to 120 min. The CSP continued to remain stable after time 60 min. The mean CSP temperature from time 0 to 120 min was 32.64±0.23ºC. Both SP1 and SP2 were significantly greater than CSP after 65 min, and SP2 was significantly greater than SP1 after 90 min.

Thigh muscle temperature remained stable at all depths from time 0 to 120 min. The muscle temperatures at depths of 0.8±0.2 cm, 1.3±0.2 cm, 1.8±0.2 cm, 2.3±0.2 cm, and 2.8±0.2 cm were 33.56±0.26ºC, 33.83±0.25ºC, 34.13±0.23ºC, 34.27±0.21ºC, and 34.47±0.20ºC, respectively. The SP1 temperature corresponded to the CMTP temperature at a depth of 0.8±0.2 cm after the 3.8 mm disk had been on the skin for at least 15 min. The SP2 temperature corresponded to the CMTP temperature at a depth of 1.3±0.2 cm after the 4.8 mm disk had been on the skin for at least 20 min. After 15 and 20 min, the SP1 and SP2 temperatures were 0.05±0.14℃ and 0.09±0.15℃ lower, respectively, than the actual muscle temperature measured by the CMTP at a depth of 0.8±0.2 cm and 1.3±0.2 cm.

Discussion

This study found that the skin temperature under a foam neoprene insulated disk can be used as an indicator of the muscle temperature at a certain depth underneath the surface of the skin under steady state resting conditions. In the present study, the diameter of the disk was kept constant (5 cm or 1.97") and the disk thickness was varied to alter the simulated depth of measurement. However, the insulative properties of the disk as well as the diameter of the disk could also be modified to change the depth of the muscle tissue measurement.

The principle of using insulation disks to non-invasively measure muscle temperature may also be useful in other ambient environments and during experimental conditions where subjects are exercising, however, more research is needed to address the usefulness of this principal during such conditions.

One key difference between Togawa et al's (1) study and the present study, was the use of a passive insulation disk (with no built-in heating element) in the present study. Togawa et al. (1) used a typical ZHF probe in which the error signal from the ZHF probe amplifier was used to control the heater so that there was no temperature gradient across the insulating layer and thus ZHF status was achieved. It is speculated that after the probe stabilized, the skin temperature underneath the ZHF probe reached the temperature of the warmest region under the insulation (e.g., near the humeral bone, if placed on the bicep). This speculation is based on past research which found that placing the ZHF probe on the occipital region of the forehead or the sternum provides body core measurements which are similar to rectal (1-3). Therefore, using the same principal of measurement it was speculated that the ZHF probe would measure the core of the thigh, if placed on the surface of the thigh. In the present study, the passive neoprene insulating disks used did not result in a ZHF state across the disk, but as a result the skin temperature underneath the probe reached a more intermediate temperature within the muscle tissue. The intermediate temperature reached being dependent on the thickness, diameter, and insulation properties of the disk.

Conclusions

The steady state temperature of the skin under 3.2 mm and 4.8 mm insulation disks which are placed on the skin for at least 15 and 20 min, respectively, may be used to estimate muscle temperature 0.8±0.2 cm and 1.3±0.2 cm, respectively, below the skin.

Acknowledgements

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COMPARISON OF TELEMETRY PILL AND RECTAL MEASUREMENT OF DEEP-BODY TEMPERATURE DURING TREADMILL WALKING AND RUNNING IN THE HEAT

A S Weller and W R Withey*

QinetiQ, Centre for Human Sciences, Cody Technology Park, Ively Road, Farnborough, GU14 0LX, UK
* corresponding author asweller@QinetiQ.com

Introduction

The accurate measurement of deep-body (core) temperature is fundamental for studying human temperature regulation and for purposes relating to clinical safety. Oesophageal temperature (T_{oe}) is regarded as the "gold standard" index of core temperature (1). Rectal temperature (T_{re}) responds more slowly than T_{oe} and gives slightly higher values, but is regarded as a suitable index of core temperature during continuous exercise (i.e. when metabolic rate is kept constant) (1). However, the invasive nature of both methods (particularly oesophageal) and the requirement for a wire connection between the sensor and logger unit make them unsuitable for ambulatory, unrestrained individuals. Consequently, telemetry-monitoring systems using ingestible temperature sensors (radio-pills) are attractive for field applications, given that they are less obtrusive and more comfortable than thermistors. In terms of the validation of such systems, previous studies have compared T_{re} (2), and both T_{re} and T_{oe} (3, 4) with radio-pill temperature (T_{pill}). Sparling *et al.* (2) found that T_{pill} was consistently lower than T_{re} (by up to 0.8 °C) during 30-90 minutes of progressive cycle exercise. Kolka *et al.* (3) reported that T_{pill} and T_{oe} were both lower than T_{re} during sustained exercise at ~40% of peak oxygen uptake (VO_2peak). However, O'Brien *et al.* (4) reported good agreement between T_{pill} and T_{re} during warm water exercise, although both T_{pill} and T_{re} exceeded T_{oe}. To provide further information on the suitability of the radio-pill system, T_{re} and T_{pill} data from two recent studies in our laboratory involving treadmill walking and running exercise in the heat, were compared.

Methods

Study 1: In a treadmill walking study, twelve men (age, 27.3 (1 SD, 5.8) y; body mass (BM), 79.1 (11.3) kg; VO_2peak, 52.8 (7.1) ml·min^{-1}·kg^{-1}) undertook 120 minutes of exercise (speed, 5.5 km·h^{-1}; incline, 5%; metabolic rate (M), 290 (24) W·m^{-2}; ~40% VO_2peak) in a hot chamber on up to three occasions (Heat Tests (HT) 1-3). During HT1&2, the thermal environment was hot (dry-bulb temperature (T_{db}), 35°C) and dry (relative humidity (rh), 20%), whereas during HT3 it was warm (T_{db}, 26°C) and humid (rh, 88%). Subjects wore leather boots and lightweight combat clothing (intrinsic thermal insulation, 0.66 clo; Woodcock moisture vapour permeability index, 0.55). Study 2: In a treadmill running study, ten men (age, 32.7 (5.7) y; BM, 73.4 (11.3) kg; VO_2peak, 53.9 (3.8) ml·min^{-1}·kg^{-1}) exercised at 65% of VO_2peak (M, 470 (47) W·m^{-2}) for up to 90 minutes on two occasions in a hot chamber; once wearing and the other not wearing an ice cap. During both Heat Tests, the thermal environment was hot (T_{db}, 36°C) and dry (rh, 24%), and the subjects wore sports shoes, socks, shorts and a t-shirt. The subjects exercised for the scheduled 90 minutes or until a withdrawal criterion had been reached (rectal temperature (T_{re}), 39.5°C; heart rate (HR), 95% of peak HR; or the subject requested to stop).

During both studies, core temperature was measured every minute before (Pre) and during the Heat Tests by a rectal thermistor (T_{re}) and by an ingestible temperature radio-pill telemetry system (T_{pill}). The radio-pill system consisted of a commercially available radio-pill individually calibrated by the manufacturer (CorTemp 2000, Human Technologies, Inc.), and a compact data logger. The radio-pill was consumed just before retiring the night before each trial (~12-18 h prior to each Heat Test). HR was also measured every minute, and an expired gas sample was collected at 10 minutes for the determination of M. The subjects were encouraged to drink at least 12 ml·kg(BM)$^{-1}$·h^{-1} of water during all Heat Tests.

The T_{re} and T_{pill} data (at 5-minute time points) were compared by analysis of variance with repeated measures (ANOVA). When a significant core temperature site (SITE) main effect or SITE-time interaction was identified by ANOVA ($P<0.05$), paired t-tests were used for *post hoc* comparison. For goodness of fit comparison between T_{re} and T_{pill}, the root mean squared deviation (RMSD) was calculated using data from all 1-minute time points:

$$RMSD = \sqrt{\sum (T_{re} - T_{pill})^2 * 1/Count}\,.$$

Results

Study 1: During the treadmill walking study, T_{re} and T_{pill} data were compared during 31 out of a possible 36 individual Heat Tests. Two subjects did not undertake HT3; one forgot to consume the radio-pill the night before HT3; and two HT3 exposures yielded spurious T_{pill} data that were not included in the statistical analysis. There was no main effect of SITE, although there was a SITE-time interaction ($P<0.01$). Paired t-tests indicated that T_{pill} was higher than T_{re} at 10 and 15 minutes ($P<0.05$), but not different thereafter (Figure 1). At 120 minutes, T_{pill} and T_{re} were 38.2 (1 SD, 0.3)ºC and 38.3 (0.3)ºC, respectively. The mean RMSD was 0.24 (0.11)ºC.

Study 2: During the treadmill running study, T_{re} and T_{pill} data were compared during 17 out of a possible 20 individual Heat Tests. On one occasion a signal could not be detected from the radio-pill, and two further exposures yielded spurious T_{pill} data. The mean exercise time was 52 (9) minutes, and only complete data up to 35 minutes and at the cessation of exercise were included in the ANOVA. There was a main effect of SITE ($P<0.01$), and a SITE-time interaction ($P<0.01$). Paired t-tests indicated that T_{pill} was higher than T_{re} at Pre and during the first 25 minutes of running ($P<0.05$) (Figure 2). The core temperatures were not different at 30 and 35 minutes, and at the cessation of exercise (Final). At Final, T_{pill} was 39.3 (0.3)ºC and T_{re} was 39.3 (0.4)ºC. The mean RMSD was 0.20 (0.08)ºC.

Discussion

The purpose of this work was to extend previous studies assessing the validity of a telemetry radio-pill system for monitoring core temperature during exercise in the heat. T_{oe} and T_{re} are widely accepted as valid measurements of core temperature (1). T_{oe} is regarded superior to T_{re} as it responds much quicker to dynamic changes in mean body temperature (1). However, many subjects find the procedure for measuring T_{oe} very uncomfortable and as continuous exercise was adopted in the present study T_{re} was used as the standard against which T_{pill} was evaluated. Prior to exercise, T_{pill} was the same as T_{re} in Study 1, but exceeded T_{re} in Study 2. During exercise in both studies, T_{pill} was higher than T_{re} in the initial stages (<30 minutes), but was not different from T_{re} thereafter. This is at odds with some previous studies in which T_{pill} was lower than T_{re} at rest and throughout exercise (2, 3).

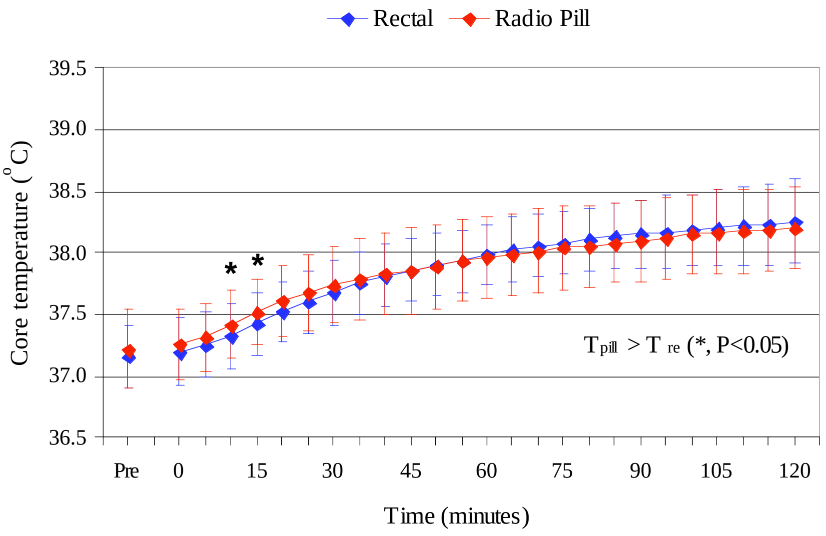

Figure 1. Rectal and radio-pill temperature during Study 1.

However, it is similar (at least after 30 minutes of exercise) to the study by O'Brien and colleagues (4) who reported that T_{pill} was not different from T_{re} during warm water exercise, although these researchers reported that T_{pill} and T_{re} were not different prior to exercise. The reason for the disparity in these findings is unclear. As variations in temperature occur due to the movement of the radio-pill through the gastrointestinal tract, one potential reason is the different periods adopted between the ingestion of the radio-pill and the start of the respective trials: 3-9 h (2); 2-3 h (3); 12 h (4); and 12-18 h (present study). The closer agreement between T_{re} and T_{pill} in the present study and that of O'Brien *et al*. (4) is likely to have reflected the positioning of the radio-pill further along the gastrointestinal tract and therefore closer to the T_{re} measurement site. Indeed, it has been suggested that longer periods may be required to avoid the greater fluctuation in temperature in the upper portions of the gastrointestinal tract, compared with the small and large intestines (4). However, the reason why T_{pill} was slightly higher than T_{re} at rest and during the initial stages of exercise in the present study is unclear, as T_{re} is usually regarded the highest core temperature in the human body (1). Nevertheless, core temperature during continuous exercise in the heat appears to be adequately represented by T_{pill}. This was confirmed by the RMSD analysis. The RMSD compares the two core temperature sites throughout an entire Heat Test, by contrasting each pair of measurements (i.e. every minute) and evaluating the overall mean deviation. The RMSD in the present study was 0.20-0.24°C, which is comparable with the 0.22°C value reported by O'Brien et al. (4). These values indicate good agreement between T_{pill} and T_{re} during exercise in the heat. However, one word of caution is that 5 out of the 53 radio-pills used (i.e. ~10%) yielded spurious data, although fortunately these data were clearly distinguished from the valid data. Therefore it is prudent to check the accuracy and precision of each radio-pill prior to use.

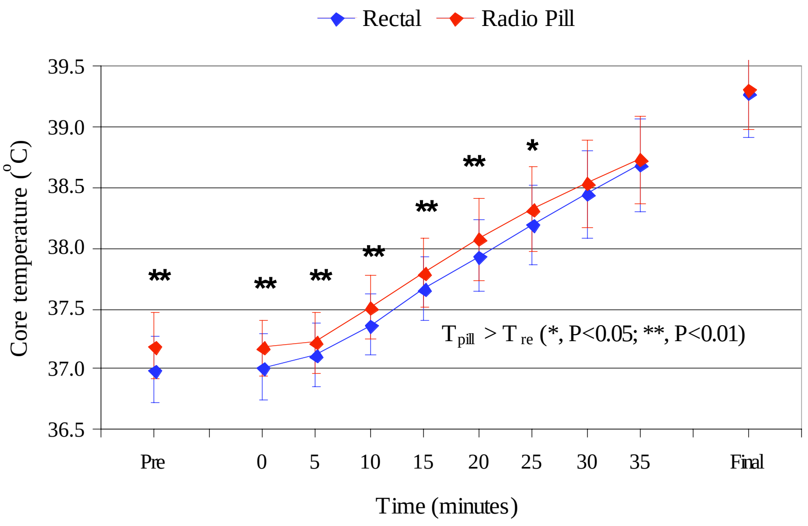

Figure 2. Rectal and radio-pill temperature during Study 2.

Conclusion

These results indicate that radio-pill temperature tracks rectal temperature adequately during continuous treadmill walking and running in the heat. Therefore, given the lack of wire connection between the sensor and logger, the radio-pill is particularly suitable for monitoring core temperature during continuous exercise in the field.

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THE SNELLEN HUMAN CALORIMETER RECREATED: DESIGN AND PERFORMANCE CHARACTERISTICS

Glen P Kenny[1*], *Paul Webb*[1,2], *René Wegmann*[1], *Michel B Ducharme*[1,3], *James A Hodgdon*[1,4], *Kalle E Leppik*[1], *Pascale Ottis*[1], *and Frank D Reardon*[1].

[1]J.W. Snellen Memorial Calorimetry Laboratory, University of Ottawa, Ottawa, Ontario, Canada
[2]Yellow Springs, Ohio, USA
[3]Defence Research and Development Canada - Toronto, Ontario, Canada
[4]Naval Health Research Center, San Diego, California, USA
*corresponding author gkenny@uottawa.ca

Introduction

Functional human calorimeters have been used by medical researchers and practitioners since early in the twentieth century. Much of our understanding of metabolism and the classical control systems active within the human body is based on data derived from calorimetric studies of the human organism. The direct measurement of body heat loss, or calorimetry, began in 1780 with Lavoisier and LaPlace, then Rubner in 1894. In 1899 Atwater and Rosa built the first human calorimeter. The Atwater-Rosa calorimeter was the first human calorimeter used to simultaneously measure the consumption of oxygen and heat production. In the ensuing years DuBois and his colleagues produced many integral studies of the pathology of human heat production and on the generation of heat during exercise. Since then some 35 human calorimeters have been created and used for primary studies in energy balance, nutrition, and thermoregulation (1).

Of the 17 calorimeters built in the most recent era, 1972 to present, 12 are still active today. These calorimeters are most commonly used for the study of energy exchange in a nutritional context. By far the interest in temperature control and thermal physiology was the driving force behind the most recent developments in calorimetry. Of particular importance in the study of human thermoregulation, was the need to develop a rapid response calorimeter. Direct calorimeters, based on the gradient layer principle, fit this specification as it provides a short response time and low thermal inertia (2).

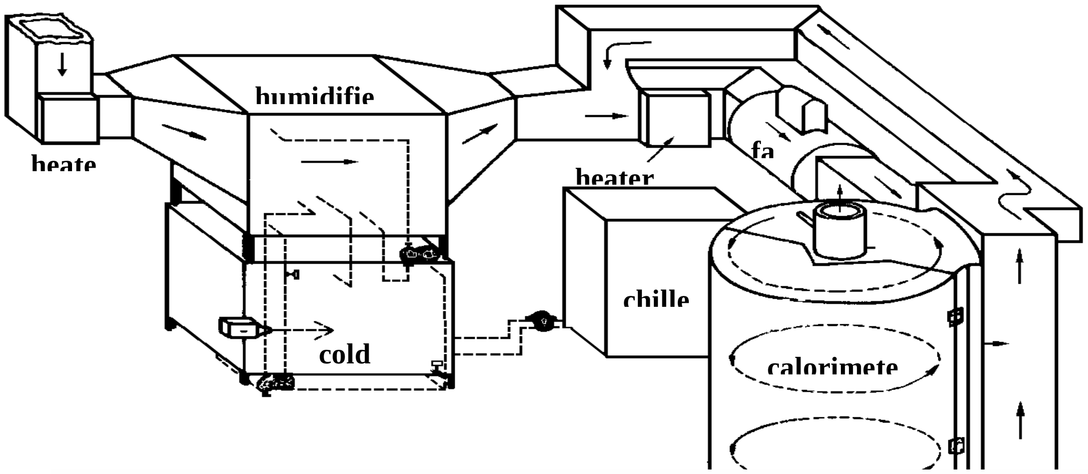
Gradient layer calorimeter – The Snellen Calorimeter

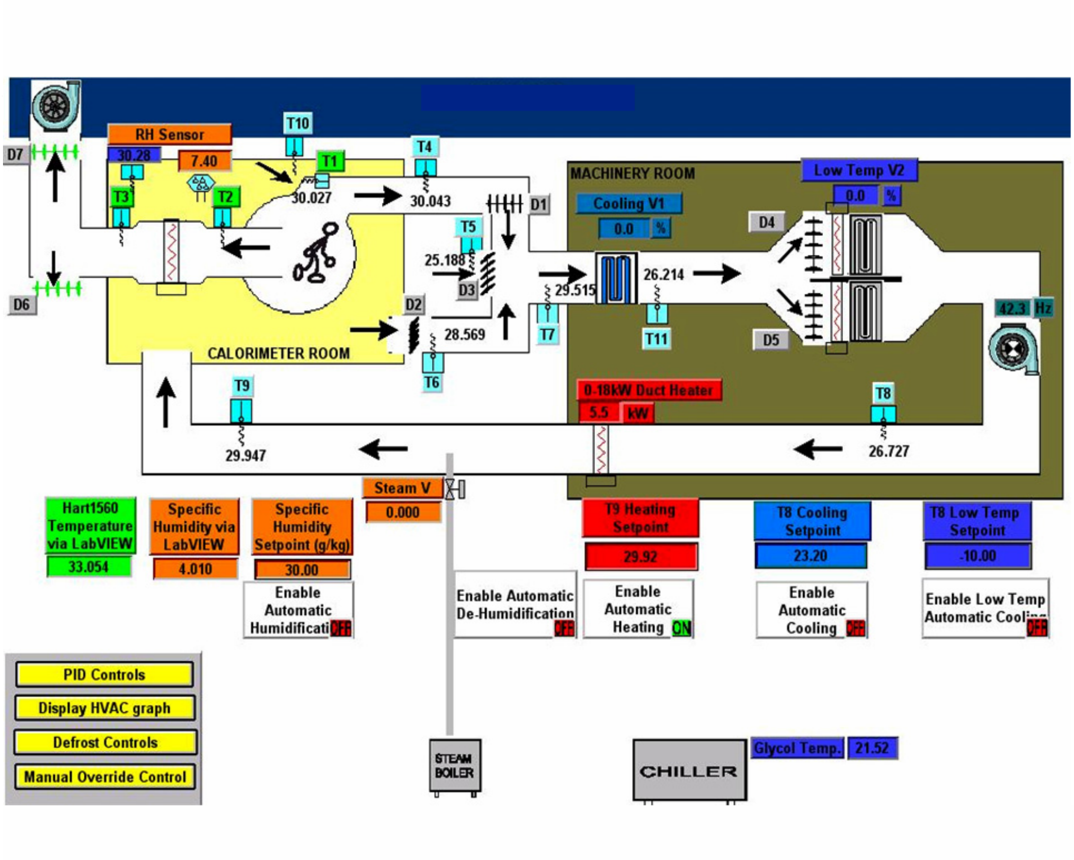
One such calorimeter built by Spinnler et al. (3) has an overall time constant of only 1.5 minutes. Similarly, and more recently, other gradient layer direct calorimeters have been developed for use with human subjects (2,4,5,6). The original Snellen direct whole body calorimeter was developed and installed at Memorial University in St John's Newfoundland in the early 1980's. Its design and operating principles were based on the Johannesburg, South Africa calorimeter of Visser and Hodgson (1960) (see Figure 1). This calorimeter was initially intended for studies in temperature regulation, so that good control of air temperature and humidity combined combined with rapid response were needed. It remained in operation until the late 1990's. When Snellen's laboratory closed the apparatus was stored at the Defence R&D Canada - Toronto. From there it was relocated to the University of Ottawa, where it was reassembled. However, the air handling equipment and the instrumentation were out of date and partially lost, so that the major useful component was the original cylindrical chamber where the subject sat. We have undertaken the task of recreating the Snellen calorimeter with new air handling equipment and state-of-the art instrumentation. The recreated Snellen air calorimeter is already in use in a study of body heat storage during exercise (Figure 2).

The basis of its function is the injection of a constant flow of precisely conditioned air partly into the calorimeter and partly into the space surrounding the calorimeter at such a rate that there is virtually no thermal gradient and therefore no heat flux across the calorimeter wall. Thus, all the heat dissipated by the subject in the chamber will be reflected in the temperature difference (sensible heat) and humidity difference (insensible heat) between the incoming and outgoing air. The temporal summation of metabolic heat production and sensible and insensible heat exchange when the system is equilibrated yields the net heat storage. As such this type of calorimeter is indispensible for the study of complete heat dissipation in large living organisms including humans.

The calorimeter is a cylinder 1.83 meters high with a diameter of 1.68 meters, enclosing a volume of 4000 litres. Just inside the insulated chamber wall is a radiation shield of thin aluminum sheet metal which also serves to distribute incoming air in a tangential manner. The air leaves via a central exhaust at the top and is discarded. Temperature change and humidity change are carefully measured to give values for sensible and evaporative heat loss. The zero gradient principle is used for thermal isolation. An annular space around the inner cylinder is formed by a larger cylinder 2.09 meters high with a diameter of 1.93 meters. Conditioned air from the same source that supplies the inner chamber circulates through this space at a rate of air mass flow rate of up to 15 Kg/min; it then returns to the air conditioning machinery to be reprocessed and recirculated.

Figure 1 shows a diagram of the general layout of the original Snellen calorimeter. The range of operating temperatures was from 12 to 40 ^{o}C and dew point temoperatures from 10 to 25 ^{o}C. Upgrades to the calorimeter now permit a larger variation of the temperature down to temperatures of -15 to +50 ^{o}C. Calibrations are made with an electric heater for sensible heat and with a steam generator supplied from an infusion pump for evaporative heat. Oxygen consumption is measured with an open air circuit, separate from the air of the calorimeter chamber and is used periodically when the subject connects to mouthpiece. The subject otherwise breaths chamber air and their respiratory heat loss may be detected as the change in overall sensible and evaporative heat loss between breathing form the mouthpiece and breathing from the chamber air.





Hart1560 Temperature via LabVIEW 33.054

Specific Humidity via LabVIEW 4.010

Specific Humidity Setpoint (g/kg) 30.00

Enable Automatic Humidificati OFF

Enable Automatic De-Humidification OFF

T9 Heating Setpoint 29.92

Enable Automatic Heating ON

T8 Cooling Setpoint 23.20

Enable Automatic Cooling OFF

T8 Low Temp Setpoint -10.00

Enable Low Temp Automatic Cooling OFF

Figure 2. The Snellen Human Calorimeter Recreated (2005).

The Snellen Human Calorimeter Recreated (2005).

Modifications to the calorimeter include i) changes in the conditioning and delivery of the input air: variable temperature (-15 ºC to +50 ºC); water content (10% to 95% RH); air mass flow rate (up to 15 Kg/min), ii) changes air mass flow measurement; input and output temperature sensing; and, input and output air water content, iii) changes to establishing and monitoring subject workload. Temperature control of ± 0.04°C has been achieved. A control strategy, better than a proportional, integral and derivative (PID) action, known as a “Smith Predictor” is currently been evaluated to reduce the ± 0.04°C fluctuation.

Humidity control of 0.05 g/kg (specific humidity) has been achieved at this time. Modifications and improvement are currently been tested to improve control. Various calibration techniques (electrical, stoichiometric, hygrometric) show a precision of total energy output measures assessed at within ± 3W over a range of air conditions and workloads.

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USABILITY OF A NEWLY DEVELOPED THERMAL MANIKIN OF INFANT TO ASSESS THERMAL STRESS IN VARIOUS ENVIRONMENTS

Takako Fukazawa[*1], *Yutaka Tochihara*[*1], *Tsuneyuki Yamamoto*[*1&2], *Ingvar Holmér*[*2], *and Kalev Kuklane*[*2]

1 Department of Ergonomics, Faculty of Design, Kyushu University, Fukuoka, Japan
2 Thermal Environment Laboratory, Department of Design Sciences, Lund Technical University, Lund, Sweden
* corresponding authors fuka@design.kyushu-u.ac.jp and tochi@design.kyushu-u.ac.jp

Introduction

Research with use of a thermal manikin research is an effective method to produce liable clothing system in various environments and to assess heat/cold stresses. A large number of the thermal manikin has been produced for sized adult while a comparatively small number for an infant even though heat (and water vapour) transfer from the infant body must not be the same as the one from the adult due to physiological differences such as in body shape, heat capacity and sweat rate. Therefore, in order to provide an appropriate clothing system and to assess heat/cold stresses for the infant, a thermal manikin of sized infant has been newly developed through the collaboration between Japan and Sweden. In this paper, characteristics of the infant manikin are provided mainly in terms of our future works.

Characteristics and usability of the infant manikin

Size and shape of the newly developed manikin is equivalent to those of a half year-old baby with a height 60 cm and with a body surface area of 0.31 in m^2. The body consists of 8 parts; those are frontal and back of head and trunk, and right and left of arms and legs. The each body part can be controlled separately through two regulation modes; the one is to set heat flux and the other to maintain the surface temperature at a desired level. This separate regulation modes is very advantageous to separately evaluate the thermal resistance of clothing such as hat/cap, gloves, and shoes. Furthermore, heat transfer of the whole body including the head part can be measured at the same time. Those two merits are indeed useful compared to another type of developed infant manikins [1, 2].

A series of measurement has been performed for obtaining local thermal resistances from the infant body under a condition, in which temperature and relative humidity was maintained at 20 °C and 50 % with an air velocity of 0.2 m/s. In the measurement, two types of posture, supine and prone, are selected. The obtained results of the thermal resistances of whole body and the each part are shown in Figure 2. The thermal resistance of each part depends upon the posture although the total thermal resistances of both postures are not so much different with each other. The resistances of the frontal head and trunk during the supine posture were statistically higher than those of back head and trunk during the prone posture. The resistances of the upper and lower limbs were not affected by the posture in this condition.

Studies on the thermal stress in the cause of sudden death syndrome (SIDS) [3, 4] have suggested that a significant increase in the SIDS ratio is caused by the increase in the thermal stress due to the sleeping posture.

Fig. 1. Picture of the newly developed infant thermal manikin. Whole body of the manikin can be controlled at the same time and each part can be also regulated separately at the desired level through two modes.

The result shown in Figure 2 indicates that thermal resistance of each body depends on the body position although the total thermal resistances of the supine and prone postures show almost the same values. Therefore, the heat stress must be elucidated not only through the total thermal resistance but also through the partial resistance effects measured using the manikin whose parts can be controlled separately.

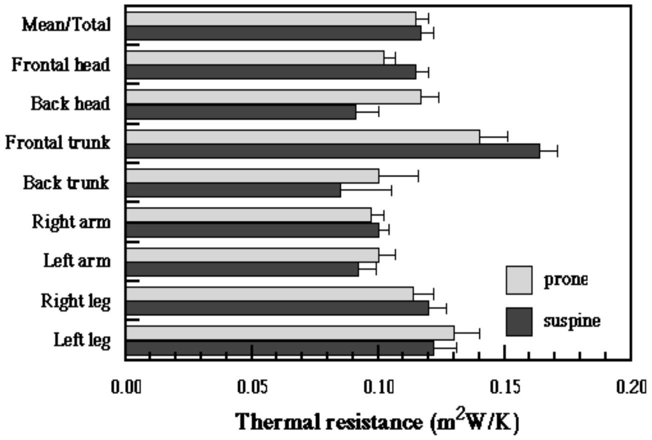

Fig. 2 The whole body and local thermal resistances during the supine and prone postures. Although statistical differences between both the postures was found to not be significant for the whole body, but was significant for the each body part.

Future works

In order to improve the design for clothing system and to explain heat stress in infant, many issues are still remaining to be solved: how one may explain the heat stress influenced by local heat stress in infant for preventing heat/cold injuries and what is the most established clothing system for infant based on both total and local heat transfer from the body, because the influence of posture must not be negligible as mentioned above.

Acknowledgements

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PHYSIOLOGICAL RESPONSE TO EXPERIMENTAL EXPOSURE TO ELECTROMAGNETIC FIELDS EMITTED BY MOBILE PHONE

A. Bortkiewicz, E. Gadzicka, W. Szymczak*

Department of Work Physiology and Ergonomics, Nofer Institute of Occupational Medicine, Lodz, Poland
*corresponding author alab@sunlib.p.lodz.pl

Introduction

Some theoretical data suggest that the use of mobile phones may be harmful to human health [1]. Epidemiological data show that from 13% (in Sweden) to 80% (in Australia) people report complaints associated with the use of mobile phones [2,3]. The most frequently reported symptoms include: non-specific neurovegetative disturbances, headache, muscle pain, sleep disturbances [4,5]. The EMF source is held very close to the user's head, and it is quite likely that, by acting directly on the brain, EMF may affect the control of many physiological functions. Some experimental data have pointed to an increase in arterial blood pressure in the exposed subjects; EEG changes during the awake and sleep hours, and changes in the cognitive functions [6,7,8]. These findings require further research.Therefore, we had undertaken the studies on the effect of mobile phone EMFs on heart rate and blood pressure.

Methodology

Group

The examined group consisted of 10 young, healthy men aged 19-29. All the participants were volunteers, and they were qualified for the experiment on their prior agreement. Before the onset of the experiment, all procedures were fully explained to each participant. The protocol was approved by the Regional Research Ethics Committee.

Methods

The experiment was performed under controlled conditions: ambient temperature and relative humidity were maintained at 24^0 C and 70%, respectively. Since it was necessary to eliminate the influence of the possible stress caused by the talking over the phone on the physiological parameters, the use of the phone consisted only in keeping the subject's head close to the receiver mounted on a stand.

Each person was examined three times:
on a day without exposure (control day, C day),
on a day with continuous exposure (60 min exposure from phone use , frequency 900 MHz), E day,
on a day with intermittent exposure (4x15 min exposure with 15 min intermission), I day.

The subjects did not know which day was the exposure and the control day (blind experiment).

The subjects had not used the cellular phone for at least one week before each experiment and they consented to the following study requirements:maintain a consistent and normal daily activities before the experiment; refrain from intake of alcohol and dietary supplementation of proteins and amino acids, avoid excessive physical exercise and sauna.

The protocol of the experiment is shown in the Figure 1

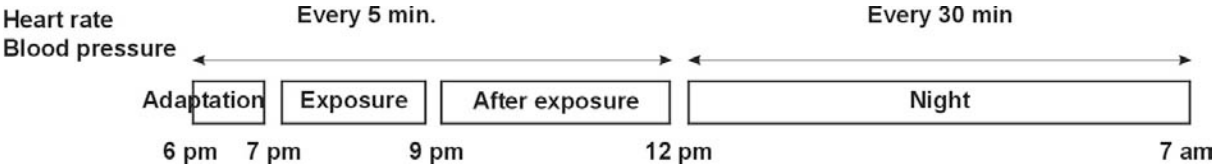

Fig. 1 The protocol of experiment

The subjects entered the laboratory at 6 p.m. From 7 p.m. to 9 p.m. they were subjected to a real or sham exposure.

Starting from 9 p.m. till midnight the subjects listened to music and then they slept till 7 a.m. the next day.

The statistical analysis was performed for the individual subjects and for the whole group separately and referred to the following periods of experiment:
during exposure,
after the exposure (two hours)
during night hours (12 pm.-7 am).

Results

The analysis of arterial blood pressure (ABP) and heart rate (HR) in the individual subjects has revealed considerable individual differences, but an attempt to explain those differences would go far beyond this paper therefore it is presenting only the changes which were characteristic of the whole group.

The figure 2 present the changes of arterial blood pressure and heart rate values during the experiment.

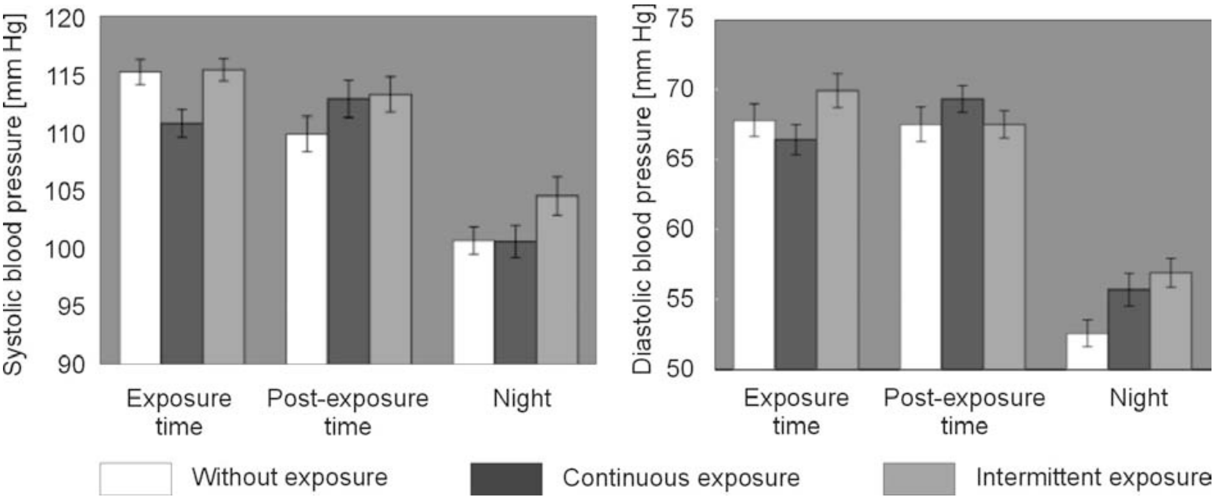

Fig. Systolic and diastolic blood pressure during experiment

During the continuous exposure, the mean level of systolic blood pressure in the examined group was significantly lower than on the non-exposed day. No statistically significant differences were recorded during two hours after exposure cessation and during the night hours between the continuous-exposure and the control days.

Higher systolic blood pressure values (close to the limit of statistical significance) were noted during the intermittent exposure, after its cessation and in the following night hours, compared to the values recorded on the control day.

No significant changes were noted in the diastolic arterial blood pressure during the continuous exposure, whereas after cessation of the exposure and during the night hours, the diastolic pressure was higher by ca. 2 mm Hg (a statistically insignificant increase) than in the control.

On the other hand, the value of the diastolic arterial blood pressure during the intermittent exposure was higher than that recorded during the same time on the non-exposed day, while at the night following the intermittent exposure the diastolic pressure was significantly higher than that recorded on the night following the non-exposed day. The mean value of the increase was 4 mm Hg.

No significant changes were noted in the heart rate in any of the analysed periods of time either on the days with continuous or intermittent exposure compared to the control.

To find out whether EMF exposure affected circadian rhythm of arterial blood pressure and heart rate, the circadian variations of the latter two were analysed separately for each exposure type by an analysis of variance. It was found that the patterns of circadian blood pressure and heart rate variations were different for each exposure type.

On the non-exposed day, the systolic blood pressure was getting steadily lower and lower according to the usual rhythm of circadian blood pressure variations.

On the continuous-exposure day, the systolic blood pressure remained substantially the same during the period of the exposure, increased during the first hour following the exposure, and decreased during the second hour after the exposure, but it did not fall below the level recorded during the exposure period. At night, the systolic pressure fell to the level observed on the non-exposed day.

During the intermittent exposure and during the first hour after its cessation, the systolic blood pressure varied insignificantly, but the values were higher than in the corresponding non-exposed and continuous exposure periods. During the next hours of the experiment, the systolic pressure continued to decrease, but did not fall below the values recorded during the non-exposed and continuous exposure stages of the experiment.

The diastolic blood pressure on the control day did not change during the consecutive hours of the experiment, and during the night hours it was getting lower according to the normal circadian rhythm.

On the continuous exposure day, the diastolic blood pressure grew during the second hour of the exposure and during the first hour after exposure cessation, and remained at the elevated level during the next hour; at night, the pressure decreased, without going below the values recorded on the control day.

During the intermittent exposure, the diastolic pressure did not change, but it was higher than at the same time of the control and continuous exposure days. During the first and second post-exposure hour, the diastolic blood pressure was getting lower and lower to reach the value recorded on the control day. The nocturnal reduction of the diastolic pressure was less evident than on the control day and after the continuous exposure.

During the non-exposed day, heart rate continued does decrease throughout the experiment, according to the normal circadian rhythm.

During the continuous exposure, heart rate increased and continued at the same higher level during the first hour after exposure cessation. Then it decreased, but remained higher than in the same period of the control day, to reach the value similar to that recorded on the non-exposed day only as late as during the night hours.

The pattern of heart rate changes during the intermittent exposure was different: heart rate decreased and reached values lower than those observed in the same period of the non-exposed and continuous exposure days. After cessation of the exposure, heart rate continued to decrease, but during the second post-exposure hour its value was higher than in the non-exposed and continuous-exposure test.

Discussion

It is difficult to compare our results with the experimental results of other authors, because different study protocols were used. Braune et al. (1999) found that during continuous exposure (35 min, GSM 900 MHz, 2 W, 217 Hz pulse) arterial blood pressure was significantly (by 5 mm Hg) higher than during the period without exposure [7]. However, they did not record blood pressure during the period after the exposure had ceased.

Thuroczy et al. (1997) recorded a significant reduction in systolic blood pressure (ca. 4 mm Hg) in a group of men after cessation of the intermittent exposure (2x7.5 min, 900 MHz, 2 W) [9]. Considering health effects of mobile phone EMF exposure, it is worth noting that the changes of arterial blood pressure (diastolic in particular) after the exposure, both intermittent and continuous, occurred late at night, many hours after exposure cessation.

Changed arterial blood pressure levels may explain the sleep disturbances reported by mobile phone users [10].

Conclusions

Results of our study show that exposure to mobile phone EMF may affect physiological functions of human organism.

The systemic response depends on individual characteristics, but predominantly on exposure type (continuous or intermittent). More intense response observed after the intermittent exposure may point to EMF stimulating effect (with prolonged exposure, an adaptation to the agent takes place; the adaptation is not possible when the exposure is frequent, but short lasting). Further research is required to verify that conclusion.

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INFLUENCE OF EXPERIMENTAL EXPOSURE TO ELECTROMAGNETIC FIELDS EMITTED BY MOBILE PHONE ON 6-HYDROKSYMELATONIN LEVEL

E. Gadzicka, A. Bortkiewicz, B. Piłacik*

Department of Work Physiology and Ergonomics, Nofer Institute of Occupational Medicine, Lodz, Poland
*corresponding author elag@imp.lodz.pl

Introduction

A lot of physiological and biochemical functions are influenced by melatonin [1]. Considering the significance of the effects of visible light on the pineal function, theoretically it is quite likely that non-visible electromagnetic fields may affect melatonin production [2]. Some studies confirmed this hypothesis and showed that extremely low electromagnetic fields altered pineal function in animals and humans [3,4,5]. Thus, it is reasonable to suppose that radio frequency electromagnetic fields emitted by cellular phones may also influence pineal production and secretion of melatonin. However, neither the experimental investigations on animals nor on humans have brought a conclusive answer to this question [6,7]. The objective of this study was to determine whether exposure to electromagnetic fields emitted by cellular phone suppressed nocturnal melatonin production.

The aim of present study was to evaluate the possible effects of exposure to EMF emitted by cellular phone on 6-hydroxymelatonin sulfate (6-OHMS) concentration reflecting melatonin level in blood.

Methods

The biological half-life of melatonin is 45 min. This implies that for research purposes blood samples need to be collected in short time intervals to determine the variations of melatonin production. These problems are avoided, when melatonin metabolite, 6-hydroxymelatonin sulfate, is determined instead of melatonin itself. 80 - 90% of melatonin is excreted as 6-OHMS in the urine and the concentration correlates well with the total level of melatonin in the blood during the collection period. The concentrations were normalised to creatinine (6-OHMS/cr). Urine samples were collected at 7 p.m., at midnight and at 7 a.m. in the same way on control day as on days with continuous and intermittent exposure. Samples were transferred to labelled bottles and frozen for later ELISA analysis of 6-OHMS. Melatonin sulfate is stable without preservative in urine for up to two years when stored at -20^{o}C and protected from direct sunlight. The concentration of 6- OHMS mesaured using ELISA kit (Immuno-Biological Laboratories, Hamburg).

Group

The examined group consisted of 10 young male, healthy students aged 19-29 years. Our experiment was carried out on volunteers, and all participants were qualified for the experiment on their prior agreement. Before the start of the experiment, all procedures were fully explained to each subject. The protocol was approved by the Regional Research Ethics Committee prior to commencement of the trial.

The subjects had not used a cellular phone for at least one week before the experiment. They consented to the following study requirements: (1) maintain a consistent and normal daily activity rhythm before experiment; (2) refrain from alcohol intake and many dietary supplements of proteins and amino acids; (3) avoid intensive physical activity and sauna.

Protocol of the experiment

Each person was examined three times:
on a day without exposure (sham exposure – control trial) C day
on a day with continuos exposure (60 min exposure from cellular phone), E day;
on a day with intermittent exposure (4 x 15 min exposure) I day

All experiments (non-exposed and exposed) were performed according to the same procedure. The subjects entered the laboratory at 6 p.m. The subjects rested between 6 and 7 p.m. From 7 p.m. to 8 p.m. the subjects were exposed to EMF emitted by cellular phone (sham or real). The subjects did not know which days were exposure days (E or I), and which day was control day (C). Since it was necessary to eliminate the influence of possible stress caused by a conversation on the physiological parameters, the use of the phone involved only keeping the subject's head close to the receiver mounted on a stand.

After exposure time till midnight the subjects listened to music and than they slept till 7 a.m. next day. There was at least one week's interval between the tests. The experiment was performed under controlled conditions The ambient temperature and relative humidity were maintained at 24^0 C and 70%. The light intensity was controlled at 50 lx till midnight and 0 lx during night (0.00-7.00 a.m.).

Assesment of exposure

For the study, Nokia 3210 mobile phone (frequency 900 MHz,) was used. Following the data obtained from the Bioelectromgnetic Laboratory of Toxicology and Biomedical Sciene ENEA Cassacia in Rome, for this type of mobile phone SAR = 1.23/kg (averaged for 1g tissue).

Statistical analysis

The data were analysed using Wilcoxon matched-pairs signed-ranks test for each subject and for the whole group. We compared 6-OHMS level on the day with continuos exposure, on the day with intermittent exposure and on the control day separately for 3 time-points: 7 p.m., midnight, 7 a.m.

Results

Table 1 presents the concentration of 6-OHMS in individual subjects and average level for the whole group on the days with exposure (E and I) and on the day without exposure (C), separately for 3 time-points.

When analysing melatonin concentration in each subject, high individual variation was observed. However, it was also noted that after intermittent and continuous exposure, the physiological nocturnal increase in melatonin metabolite concentration was less pronounced than that recorded during the control experiment, respectively in 8 and 7 subjects.

Table1. Mean concentration of 6-OHMS related to experimental condition

		7 pm		12 pm		7 am		Δ 7 pm– 12 pm	Δ 12 pm– 7 am	Δ/Cr 7 pm– 12 pm	Δ/Cr 12 pm – 7 am
		6-OHMS	6-OHMS/Cr	6-OHMS	6-OHMS/Cr	6-OHMS	6-OHMS/Cr				
C	AVG	6,4	4,1	23,8	15,6	174,9	64,2	17,4	151,1	11,5	48,6
day	STD	2,5	1,5	17,3	9,7	49,4	17,5	18,2	46,8	10,0	18,9
E	AVG	7,6	6,3	40,6	22,3	170,9	61,1	33,0	130,3	16,0	38,8
day	STD	5,6	4,8	35,8	19,6	71,5	23,5	33,7	45,0	17,6	21,7
I	AVG	6,8	4,5	42,1	21,0	133,9	62,5	35,3	91,8	16,5	41,5
day	STD	7,0	3,0	38,8	14,4	58,5	15,5	33,1	59,0	12,5	15,3
p		ns	ns	ns	ns	ns	ns	ns	0,04 1-3	ns	ns

6-OHMS/Cr - concentration normalised to creatinine

The characteristic daily variations of 6-OHMS concentration were detected in all subjects. In our experiment, maximum 6-OHMS concentrations were recorded at 7 a.m., because there is a 2- to 4-h lag between the maximum blood serum and urine 6-OHMS concentrations (the maximum for blood occurs between midnight and 3 a.m.). The differences between day-and night 6-OHMS concentration were greater on the exposed days than in control day. The greatest differences were recorded at midnight after intermittent exposure.

Before the experiment, at 7 p.m., the mean 6-OHMS levels did not differ either on exposure or control days. At 12 p.m., both after continuous and intermittent exposure, the mean 6-OHMS concentration was higher (statistically insignificant difference) than on the control day. After the intermittent exposure, at 7.00 a.m., 6-OHMS concentration was lower than after E and C days. When analysing the nocturnal, physiological increase in melatonin level, we noted that it was significantly lower (p=0.04) during night hours after intermittent exposure than after the control day (Figure 1).

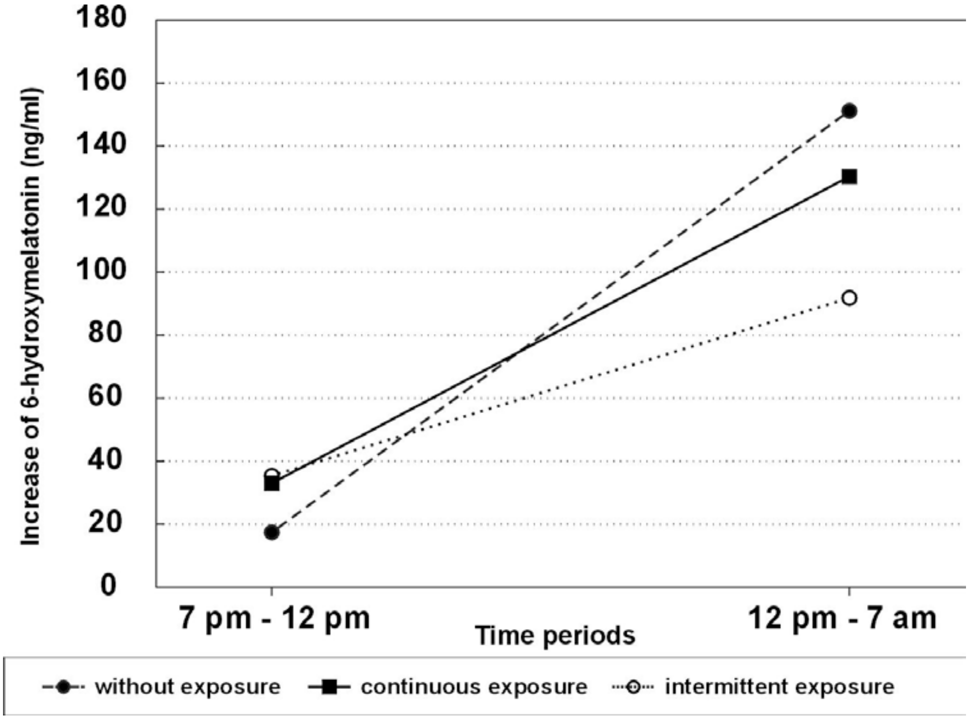

Fig. 1 Night increase of 6-hydroxymelatonin level during experiment

Discussion

The reaction to the exposure varied considerably from individual to individual. The changes in the levels of melatonin metabolites significantly depended also on exposure type. After intermittent exposure the nocturnal physiological increase of melatonin level was distinct than during the control conditions. This shows that even a short -term exposure to EMF from mobile phone may disturb the circadian rhythm of melatonin secretion, which may explain the sleep disturbances observed in some experimental studies or reported by mobile phone users. It is difficult to compare our results with the experimental results of other authors, because different study protocols were used. Earlier studies performed by de Seze and et al (1999) did not reveal any changes in the circadian rhythm of melatonin secretion after exposure to electromagnetic fields emitted by cellular phone [8]. Also Mann et al. in an experiment involving people exposed to low-intensity (0.2 W/m^2) 900 MHz EMFs did not record changes in melatonin level [9]

Conclusion

Our study indicates that EMF emitted by cellular phones may have influence on melatonin level. Further research is required to confirm this observations.

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ERGONOMIC EVALUATION OF MUSCULOSKELETAL DISCOMFORT AMONG PUBLIC BUSES DRIVERS

** Habibi,E; ** Mirlohie, M; ***Hajazee,a; Babaee,A.*

*Associate professor, Esfahan Medical University, School of Health
Department of Occupational Health, P.O.Box 131,Esfahan, Iran, 81745-131
Habibi@hlth.mui.ac.ir

Bus Drivers are subjected to vibration and indices of fatigue, discomfort and Musculosketal disorders that are directly related to the characteristics of the vehicle and ergonomic design. Vibrations are transmitted to the buttocks and back of the driver along the vertebral axis via the base and back of the bus seat.

In addition, the pedals and steering wheel transmit additional discomfort to the feet and hands of the drivers. These vibrations and discomfort, in combination with a seated posture, produce a measurable level of discomfort for driver, especially during journeys of long duration. Moreover, prolonged exposure can result in a range of physiological problems such as postural instability, cramp, and numbness.

This is a cross-sectional study, 178 male drivers were randomly chosen and participated in the study. Tool of identification of there disorder were ergonomic checklist, observation of jobs, measurements of fatigue and questionnaires. Also SEMG signals were recorded bilaterally from cervical erector spine and external oblique muscles.

Surveying shown that % 85 according had low back pain shoulder, neck and legs %76 had there discomfort during long duration of bus driving. Also it showed that by increasing the hours of work per week and bad design of driver seat the risk of musculoskeletal disorder increases. Subjects rating of their total discomfort significantly increased during the trial. The effects for local discomfort were the same as for total discomfort, so only total discomfort measures will be discussed

HUMAN TIME SENSE UNDER THE INFLUENCE OF BRIGHT AND DIM LIGHT INTENSITIES

Takeshi Morita[1], Tomoko Fukui[2], Masayo Morofushi[3], Hiromi Tokura[4]*

[1] Department of Living Science, Fukuoka Women's University, Fukuoka, Japan
[2] Department of Environmental Health, Nara Women's University, Nara, Japan
[3] Department of Translational Medical Sciences, Nagasaki University, Nagasaki, Japan
[4] Institute of Textiles & Clothing, The Hong Kong Polytechnic University, Hong Kong, China
* corresponding author morita@fwu.ac.jp

Introduction

Since we feel that time runs faster on a fine day and more slowly on a cloudy day, it is tempting to speculate that such different time sensations might also be interpreted as due to a different load error between actual core temperature and its set-point under the influence of bright or dim light during the daytime. This view is supported by the finding of Aizawa and Tokura (2 - 4) who found convincing evidence that the set-point of actual core temperature became significantly lower under the influence of bright rather than dim light exposure for several hours during the daytime.

Therefore, we have hypothesized that the time-sense system may be influenced by the load error between actual core temperature and its set-point; the greater is this load error, the faster the time-sense system runs. The aim of the present experiment is to test this hypothesis experimentally.

Methods

Subjects

Nine healthy women served as participants. Their age was 19.9,±2.2 yrs, height 156.4,±6.5 cm, body weight 51.2,±6.0 kg (means,±SD). The experimental procedures were fully explained to each participant before the beginning of the experiment. They were paid for their participation. The experiments were carried out during the follicular phase of the menstrual cycle.

Protocol

Subjects entered a bioclimatic chamber at 10:00 h on the day prior to the time-sense test, the ambient temperature and humidity of which were controlled at 25 Celsius and 60% RH, respectively. The subject sat quietly on a sofa under the dim light (50 lx) until 22:00 h, were allowed to read books and listen to music, retired at 22:00 h and then slept in total darkness. The subject rose at 07:00 h the following day and sat quietly on a sofa until 13:00 h, either in bright (2500 lx) or dim (50 lx) light. The order of exposure to bright or dim light was randomized. The time-sense test consisted of time estimation and time production, and was performed from 13:00 to 13:10 h by turns. The subject estimated the time that elapsed between two buzzes, ranging over 5-15 seconds, by inputting the estimate into a computer. They also produced a time interval, ranging over 5-15 seconds and displayed on the computer display, by pressing the space key of the computer. The test was performed in an adjacent room where the ambient light intensity was ca. 200 lx.

Statistics

A paired t-test was used to compare the estimates during the bright and dim light conditions.

Results

Figure 1 compares estimated times with actual times in the nine participants under the influence of bright or dim light exposure during the previous 6 h. As seen in the figure, S-2, S-4, S-5 and S-9 clearly estimated the time that had elapsed between the two buzzes as higher after bright light exposure, and S-1, S-3 and S-8 showed the same effect but more weakly. However, S-6 and S-7 behaved oppositely, estimating the time that had elapsed as being greater in dim light. Table 1 compares the slopes of the regression lines fitted to the relationships between the estimated intervals and the actual intervals. The mean (±SD) slopes were 1.269 ± 0.351 after bright light exposure and 1.028 ± 0.166 after dim light exposure, indicating that, after bright light exposure, subjects estimated the times as higher. The difference was significant, $p<0.05$.

Table 1. Slopes of regression lines relating actual time and estimated time interval in the rang 5 to 15 sec.

	Bright	Dim
S-1	1.4760	1.4030
S-2	1.4980	1.0630
S-3	1.1380	1.0900
S-4	1.2980	0.8630
S-5	1.7560	0.9400
S-6	0.6380	0.8490
S-7	1.0090	1.1220
S-8	0.9220	0.8690
S-9	1.6820	1.0490
Mean	1.2690	1.0280
SD	0.3510	0.1660

Table 2. Slopes of regression lines relating actual time and produced time interval in the rang 5 to 15 sec.

	Bright	Dim
S-1	1.2810	1.3620
S-2	0.7930	1.0770
S-3	0.9830	1.0370
S-4	0.8560	0.8910
S-5	0.6660	0.7680
S-6	1.0870	1.6270
S-7	1.1660	0.9970
S-8	1.1640	1.3230
S-9	1.1140	1.0770
Mean	1.0120	1.1290
SD	0.1910	0.2490

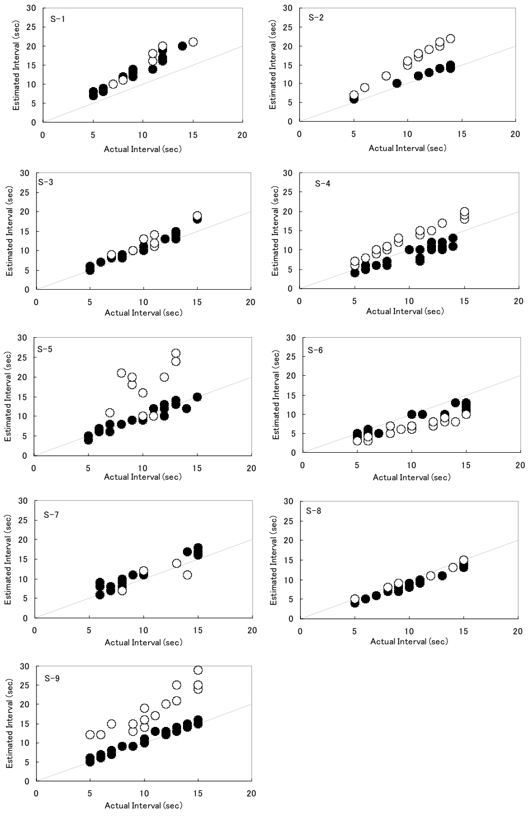

Figure 1. Time estimation in nine female participants.Closed circles: Dim light. Open circles: Bright light

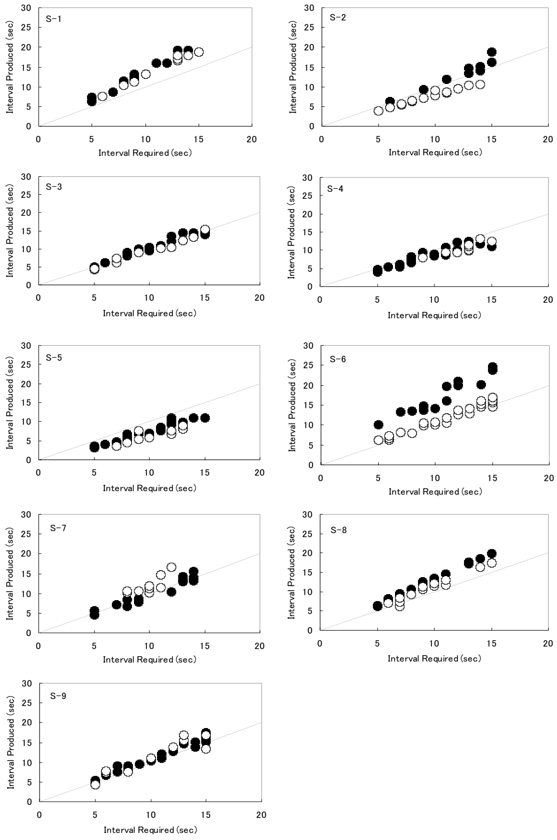

Figure 2. Time production in nine female participants. Closed circles: Dim light. Open circles: Bright light

Figure 2 compares the time intervals produced with those required in the nine participants under the influence of bright or dim light exposure during the previous 6 h. As seen in the figure, S-2, S-5, S-6 and S-8 clearly produced actual time as lower after the bright light exposure. S-1, S-3 and S-4 produced actual time as slightly lower after the bright light exposure. However, S-7 and S-9 behaved oppositely.Table 2 compares the slopes of regressionlines fitted to the relationships between thetime intervals produced and those required.The mean (±SD) slopes were 1.012 ± 0.191 after bright light exposure and 1.129 + 0.249 after dim light exposure, indicating that the subjects tended to produce shorter intervals after bright light exposure. This difference was marginally significant, $p<0.06$. Rectal temperatures at 13:00 h were 36.95 and 36.98 Celsius after bright and dim light exposure, respectively. These values were not significantly different.

Discussion

Hoagland (9) proposed that psychological time depends on chemical metabolism in the brain, a so-called biochemical clock, and described a woman who judged time to run faster in the febrile than the normothermic state. According to Bell (7), if the temperature of the ear canal was lowered, the subjects produced a period of 60 sec became longer, suggesting that the time-measuring system ran slower at the lower brain temperature. Pfaff (13) found that with an increase in oral temperature, interval production (short intervals, range 15 to 60 sec) became shorter, and estimates of such intervals (range 10 to 30 sec) became longer, supporting such a concept. Aschoff (5) stated that the production of short intervals in the range of seconds is independent of the duration of time awake, but showed a negative correlation with body temperature, suggesting the relevance of body temperature to time production.

Our results are opposite and seem to contradict the concept of a biochemical clock. According to Aizawa and Tokura (1, 3, 4), after subjects spent time under bright light for several hours, blood flow was significantly higher for the same mean body temperature and sweating and cutaneous vasodilatation were initiated by heat stimulation at a lower tympanic temperature. Teramoto et al. (14) found that, while experiencing a gradual decrease of room temperature (from 31ºC to 15ºC over the course of 4 h), subjects felt less cool in the afternoon if they had spent 3 h in the morning in bright rather than dim light. These results clearly suggest that the thermoregulatory set-point was shifted downwards under the influence of several hours of bright light exposure. In our present experiment, the rectal temperature did not differ at 13:00 h between bright and dim light exposure conditions, from which we assume that any load error would have been greater after the exposure to bright light. Thus, the body's time-measuring system may have run faster under the influence of the higher load error due to this light exposure.

According to Delay and Richardson (8), increased light levels over a period of 10 minutes (from < 0.33 lx through 80 lx to 170 lx) lead to a decrease in production of a 15-sec time interval in women. This is the similar result of ours, although their hypothesis was arousal theory and it was quite different from ours. Aschoff and Daan (6) found that short-interval production (10 to 120 seconds) was increased under high light intensity. This finding is inconsistent with ours. Thus, the relationship between time sense, body temperature and light intensity remains to be understood more systematically.

Our present hypothesis – concerning the effects upon time estimation of a different load error between the actual core temperature and its set-point - should be tested further. According to Morita et al.(12), women felt that time ran faster in the luteal than in the follicular phase. It seems true at first sight that the concept of a biochemical clock is correct. However, we could not deny that our hypothesis is valid, because there exist several lines of evidence that the error between the actual core temperature and its set-point is higher in the luteal phase than in the follicular phase. For example, women feel cooler in the luteal than the follicular phase when exposed to identical cold air temperatures (10), higher room temperatures are selected as being comfortable in the luteal than in the follicular phase (11). These results could all be interpreted from the viewpoint that the error between actual core temperature and its set-point is higher in the luteal phase than in the follicular phase. Thus, it is not the absolute level of core temperature, but rather the difference between the core temperature and its set-point that seems to be linked to the determination of time sense. However, our hypothesis remains to be studied systematically, by studying experimentally how time sense varies under the influence of experimentally changing the load error.

Thus, it is concluded that exposure to 6 h of bright light in the morning can make the human timing system (dealing with intervals in the range 5 - 15 sec) run faster.

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A COMPARATIVE ANALYSIS OF IMPULSE BUYING BEHAVIOR AND SHOPPING EMOTION BETWEEN KOREAN AND AMERICAN COLLEGE STUDENTS.

Eun Joo Park.

Division of Clothing & Textiles, Dong-A University, Busan, South Korea
* corresponding author ejpark@daunet.donga.ac.kr

Introduction

In the modern marketplace, spontaneous urges to buy and consume often compete with the practical necessity to delay the immediate gratification that purchasing provides. Impulse buying behavior can be defined as a sudden, compelling, hedonically complex buying behavior in which the rapidity of impulse decision process preludes thoughtful, deliberate consideration of all information and choice alternative. Although impulsive behavior can occur in any setting, consumer’s impulse buying behavior is extensive in everyday contexts. Impulse buying behavior has increased over the last two decades, as a consequence of linked economic and social changes in advanced Western economies, such as dramatic increases in personal disposable incomes and credit facilities. Along with these developments in modern consumer spending, there are important shifts in the psychological, social and cultural significance of buying consumer goods which may be described in the stereotype of modern consumerism “I shop therefore I am” (2).

The cues that triggered impulse buying were found largely be divided into two dimensions: environmental and sensory factors (e.g., advertisements, visual elements, clothing and looks, food, price, promotional gifts, and music) and consumers’ feeling states (e.g., positive feelings, depressed feelings, feeling fat, and painful feelings). External cues may be specific triggers associated with buying shopping, involving marketer-controlled environmental and sensory factors, and internal cues may refer to consumers’ self-feeling, moods, and emotional states (10). Researchers have stated that atmospheric cues in the retail environment (i.e. sights, sounds, and smells) are important triggers that can influence a desire to purchase impulsively (4,9). High impulsive buyers were more reactive to factors reflecting external triggers, compared to low impulsive buyers (13).

Shopping emotion experienced by consumers influences in purchasing intentions, spending, quality perceptions, satisfaction, and value (1), and strongly influences impulse buying behaviors (13).

Cross-national effects have been the backbone of international consumer behavior research. The importance of understanding the cultural context of consumer behavior in an increasing globalized marketplace (8).

In an effort to extend understanding of consumer behavior across cultures, this paper examines the cultural differences of impulse buying behavior and shopping emotion between Korean and American college students, and to investigate the relationships between impulse buying behavior and shopping behavior in each group.

Methods

Measurements

Questionnaire items were developed from a literature review. The instrument consisted of measurements for impulse buying behavior and shopping emotion. These variables were used as the basis for the latent constructs. The questionnaire was developed in English and translated into Korean. The English instrument was translated into Korean by a bilingual native speaker and then translated back into English by another bilingual Korean person. The process was repeated until items were deemed conceptually equivalent. Twelve items of impulse buying and eight items of shopping emotions developed by researchers were used (1, 6, 9). All items were asked into 7-point Likert-type scale (range: 1=strongly disagree to 7=strongly agree). Respondents were asked “During my last shopping, I feel…..” on a 7-point rating scale (range: 1=very unlikely to 7=very likely).

Sample and procedure

A relatively more homogeneous sample of undergraduate students is deemed to be desirable for a cross-cultural study (11, 12) and also minimizes random error that might occur by using a heterogeneous sample such as the general public (3). Data were obtained from students attending universities in metropolitan areas in the Korea (N = 412) and America (N = 290). The self-administrated questionnaire was given during a scheduled class. The Korean and American samples consisted of college students who were female (63.0%, 73.7%) and male (37.0%, 26.3%) respectively, and were primarily 21-24 ages (61.0%, 50.5%) and junior (29.1%, 30.1%) or sophomore (16.7%, 35.6%) standing. Most respondents had $201-$500 income/allowance (56.9%, 32.3%) in the Korean and American sample respectively.

Data analysis

For identifying dimensions of impulse buying behaviour and shopping emotions, we preliminarily conducted exploratory factor analysis. Then, we performed a confirmatory factor analysis using LISREL 8 to assess the measurement properties (5, 7). The criteria for evaluating the goodness of model fit used the chi-square value and alternative fit indices, such as Goodness of Fit Index (GFI), Normed Fit Index (NFI), Comparative Fit Index (CFI) and Root Mean Square Residual (RMR). In order to determine if the Korean and American students differ with respect to impulse buying behaviour and shopping emotion, mulitivariate analysis of variance (MANOVA) and univariate analysis were conducted for variables. For relationships of impulse buying behaviours and shopping emotion, regression analysis was conducted between two variables in each group.

Results and discussion

An exploratory factor analysis using principal component with varimax rotation was conducted to identify underlying constructs of impulse buying behaviour and shopping emotion for Korean and American students. A completely standardized solution of impulse buying behaviours and shopping emotion is shown in Table 1. CFA revealed the following fit statistics for impulse buying behaviour: $\chi^2_{(48)} = 209.31$ ($p = .000$), GFI = .90, NFI = .93, CFI = .95, and RMR = .05., and for shopping emotion: $\chi^2_{(17)} = 58.39$ ($p = .000$), GFI = .95, NFI = .96, CFI = .97, and a RMR of .06.

The results indicated there are significant differences of planned impulse buying, reminded impulse buying, fashion-oriented impulse buying and positive shopping emotion between American and Korean college students (See Table 2).

Table 1. Confirmatory factor analysis of impulse buying behaviour and shopping emotion**.**

Factors and Items	**Factor Loading**	**Composite Reliability**
Impulse Buying Behaviours		
Planned impulse buying		.61
I decide what to buy while looking around the store.	.83	
I expect to find something I want to buy when I get to the store.	.50	
I decide what to buy only after I look around a store.	.39	
Reminded impulse buying		.78
I buy something if I think I need it, even though I went shopping for other purposes.	.84	
I buy something if it reminds me of an item I want.	.73	
I buy clothing I had looked for before, even though I went shopping for other items.	.64	
Fashion-oriented impulse buying		.87
I buy clothing with a new style if I see it.	.86	
I like to buy new clothing that just came out.	.85	
I buy to try out a garment with a new feature.	.80	
Pure impulse buying		.83
I buy anything I suddenly feel compelled to buy.	.84	
I can't resist buying clothing if I really like it.	.82	
I buy any clothing I like without a lot of thinking.	.71	
Shopping Emotion [b]		
Positive emotion		.76
I was satisfied.	.78	
I was proud of myself.	.77	
I felt I was pleased.	.75	
I felt I was excited.	.73	
Negative emotion		.78
I felt I was upset.	.80	
I was displeased.	.77	
I was irritable.	.77	
I felt I was ignored.	.74	

The positive emotion is likely to predict the impulse buying behaviour both American and Korean students, while the negative emotion is likely to predict for only Korean students (See Table 3).

Conclusions

This study provides evidence that Korean students are more likely to buy something while or after looking around a store, and to buy clothing that they need, want and look for before even though shopping for other purposes than American students. However, American students are more willing to buy impulsively new style clothing, a new feature garment and clothing that just came out than Korean students. Additionally, American students are more likely to be satisfied, to be proud of themselves, to be pleased, and to be excited during their shopping than Korean students. Findings suggest that the shopping emotion, especially positive emotion, is important in predicting impulse buying behaviour across these two groups. Implications are drawn for the increasing global phenomenon of impulse buying behaviour and shopping emotion.

Table 2. Comparisons of impulse buying behaviour and shopping emotion between Korean and American students.

Factors	**Univariate *F* value**	**Group Means^a**	
		Korean (*n* = 412)	**American (*n* = 290)**
Impulse Buying Behavior			
Planned impulse buying	5.17*	**5.08**	4.87
Reminded impulse buying	7.09**	**4.94**	4.70
Fashion-oriented impulse buying	32.62***	3.78	**4.43**
Pure impulse buying	.40	4.29	4.21
Multivariate *F* value	23.18***		
Wilks' Lambda	.88		
Shopping Emotion			
Positive emotion	10.21***	4.43	**4.71**
Negative emotion	1.83	2.77	2.65
Multivariate *F* value	5.35**		
Wilks' Lambda	.98		

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 3. Regression analysis between impulse buying behaviour and shopping emotion for Korean and American students.

	Korean Students			***American Students***		
	Positive emotion	**Negative emotion**	**R^2**	**Positive emotion**	**Negative emotion**	**R^2**
Planned impulse buying	.19***	-.04	.04	.46***	.03	.21
Reminded impulse buying	.17***	-.12	.05	.51***	.08	.25
Fashion-oriented impulse buying	.33***	.17***	.12	.55***	.03	.29
Pure impulse buying	.34***	.10*	.12	.39***	.05	.15

* $p < .05$. ** $p < .01$. *** $p < .001$.

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EFFECTS OF FOREST BATHING ON PHYSIOLOGICAL RESPONSES.

Tomoaki KOZAKI[1], Kazuhiko HORINOUCHI[2], Juri NOGUCHI[3], Kana HASHITOMI[3], Kuniyoshi SHIMIZU[4], Keita ISHIBASHI[1] and Akira YASUKOUCHI[1]*

[1]Faculty of Design, Kyushu University, Fukuoka, Japan
[2]Graduate School of Design, Kyushu Institute of Design, Fukuoka, Japan
[3]Department of Design, Kyushu Insitute of Design, Fukuoka, Japan
[4]Faculty of Agriculture, Kyushu University, Fukuoka, Japan
[*]corresponding author kozaki@design.kyushu-u.ac.jp

Introduction

Forest bathing may attenuate physiological stresses in humans. It has been reported that auditory stimulations of acoustic effects in the wild environment such as that of a forest (e.g. chirpings of birds and the murmuring of cascading/bubbling streams) induce diminished cerebral blood flow (1). According to Suda et al., visual stimulations of a forest environment elicit favorable changes on physiological responses in humans (2); viz., decreases in cerebral blood flow and systolic blood pressure (SBP). Furthermore, it has been documented that SBP is decreased after inhalation of the odor of old Taiwanese cypresses (3). All these findings suggest that physicochemical and non-physicochemical elements (such as acoustic and odorous components) of the forest decrease brain and autonomic nervous activities.

However, the physiological effects of forest bathing have yet to be established. In this study, we compared the physiological responses in forested and urban environments.

Methods

Subjects

A total of 11 young males (age range: 21 - 27 years) participated in the present study with written consent.

Experimental Design

The experiments were executed in selected environments; viz., an urban site (Fukuoka-city, Fukuoka, Japan) and a forested site grown with Japanese cedar (Oguni-town, Kumamoto, Japan). Subjects divided into two groups of 5 - 6 participants each were scheduled to participate in this experiment for 2 days (Fig. 1). Each group was first tested in a selected environment before being allowed to cross-over to the other designated environment to neutralize any cross-effects in the tested group. Each group was tested on a specified site per day. On the day before the experiment, subjects stayed at hotels not far from the experimental site. In the morning, the heart rate (HR) as well as systolic (SBP) and diastolic (DBP) blood pressures (BP) of the respective subjects were measured, and their saliva samples were collected for biochemical analysis before being taken to the experimental site. They were instructed to take a walk on the experimental site for 20 min (walking condition) at midmorning (09:30 – 11:30 hr) before similar parameters and samples were noted. Similar monitoring of physiological responses before and after the experiment were repeated in the afternoon (13:30 – 15:30 hr) with another activity; viz., measurements taken before and after each subject sat on a chair at the site for 20 min (sitting condition). Note that physiological response measurements and saliva sampling were conducted before and after both conditions.

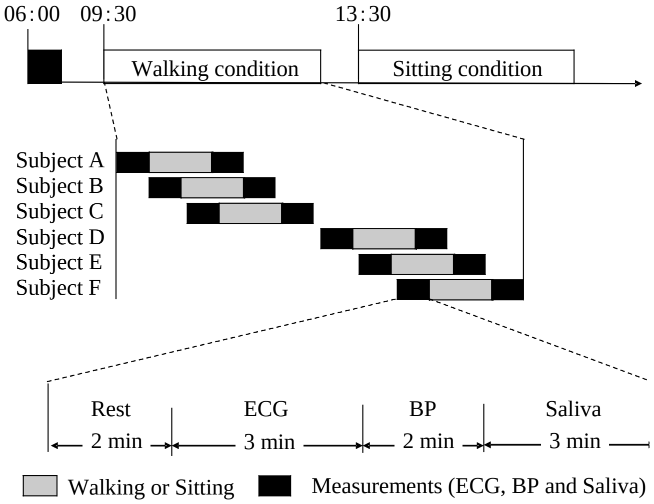

Fig 1 Time schedule of the experiment

Meteorological conditions

Environmental parameters in each experimental site (Table 1) indicated that the ambient temperature and air pressure were lower in the forest-site than those in the urban site. However, a higher relative humidity was obtained in the forest-site than the urban site.

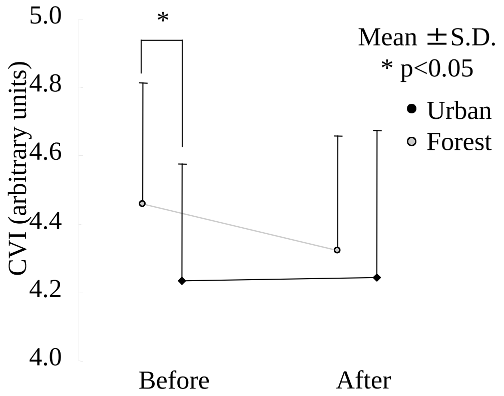

Fig 2 Cardiac vagal indices (CVI) before and after the walking condition

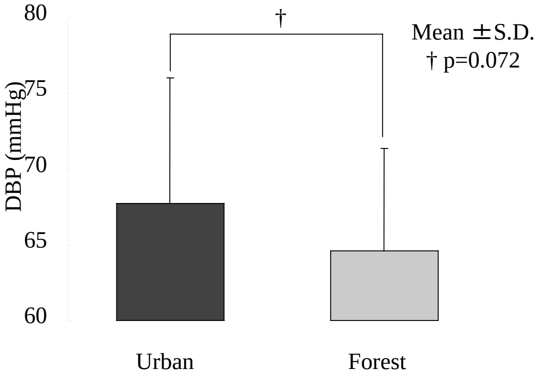

Fig 3 Diastolic blood pressure (DBP) in the walking condition

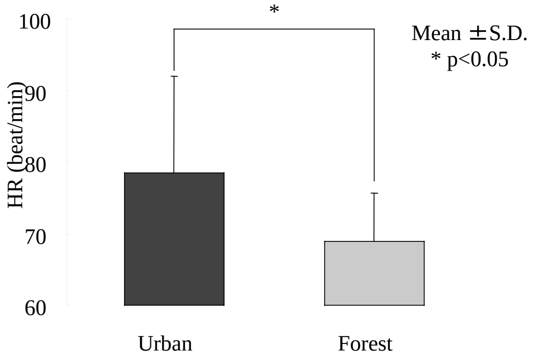

Fig 4. Heart rate (HR) in the sitting condition

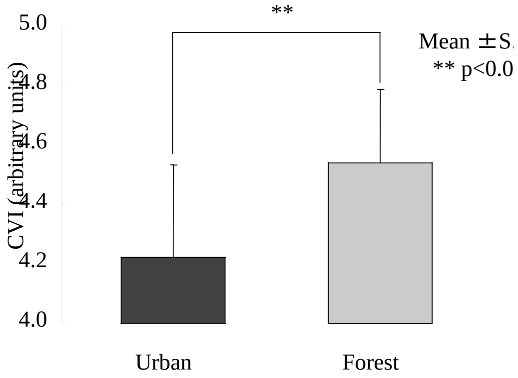

Fig 5. Cardiac Vagal Index (CVI) in the sitting condition

Table 1 Meteorological parameters in the 2 experimental sites

	Forest	Urban
Weather	cloudy with intermittent rain	cloudy with intermittent rain
Ambient Temperature	19.9±2.1℃ (n=11)	25.7±0.7℃ (n=12)
Relative Humidity	92.7±6.6% (n=11)	77.3±4.6% (n=12)
Air Pressure	948.3±0.6hPa (n=3)	1014.5±0.8hPa (n=6)

Analysis

The electrocardiogram (ECG) was recorded with a 12-bit analog-to-digital converter at 1000 Hz (INTERFACE, CBI-3133A, Japan). Data of the R-R intervals in ECG were analyzed by the method of Lorenz plot to obtain the cardiac vagal index (CVI) and the cardiac sympathetic index (CSI) (4).

After termination of experiments, salivary samples were centrifuged at 1930 g for 15 min at 10 °C before being frozen at -30°C until determination. Cortisol (CT) and immunoglobulin-A (IgA) were measured by radioimmunoassay (RIA) and enzyme immunoassay (EIA), respectively.

Using time-blocks (before and after each condition)~~,~~ with the experimental site (forest and urban area) and subject as variables of the measurements, correlations of these variables were analyzed first by the three-way analysis of variance (ANOVA) followed by the multiple comparison test (Turkey's HSD). Differences where $p<0.05$ were considered statistically significant.

Results

In the morning, there were no significant differences on HR (F[1,10]=1.00), CVI (F[1,10]=1.39), CSI (F[1,10]=0.96), SBP (F[1,10]=1.49), DBP (F[1,10]=0.06) and IgA concentration (F[1,10]=1.93) between the 2 experimental sites. CT concentrations in the forest-site were significantly higher than those in the urban site (F[1,10]=6.86, $p<0.05$).

Three-way ANOVA performed on the cardiac vagal index revealed significant interactions of the experimental site with the time-block in the walking condition (F[1,10]= 5.00, $p<0.05$). CVI in the forest-site was significantly higher than that in the urban site before walking (Fig 2). The factor of the experimental site on DBP was not significant, albeit displaying a low p-value of 0.072 without statistical significance (F[1,10]=4.03), and a lower DBP in the forest-site was established (Fig 3). In the sitting condition, there were significant effects of the experimental site on HR (F[1,10]=4.03, $p<0.05$) and CVI (F[1,10]=5.00, $p<0.05$). A lower HR was obtained in the forest-site than those in the urban site (Fig 4) and CVI (Fig 5). CT concentrations in the forest-site were significantly lower than those in the urban site in the walking (Fig 6; F[1,10]=36.98, $p<0.01$) and the sitting conditions (Fig 7; F[1,10]=5.79, $p<0.05$).

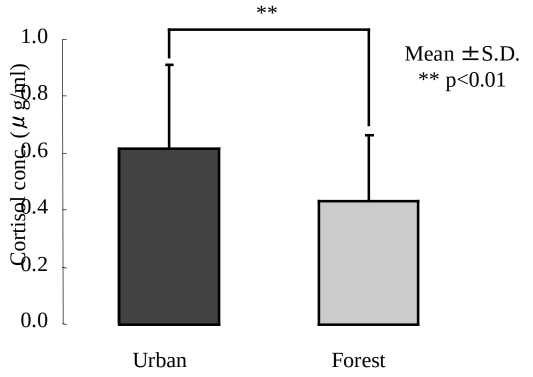

Fig 6. Cortisol Concentration (CT) in the walking condition

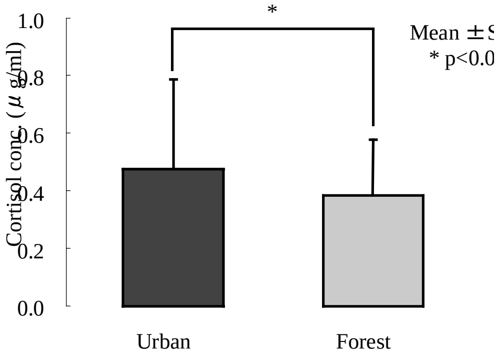

Fig 7. Cortisol Concentration (CT) in the sitting condition

Discussion

In this study, differences between the forest and the urban sites were observed on HR, DBP and CVI, although no differences on the physiological indices were noted in the morning. CT concentrations in the forest-site were significantly lower than those in the urban site, whereas a reverse tendency (i.e. higher CT concentrations) was observed in the forest-site in the morning. These findings suggest that physiological stresses were attenuated in the forest-site. Furthermore, these favorable physiological effects were obtained even without having to stay in the forest for long hours, because differences in the indices between the 2 experimental sites were obviously observed before walking and sitting.

Present findings could not have been caused by meteorological elements, as ambient temperature and air pressure were lower in the forest-site than those in the urban area. Given the fact that lower ambient temperature and lower air pressure activate the autonomic nervous functions, sympathetic tone might be expected to increase in the forest-site. Despite such obvious outcomes, there was no difference in CSI between the 2 experimental sites in this study.

This study provided novel quantitative findings on the favorable physiological effects of forest bathing. As the present experiment was endeavored in a site forested with Japanese cedar, factors other than the air could have contributed to the environment in inducing the favorable physiological responses. As the content of phytoncide is known to differ among the different types of trees, α-pinene, a phytoncide, might have selectively decreased the sympathetic tone of human subjects (5). Further studies on the environmental components affecting the physiological responses in the forest-site are warranted to further understand the relieving effects of forest bathing.

Acknowledgment

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EVALUATING THE LONG-TERM IMPACTS OF DEVELOPMENT WORK. CASE: COLD WORK AT FINNISH MARITIME ADMINISTRATION

Risikko Tanja[1], Remes Jouko, Hassi Juhani*

1 Rovaniemi Polytechnic, Rovaniemi, Finland
2 Oulu Regional Institute of Occupational Health, Oulu, Finland
3 Oulu University, Oulu, Finland
* corresponding author tanja.risikko@ramk.fi

Introduction

During the years 1999-2001 a development project for improving the occupational health and safety in cold work was carried out at Finnish Maritime Administration (FMA), an organisation of 1500 persons, 1000 of whom work at least part of their working hours outdoors. In the development project, FMA worked in co-operation with the experts of Cold Work Action Program of Finnish Institute of Occupational Health.

Methodology

A follow-up study was carried out in 2003-2004 to evaluate the longer-term impacts of the development work. First, a questionnaire was sent to FMA personnel, aimed to find out whether changes in occupational safety risks and cold-related adverse effects had occurred since the earlier questionnaire study (1999). The aim was also to examine if improvements in preventive actions against cold had taken place. Secondly, 22 persons from various maritime districts and positions were interviewed by using a structured interview form. The purpose of the interview was to collect more detailed information about the development activities after the project, and to evaluate the utilisation of the results of the project.

Results

The questionnaire was answered by 314 persons. 16% of the respondents were from Bothnia Bay Maritime District, which was the pilot group in the development work during the years 1999-2001. Compared with the earlier questionnaire study, there were no differences in cold-related adverse effects in their work environment. Nor were there differences between the answers from the Bothnia Bay Maritime District compared to the personnel from other maritime districts. According to 38% of the respondents, there have been improvements their cold protective clothing.

Discussion and Conclusions

The workers of the FMA were well informed about the development project. All 22 interviewed persons knew that a development project concerning cold work had been carried out in the organization. 20 interviewed persons had participated in the project. 21 persons felt that cold work is an important or very important issue to them. Immediate improvements were noted, such as clothing etc. Further implementation was done insufficiently, in some cases not at all. Big organizational changes, the lack of devoted persons, or the lack of financial resources were the most important reasons for poor implementation of results. The results suggest that more effort should be put into involving people into development work and into the further development actions after the project.

THE INFLUENCES OF BREATHING FREQUENCY ON BRAIN ACTIVITY

Sachiko Nagayoshi[1], Minoru Koriyama[1], Yeon-Kyu Kim[1], Jeong-Mi Lee[1], Ryuichi Uchikawa[1], Satsuki Matsumoto[2], and Shigeki Watanuki[1]*

[1] Ergonomics Laboratory, Department of Human Living System, Kyushu University, Fukuoka, Japan
[2] Sony PCL Inc., Japan
* corresponding author s-naga@rms.kyushu-id.ac.jp

Introduction

It is said that there are various diseases caused by daily stresses and that human body adapted to the ancient hunting-and-gathering life may become maladaptive states in modern artificial environments. So, our body might have constant tension, and it is necessary to reduce such stresses.

Although there are various ways to reduce stresses, most of them need much time, money, and some require special skills. We attend to voluntary regulation of breathing cycle as a way to reduce stresses easily. It is said that breathing center is closely connected to cardiovascular center. For example, the phenomenon that heart rate increases during inspiration and decreases during expiration (respiratory sinus arrhythmia; RSA) is known. Moreover, breathing muscles are voluntary muscles, and breathing cycle seems to be the easiest to control among some breathing factors (breathing cycle, tidal volume, and velocity of the inspiration etc.). It is also said that voluntary regulation of breathing is done in the brain cortex (4). Therefore, the influences of breathing frequency on brain activity were examined through EEG in this study.

Method

Subjects

Fifteen healthy male students (aged 20-24 years, mean 21.8) participated in the experiment. All subjects received credits for their participation. Informed consent was obtained from all of them in written form after the experimental purpose had been explained. All subjects were instructed not to smoke and consume any foods or beverages before two hours of the experiment.

Experimental Conditions

For the pacing conditions, visual metronome was used. The light of the experimental room was turned off during the experiment. During the rest condition, a black picture was displayed on the monitor.

Experimental Procedure

The subject, with scalp electrodes and breathing mask, was seated in a chair with his eyes open quietly. Spontaneous breathing was recorded for three minutes. Then, the subject was seated quietly for three more minutes. After that, he was instructed to breathe pacing the metronome. The pacing conditions were 0.16 Hz, 0.25 Hz, 0.33 Hz, and mean frequency of unpaced breathing (MFUB), each lasting three minutes.

Subjective Measure

After each pacing condition, the subject was asked about the accuracy of following the specific rhythm. Estimate was given on 7-point numeric scales with "0" indicating middle accuracy.

Physiological Measures

EEG was recorded from 19 electrodes in the International 10-20 System. Digitized EEG signal (sampling frequency: 256 Hz, High cut: 32 Hz, Low cut: 0.5 Hz) was stored for offline analysis using NEC digital encephalograph (SYNAFIT 5000).

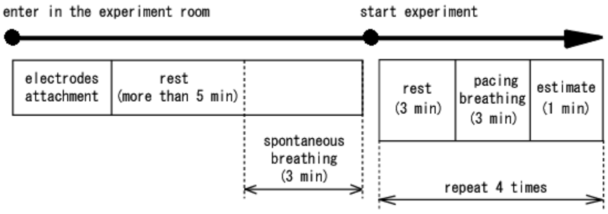

Figure 1. Experimental Procedure.

The data of the rest condition (3 min) and the pacing condition were analyzed by BIMUTAS Ⅱ(KISSEI COMTEC CO., Ltd.). 15 epochs without any artifacts were obtained from each breathing condition. A hamming window was applied to each 512-point segment, and the spectral densities of delta (2-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and Fm theta (6-7 Hz) were calculated using FFT (Fast Fourier Transform). Then, they were transformed to relative spectral densities.

It is said that phasic state changes in emotion result in shifts in anterior activation asymmetry (1-2). To examine if regulation of breathing is appropriate for relaxation, we examined anterior activation asymmetry by calculating the following indices about alpha and beta: (Fp1-Fp2) / (Fp1+Fp2), (F3-F4) / (F3+F4), (F7-F8) / (F7+F8), and (Fp1+F3+F7)-(Fp2+F4+F8) / (Fp1+Fp2+F3+F4+F7+F8). Each of Fp1 to F8 is the relative spectral density in the region.

Breathing activity was transduced by a respiratory flow meter (RF-2, Minato Medical Science Co., Ltd.). The analog signal was digitized at 100 Hz. The breathing frequency was determined by the maximum of the breathing power spectrum.

Statistical Analysis

Statistical analyses were performed for the physiological and subjective variables using SPSS 11.5J for Windows. The accuracy of following the specific rhythm, the comparison of the relative spectral densities at rest condition (baseline), the comparison between breathing frequencies, and the asymmetry of the brain activity were tested by means of an analysis of variance for repeated measures (ANOVA). The factor was a repeated-measures factor consisting of the pacing frequencies (0.16 Hz, 0.25 Hz, 0.33 Hz, and MFUB). If any statistical difference was obtained, Turkey's HSD test was performed.

Results

Pacing Accuracy

The breathing frequency of the subject was corresponded with that of the metronome in all four conditions. And the estimate of following the specific rhythm was almost constant in all conditions. So, it can be said that despite breathing frequency change, subjects were able to breathe pacing the metronome precisely.

Effects of breathing frequencies

1) Comparison between breathing frequencies

At first, we compared relative spectral densities at rest condition (baseline) of the four conditions (0.16 Hz, 0.25 Hz, 0.33 Hz, and MFUB). The ANOVA revealed the baseline was different in the C4 (delta, alpha), P4 (alpha, Fm theta), O1 (Fm theta), T5 (delta, theta), and T6 (alpha). So, we excluded the scalp sites from the comparison between breathing frequencies.

For the pacing conditions, significant differences regard to alpha in the Fp2 was obtained. Turkey's HSD test revealed that alpha decrease in the Fp2 was smaller at 0.16 Hz than 0.25 Hz and 0.33 Hz (Fig. 2).

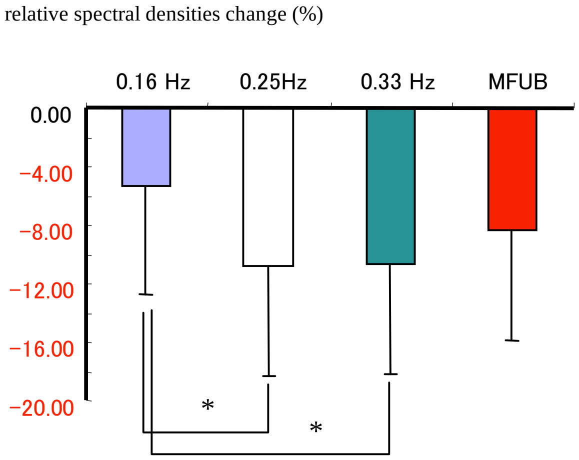

Figure 2. Alpha decrease in the Fp2.
'*' indicates that there are significant differences (p≦0.05).

2) The asymmetry of the brain activity

The asymmetry on brain activity was examined by calculating (Fp1-Fp2) / (Fp1+Fp2), (F3-F4) / (F3+F4), (F7-F8) / (F7+F8), and (Fp1+F3+F7)-(Fp2+F4+F8) / (Fp1+Fp2+F3+F4+F7+F8). (Fp1+F3+F7)-(Fp2+F4+F8) / (Fp1+Fp2+F3+F4+F7+F8) indicates total anterior asymmetry. No significant difference was obtained between breathing frequencies.

Discussion

It is said that phasic state changes in emotion result in shifts in anterior activation asymmetry (1-2). But, it was not seen any anterior asymmetry between breathing frequencies. In other words, if breathing frequency changed, the emotional state might not change. However, alpha in the Fp2 was affected by breathing frequency exceptionally.

Fm theta observed during mental task was not affected by breathing frequency. But there is a report that Fm theta increase is not seen about half of the subjects during mental task (3). Moreover, it is said that Fm theta activity is provoked when the subjects are relieved from anxiety (5). Therefore it is too early to say that breathing frequency did not induce attention and concentration.

In conclusion, breathing frequency might not be appropriate for relaxation because the anterior asymmetry observed during phasic emotional changes was not seen. However, it is necessary to examine whether phasic emotional change is also not seen in physiological responses in the future.

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ANTHROPOMETRY, COMFORT AND ERGONOMICS BASED DESIGN OF GLOVES FOR A WEARABLE KEYBOARD

Myoung sook Kwon[1], *Gi soo Chung*[2*], *Dae Hoon Lee*[3]

[1, 2, 3] Korea Institute of Industrial Technology, Seoul, Korea
* corresponding author gschung@kitech.re.kr

Introduction

A prototype of our wearable keyboard works by sensing finger movement so that a user can type in mid-air or a table without a keyboard to input data into personal assistant or other handheld device. It contains 6 motion sensors laid on the back of the hand in correspondence of each finger tracking movement; one sensor placed at the thumb, three sensors at other fingers and the other on the wrist. For a commercial success, the design of our wearable keyboard was improved by attaching it to gloves, especially for easy slip off and uses in both cold and warm environmental condition. However, gloves have been found to affect the effectiveness of hand performance, such as dexterity, task time and range of motion, adversely. Thicker gloves result in greater perceived discomfort. The extent of fit between the hand and gloves also influences on the performance considerably. Moreover, anthropometrical variation in hand size makes this glove-hand fit concern a very complex one. Therefore, it is very difficult to make the gloves for our wearable keyboard that satisfy all the factors of comfort and ergonomics.

Most of the existing research on the human hand can be classified into biomechanical studies, force distribution studies, pressure sensitivity studies and so on [1,2,3,4,5)]. Research has not been done much on the area of hand comfort.

The purpose of this study was to measure the hand size of Korean male and female and to make the gloves for our wearable keyboard that fit well to hands, based on these sizes. And another purpose was to design gloves based on physiological data on hand and textile comfort to reserve the desirable dexterity and comfort, optimizing the trade-off between performance and comfort to make final gloves for our wearable keyboard.

Methods

Posture Analysis

Subjects and methods. Four computer users, two males and females participated in this study. Their physical characteristics are shown Table 1. They were asked to do normal computer work (typing for 30 minutes and internet search for 30 minutes) for total 1 hr with naturally preferred postures of hands and arms wearing our wearable keyboard. Their postures of hands and wrist in these positions were tape-recorded and analysed.

Table 1. Subject Characteristics

No.	Sex	Age	Height (cm)	Weight (kg)
1	Male	22	168	72.8
2	Male	34	172	66.6
3	Female	24	158	52.9
4	Female	32	159	48.0

Measurement of Hand Sizes

Based on required sizes for gloves pattern making and decision of sensor locations, total 63 measurements of hand to be measured were selected. They are lengths, circumferences and widths of hand based on basic points. Their sizes were measured using callipers and a measuring tape. The hand sizes of total 264 subjects (male 132, female 132) were measured. They were all Korean. Since the size of hands doesn't change after 30's, we selected the group of people between 18 to 30 years old as our subjects. Their physical characteristics are shown in Table 2. Their hand sizes were assorted for size system of our ergonomics based gloves.

Table 2. Characteristics of subjects

	Male		Female	
	Height (cm)	Weight (kg)	Height (cm)	Weight (kg)
Mean	69.4	175	53.3	161.7
St.	10.5	4.4	6.6	4.8

Perspiration Rate Analysis on Hand

To develop a glove pattern with optimum comfort of hand, perspiration rates according to regions of hands were evaluated.

1. Subjects. Four computer users (same as above) participated in the test. Subjects were asked to do normal computer work (without mental stress) for one hour in environmental temp. 22℃, a comfortable condition for subjects. They were asked to put on a long cotton pants and long sleeve cotton T-shirt.
2. Methods. Filter papers (3x4cm) were attached on the back of the hand, forehead, fingers and palms of subjects (forehead 1, right hand 12, left hand 12, total 25). A vinyl sheet was covered on it and adjusted by using Thermal Tape (3M). The perspiration rates of the back and the palm of both hands (mg/12cm^2/hr) were compared by a weight difference of filter paper after one-hour computer work. Subjects put on cotton gloves and then latex gloves on it. Total perspiration amount of both hands (mg/hr) were measured by weight difference of cotton gloves and latex gloves before and after test. Total body perspiration rate (mg/m^2/hr) was calculated by body weight difference before and after test.

Results and discussion

Posture analysis

All subjects preferred the position with arms attached on a table to the position with arms not attached. This is because subjects felt fatigued due to load on arms for a long time.

All subjects posed a stretched arm position during the beginning period of test. As a test proceeds, all subject posed with arms bended toward upper part of the body. Therefore, hand postures in this position can be analyzed into two final postures, stretch and crouch type. They are shown in Figure 4.

Figure 4. Hand posture

For easy slip off, the pattern of final gloves should be designed to keep this three dimensional shape. And also for the comfort, the selection of textile and accessories is very important.

Measurement of hand size

Some of total 63 measurements (No. 1 to 20) for hand size are shown in Figure 6. Measurement No. 1 is total hand length. From measurement No. 2 to 5 are length of interval between fingers that are required to decide interval between fingers in glove pattern making. From measurement No. 6 to 19 are length of finger and knuckle that are needed to decide finger length in gloves pattern making. Measurement No. 20 is the length between wrist line and elbow line which is required to decide sizes of accessories.

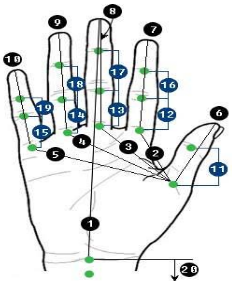

Figure 5. Measurement regions for hand size (No. 1 to 20)

Mean and standard deviation of measurements are shown in Table 3. These are the sizes that are used to make the medium size glove. We assorted glove size into 3 kinds; small, medium, large.

Analysis of Perspiration Rate on Hand

There was no big difference in perspiration amount between male and female. There was no big difference in perspiration amount between left and right hand, either.

Perspiration rate in the palm was larger than that in the back of the hand. A same tendency was shown in finger parts. In the back of hand, perspiration rate in its center was smaller than that in fingers. In palm, there was no difference in perspiration amount between its center and finger part. In fingers, perspiration rate of thumb was largest and that of middle finger was smallest. Figure 6 shows individual perspiration rates according to hand regions during computer work.

Table 3. Mean and standard deviation of measurement (No 1 to No 20)

Measurement No.	Male (cm)		Female (cm)		Measurement No.	Male (cm)		Female (cm)	
	Mean	St.	Mean	St		Mean	St.	Mean	St
1	19.3	0.8	17.7	0.8	11	2.5	0.4	2.3	0.3
2	5.7	0.6	4.8	0.5	12	2.3	0.2	2.2	0.2
3	7.1	0.6	6.1	0.5	13	2.6	0.2	2.4	0.2
4	8.1	0.6	7.1	0.5	14	2.3	0.2	2.1	0.2
5	9.2	0.6	8.0	0.5	15	1.8	0.2	1.6	0.2
6	5.8	0.6	5.2	0.5	16	2.2	0.2	2.1	0.2
7	7.2	0.4	6.6	0.4	17	2.6	0.2	2.5	0.2
8	8.0	0.4	7.4	0.4	18	2.4	0.2	2.3	0.2
9	7.5	0.4	6.8	0.4	19	1.7	0.2	1.6	0.3
10	6.0	0.6	5.4	0.4	20	27.2	1.3	14.4	1.2

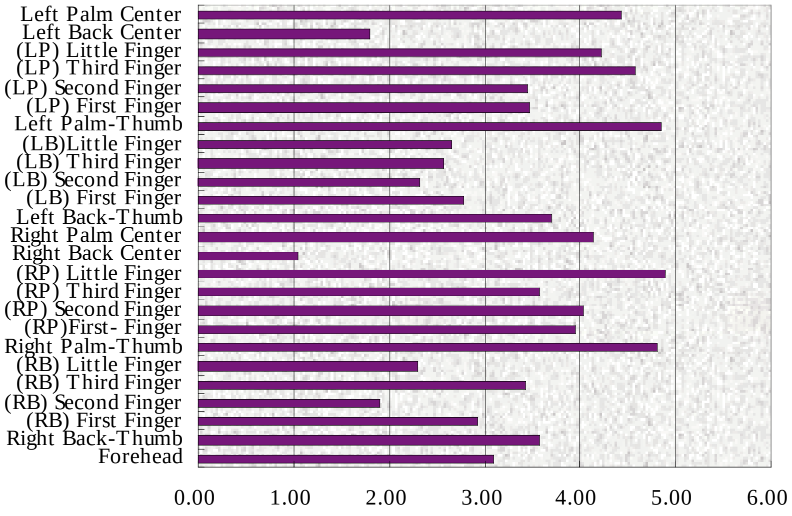

Figure 6. Perspiration Rate (mg/2.25m^2/hr)

Pattern Making and Glove Design

Based on posture analysis and hand sizes, two kinds of medium size patterns (stretch, crouch type) for male and female were made. We laid out 10 kinds of glove design with these patterns with reference to perspiration data.

Conclusions

The intent of this study was to design anthropometry, comfort and ergonomics based gloves for our wearable keyboard.

We measured the hand size to make size system of gloves. Total 63 measurement regions were required to make hand pattern and to decide the location of sensors. Hand postures that are preferred during using our wearable keyboard were analyzed into two final postures, stretch and crouch type. We designed patterns to keep gloves as three-dimensional postures (stretch and crouch type) even at the condition of take off. Perspiration rate in the palm was larger than that in the back of the hand. Therefore, a wearer will feel comfortable wearing the gloves which has more open space the palm. Final gloves pattern were designed based on physiological data on hand and fabric comfort to preserve the desirable dexterity and comfort, optimizing the trade-off between performance and comfort. Total 10 final gloves were designed. Final gloves' performance and comfort were not evaluated will be studied in next research. More investigation is needed on the relationship between comfort and function.

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AGE-RELATED DIFFERENCES IN SWEAT LOSS AND FLUID INTAKE DURING SUMMER BASEBALL PRACTICE

Yoko Kajiwara [1], Masami Hirashita [2], Saburo Yokokura [3], Shinichiro Ono [4], Seiichi Nakai [5]*

[1] The Faculty of Education, Bunkyo University, Japan
[2] Department of Social welfare, Kinjyo University, Japan
[3] Material Science Research Center, Meisei University, Japan
[4] Department of Natural Science Studies, Maizuru National College of Technology, Japan
[5] Department of Food and Nutrition, Kyoto Women's University, Japan
* corresponding author kajiwara@koshigaya.bunkyo.ac.jp

Introduction

The dehydration resulting from a large amount of sweating during sports activities in a hot environment increases the workload of thermoregulatory responses and cardiovascular system1,2,3), which could decrease the athletic performance4,5) and increase the incidence of heat disorders. According to studies on heat disorder during sports activities in Japan, the incidence was highest during baseball practice, and the mortality rate of heat disorder was high6,7). Recently, an increasing number of elementary schoolchildren in the growth stage have become involved in sports activities, and the age of children participating in these activities is becoming lower. Since the circulatory function and thermoregulatory in response to exercise and heat in children is lower to those in adults8), and since global warming and heat island phenomena will become severer in the future, heat disorder in children may increase. Therefore, sufficient countermeasures against heat disorder are required. Studies on the environmental conditions and thermoregulatory responses during baseball practice in summer have mainly focused on university and high school students9), and there have been few studies on schoolchildren and junior high school students. It has been reported that fluid intake is important to prevent heat disorders, as it inhibits excessive hyperthermia and dehydration. However, few studies have reported sweat loss and fluid intake in junior athletes.

In this study, we monitored environmental temperature, and measured sweat loss, fluid intake and tympanic temperature during summer baseball practice in elementary schoolchildren, junior high school students, high school students and university students to investigate the age-related features of thermoregulatory response.

Methods

Table 1 shows physical characteristics of the subjects. A survey was conducted during a summer camp, and wet-bulb globe temperature (WBGT), total sweat rate, fluid intake, tympanic temperature, and

Table 1. Physical characteristics of subjects.

Paramaeters	Children (n=29)	Junior high students (n=19)	High students (n=27)	University students (n=15)
Aeg	**11.34±1.31**	**13.68±0.75**	**15.52±0.51**	**20.07±0.80**
Height(cm	**140.08±9.82**	**158.53±6.83**	**173.33±4.84**	**170.86±3.88**
Body weight kg	**37.74±10.16**	**50.92±7.22**	**63.81±6.51**	**63.96±5.90**
BMI	**18.68±2.89**	**20.22±2.29**	**21.24±2.07**	**21.81±1.93**
BSA(m^2)	**1.187±0.191**	**1.473±0.124**	**1.71±0.10**	**1.700±0.083**
BSA/Body weight(cm^2/kg)	**322.99±35.39**	**288.67±18.91**	**269.52±14.35**	**267.49±13.08**

Values are means±SD. BSA : Body surface area ,BMI : body mass index,Children : elementary schoolchildren, Junior high students : junior high school students, High students : high school students

practice time were measured 4 times. Total sweat loss (TSL) was calculated from body weight values before and after practice and fluid intake using the following formula: TSL = (body weight before practice + fluid intake) – body weight after practice. In comparing total sweat loss, total sweat rate per body surface area and per hour (TSR: $g/m^2/h$) was calculated, since the practice time and subject's physical characteristics differed. Furthermore, the percentage of total sweat loss to initial body weight (%TSL) was calculated using the following formula: %TSL (%) =TSL/ body weight before practice × 100. For fluid intake (g), a sports drink containing sodium was stored at 8°C, and given *ad libitum*. As the subject's physical characteristics varied, the percentage fluid intake volume to total sweat loss was calculated using the following formula: %FIV=fluid intake/TSL × 100. The % dehydration rate (%DHR) was calculated using the following formula: %DHR (%) = (body weight before practice – body weight after practice)/body weight before practice × 100. Tympanic temperature (T_{ty}) was measured using a infrared tympanic thermometer immediately before and immediately after practice and during practice.

Statistical analysis, the comparison among 4 groups was performed using one-way analysis of variance (ANOVA). Pearson's correlation coefficient was used for the evaluation of the correlation. The acceptance level for significance was $p < 0.05$ and all results are expressed as mean ± SD.

Results and discussion

In this study, factors such as the duration of practice, exercise intensity, and environmental conditions could not be controlled because of the limitations of a field survey.

Table 2 shows the number of subjects, practice time, WBGT, TSL, TSR, %TSL, FIV, %FIV and %DHR during each baseball practices time. Figure 1 shows the mean value of TSR, %TSL, and %FIV during the entire practice period among 4 groups. TSR of university students(US) were significantly higher than those of elementary schoolchildren(ES), junior high school students(JS) and high school students(HS) (US 359.6±115.8 > HS 303.4±139.1·JS 283.7 ±76.1 ES 272.6

Table 2. Variables associated with sweat loss and fluid volume in elementary school children, junior high school students and high school students during baseball practices.

Subjects	No. of exercises	( )	WBGT ( )	Time (h)	TSL (g)	TSR (g/m2/h)	%TSL (%)	FIV (g)	%FIV (%)	%DHR (%)
Children	No.1	29	27.5	3.41	1052.8±286.17	265.1±63.53	2.93±0.79	869.0±270.06	84.35±20.35	0.50±0.66
	No.2	29	23.9	2.81	964.4±262.60	302.3±83.81	2.75±0.87	729.2±230.20	77.13±22.98	0.76±0.60
	No.3	29	25.3	3.11	922.1±395.14	245.2±88.66	2.46±0.86	416.9±191.10	49.73±26.00	1.36±0.73
	No.4	15	25.2	4.18	1501.1±300.05	282.4±53.90	3.63±0.88	844.4±197.59	56.75±10.47	1.61±0.67
Junior high students	No.5	19	27.5	3.41	1504.7±365.49	300.5±62.75	2.98±0.68	931.6±285.39	62.55±15.36	1.11±0.48
	No.6	19	23.4	3.93	1336.3±222.07	232.8±31.05	2.65±0.40	339.0±107.59	25.83±8.35	1.95±0.39
	No.7	19	25.4	2.73	1424.7±357.05	353.4±79.83	2.80±0.68	648.4±295.92	46.36±18.56	1.56±0.64
	No.8	19	25.1	4.33	1497.8±410.81	237.9±64.24	2.99±0.90	597.8±308.36	40.80±24.83	1.82±0.63
High students	No.9	27	28.1	2.58	1480.0±444.42	332.8±97.58	2.30±0.65	790.4±164.16	58.91±26.07	1.05±0.83
	No.10	27	27.4	2.50	1499.4±697.43	352.4±168.04	2.30±1.19	984.6±537.14	67.84±22.28	0.83±0.59
	No.11	26	26.2	3.50	1244.5±663.06	207.3±106.71	2.44±1.17	985.8±585.30	87.18±49.18	0.41±0.83
	No.12	26	30.0	2.80	1567.1±1124.88	338.3±223.80	2.56±1.68	1279.3±846.68	69.82±50.70	0.53±0.90
University students	No.13	12	24.3	3.00	1872.7±652.92	363.1±123.31	2.86±0.93	900.0±171.23	54.52±23.08	1.47±1.03
	No.14	15	26.2	3.00	1536.9±459.10	303.2±87.81	2.44±0.67	729.2±322.86	49.01±22.46	1.27±0.59
	No.15	15	26.5	3.00	1595.7±500.01	314.6±94.00	2.51±0.68	684.3±278.31	46.37±22.02	1.43±0.81
	No.16	15	27.0	3.00	2347.7±534.31	461.7±93.83	3.70±0.66	1320.8±484.54	56.31±18.58	1.64±0.76

Values are mean values or means±SD. Time : time of the baseball practice, TSL : total sweat loss, TSR : total sweat rate, %TSL : percentage of total sweat loss to initial body weight , FIV : fluid intake volume, %FIV : percentage of fluid intake volume to TSL, %DHR: dehydration rate,Children : elementary schoolchildren, Junior high students : junior high school students, High students : high school students.

±78.4, US vs. HS: $p<0.05$, US vs. JS: $p<0.001$, US vs. ES: $p<0.0001$). However, there was no significant difference in TSR among 3 groups. WBGT in HS were significantly higher than those in ES, JS and US. However, %TSL of HS was significantly lower than those of ES, JS and US (HS 2.29±0.92·< JS 2.88 ±0.67 US 2.87±0.88 ES 2.85 ±0.91, HS vs. US ES: $p<0.01$, HS vs. JS: $p<0.001$). %FIV (%) of JS was significantly lower than those of ES and HS (JS 42.91±20.29·< ES 61.89 ±33.25 HS 70.37±39.66, JS vs. ES: $p<0.01$, JS vs. HS: $p<0.0001$), and %FIV (%) of US was significantly lower than those of HS (US 51.34±21.29·< HS 70.37±39.66, US vs. HS: $p<0.01$). Figure 2 shows the correlation between FIV and TSL. FIV tended to increase with increases in TSL. FIV was less than TSL and % FIV was extremely low in ES, JS and US.

%DHR (%) of JS and US was significantly higher than that of ES and HS (JS 1.62±0.61 US 1.45±0.79 > ES 0.96±0.79 > HS 0.72±0.79, JS vs. ES: $p<0.01$, HS vs. JS US: $p<0.0001$, HS vs. ES: $p<0.01$, US vs. ES: $p<0.01$). During the entire practice period, 2% or more dehydration was

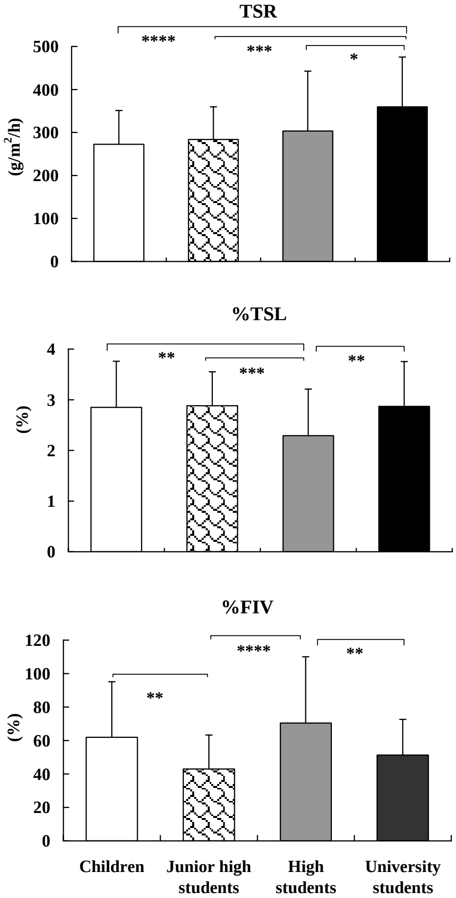

Figure . Total sweat rate (TSR: g/m2/h), the percentage of total sweat loss to initial body weight (%TSL),and the percentage of fluid intake volume to total sweat loss(%FIV) during the entire practice period in children (n=102), junior high school students(n=76), high school students(n=106), and university students(n=57).*:$p<0.05$,**:$p<0.01$,***:$p<0.001$,****:$p<0.0001$

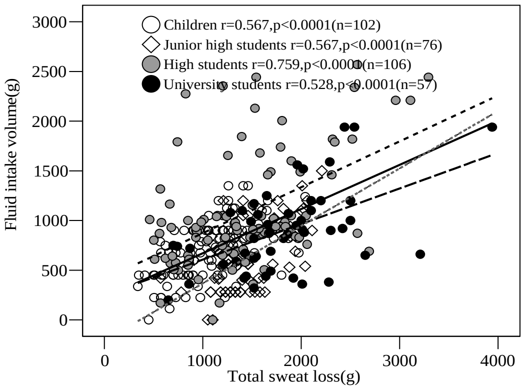

Figure2. Relationship between fluid intake volume and total sweat loss.

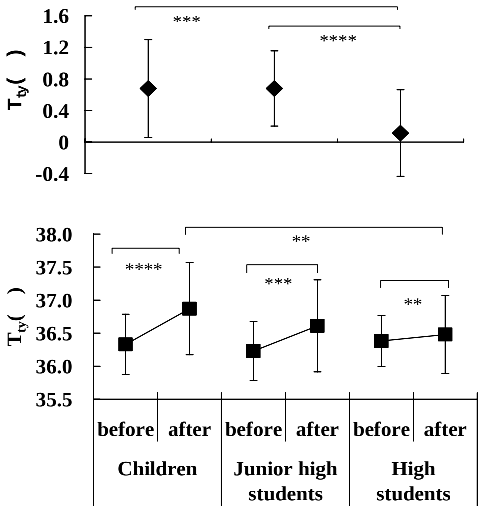

Figure3. Changes in tympanic temperature (T_{ty}) before and after baseball practice during the entire practice period in children (n=102), junior high school students (n=76), and high school students (n=106) (except for university students). **: $p<0.01$, ***: $p<0.001$, ****: $p<0.0001$

observed in 8% of ES, in 25of JS and in 28% of US. This cause is to with a small amount of fluid intake during baseball practices. Figure 3 shows T_{ty} of before and after baseball practice. T_{ty} after practice was significantly higher than that before practice in 3 groups. ΔT_{ty} of ES and JS was significantly ($p<0.001$ or $p<0.0001$) higher than that of HS. In addition, T_{ty} after practice in ES was significantly higher than that in US ($p<0.01$). There were positive correlations ($p<0.0001$) between WBGT and tympanic temperature (T_{ty} after practice and ΔT_{ty}) of ES and JS. WBGT tended to increase with increases T_{ty}.

The incidence of death from heat disorder during school activities between 1975 and 1999 in Japan was 127. The number was the highest during baseball practice (31 students)$^{6,7)}$. Recently, increases in death caused by heat during sports activity have been reported$^{10)}$. It has been reported that worsening of the thermal environment is a factor involved in the high incidence of death caused by heat in the past 10 years$^{10)}$.

Humans do not supply water naturally lost when they sweat, this phenomenon has been known as involuntary dehydration$^{11)}$. According to the guidelines for the prevention of heat disorders during sports activities established by JASA$^{6)}$, an aim of fluid intake recommends 80% from 70% of body weight loss by sweat. However, the mean value of %FIV was 62% in ES and 43% in JS, suggesting that involuntary dehydration cannot be prevented even when a sports drink is given *ad libitum* to schoolchildren such as junior high school students$^{1)}$. This was not consistent with the results reported by Inoue et al$^{8)}$. Therefore, it is necessary to make children more aware about the importance of fluid intake.

In conclusion, to prevent heat disorders during sports activities in children and junior high school students (junior athletes), only encouraging them to drink liquids periodically is insufficient, and they should be instructed to aggressively increase the frequency of fluid break, shorten the practice time, and reduce exercise intensity in accordance with WBGT.

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COMPARISON BETWEEN PREDICTIONS OF A NUMERICAL THERMAL MANIKIN MODEL AND EXPERIMENTS UNDER SOLAR RADIATION

*Kazuhiko Matsunaga*1), *Mai Anamizu*1), *Yoshiichi Ozeki*2) , *Toru Takabayashi*3)
*and Shin-ichi Tanabe*4)

1) EE & Vehicle Control Dept., Isuzu Motors Ltd., Japan
2) DAPT, Asahi Glass Co., Ltd., Japan
3) Fabricated Glass General Div., Asahi Glass Co., Ltd., Japan
4) Department of Architecture, Waseda Univ., Japan
* corresponding author kazuhiko_matsunaga@notes.isuzu.co.jp

Introduction

Evaluation of thermal comfort in vehicles has been discussed on ISO/DIS-14505 (1). It is based on the measurements of the thermal manikin in the experiments. However, a numerical simulation method which is combined the radiation models and CFD (Computational Fluid Dynamics) with the numerical thermal manikin model including the algorithm of control system of thermal manikin is considered to be suitable for the evaluation of the thermal comfort (2). In this paper, prediction results by the numerical thermal manikin model are compared with measurements by the thermal manikin in the truck cabin in the conditions of IR(infrared)-cut glass and solar reduction glass (coated) under solar radiation, which indicates the possibility of substitution for the evaluation of the thermal manikin in the experiments.

Measurements in vehicle

A hot wind tunnel is utilized for the reproduction of the summer hot conditions. A truck cabin with the thermal manikin (Mette) at the assistant side (left side of the seat) is conducted (3). Indoor climate such as indoor air temperature and surface temperature on the interior of cabin, and wind tunnel conditions such as outside air temperature, humidity and solar radiation on the roof are measured. The skin temperature, heat loss and equivalent temperature of the thermal manikin are also measured. Two types of glass (IR-cut glass and functional solar reduction glass (coated)) for the windshield are equipped for the comparison. Detailed test conditions are arranged in Table 1. In this condition, the thermal manikin received direct solar lamp's radiation through the windshield and sidelite.

The air temperature in the interior of the cabin and the surface temperature of a component are shown in Figure 1. The equivalent temperature obtained by the thermal manikin is shown in Figure 2. In this paper, the steady state data at the end of the cooling-down at the speed of 40 km/hr after soaking the truck cabin under the solar lamps is used for the analysis. IR and LEW indicate IR-cut glass and solar reduction glass, respectively. Surface temperature on the body part where solar radiation reaches in the case of the solar reduction glass is slightly lower than the case of the IR-cut glass. No significant difference is found in the air temperature in two cases. However, slight difference is found in the equivalent temperature obtained by the thermal

Table 1. Test conditions

(a) Wind tunnel condition

Outside Air Temperature	35 (C)
Solar Radiation	814 (W/m^2)
Humidity	70 (%)
Load Temperature	50 (C)

(b) Test pattern

Soak	1 hour |
Coolingdown	4th 40km/hr : 40 min. | 5th 80km/hr : 20 min. | idle : 30 min.

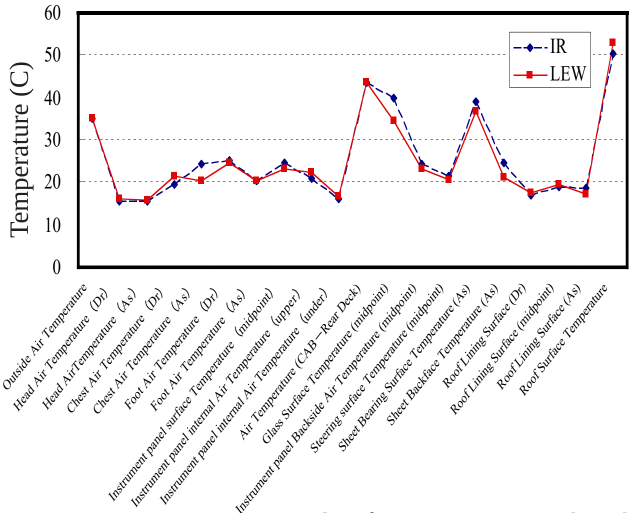


Figure 1. Air temperature and surface temperature in the cabin

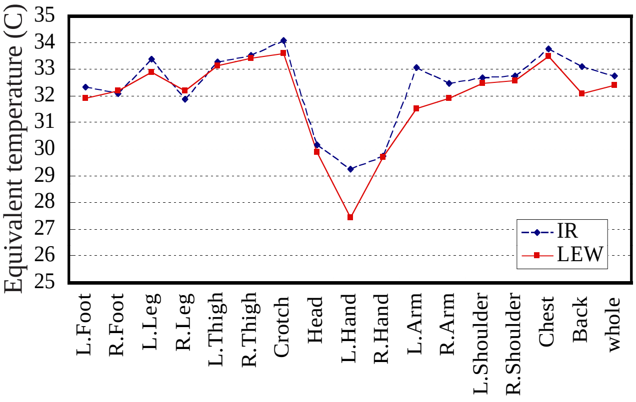


Figure 2. Equivalent temperature by the thermal manikin

manikin in the whole body and each body part although they are both functional glass. It is noted that the equivalent temperature by the thermal manikin is suitable for the comprehensive evaluation of the thermal environment in the cabin under solar radiation.

Comparison between numerical predictions by a numerical thermal manikin model and measurements by the experiment

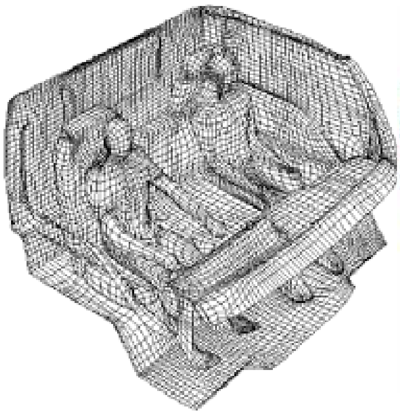
The skin temperature, heat loss and equivalent temperature predicted by a numerical manikin model are compared with measurements at the end of the cooling-down under the solar lamps. In general, a numerical thermal manikin model is based on a comprehensive combined analysis with thermoregulation model within a human body, radiation models including thermal radiation and solar radiation, and CFD. The skin temperature, heat loss and equivalent temperature is derived by the heat balance on skin surface of the thermal manikin which consists of convection, thermal radiation, solar radiation and heat loss inside the thermal manikin. Since there are many unknown factors such as prediction accuracy of surface temperature on the interior of the cabin, air temperature and air velocity in the cabin, and convective heat transfer coefficient at the skin surface of the thermal manikin, and geometrical accuracy such as truck cabin and thermal manikin in this situation, differences between predictions and measurements are difficult to investigate. This paper focuses on the performance of the numerical control algorithm of the thermal manikin in equation (1) for applying to the thermal manikin in the cabin as a first step to the numerical thermal manikin (4),(5).

$$T_{sk_i} = 36.4 - 0.054 Q_{t_i} \tag{1}$$

For this purpose, surface mesh model inside the truck cabin including the thermal manikin is generated based on the CAD model as shown in Figure 3. Equation (1) is applied to each surface mesh. Air temperature and body surface temperature are given by the measurements instead of both CFD analysis and heat balance on the body surface of the cabin. Incoming solar radiation to the surface of the thermal manikin from the lamps is predicted numerically taking into account the directional characteristics and the spacial extinction of each lamp's emission whose validities are confirmed in reference (6). However, since convective heat transfer coefficients at the skin surface of the thermal manikin are unknown, they are calculated based on the steady heat balance on the skin surface of the thermal manikin by the numerical simulation of solar radiation and thermal radiation combined with measurements of air temperature, surface temperature in the cabin and heat loss of the thermal manikin in equation (2) (note 1).

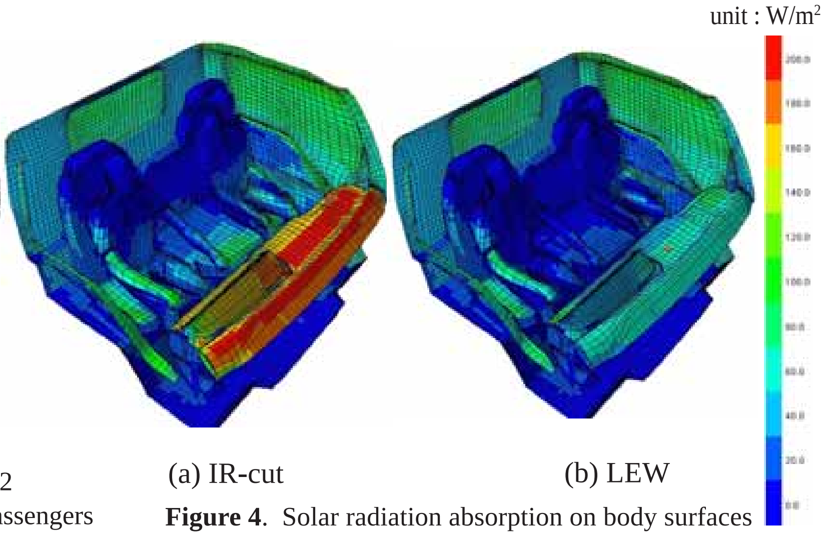
$$\alpha_{c_i} = (Q_{t_i} + Q_{r_i(net)} + Q_{s_i}) / (T_{sk_i} - T_{in_i}) \tag{2}$$

Figure 4 shows the distributions of solar radiation absorbed on body surfaces in the conditions of IR-cut glass and solar reduction glass. Solar radiation mainly reaches the l_thigh, l_hand and pelvis parts of the thermal manikin, and significant difference of the solar radiation absorbed is found on the instrument panel in two cases. Figure 5 shows the calculated convective heat transfer



Number of surface mesh : 21552

Figure 3. Truck cabin model with passengers



(a) IR-cut (b) LEW

Figure 4. Solar radiation absorption on body surfaces

coefficients at skin surface of thermal manikin with equation (2). They are averaged figures in each body part which are calculated in each surface mesh. Convective heat transfer coefficient at head, shoulder and hand parts of which air velocity from air-conditioner is large is calculated large. Convective heat transfer coefficients at hand parts are asymmetric because of the asymmetry of the position of the outlet. Figure 6 and Figure 7 show the results of the comparisons of skin surface temperature and heat loss from the skin surface between predictions and measurements, respectively. They are also averaged figures in each body part which are calculated in each surface mesh. Predictions and measurements in the skin surface temperature and heat loss meet quite well each other except the r_thigh part in the case of the solar reduction glass. Skin surface temperature and heat loss of the body part can be predicted with enough accuracy by the averaged convective heat transfer coefficient of each body part and the numerical control algorithm in equation (1). Figure 8 shows the result of the comparison of equivalent temperature between predictions and measurements. Predictions and measurements in the equivalent temperature also meet well except the r_thigh part in the case of the solar reduction glass. However, it must be noted that the combined heat transfer coefficient h_{cal}, determined during calibration in a standard environment, is important factor for the calculation of the equivalent temperature. It must be determined how to calibrate the combined heat transfer coefficient h_{cal} in the numerical thermal manikin in each situation. In addition, further research might be required for the prediction accuracy of air temperature, surface temperature and convective heat transfer coefficient at skin surface, appropriate shape of the thermal manikin in the numerical thermal manikin.

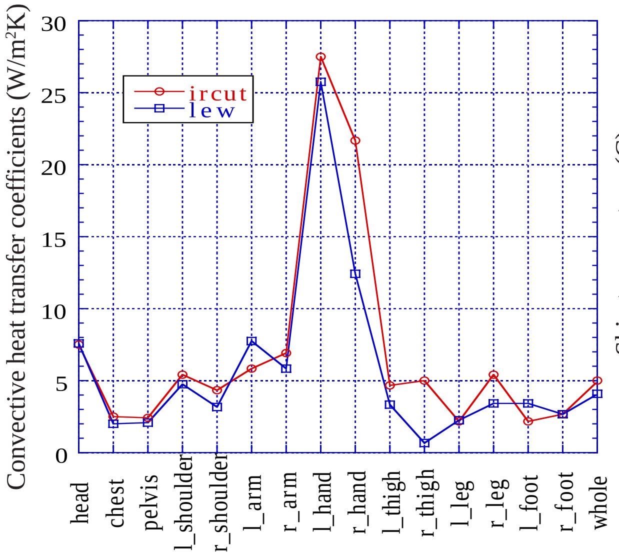


Figure 5. Convective heat transfer coefficients at skin surface of thermal manikin

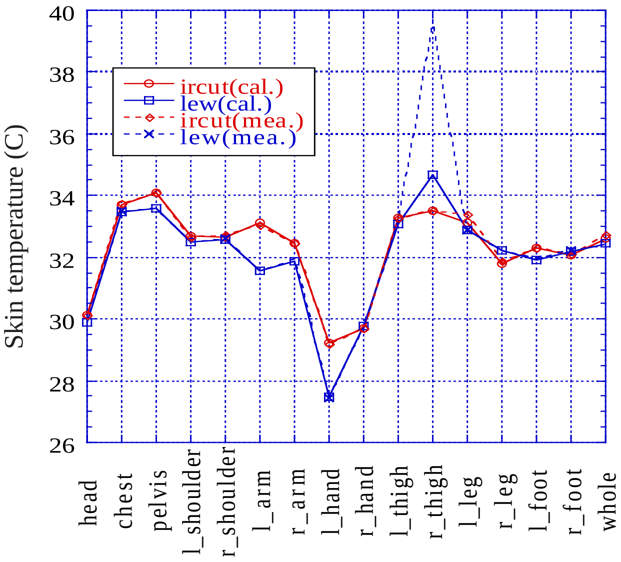


Figure 6. Comparisons of the skin temperature between predictions and measurements

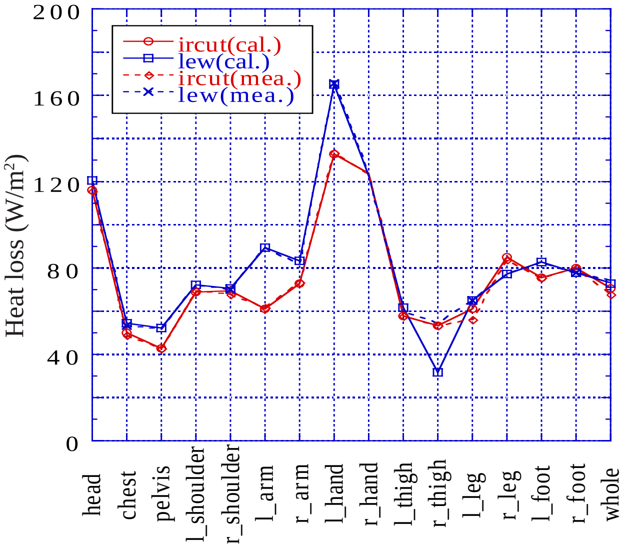


Figure 7. Comparisons of the heat loss between predictions and measurements

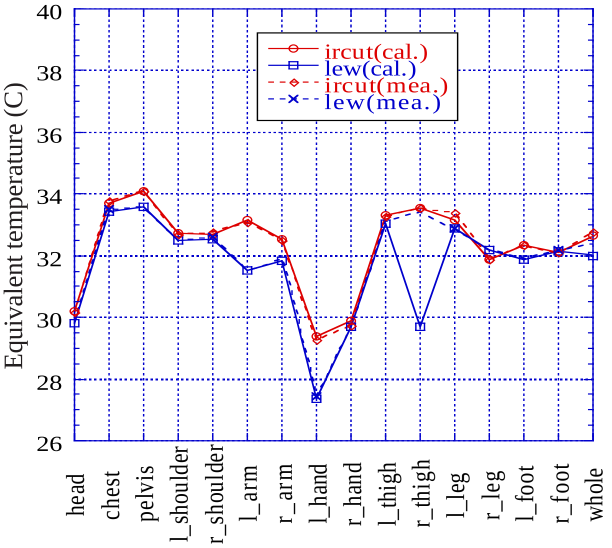


Figure 8. Comparisons of the equivalent temperature between predictions and measurements

CONCLUSIONS

1) Prediction results by the numerical thermal manikin model are compared with measurements by the thermal manikin in the truck cabin in the conditions of IR-cut glass and solar reduction glass under solar radiation.
2) The equivalent temperature by the thermal manikin is suitable for the comprehensive evaluation of the thermal environment in the cabin under solar radiation.
3) Skin surface temperature and heat loss of the body part can be predicted with enough accuracy by the averaged convective heat transfer coefficient of each body part and the numerical control algorithm inside the thermal manikin which is applied to each surface mesh ($T_{sk_i} = 36.4 - 0.054Q_{t_i}$).
4) Equivalent temperature can be predicted with enough accuracy. However, the calibration method of the combined heat transfer coefficient h_{cal} must be determined for the calculation in the numerical thermal manikin in each situation.

NOTE

1) Thermal radiation absorbed at the i-th skin surface $Q_{r_i(net)}$ is derived by the angle factors between the i-th skin surface of the thermal manikin and each body surface of the cabin, and each surface temperature. Reference air temperature corresponding to the i-th skin surface T_{in_i} is derived by interpolating air temperature measured vertically. Validities of the thermal radiation absorbed and solar radiation absorbed at the i-th skin surface are confirmed in references (7), (8).

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NOMENCLATURE

Q_{t_i} : heat loss from the i-th skin surface, $Q_{r_i(net)}$: thermal radiation absorbed at the i-th skin surface, Q_{s_i} : solar radiation absorbed at the i-th skin surface, Q_{c_i} : convective heat transfer at the i-th skin surface, T_{sk_i} : the i-th skin temperature, T_{in_i} : reference air temperature corresponding to the i-th skin surface, α_{c_i} : convective heat transfer coefficient at the i-th skin surface.

GENDER DIFFERENCES BETWEEN MEN AND WOMEN RECRUITED FOR COMBAT TRAINING UNITS

DS. Moran[1], R. Evans[2], R. Yanovitch[1], Y. Cohen-Sivan[1], S. Berlin[1], G. Khomenok[1], A. Finestone[1], N. Constantini[1], D. Merkel[1], E. Israeli[1]

[1]Heller Institute of Medical Research, Sheba Medical Center, Tel Hashomer, Israel, [2]US Army Research Institute of Environmental Medicine, Natick, MA, USA.

Purpose

To compare anthropometric and physiological measurements of new recruits, male and female, for an integrated combat unit.

Methods

98 females and 34 males (19±1yr) participated in this study. Volunteers were candidates for a 4-month basic training course in a combat integration unit. All volunteers underwent anthropometric and physiological measurements that included body weight (wt), body mass index (BMI), % fat, maximum oxygen consumption (VO_{2max}), quadriceps force (QF) and hemoglobin (Hb).

Results

Significant differences ($P<0.05$) between genders are depicted in the table below.

	wt* (kg)	BMI ($kg\cdot m^{-2}$)	Fat* (%)	VO_{2max}* ($ml\cdot min^{-1}\cdot kg^{-1}$)	QF* (au)	Hb* (g/dl)
Women (±SD)	60.6±10.8	23.0±3.3	24.8±3.1	38.0±6.5	58.2±21.3	12.8±1.3
Range	42.6-94.8	16.2-31.9	17.1-31.6	23.9-50.5	10.1-110.2	7.8-14.6
Men (±SD)	67.7±11.3	21.8±3.0	18.8±4.4	53.2±5.8	136.1±17.0	15.2±0.9
Range	50.8-102.1	17.3-30.2	8.9-25.8	38.3-63.0	90.1-148.0	13.5-17.2

*$P<0.05$

Conclusions:

Anthropometric and physiological advantages for male volunteers may allow for better performance of physical tasks in an integrated combat unit. Based on these results, it should be determined if changes in physical training can narrow or eliminate this gender gap. If significant gender gaps still exist following training interventions, a selection process and longer training program for women entering an integrated combat unit might be considered, taking into account baseline fitness measures. Finally, further medical assessment should be used to identify individuals who would benefit from treatment for marginal iron deficiency or other conditions that affect performance.

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INFLUENCE OF NEONATE’S BODY POSITION WITH AND WITHOUT A PLASTIC BLANKET ON BODY HEAT LOSS ASSESSED FROM A THERMAL MANNEQUIN

KHALID BELGHAZI (*)*, LAURENT GHYSELEN, ELMOUNTACER BILLAH ELABBASSI, BOUCHRA AGOURRAM AND JEAN-PIERRE LIBERT*

DMAG EA 3901- INERIS, Faculté de Médecine, Université de Picardie Jules Verne, 3 rue des louvels,
F-80036 Amiens Cédex, FRANCE.
(*) Email : khalid.belghazi@u-picardie.fr

INTRODUCTION

The present study aimed at assessing the net gain of body heat storage induced by a transparent plastic blanket draped over small premature neonates in the prone and the supine positions. Thermal stress is particularly important in premature and small-for-gestational-age infants characterized by high values of the ratio between skin surface area and body mass, the greater this ratio, the greater the body heat exchanges. The large skin permeability enhances body water loss. The risk of hypothermia is particularly increased at birth and during operations on naked neonates implying opening of the canopy (surgical operation, blood sampling and gastric aspiration). In the first day of life, the rate of evaporation can reach 100 $g.h^{-1}.m^{-2}$ in very preterm infants. To prevent the large amount of water loss it is sometimes recommended to cover the neonate with a plastic blanket. In closed incubator Fanaroff et al.(3) pointed out that a transparent plastic heat shield reduces the insensible water loss of 44 % in low birth weight neonates lower than 1250 g and postnatal age less than 10 days. For postnatal age greater than 10 days, the magnitude of this reduction was only 19 %. Bell et al.(2) also reported that the addition of a heat shield in an incubator decreased the water loss by 10 % in infants with mean birth weight of 1570 g. However the efficiency of this solution which depends on the physical environment but also on the inter individual difference in the ability to exchange heat with the environment remains questionable and the use of a plastic blanket is still a controversial topic.

The total heat loss of premature infants depends on various factors such as gestational age, nutritional state, mean skin temperature, body hydromineral balance, vigilance state, metabolic rate and of the postnatal age which modifies the skin keratinisation. Thus, it is difficult to obtain homogeneous data base that takes into account all these factors and there are conflicting data on the effectiveness of plastic blanket. To rule out these confounding factors we use a sweating mannequin the advantage of which is that it measures directly the total heat loss with the environment without interference with these factors.

METHODS

· *Mannequin:*

The multisegment anthropomorphic, sweating mannequin (Belghazi et al.)(1) represents a small-for-gestational-age newborn with a body surface area of 0.086 m^2 and a simulated birth weight of 900g (Fig 1). It was cast in copper and painted matt black (surface emissivity = 0.95). Temperatures at various points of the outher surfaces were measured by attached thermistors (CTN siemens 10 kΩ at 25 °C, precision ± 0.1 °C after calibration) protected from radiant energy by an aluminium foil patch. To take into account the regional thermal heterogeneity of the surface, each segment was separately heated to reach a set point temperature. The temperature of the surface of the head was set to 36.4 °C, the trunk to 36.6 °C and the upper and lower limbs to 33.3 and 35.5 °C, respectively. These values corresponded to those currently recorded for neonates nursed at thermoneutrality in closed incubators.

· *Simulation of sweating*:

Contrary to most models found in the literature which only assess dry heat exchanges, the present mannequin can simulate skin water loss. A black cotton stocking water was tightly held onto the surface so as to eliminate any air trapped between the fabric and the mannequin surface.

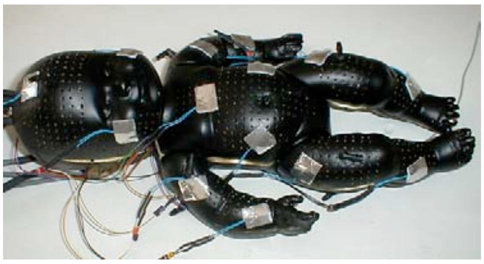

Fig.1: Thermal mannequin lying on the mattress of the incubator

A pumping system was used to supply water to the mannequin surface (i.e. simulated skin hydration). It consisted of two peristaltic pumps (MS-CA 4 cassettes, B32089, 40 rpm and Mini-S 3 canaux, B32067, 40 rpm) which were designed for transferring water with a high degree of speed stability and a low pulsation level. Each pump consisted of a rotor with rollers pressing a flexible tube: the water was thus pumped by a peristaltic effect.

The mannequin's segments (head, trunk, two lower limbs, two upper limbs) were separately supplied with water.

Preliminary trials have shown that to perform water evaporation close to the level observed at birth, the mass of water supplied to the nude mannequin could be 4.1 g and 12.5 g (evaporative rates from the mannequin's surface of 117 $g.h^{-1}.m^{-2}$ and 244 $g.h^{-1}.m^{-2}$, respectively). The ratio between these measured evaporative rates and the maximal evaporation recorded for a fully wetted surface (352 $g.h^{-1}.m^{-2}$) corresponds to the surface wettednesses about 30 % and 70 %, respectively. To reach these levels of skin wettedness over each segment, the mass of water supplied was 1.3 g and 4 g for the head, 0.8 g and 2.4 g for the trunk, 0.6 g and 1.8 g for each lower limb and 0.4 g and 1.2 g for each upper limb.

At thermal equilibrium the heat exchanges between the mannequin and the surrounding (expressed in W) can be described by the body heat balance equation:

$$P = \pm K \pm C \pm R - E$$

The heating power (P) supplied to the mannequin balances the total heat losses by conduction (K), convection (C), radiation (R) and evaporation (E).

EXPERIMENTS

The experiments were performed to simulate the first day of life during which skin water loss is very high. The mannequin was lying in a relaxed supine or prone position on a mattress in a single-walled, convectively heated incubator for intensive care or outside the apparatus to simulate surgical operations. The air temperature was 33 °C, air humidity 50 %, air velocity 0.02 $m.s^{-1}$ in the incubator and 25 °C, 50 %, 0 $m.s^{-1}$ outside the apparatus. In each experimental condition the mannequin was nude or covered by a flexible plastic blanket (except the head and an upper limb).

RESULTS AND DISCUSSION

The heat loss from the whole mannequin under the various experimental conditions and the changes in mean body temperature ΔT_b due to the covering are shown in table 1

ΔT_b (in $°C.h^{-1}$) was calculated from the equation of body heat storage $\Delta S = m_b \times C_p \times \Delta T_b$ (where ΔS is the body heat storage increase induced by the placement of the plastic blanket in W, m_b is the mass of the tissues in kg, C_p is the approximate specific thermal capacities of body tissues in 1 $W.kg^{-1}.°C^{-1}$).

For the covered mannequin, statistical analysis showed that the body position did not significantly modify the heat loss from the whole mannequin inside or outside the incubator whatever the level of the surface wettedness. On the contrary, for the nude mannequin, the total heat loss was significantly reduced (*P* < *0.0001*) by the prone position in all the experimental conditions.

As expected lower heat powers are required to maintain a thermal equilibrium where the mannequin was covered by the plastic blanket. The reduction of heat loss was significant (*P* < *0.0001*) in all experimental conditions. Covering the mannequin prevents a fall of mean body temperature ranging from 3 to 13 °C.h^{-1}. The plastic blanket is particularly efficient where the mannequin was placed outside the incubator and for high levels of surface wettedness.

Table.1: Total heat loss from the mannequin in the different experimental conditions.

		Total heat loss (W)			
	Wettedness surface(%)	Supine position		Prone position	
		Nude	Covered	Nude	Covered
Inside incubator	30%	15.0±0.7	10.1±0.4	12.9±0.9	9.7±0.4
	70%	20.4±0.3	11.2±0.3	17.3±0.4	10.8±0.2
Outside incubator	30%	23.5±0.3	16.8±0.2	20.5±0.5	16.4±0.3
	70%	31.5±0.5	19.5±0.5	28.8±0.4	18.8±0.7

CONCLUSION

The present data points out that this simple device night be useful in very preterm small for gestational age neonates to avoid sudden body hypothermia in the first hours after birth particularly in situations during which large amounts of water can be loss during surgical operations implying the opening of the canopy.

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