Evaluating Swedish soldiers’ physiological demands in combat

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2022



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# Evaluating Swedish soldiers' physiological demands in combat

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DOCTORAL DISSERTATION

Doctoral dissertation for the degree of Doctor of Philosophy (PhD) at the Faculty of Medicine Lund University to be publicly defended on 30th of May, 2022 at 1.00 p.m, in room 2005/2007, Department of Medical Imaging and Physiology, Skånes University Hospital, Carl-Bertil Laurells gata 9, 205 02 Malmö

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LUND UNIVERSITY
Department of Translational Medicine

Author(s) Jonas Larsson

**Document name**
DOCTORAL DISSERTATION

**Date of issue** 2022-05-30

Sponsoring organization

**Title and subtitle**
Evaluating Swedish soldiers' physiological demands in combat – a model for development of physical employment standards

**Abstract**
The Swedish Armed Forces have not performed any physical work demands analysis with different physical requirements for different duties or tasks. This is important in order to avoid discrimination based on sex, age or anthropometric measures. The overarching aim of this thesis is to describe and understand physical job demands for ground combat soldiers in the Swedish army with a specific focus on identifying and evaluating a potential model to identify physically demanding tasks, and thus define appropriate limits for the soldier's physical employment standards.

Different methods were used to evaluate the physiological demands for Swedish soldiers. First a questionnaire was developed and evaluated in focus groups. This survey was distributed to 231 soldiers, of whom 165 responded (71%). Based on these results, a study protocol was developed to assess the physiological demands during combat field exercises. Next, we investigated the impact of combat gear and body armor (CB) on pulmonary ventilation, the cardiovascular system, and muscle oxygen delivery-utilization. In addition, we assessed whether tests performed in light training clothes can be used interchangeably to predict maximal aerobic uptake when wearing CB. Finally, data from real-time training was collected from soldiers while conducting urban operations and retrograde in rough terrain to provide an understanding of the physiological demands of soldiers' performed work.

The results revealed that, regardless of sex, soldiers´ perception of the most physically demanding tasks contain elements of lifting and carrying, which requires muscular strength and muscular endurance. Data from the graded treadmill test revealed that wearing CB decreased the time to exhaustion, lowered $\dot{V}O_{2peak}$ and minute ventilation ($\dot{V}_E$). The $\dot{V}O_2$ and HR relationship showed a cardiorespiratory reduction wearing CB vs. NL (no load). During submaximal intensities, HR was up to 25% higher with CB compared to NL, with an increase in oxygen uptake ($\dot{V}O_2$). These demands of increased $\dot{V}O_2$ were met by an increased $\dot{V}_E$, with increased breathing frequency ($f_b$) and lower tidal volume ($V_T$). Power output was reduced at the ventilatory threshold (women 50% and men 36.7%) in CB condition but less at the respiratory compensation threshold (men 15% and women 18%) with no difference between sexes. Muscle oxygen delivery-utilization data showed a greater decrease in m. vastus lateralis in both conditions for men, but a similar deoxygenation between sexes at peak exercise. Data from real-time training exercises revealed that the soldier's cardiorespiratory system is highly affected in the military. The soldiers worked between 15-33% of the mission time close to 40% of their $\dot{V}O_{2max}$. Soldiers performed few sprints at high intensity (>2 $m \cdot s^{-1}$) with mean accelerations ~4.9 accelerations/min. There was a positive correlation between $\dot{V}O_{2peak}$, accelerations and $m \cdot min^{-1}$.

In conclusion, this thesis reveals that it is feasible and practical to use a questionnaire to collect data on which tasks are perceived as the most physically demanding. Quantitative data demonstrates that tests of aerobic capacity wearing light training clothes should not be used to estimate energy expenditure from HR measured while wearing CB. The data also suggests that entry tests and physical employment standards for soldiers should be based on input from actual training field exercises. The results from this thesis can be used in the development of physical employment standards targeting Swedish soldiers.

**Key words**

Classification system and/or index terms (if any)

Supplementary bibliographical information

**Language English**

**ISSN** 1652-8220

**ISBN** 978-91-8021-247-2

Recipient's notes

**Number of pages** 94

Price

Security classification



Signature

Date 2022-04-22

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Cover photo by Försvarsmakten & Johanna Åkerberg Kassel



Faculty of Medicine
Department of Translational Medicine

ISBN 978-91-8021-247-2
ISSN 1652-8220

Printed in Sweden by Media-Tryck, Lund University, Lund 2022

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*Never venture, never win*

*(Sun Tzu)*

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# Abstract

The Swedish Armed Forces have not performed any physical work demands analysis with different physical requirements for different duties or tasks. This is important to avoid discrimination based on sex, age or anthropometric measures. The overarching aim of this thesis is to describe and understand physical job demands for ground combat soldiers in the Swedish army with a specific focus on identifying and evaluating a potential model to identify physically demanding tasks, and thus define appropriate limits for the soldiers' physical employment standards.

Different methods were used to evaluate the physiological demands for Swedish soldiers. First a questionnaire was developed and evaluated in focus groups. This survey was distributed to 231 soldiers, 165 of whom responded (71%). Based on these results, a study protocol was developed to assess the physiological demands during combat field exercises. Next, we investigated the impact of combat gear and body armor (CB) on pulmonary ventilation, the cardiovascular system, and muscle oxygen delivery-utilization. In addition, we assessed whether tests performed in light training clothes can be used interchangeably to predict maximal aerobic uptake when wearing CB. Finally, data from real-time training was collected from soldiers while conducting urban operations and retrograde in rough terrain to provide an understanding of the physiological demands of soldiers' performed work.

The results revealed that, independent of sex, soldiers´ perceptions of the most physically demanding tasks contain elements of lifting and carrying, which requires muscular strength and muscular endurance. Data from the graded treadmill test revealed that wearing CB decreased time to exhaustion, lowered $\dot{V}O_{2peak}$ and minute ventilation ($\dot{V}_E$). The $\dot{V}O_2$ and HR relationship showed a cardiorespiratory reduction wearing CB vs. NL (No load). During submaximal intensities, HR was up to 25% higher with CB compared to NL with an increase in the oxygen uptake ($\dot{V}O_2$) required to carry the added weight. These demands of increased $\dot{V}O_2$ were met by an increased $\dot{V}_E$, with an increased breathing frequency ($f_b$) and lower tidal volume ($V_T$). Power output was reduced at ventilatory threshold (women 50% and men 36.7%) in CB condition but less at the respiratory compensation threshold (men 15% and women 18%), with no difference between sexes. Muscle oxygen delivery-utilization data showed a greater decrease in m. vastus lateralis in both conditions for men, but a similar deoxygenation between sexes at peak exercise. Data from real-time training exercises revealed that the soldier's cardiorespiratory system is highly tasked in the military. Soldiers work between 15-33% of mission time close

to 40% of their $\dot{V}O_{2max}$. Soldiers performed few sprints at high intensity (>2 $m \cdot s^{-1}$) with mean accelerations ~4.9 accelerations/min. There was a positive correlation between $\dot{V}O_{2peak}$, accelerations and $m \cdot min^{-1}$.

In conclusion, this thesis reveals that it is feasible and practical to use a questionnaire to collect data on which tasks are perceived the most physically demanding. Quantitative data demonstrates that tests of aerobic capacity wearing light training clothes should not be used to estimate energy expenditure from HR measured while wearing CB. The data also suggests that entry tests and physical employment standards for soldiers should be based on input from actual training field exercises. The results from this thesis can be used in the development of physical employment standards targeting Swedish soldiers.

# List of papers

**I**. Larsson J, Dencker M, & Olsson. M. C & Bremander A. Development and application of a questionnaire to self-rate physical work demands for ground combat soldiers. *Applied Ergonomics*, 83, 2020.

**II.** Larsson J, Dencker M, & Bremander A. & Olsson. M. C. Cardiorespiratory responses of load carriage in female and male soldiers. *Applied Ergonomics*, 101, 2022.

**III.** Larsson J, Dencker M, & Bremander A. & Olsson. M. C. Effect of combat gear and body armor on gas exchange, oxygen delivery and tissue deoxygenation in male and female soldiers during incremental exercise. *In manuscript.*

**IV.** Larsson J, Bremander A. & Olsson. M. C Dencker M. Physiological demands and characteristics of movement during simulated combat. *Manuscript submitted for publication.*

# Abbreviations

| | |
|---|---|
| 95 % CI | 95% Of confidence interval |
| ANOVA | Analysis of variance |
| $\beta$ | Regression coefficient |
| BM | Body mass |
| BMI | Body mass index |
| Bpm | Beats per minute |
| CB | Combat gear + body armor |
| cm | Centimeters |
| ES | Effect size (Cohens) |
| $f_b$ | Respiratory rate |
| $f_{bpeak}$ | Peak respiratory rate |
| GXT | Graded exercise test |
| HR | Heart rate |
| $HR_{max}$ | Maximal heart rate |
| Kg | Kilogram |
| L | Liter |
| min | Minute |
| mL | milliliter |
| mmol/L | Millimoles per liter |
| NL | No Load (light training clothes) |
| RER | Respiratory exchange ratio |
| RPE | Ratings of perceived exertion |
| SD | Standard deviation |
| $\dot{V}CO_2$ | Carbon dioxide output |
| $\dot{V}_E$ | Minute ventilation |
| $\dot{V}_{Epeak}$ | Peak minute ventilation |
| $\dot{V}O_2$ | Oxygen uptake |
| $\dot{V}O_{2max}$ | Maximal oxygen uptake |
| $\dot{V}O_{2peak}$ | Peak oxygen uptake |
| $V_T$ | Tidal volume |
| $V_{Tpeak}$ | Peak tidal volume |

# Preface

I have always been interested in human anatomy and physiology although I choose another path in the beginning of my career: I became an officer in the Swedish army. Eventually I began my studies in sport and exercise science with a focus on human performance. The physical demands in the military and premature discharge were of interest to me early in my career. I was keen to understand the physical demands on soldiers. My interest in research started at Halmstad University, where I finished my master's degree in Sports and Exercise Science – Human Performance in 2013. In May 2016, I was accepted into the PhD-program. I also continued to work as an officer during my PhD studies.

My first encounter with research within the military was when I aided another PhD student with her work in 2004. At that point, I had not thought about being a researcher and a PhD student. But looking back now, I have gained a lot of experience. After having developed a study protocol, constructed a questionnaire, followed 42 soldiers during 4 different combat exercises, I have gained a much deeper understanding of the physical demands on soldiers. Foremost, I have gained experience of science during these years. I am delighted that I had the opportunity to develop and run an entire research project from beginning to end in my PhD-project. I have had the opportunity to present my research at several international conferences, attended many courses and lectured, which has all served to sharpen and deepen my research skills. I have met colleagues within the same research area from all around the world, hopefully allowing future collaborations. I sincerely hope that I can continue with research in the future. PhD-studies are challenging, but also an exciting journey in life, and it is my belief that the experiences and knowledge that I have gained from this thesis are in many ways unique.

# Context of this thesis

This PhD-project was carried out within the Clinical Physiology and Nuclear Medicine research group, Faculty of Medicine, Lund University. The project has been pursued in direct dialogue with the Swedish Armed Forces. Close collaboration also has been established with the Human Movement Lab, Halmstad University. Knowledge about models to conduct physiological work demand analysis and validate physical employment standards was limited within the Swedish Armed Forces at the start of this project in 2016.

I was accepted as a PhD-student in 2016, and in collaboration with my supervisors Magnus Dencker, Charlotte Olsson and Ann Bremander, I designed the research project Evaluating Swedish soldiers' physiological demands in combat. Related Injury and Illness in Paralympic Sport Study (SRIIPSS). I first conducted a survey study where I designed and distributed a questionnaire to 231 ground combat soldiers within the Swedish Armed Forces. Based on the results from this survey, a study protocol for collection of data from a field combat exercise was developed and described. A study protocol was then developed in collaboration with Halmstad University to evaluate whether data from unloaded $VO_{2peak}$ testing could be used interchangeably for soldiers wearing combat gear and body armor. Finally, data on cardiorespiratory response and movements during combat in different terrains was collected. I have developed the project plans, research questions, developed the questionnaire, performed the data analyses and written the manuscripts for all of the studies in this PhD-project, all in close collaboration with my supervisors. I have also written the applications to the Regional Ethical Review Board, completed all compulsory PhD courses and an additional six elective courses and presented my research at three scientific conferences, applied for external grants and lectured at the School of Business, Innovation and Sustainability, Halmstad University.

To the best of my knowledge, this is the first project within the Swedish Armed Forces that performed a physical job demands analysis and assessed the soldiers´ perceptions of demanding tasks. The results from this thesis could serve as a starting point for greater knowledge of job demands analysis and physical employment standards within the Swedish Armed Forces.

# Introduction

The job of being a soldier is, and has always been, very physically demanding. Roman legionaries were trained to march 20 miles in five summer hours carrying a load of about 27 kg, which is equivalent to the load of today's soldiers approach march. [1] The amount and weight of a soldier's personal combat equipment has been raised increasingly throughout history. In the 18th Century, soldiers generally did not carry more than 15 kg of personnel equipment, with extra materiel mostly handled by auxiliary transports. [2] The modern soldier carries equipment (backpack, webbing, and rifle) weighing between 40-60 kg, a burden up to as high as 60% of their body mass. [3, 4] The physical strain of the modern soldier is varied among the different branches since the military forces are more specialized today. Some branches are not physically demanding at all, while others need a high physical capacity to carry out their objectives. [5] These demands are the foundation for testing and physical training within the military services. Even if today's soldiers have access to motorized transportation, the success of military operations is often dependent on mobility and the ability of soldiers to carry their own equipment. Therefore, it is necessary for soldiers to achieve and maintain a certain level of physical capacity and fitness. [6] Personnel with inadequate physical work capacity necessary for carrying their own equipment and combat gear increase their susceptibility to physical fatigue or injury, which in turn can jeopardize the success of the mission. [7] Studies have shown that the risk of physical fatigue increases when the average intensity exceeds the metabolic equivalent of 40%, [8] or 50%, [9] of a person's maximum oxygen capacity ($\dot{V}O_{2max}$). To avoid fatigue, it is important to establish the physical demands for different work tasks encountered by combat forces. [10, 11]

**Physical demands** refer to duration and level of physical exertion required to perform critical tasks. Physical demands in operational environments as well as physical performance and fitness have been identified as important priority research areas, suggesting that these critical areas need more attention. [12] The definition of **physical activity** is any movement that the skeletal muscles produce and results in energy expenditure and can be measured in kilocalories. In everyday life, physical activity can be categorized into occupational, sports, conditioning, household, or other activities. [13] **Physical fitness** includes different components, but the most frequent components evaluated in military personnel are aerobic capacity, muscular strength/power/endurance and body composition. The degree of physical fitness can be measured by specific tests. [13] During mustering, the prospective soldier who has a fitness level below the minimum standard might be excluded from conscription. During military service, a soldier who does not meet standards might be given a chance to reach the necessary fitness level after a period of relevant physical training**. Physical training** is a subcategory to physical activity: it is planned, structured, and the goal is improvement or maintenance of physical fitness. [13] Within the military, physical training is important, not only for those soldiers who do not pass the test, but also to prepare soldiers for the battlefield.

This thesis explores soldiers’ experiences of physiological demands during combat. In addition, it serves as a foundation for future development of a work demand analysis to develop work-specific physical employment standards. These standards could be used both during mustering and annual physiological testing. The following chapter introduces what is already known about mustering and selection tests in Sweden. Existing knowledge on job demands analysis and physical employment standard also is presented. Hence, this thesis starts with a review of the development from the Swedish allotment system to conscription.

# Background

## From the Swedish Allotment System to the Swedish Defense Conscription and Assessment Agency

> Krigsman skall frukta Gud och vara Konungen huld och trogen. Han skall med nit och trohet uppfylla alla de plikter, honom i tjänsten åläggas, samvetsgrant och efter bästa förmåga verkställa mottagna befallningar och föreskrifter samt vid alla tillfällen iakttaga ett värdigt och rättskaffens uppförande. Hans oavlåtliga strävan skall vara att väl bereda sig för krigets värv. Vid ofred skall han mot rikets fiender sig städse manligen och väl förhålla samt med liv och blod Konung och Fädernesland försvara.
> [14] Krigsmans erinran 1887 till 1966.

Recruiting men and more recently women for military service and conscription has a long history in Sweden. The allotment system came to replace the costly method of renting mercenaries from the time of the reign of King Karl XI in 1682. The allotment system, with its constant staffing as a personnel supply system, aimed to keep "the largest possible army at the lowest possible cost". [15] The system ensured that one or several farms merged to form rustholds and roots that were responsible for either a rider, soldier or boatman whom they paid and gave a soldier's croft and some land to cultivate. Each officer was given a farm and a salary. This created the conditions for all counties in Sweden to set up a regiment. Sweden could not afford to pay an entire army of soldiers during peacetime, but it needed to be able to gather large numbers of soldiers during war. The economic problem was solved by the allotment system being paid for by the peasants and serving as their tax to the state [15]. In the 19th Century, mustering was very different from what it looks like today. The most well-known soldier is perhaps Gustav Karlsson, a character in Swedish author Vilhelm Moberg's novel of the same name, who managed to be selected as a soldier [16] (s 42).

> Du ä en rask gosse du! sa han [kapten Jägerschiöld]. Va ska du ha för soldatnamn nu igen, du? Jo, just Rask ska du heta! Det namnet passar bra för dej – dä blir ett bra namn, det! Så hade nu drängen Gustav Karlsson blivit soldaten nummer 32 Rask vid Konga kompani av Kung. Kalmare regemente (…)

Criticism of the allotment system was raised during the second half of the 19th Century. In other parts of Europe, militaries had developed into large armies with conscripts, which also created pressure for Sweden to do the same. [15] The issue became important for the Swedish parliament, where the idea of conscription as a "national defense" was connected to the voting rights issue. After the Swedish parliament voted in favor of general conscription, the allotment system ceased. General conscription applied to men between 21 and 40 years of age. They underwent a simple physical body examination and were asked a set of personal questions. Decisions on placement were made by a special enrollment board chaired by a regimental officer. [17]

In 1968, the Swedish parliament voted to form the Swedish Conscription Agency. In connection with this, enlistment was extended to two days to accommodate new medical, physical and psychological tests. The physical tests consisted of muscle strength (hand grip, elbow, and knee stretch) and were performed in the so-called muscle chair (Figure 1). In addition, a cardiovascular fitness test was performed on a test ergometer bicycle and begins with a sub-maximum test that lasts for five minutes (Figure 4), followed by a graded test to maximum effort. [17]

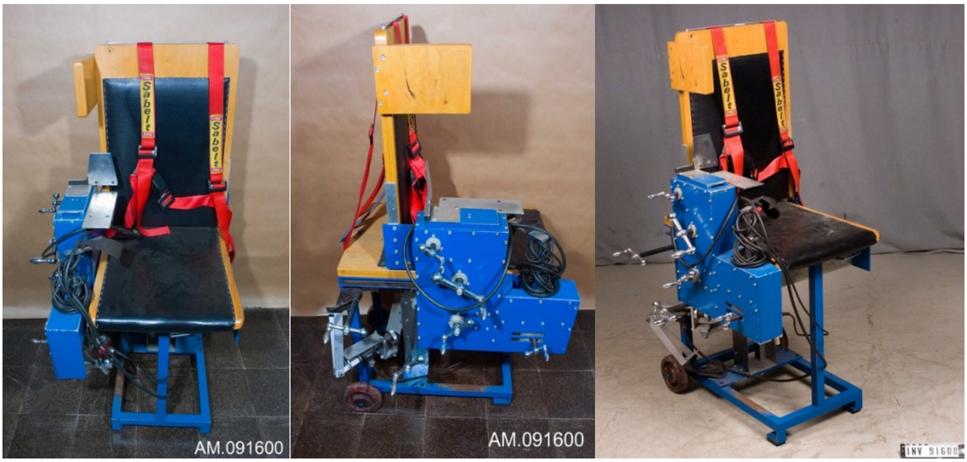


**Figure 1.** Chair used for muscle strength measurement during mustering in Sweden. © Armémuseum:

In 1980, women were allowed to enlist in the Swedish Air Force. In 1983, women were also permitted to enlist in the Swedish army and navy, and from 1989 there have been no obstacles to female conscription regardless of role. [18] The amendment to the law from 1995, [19] meant that men were obliged to enlist, have their personal circumstances investigated and serve in the total defense. In 1995, after questions were raised about the muscle chair’s relevance to job demands as it was unable to measure back strength or coordination, the muscle chair was replaced by the ISOKAI-test. In the ISOKAI-test (Figure 3), a test with a constant speed, the resistance increases in relation to the test person's strength. [20]

From 2007/2008, a web-based suitability survey was added as an initial selection step. Based on the results, the most suitable were called up for mustering, cutting the number of people called up for mustering to 16,803 people in 2007, compared with 41,720 in 2006 (SOU 2008;98 p13).[21 18] In 2010, the Swedish parliament voted in favor of the new direction for the Swedish national defense. Thus, in 2010, compulsory military service was abandoned and replaced by a new voluntary service for both sexes, which changed how the Swedish Armed Forces recruited their personnel. In 2017, compulsory military service was reinstated for both sexes, alongside voluntary service. In the new military service organization, a new basic military training, called GMU (e.g., basic military training), was introduced. GMU is a three-month-long compulsory basic military training necessary for applying to the Swedish Armed Forces and must be supplemented with further training.[22] From 2016, the Swedish Armed Forces introduced military training called GU ny (e.g., basic training). In this new concept GU is followed by a supplemented training period of 9-11 months in the army depending on the soldier's job description.

# Swedish current conscription system with mustering and selection tests

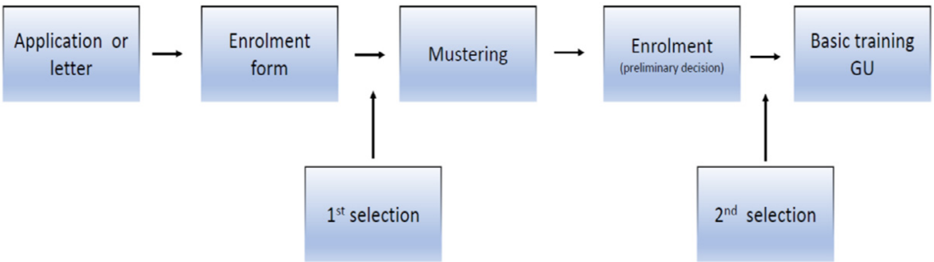


**Figure 2**. schematic picture of mustering process.

When a Swedish citizen turns 18, they receive a letter from The Swedish Defence Recruitment Administration. The process (Figure 2) starts with an internet-based survey (enrollment form) with questions about health, physical status, personality, lifestyle, level of education, social life, personality, attitude, and interest in different posts in the Swedish Armed Forces. If an applicant is assessed as suitable, he/she is called to The Swedish Defense Recruitment Administration for an admission test, which consists of a theoretical test, medical tests and physical tests. The physical examination consists of different physical tests such as strength and work rate tests where results are graded on a 1-9 scale where 9 is the highest and correspond to the requirements of a position. Muscular strength is measured in an isokinetic test (ISOKAI) during a simulated work-related heavy lift. The test consists of two attempts with two pulls each. After the first attempt, the mean force is calculated in Newton of the whole pull, and the mean value results of two pulls in Newton are divided into a 9 graded scale. [20]

**Figure 3**. ISOKAI-test ©Emil Malmborg

The physical work capacity measures qualifications individually and is measured by a cycle ergometer test starting with a five-minute, submaximal test with an added load from 75-175 watts depending on bodyweight, and with a progressively increasing load, 25 watt per minute, until exhaustion. A formula for calculating the result is used which reads maximum measured value in watts divided by bodyweight times a correction factor 0,64 (Wmax/kg×0,64). The result is graded and then compared with the requirements for different positions.

**Figure 4**. Cycle ergomete- test ©Emil Malmborg

Other criteria for selection to admission for basic military training are, for example, medical fitness for service and psychological capacity tests. [23] To date, there is a question whether the tests and their grading are relevant to the demands of the different job descriptions in the Swedish Armed Forces. Because no work demand analysis for different work areas and posts have been conducted, it is possible that the criteria for selection could be invalid. [23] If the applicant passes the test and is offered a place at basic training (GU), there are additional strength, endurance and swim tests for more demanding work areas such as ranger or paratrooper. The individual applicants' physical capacity in relation to the physical demands during basic military training is one of several factors that are decisive for managing the service. [24] In Sweden, the physical demands on the soldiers during conscript training is yet to identified. [20]

# Military service and selections tests in other countries

Around the world, nations have military forces. The recruitment to military service varies based on the country's laws. In some nations, there is a conscription system. Most compulsory service is for adult males. However, 11 nations have compulsory service for women. In Israel, Eritrea, Mali, Morocco, North Korea and Tunisia they conscript women as part of universal military service schemes, while Benin, Cape Verde, Mozambique, Norway and Sweden have selective service systems that encompass men and women. [25] Only Norway and Sweden have a gender-neutral conscription system, where men and women are conscripted and serve on equal terms. [26] Some nations with armed forces do not conscript their personnel (e.g., most NATO and European Union states). In these countries, volunteers either perform a physical entry test (Table 1) or a test after initial training to get a pass and further employment.

**Table 1.** Examples of physical pre-enlistment tests.

| Country | Type | Aerobic test | Strength test | | Note |
|---|---|---|---|---|---|
| British Army | Role Fitness Test | 1.2 mile run below 11.30 | The medicine ball throw<br>At least 2.7 meters | The mid-thigh pull.<br><br>50 kg or more | https://www.army.mod.uk/people/join-well/physical-employment-standards/ |
| U.S. Army | Basic training physical fitness test to pass boot-camp | Timed 2-mile run | Two minutes push-ups | Two minutes sit-ups | https://usarmybasic.com/army-physical-fitness/apft-standards |
| US Army | Ore-enlistment physical screening test | Beep-test | Deadlift | Standing long jump<br>Seated power throw | [27]<br>https://www.army.mil/article/180199/army_implements_new_fitness_standards_for_recruits_and_mos_transfers |
| US Marines | Initial Strength Test (IST), required before aspiring marines begin recruitment training | Male:<br>1.5 mile run in 13:30<br><br>Female:<br>1.5 mile run in 15:00 | Pull-ups / push-ups<br>Male: 3 pull-ups or 34 push-ups (2:00 time limit)<br><br>Female: 1 pull-up or 15 push-ups (2:00 time limit) | Plank or crunches<br>40-second plank (1:03 minimum)<br><br>44 crunches (2:00 time limit) | https://www.marines.com/become-a-marine/requirements/physical-fitness.html |
| Australian Army | Pre-Enlistment Fitness Assessment (PFA) | Beep-test 7.5 both sexes.<br>Special Forces 10.1 | Push-ups Male 15,<br>Female 8<br>Special Forces 30 | Sit-ups both sexes 45<br>Special Forces 60 | https://www.army.gov.au/our-life/training/soldier-training/physical-fitness-assessment |
| Belgium | 3-component fitness test | Treadmill walking test | Push-up's maximum in 1 minute | Sit-up's maximum in 1 minute | |
| Canada | Physical fitness test, conducted by Canadian Forces Leadership and Recruit Scholl during first week of training | Intermittent loaded shuttles.<br>20-meter rushes | Sandbag lift | Sandbag drag | https://forces.ca/en/how-to-join/#bt |
| Ireland | Defense Forces Induction Fitness Test | 2.4 km run in 11.4 male or 13.10 female | 20 push-ups<br>Modified push-ups (female) | 20 Sit ups | https://www.military.ie/en/careers/faqs/defence-forces-fitness-testing/ |

## Job demands analysis

**Job Demand Analysis (JDA)** is the analysis of a particular job, on-site, to determine the exact physical and positional demands of the job. Information is systematically collected through observation, onsite measurement and interviews or questionnaires with employees and supervisors. [28, 29] The process involves determining what tasks are included in the target job and what job skills or other characteristics are required. [30] Most published sources that study job analysis originate from industry or from a perspective of organizational psychology. Although their focus is different from military services, focusing on psychosocial perspectives rather than physical factors, they provide useful measurement tools. [31]

JDA determines physical demands associated with essential functions in regard to frequency, duration and intensity of every task, and then they develop a report to outline the physical demands required for full-duty work. [31] In military services, there is a close association and interdependencies between aspects of the job, (equipment, armor, load but also duration and frequency of tasks, etc.), mission environment (temperature, humidity) and the physical capacity of the soldiers. Therefore, a job analysis must encompass all parts of the system. A JDA would not be realistic if it only assesses the physical demands of a soldier without taking into account the uniform and protective gear i.e., armor worn by soldiers. The combined load on the soldiers body must be considered, not just the requirement of the task. [31]

The analysis results in a specific job description and Bona Fide Occupational Requirements, which are the minimum and absolute requirements an individual needs to safely perform the job. Job Demand Analyses are used to Physical employments Standards (PES) but also for both Pre-Placement Assessments and Return to Work Assessments. Benefits from a JDA could include reduced injuries during work resulting from the assessment and match of demands with abilities and also appropriate treatment and rehabilitation.

**Physical work capacity** is the ability to perform maximal physical work. As it is a function of the intensity and duration of work, each individual has many different capacities such as anaerobic/aerobic fitness, endurance capacity, balance and muscular strength, each with its own limiting factors. [32, 33] In practice, aerobic work capacity ($\dot{V}O_{2peak}$) is the capacity most often considered when determing the capacity to perform hard or prolonged work. [34] It is important that workers' abilities match the demands of the work so the task can be successfully completed with minimal problems. [35]

**Work ability and work capacity.** An adequate assessment of a person's ability to work should include the person's ability to perform tasks in a given work situation. The ability to work depends on the type and level of physical, mental and social demands of the job. High work demands not adapted to the employee could result in a lack of work capacity. [36] Many employees work over their capacity, which leads to a reduction in their full ability to work. [37] Therefore, low physical training status is a limiting factor for work capacity even in sedentary office work, since an untrained person can only use 20-25% of his capacity compared to a well-trained person who is able to use approximately 40-50% of their capacity over an 8-hour working day. [36] Relevant and necessary capacities vary between different professions and situations. Some examples of necessary physical capacities factors include oxygen uptake capacity, strength and balance; necessary mental factors include memory and stress tolerance; and necessary social factors include problem solving and verbal ability. [36] Previous studies have shown that insufficient physical work (aerobic and anaerobic) capacity could lead to work-related injuries and/or symptoms of fatigue. [8, 9, 38, 39] Therefore, it is important to be able to correctly assess the individual's work performance capacity and match the individual's ability to the demands of the job.

# Physical Employment Standards

The process of creating professional requirements for physical ability are based on scientific evidence and proven experience. The physical demands of a job includes a description and quantification of the physical fitness required to execute the actual job. [31] The analysis can be divided into two parts: the task analysis and the demand analysis. [31, 40] The analysis of the tasks includes identifying which activities are physically demanding. Demand analysis relates to frequency, duration, intensity, etc. of the specific activity.

During the 3rd International Congress of Soldiers Physical Performance (ICSPP) 2014, physical employment standards (PES) was prioritized, including the integration of women in military roles, where male vs. female performance was ranked as an important research topic. [41] The topic of understanding PES has seen new research from Australia, [42-44] which studied the relevance of predictive tests; from the United States, which studied the accurate identification of physically demanding soldier tasks; [27] and from Canada, which studied development and implementation of evidence-based PES and found that PES research must involve military personnel and should be revalidated every 5-8 years. [45] The prioritized areas from the 4ht ICSPP 2017 was physical demands in operational environments and measuring physical performance/fitness, rated as the two most important two topic areas. [12]

Several countries within the NATO group: the United States, [46] the United Kingdom, [24, 47, 48] Netherlands [49] and Canada [50, 51] have studied military physical demands since the 1980s. These studies were summarised in 2009 [52] and concluded that the most common physically demanding tasks in their military forces involved

1) manual material handling (lifting and carrying), 2) marching (loaded march, road march and running) and 3) digging (entrenchment dig, trench dig).

In the Canadian, US and UK armies, **manual material handling** was ranked as the most frequent physical task. [52] The different tasks typically include casualty evacuation, moving sandbags, loading trucks, loading shells, carrying jerry cans, handling food rations and moving and assembling mobile camps. [51, 52] Manual material handling affects both the aerobic and anaerobic systems, and which system is affected the most depends on the duration and intensity of the task. [51] $\dot{V}O_2$ varies between 0.4 to 3.4 $L \cdot min^{-1}$ for different manual material handling tasks and depends on different factors, i.e., lifting frequency and technique, weight and shape of the object, carrying distance and moving speed. [52] Therefore, NATO recommends a $\dot{V}O_{2max}$ of 3─3.5 $L \cdot min^{-1}$ (37.5─43.75 $mL \cdot kg^{-1} \cdot min^{-1}$ for a soldier weighing 80 kg) to avoid acute fatigue and to be able to perform their tasks for a prolonged length of time. [53]

**Loaded marching** could challenge the soldier’s aerobic capacity although the soldiers´ maximal strength could be a limitation when the load is high. [54, 55] A modern soldier must be able to carry a load consisting of body armor, helmet and combat equipment as well as sustainment stores (food, water etc.). Their load could also include mission specific equipment for dismounted personnel and can be as high as 60% of a soldier’s body mass. [4, 56] As mentioned previously, there are a number of studies that have measured the cardiovascular demands of different military-related tasks. Wearing combat gear (army boots, uniform, helmet) with backpack and/or body armor results in increased oxygen consumption ($\dot{V}O_2$). [10, 57-59] However, only a few studies have investigated the effects of combat gear and body armor on soldiers’ ventilatory responses, [59, 60] and they found increased minute ventilation ($\dot{V}_E$) and breathing frequency ($f_b$) with load and time, and increased $\dot{V}_E$ and $f_b$ with heavier loads. Only one study investigated the effect of load, i.e. combat gear and body armor, on peak exercise [58] and none of these studies investigated sex-differences in the different loads. Due to the increase in occupational specialties open to women, including direct combat roles within the soldier profession, there is a need for a greater understanding of sex differences in load carriage and ventilatory restriction.

It is also important to understand the parameters of different combat tasks in field conditions to accurately imitate the physiological work demands of each task and to develop valid PES. Pihlainen et al. [11] investigated cardiorespiratory responses in field conditions to different tasks, unloaded and loaded march, artillery field preparation and digging defensive positions. Mean measured oxygen consumption ($\dot{V}O_2$) for the different tasks was close to 50% of their maximal aerobic capacity, where digging had the highest $\dot{V}O_2$ and artillery field preparation the lowest. [11] The intensities of various military tasks are often prolonged at moderate to high exercise levels where the intensity often is quantified by the different lactate thresholds (LT1 and LT2). These thresholds are mostly obtained from blood sampling or the ventilatory thresholds (VT1 and VT2). [61, 62] For both VT and LT, studies have detected two separate thresholds occurring at ~50-60% of $\dot{V}O_{2peak}$ called VT1 or LT1, or occurring at ~70-80% where the names differ greatly, but can also be named VT2 and LT2. [63] Prolonged work exceeding 50% of $\dot{V}O_{2max}$ may affect the soldier's performance, limiting e.g., shooting accuracy, and increasing the risk of fatigue or injury. [9] The first threshold is highly correlated with prolonged exercise, where sustaining a high fractional utilization of the $\dot{V}O_{2max}$ for a long time delays the metabolic acidosis. [64] Although studies investigating physical demands exists, the effect of body armor in intermittent or repeated high-intensity military work in different combat tasks in field and their physiological responses remains unknown. Knowing these demands is essential for a safe and reliable performance and should be used in assessment of the soldier's capacity to fulfil these requirements.

$\dot{V}O_2$ is commonly used to determine work intensity, where $\dot{V}O_{2max}$ is generally recognized to be the functional limit of the cardiorespiratory system's ability to transport oxygen to the tissues so the aerobic requirements of the body can be met. [65] $\dot{V}O_2$ is also the best physiological indicator of muscular capacity for sustained work. [66] Heart rate (HR) monitoring has often been used to assess aerobic work intensity since HR is linearly related to $\dot{V}O_2$ and is easy to measure. [67] There are inconclusive results from previous studies as to whether the HR and $\dot{V}O_2$ relationship during load carriage follows the same slope as unloaded work in soldiers. Similarities were found for the rate of oxygen consumption with incrementing speed between loaded marching and treadmill running. [68] Whereas other studies found a greater increase in HR at a given $\dot{V}O_2$ in loaded marching compared to unloaded marching or running, [69, 70] these studies did not investigate sex differences but assessed men and women on different protocols separately.

Studies have shown that Near Infrared Spectroscopy (NIRS) responds faster than HR and $\dot{V}O2$ during exercise and recovery and, therefore, could be a valid alternative to HR monitoring for use in determining exercise training intensity [71]. NIRS estimates active muscle deoxygenation and has been verified to show a decrease in tissue oxygenation when work rate increases. [72] Combining NIRS and indirect spirometry could be a method to simultaneously compare changes in gas exchange measurement, centrally through expired air and locally via tissue oxygenation kinetics in the microcirculation. [73]

There is a scarcity of studies in the military population assessing $\dot{V}O2$ kinetics and contributions of $O_2$ delivery-utilization systems simultaneously during exercise transition in men and women. Studies in a civilian population has shown that men have a greater deoxygenation of the locomotor muscles in comparison with women. [74] Other research, however, has shown lower leg muscle deoxygenation in women at the same relative exercise intensity compared to men, with no difference at peak exercise. [72] For military commanders planning missions, it could be important to minimize load carriage-induced fatigue, hence, gauge when muscles are fatiguing and, more importantly, provide the time needed for recovery, while solving military tasks.

The aim of PES are to ensure that employees' physical and physiological capacities are commensurate with work requirements. [75] The implementation of PES has been shown to increase capability and productivity and reduce workplace injury [76-78] and is a critical component in both recruiting and training as well as maintaining operational effectiveness for personnel in physically demanding occupations, e.g., military. [79] It is paramount that PES is legally defensible, based on empirical evidence and expert opinion within the concerned occupation to ensure the best job-person fit. PES might be used at different stages such as recruitment or mustering, yearly in-job assessment, but also in the selection process for various specialist roles within the military services. There are a number of studies that have proposed how to develop PES. These studies suggest that development usually comprises four stages. [31, 40, 80, 81] The steps are described by Blacker et al. [79]

1. Conducting a job analysis to identify the physical demands of key criterion tasks (e.g., mass of objects, distance of movement, physiological strain).
2. Developing simulations of these tasks that are representative of the actual job but sufficiently controlled to be safe and reliable (i.e., criterion tests).
3. Establishing the efficacy of using selection tests and/or generic fitness tests to assess personnel and establish whether training conducted between point of selection and taking up a qualified role influences criterion task performance.
4. Proposing evidence-based performance standards.

The observation of task and analysis has mostly been divided in two parts: a job task and a physical demand analysis. The most common methods in a job task analysis includes questionnaires, interviews, consulting subject matter experts and observing the actual job to ascertain task details, such as frequency and duration. The analysis of physical demands concerns quantifying the physical elements of the task, the equipment used, but also the environment in which the work is conducted as well as the physiological strain which includes measurements of heart rate and oxygen consumption. [75]

To understand and quantify the parameters of different combat tasks to accurately imitate the physiological work demands of each task is very important to eventually develop valid physical employment standards (PES). Knowing the demands is essential for a safe and reliable performance and should be used in the assessment of the soldier's capacity to fulfil these requirements.

After measurement and quantification of the physically demanding job tasks, the PES tests are developed. The aim of these PES tests are to replicate or induce the physiological demands for the specific tasks and are commonly divided into three different types of tests: generic predictive, task-related predictive and task simulation tests. [40] The generic predictive or basic physical ability tests do not have specific job-related characteristics. A task-related predictive test is not based on a specific job criterion task but on a more general job-related task. And the predictive task-related test includes elements from both of the two aforementioned tests. [40] For a successful recruitment process, it is imperative that the soldiers meet the physical demands of their work.

In the Swedish Armed Forces, while some studies have examined injury prevention and training optimisation for recruits during military training, [82] none have investigated the physical demands of the tasks for ground combat forces. Valid and reliable physical fitness tests will ensure that they correctly assess military personnel so they have the physical work capacity commensurate with the demands of the task.

# Rationale

Since 1968 when the physiological and strength test was introduced within the mustering process, testing has been done without validated demands. The Swedish Armed Forces today has approximately 190 different work areas, e.g., artillery, diver, flight combat control, and ground combat forces. No previous study has examined physical work demands for different duties or tasks in these work areas, hence, the lack of validation.

Soldiers frequently carry loads consisting of combat gear, e.g., webbing, rifle, helmet, and body armor (CB) during both training and operations. A backpack is added mainly during road marching and approach march. Therefore, it is important to study the effect of combat gear to correctly measure the energy demands of wearing body armor. In addition, it is important to gain a greater understanding of sex differences associated with load carriage and ventilatory restrictions since knowledge about the cardiorespiratory responses during work until exhaustion wearing added load and combat gear is limited, especially in female soldiers.

As previously discussed, compulsory military service was reinstated for both sexes in 2017, and the number of women serving in The Swedish Armed Forces has increased. The proportion of female conscripts in today's Swedish Armed Forces is approximately 17%. Therefore, more knowledge about how military work affects women's physiology and physical performance is needed. Women might respond differently to men due to physiological differences, hence, using tests designed for men’s physique and body constitution could unfairly exclude women. It is therefore important to study potential sex differences in responses to demanding military tasks to avoid discrimination based on sex, age or anthropometric measures. The consequence of not knowing the physical work demands could be that the most suitable persons are not admitted to military training or that women are disadvantaged due to inadequately validated demands.

Unknown demands could also lead to injuries if the workload exceeds the conscripts physical work capacity. Until physical work capacity analyses are made for the different job descriptions/physical demands in Swedish Armed Forces, validation of different entry tests for selection is a difficult task. If new tests should be implemented, it is important that they are validated to the different tasks. [20]

# Aim

The overall aim of this study was to identify which tasks are the most physically demanding and to evaluate their physical work capacity demands from a cardiovascular point of view. In addition, to identify potential sex differences in the physiological response to load carriage.

The specific aims of this thesis were:

- To identify the most physically demanding work tasks for Swedish ground combat soldiers through the development and application of a questionnaire since existing questionnaires are not fully applicable to Swedish conditions, and to study possible gender differences in perceived difficulty of the tasks.
- To examine differences of load carriage (combat gear and body armor [CB]) in female and male soldiers on both submaximal HR, $\dot{V}O_2$ responses and $HR_{max}$, $\dot{V}O_{2peak}$ compared to no load during a graded treadmill protocol.
- To examine whether the relationship between HR and $\dot{V}O_2$ differ between the two load conditions, or between women and men.
- To investigate $\dot{V}O_2$ and HR kinetics responses to unloaded (NL) or CB exercise with simultaneous measurements of NIRS.
- To examine kinetic responses at different exercise milestones, at the two separate ventilatory threshold, VT 1, VT 2, and at peak exercise in male and female soldiers.
- To perform a physical job demand analysis of five of the tasks for ground combat forces of the Swedish army investigated in the first study of this thesis, and to evaluate these physical work capacity demands from a cardiovascular point of view.

# Study design and overview

This project started many years ago to investigate whether the admission requirements were correct. There were conscripts who despite enrollment and enlistment did not meet work requirements and were therefore prematurely discharged from the Swedish Armed Forces. Four studies were thus conducted in a stepwise progression to gain greater knowledge in this area. First, to obtain an understanding of which tasks the Swedish ground combat soldiers perceive as the most physically demanding, a pertinent questionnaire was developed with an additional goal of identifying possible gender differences in perceived difficulty of the tasks. Based on the results from the questionnaire, five tasks were identified and selected for further research.

Thereafter, a study to assess the effect of sex and load carriage on cardiorespiratory responses to high-intensity exercise in male and female soldiers was conducted.

Finally, the physiological demands of soldiers during military field exercises were evaluated during four different field exercises in urban and retrograde in rough terrain

The studies included in this thesis are all summarised in Table 2. In the following chapters, the methods and results are then presented for each study.

**Table 2.** Overview of the four different studies in the thesis

| | |
|---|---|
| **Study I.** | |
| *Aim* | To identify the most physically demanding work tasks for Swedish ground combat soldiers and to study possible gender differences in perceived difficulty of the tasks. |
| *Study design* | Exploratory study |
| *Number of participants* | 251 Swedish ground combat soldiers |
| *Data collection* | Study specific questionnaire |
| *Analysis* | Cross-tabulation, Mann-Whitney test |
| **Study II.** | |
| *Aim* | To investigate cardiorespiratory responses in female and male soldiers during a GXT wearing light training clothes or combat gear, whether the relationship between HR and $VO_2$ differ between the conditions, and potential sex differences. |
| *Study design* | Cross-sectional observation study |
| *Number of participants* | 18 Swedish ground combat soldiers (9 women) |
| *Data collection* | Clinical test, indirect calorimetry |
| *Analysis* | Two-way repeated measures ANOVA, Three-way mixed ANOVA, paired t-test, independent sample t-test, Mixed effect linear regression |
| **Study III.** | |
| *Aim* | To investigate the effect of body armor and combat gear on ventilatory responses, oxygen delivery-utilization, muscle oxygen recovery and potential sex differences between male and female soldiers during a GXT |
| *Study design* | Cross-sectional observation study |
| *Number of participants* | 18 Swedish ground combat soldiers (9 women) |
| *Data collection* | Clinical test, indirect calorimetry |
| *Analysis* | One-way repeated measures ANOVA, two-way repeated measures ANOVA, Three-way mixed ANOVA, paired t-test, independent sample t-test, |
| **Study IV.** | |
| *Aim* | Study cardiorespiratory responses and movements during simulated combat |
| *Study design* | Cross-sectional observation study |
| *Number of participants* | 42 (3 women) |
| *Data collection* | Clinical test, indirect calorimetry, field observation |
| *Analysis* | Spearma´s rho, Kruskal-Wallis H Test, Levene´s test, Welch´s ANOVA, Wilcoxon signed rank test |

# Development of a questionnaire (Study I)

## Study design

This first step in the project intended to serve as a foundation for the development of a valid admission and physical work capacity test applicable to the Swedish army. This study developed and used a questionnaire to explore Swedish combat soldiers' perception of which tasks conducted during service were the most physically demanding. Questionnaires are a common method used in job task analysis together with interviews and consulting subject matter experts. [75]

> A job analysis involves systematically collecting information about a job in order to prepare a job description. The process involves determining what tasks are included in the target job and what job skills or other employee characteristics are required Current subject-matter experts can provide information on whether or not the tasks and skills are part of or required for the job, and their frequency or occurrence or use on the job. [30]

The process of conducting a job analysis is costly, complex and requires a considerable amount of time. The outcome should be a solid foundation for establishing occupational fitness standards, physical employment standards as well as physical training programs. [31] The best practice is often to use a combination of different techniques, since it would provide a more valid and holistic outcome. The selection of methods depends on a number of different factors, i.e., willingness and ability of the employees and the environment where the analysis will be conducted. [31] For this study, a questionnaire was used. The focus in this study was to gain an understanding of the soldiers' perceptions, based on their service experience, of which tasks were the most physically demanding.

### Setting and recruitment

A total of 231 ground combat soldier from five different regiments within the Swedish Armed Forces were invited to participate in this study. Of those, 165 soldiers (25 women) from three regiments accepted the invitation. The age of the soldiers ranged from 19 to 44 years, and the number of years in military service ranged from 0.5 to 16 years.

## Data collection and analysis

The questionnaire was distributed from the period of late 2016 to spring 2017 to 231 ground combat soldiers, aged 18–50 years via personal visits to the regiments. All visits and surveys were performed by the PhD-student. The structure of the questionnaire is presented in Table 3.

The questionnaire was developed in five steps. Step 1 consisted of studying questionnaires from other countries and other physically demanding professions. Step 2 was an inventory of the tasks for ground combat soldiers with the use of combat manuals and procedural documentation from the Swedish Armed Forces. Step 3 was consulting an expert group consisting of both male (n=7) and female officers (n=1) to establish interpretation, cultural relevance, face validity and content validity. Step 4 was an initial test conducted by 4 soldiers (2 men and 2 women). Step 5 was a final test with 14 soldiers. The final questionnaire is presented in Appendix 1. The answers were analysed separately in the sub-categories:

- Aerobic capacity
- Hand strength
- Arm strength
- Core strength
- Leg strength.

Sex differences were investigated within the five work tasks, with the highest proportion of subjects responding *very hard* for aerobic capacity, *strong* and *very strong* for muscle force within each sub-category. Descriptive data were expressed as mean and standard deviation (SD). Missing items were reported for each subscale, and Chronbach's alpha was used to analyse internal consistency in the subscales measuring aerobic capacity and strength. Differences in the distribution of answers between men and women within each rated work task were analysed with the Mann-Whitney test. The probability level of acceptable significance was set to 0.05. SPSS version 23 was used for statistical calculations (IBM SPSS Statistics for Windows, Version 23.0. IBM Corp., Armonk, NY).

**Table 3.** Structure of the questionnaire.

| Area of interest | Question | Number of tasks |
|---|---|---|
| Background | Soldier's age, sex, anthropometric data, and the nature of his/her job | |
| Aerobic capacity | How strenuous do you experience the following work tasks in your current post (exercise and service) to be in terms of your aerobic fitness (oxygen uptake, aerobic capacity) | 31 |
| Hand strength | Rate how strong you need to be in your hands to solve the following work tasks | 30 |
| Arm strength | Rate how strong you need to be in your arms to solve the following work tasks | 30 |
| Core strength | Rate how strong you need to be in your core to solve the following work tasks | 30 |
| Leg strength | Rate how strong you need to be in your legs to solve the following work tasks | 30 |
| Physical tests | Opinion regarding mandatory physical tests | |

# Physical domain findings

## Aerobic demands

Soldiers' perception of which tasks are the most aerobically demanding were 1) transport of a wounded soldier, 2) movement in combat, 3) attack in close terrain, 4) attack in urban terrain and 5) attack in rough terrain. No differences between male and female soldiers in the ratings for aerobic demands were found ($p=0.09$) (Figure 5).

## Muscle strength demands

Eleven work tasks out of 30 were ranked as demanding (strong) or very demanding (very strong) although many of them only in one of the strength areas for hand, arm, leg and core. The findings, based on proportions, are summarised in Table 4. Within each task, the top five most strenuous tasks are ranked from 1 (most demanding) to 5 (least demanding). Both men and women ranked transport of wounded as the most challenging task for hand strength (80% men and 68% women), arm strength (81% men and 84% women), leg strength (82% men and 84% women) and core strength (81% men and 84% women). Carrying heavy load was ranked as the second most demanding task for hand and arm strength and third for leg and core strength (Table 4). There were no significant differences between men and women although they sometimes ranked the tasks in different order ($p \geq 0.3$).

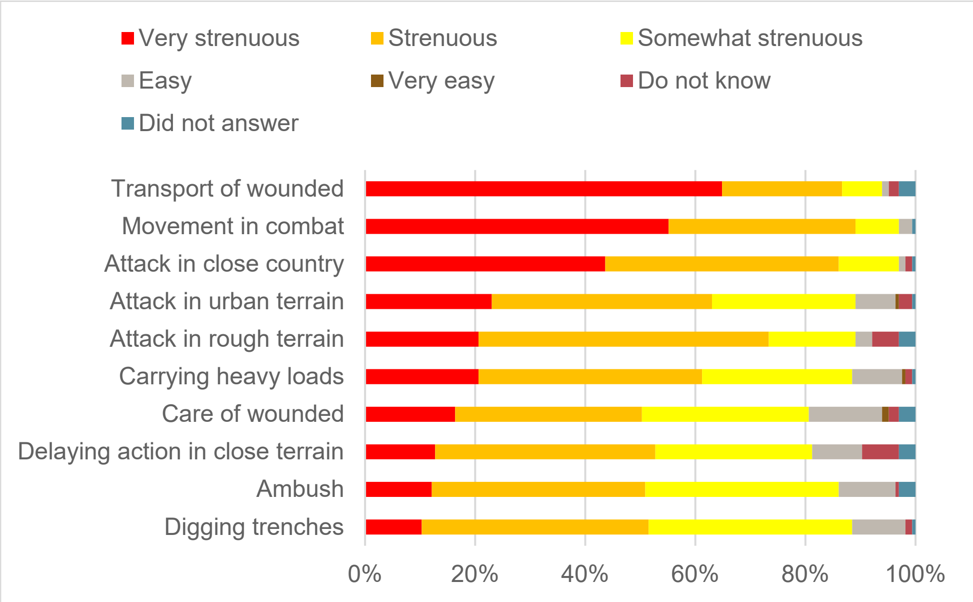


**Figure 5**. The 10 most demanding work tasks regarding aerobic capacity for all soldiers, N=165.

**Table 4.** Ranking of the top five (1 to 5, 1=most demanding task) muscle strength demanding tasks: total (T), men (M) and women (W). The ratings are based on proportions of subjects who have rated the demands of the tasks. Blank space indicates that the tasks were ranked lower than top five.

| Work tasks | Hand strength | | | Arm strength | | | Leg strength | | | Core strength | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | M | W | T | M | W | T | M | W | T | M | W |
| Transport of wounded | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Carrying heavy loads | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | | 3 | 3 | 2 |
| Care of wounded | 3 | 3 | 3 | | | 3 | 4 | 4 | 3 | 5 | | 4 |
| Attack in urban terrain | 4 | 4 | 5 | 3 | 3 | | | | | | 4 | |
| Digging foxholes | 5 | | 4 | 5 | | 5 | | | | 4 | 5 | 5 |
| Delaying fieldwork | | 5 | | | | | | | | | | |
| Movement in combat | | | | 4 | 5 | | 2 | 3 | 2 | 2 | 2 | 3 |
| Delaying action in urban terrain | | | | | 4 | | | | | | | |
| Loading equipment | | | | | | 4 | | | | | | |
| Attack in close terrain | | | | | | | 5 | 5 | 5 | | | |
| Executing ambush | | | | | | | | | 4 | | | |

# Investigating cardiorespiratory responses of load carriage (Study II and III)

## Study design

The second step in this project was to investigate the impact of combat gear and body armor (CB) on pulmonary ventilation and the cardiovascular system. A test protocol was developed, adapted from Bruce graded test protocol, [83] and evaluated on a graded exercise test (GXT). In the initial part of the exercise test, we used the speed 5.4 km·h$^{-1}$ since it represents regulated speed during loaded marches in the Swedish Armed Forces. It also corresponds to approximately 50% of the soldiers maximal work capacity marching on gravel road. [84] After 5 minutes of marching, treadmill speed was increased to 8 km·h$^{-1}$, representing the speed of rapid march wearing combat gear and body armor. All stages of GXT are described in Table 5.

**Table 5.** Graded exercise test, treadmill protocol. (Adopted from Bruce graded treadmill protocol)

| Stage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration (min) | 5 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Speed (km·h$^{-1}$) | 5.4 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Grade (%) | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |

The ultimate goal of these studies was to assess whether test protocol on a GXT with physical training gear can be used interchangeably to predict maximal aerobic uptake when wearing CB.

### Setting and recruitment

Eighteen active-duty soldiers (9 women) from a Swedish regiment were recruited for this study. Service time ranged between 1 to 6 years. Characteristics of the participants are summarised in Table 6.

In the unloaded test (NL) the soldiers were equipped with top and shorts/tights and running shoes. In the loaded condition (CB) the soldiers wore their familiarised personal equipment adjusted for an optimal fit. Combat gear consisted of army boots, uniform (M90), helmet and different body armor dependent on their post and a dummy weapon simulating the Swedish Army standard weapon AK5 (weight 4.5 kg). The different body armor included the following (Figure 6):

- Kroppskydd 90 A, manufacturer Stormark K Konfeksjonsfabrikk A/S, Norge (size small to large, weight 3.3-3.5 kg), webbing with armored plates,
- Kroppsskydd 12, manufacturer Mehler Vario Systems Gmbh, (size 1-7, weight 6-14 kg)
- Kroppsskydd 94, manufacturer Åkers Krutbruk Protection AB, (size small to large, weight 4.5-10.5 kg)

**Figure 6**. Different body armor, Kroppsskydd 90 A, Kroppsskydd 12, Kroppsskydd 94 © www.soldf.com

No difference in added load (CB) between men 15.7 ± 2.0 kg ($p=0.56$) and women 16.3 ± 2.5 kg was shown. However, when the added load was expressed as a percentage of body mass, there was as difference between sexes (women 24.8 ± 0.4% and men 20.0 ± 0.1%, respectively, $p< 0.01$) (Table 6).

## Data collection and analysis

The participants were tested at the laboratory twice, with 2-14 days between sessions, and they performed the same GXT protocol twice with a cross-over design. The first visit at the laboratory included familiarisation with the test. They were informed about the study and signed the consent form. Their body composition values were measured in a fasting state. Body mass and body fat along with right leg fat and fat free mass was determined by bioelectrical impedance analysis (Inbody 770, Biospace, Co, Ltd, Seoul, Korea). Height was measured and their BMI calculated as the body mass (kg) divided by the height (m) squared. All the GXTs were conducted on a motorized treadmill (Rodby Innovation AB, Vänge, Sweden).

Cardiorespiratory and pulmonary values were obtained with indirect calorimetry (Oxycon Pro, Jaeger, Hoechberg, Germany). Calibration of the gas analysers was completed immediately prior to each test according to the manufacturer's instructions. Heart rate was monitored continuously using a Polar HR monitor (FT4, Polar Electro Oy, Kempele, Finland) placed on the chest of the participants and synchronized with the Oxycon Pro system.

Muscle oxygen saturation ($SmO_2$) was monitored continuously using a non-invasive method (Moxy Monitor, NIRS device 630-850 nm, Fortiori Design LLC, Minnesota, US). The device was placed on the right m. vastus lateralis between the lateral femoral epicondyle and the great trochanter of the femur at the largest girth of the muscle belly according to methods as previously described. [85] Moxy measures the absorbance of infrared light by oxygenated ($O_2Hb$), deoxygenated hemoglobin (HHb), and myoglobin (mHb) at a microvascular level. To normalise the data, we calculated $SmO_{2baseline}$ as the average of the $SmO_2$ during 30 s reached at steady state in standing position, as previously described. [86] The lowest value attained during exercise ($SmO_{2low}$) was considered as the measure of oxygen consumption. To find the magnitude of oxygen consumption ($SmO_{2Ex}$) we calculated the difference between $SmO_{2baseline}$ and $SmO_{2low}$. Furthermore, we calculated the oxygen downslope ($SmO_{2down}$), oxygen desaturation rate as percentage per minute, $\%\cdot min^{-1}$ during exercise. To study recovery after the initial 10 minutes after cessation, the upslope percentage per second, $\%\cdot s^{-1}$ of $SmO_2$ was calculated as oxygen resaturation rate ($SmO_{2up}$).

In addition, individual NIRS responses at VT1 ($SmO_2VT$) and VT 2 ($SmO_2VT2$) were calculated to study the effect of CB on tissue oxygenation, as well as any sex differences during incremental exercise. Power output during treadmill exercise was calculated using the following equation: mass × speed × grade. The mass used included the bodyweight of the subject and, in the CB condition, the weight of combat gear and body armor was added. Data from the NL-test was used as reference values to compare with the values from the CB-test. Primary outcome measures were heart rate (HR), oxygen uptake ($\dot{V}O2$), minute ventilation ($\dot{V}_E$), carbon dioxide output ($\dot{V}CO2$) and muscle oxygen saturation (SmO2).

## Statistical methods (Study II and III)

Descriptive data were assessed for normality and analysed with descriptive statistics (mean, standard deviation). To compare the effect of load on $\dot{V}O_2$, HR, $\dot{V}_E$, $V_T$, $f_b$, power, $SmO_2$ and time to exhaustion at peak effort, paired t-tests were used, and to compare effect of load between sexes at peak effort, independent sample t-tests were used. To analyse potential sex differences in response to load carriage during the GXT, individual responses for $\dot{V}O_2$, HR, $\dot{V}_E$, $V_T$ and $f_b$ was calculated as a percentage of peak values (called exercise intensity) at 5 levels: 15, 25, 50, 75, and 100%. Data from the same individuals were compared over different loads (NL vs.

CB). Thus, data were analysed as two-way repeated measurements. Sex differences over different loads for the same individuals were analysed as three-way repeated measurements. To compare the change in HR and $VO_2$ (dependent variable) between NL and CB over the time course of the GXT and between sexes, a generalised mixed effect linear regression model was used.

To study the magnitude of change between NL and CB and between women and men for peak values, effect sizes (ES) were calculated using Cohen's D, effect statistic [87], and interpreted according to the following thresholds for ES: <0.2 (trivial), 0.20-0.59 (small), 0.60-1.19 (moderate), 1.20-1.99 (large), 2.00-3.99 (very large) and >4.00 (extremely large). [88] In study II, a generalised mixed effect linear regression model was used to compare the change in HR and $VO_2$ (dependent variable) between NL and CB over the time course of the GXT and between sexes.

Statistical analyses were performed in SPSS software (SPSS Statistics, Version 25, IBM Corporation, New York).

# Cardiorespiratory responses

## Anthropometrics and body composition

Anthropometrical data and body composition are presented separately for women and men in Table 6. Men had significantly lower body fat and higher skeletal muscle mass compared to women. Among women, 77% had a BMI $\leq$ 25 kg·m$^{-2}$, while the corresponding number was 67% among men. Studying the fat percentage in the right leg, 67% of the women had a fat percent $\geq$ 30% whereas the number was 0% for men.

**Table 6.** Anthropometrics and body composition in female and male soldiers.

| | Women (n=9) | Men (n=9) | p-value |
|---|---|---|---|
| Age (years) | 26.2 ± 4.8 | 22.6 ± 2.4 | 0.056 |
| Height (cm) | 167.0 ± 6.0 | 181.3 ± 5.2 | <0.001 |
| Body mass (kg) | 66.5 ± 8.6 | 78.3 ± 8.9 | 0.012 |
| Added load (kg) | 16.3 ± 2.5 | 15.7 ± 2.0 | 0.559 |
| FFM (kg) | 50.7 ± 5.4 | 68.9 ± 7.9 | <0.001 |
| FFM right leg (kg) | 5.2 ± 0.7 | 9.3 ± 1.1 | <0.001 |
| Body fat (%) | 23.6 ± 2.8 | 11.4 ± 4.5 | <0.001 |
| Right leg fat (%) | 31.4 ± 3.8 | 13.4 ± 4.7 | <0.001 |
| BMI (kg/m2) | 23.7 ± 2.2 | 23.7 ± 2.2 | 0.950 |

Values are means ± standard deviation. BMI, body mass index; FFM, fat-free mass.

## Treadmill graded exercise

The 18 soldiers performed the GXT as described in Table 5. Time to exhaustion in minutes are presented in Table 7. Female soldiers completed on average 7.7 ± 1.2 stages in NL condition (range 5 to 9) and 5.1 ± 0.7 stages (range 4 to 6) wearing CB, whereas male soldiers completed 8.6 ± 0.8 (range 7 to 10) vs. 5.3 ± 0.9 (range 4 to 7) stages (Figure 7). Time to exhaustion was 55% shorter for women and 47% shorter for men wearing CB with no sex difference (p=0.79). Wearing CB resulted in a reduction of time to exhaustion by approximately 40 seconds for every 1 kg of additional external mass (estimated as; -660 sec divided by 16 kg added load).

**Table 7.** Mean, standard deviations (SD), effect size (ES) and p-value, results for 9 men and 9 women, Treadmill data at peak exercise, unloaded (NL) and loaded (CB) condition.

| | Sex Men, women | NL Mean ± SD | CB Mean ± SD | Change NL–CB | ES | t-test p-value |
|---|---|---|---|---|---|---|
| TTE (min) | M | 20.3 ± 2.79 | 10.7 ± 2.59 | -9.63 | 3.56 | <0.001 |
| TTE (min) | W | 20.1 ± 3.81 | 9.0 ± 2.56 | -11.10 | 3.41 | <0.001 |

TTE, Time to exhaustion

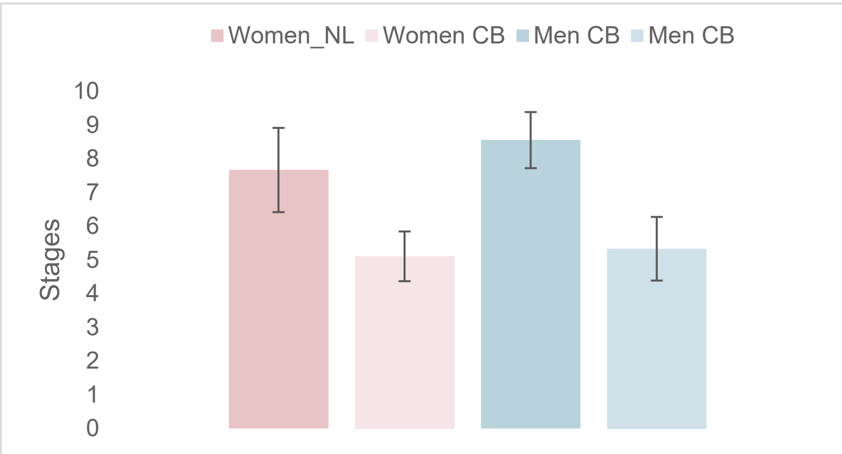


**Figure 7.** Completed stages during graded exercise test. Variables are presented as mean and standard deviation. NL denotes no load and CB denotes combat gear and body armor.

## Maximal exercise

We found that the mean $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) was higher for male soldiers compared to female soldiers (Table 8). Female soldiers $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) ranged between 2.55 to 3.69 $L \cdot min^{-1}$, whereas male soldiers ranged between 3.61 to 4.79 $L \cdot min^{-1}$, with a mean sex difference of 23% (p<0.001) in the NL condition. Wearing CB induced a decrease in both female, -6% (range 2.57 to 3.65 $L \cdot min^{-1}$), and male soldiers, -11%

(range 3.00 to 4.43 L·min$^{-1}$). The sex difference in CB condition was 18% ($p=0.004$). No significant sex difference was observed for mean $\dot{V}O_{2peak}$ (mL·kg$^{-1}$·min$^{-1}$), either in NL (-8%), nor CB (-9%) condition ($p=0.074$; $P=0.061$ respectively). Comparing difference between load conditions within sexes revealed a 24% reduction wearing CB for both sexes, compared to L·min$^{-1}$. When the variables were adjusted to FFM (mL·FFM·kg$^{-1}$·min$^{-1}$), differences in $\dot{V}O_{2peak}$ were altered and women peak values were approximately 105% compared to men ($p>0.05$).

**Table 8.** Mean, standard deviations and Cohen´s d effect size results 9 men and 9 women, cardiorespiratory data at peak exercise, unloaded (NL) and loaded (CB) condition.

| | Sex Men, Women | NL Mean ± SD | CB Mean ± SD | Change NL – CB | Cohen's ES | t-test p-value |
|---|---|---|---|---|---|---|
| $\dot{V}O_{2peak}$ (L·min$^{-1}$) | M | 4.16 ± 0.47 | 3.70 ± 0.51 | -0.46 | 0.93 | <0.001 |
| $\dot{V}O_{2peak}$ (L·min$^{-1}$) | W | 3.23 ± 0.39 | 3.03 ± 0.33 | -0.20 | 0.55 | 0.087 |
| $\dot{V}O_{2peak}$ (mL·kg$^{-1}$·min$^{-1}$) | M | 53.33 ± 3.92 | 40.55 ± 3.52 | -12.78 | 3.43 | <0.001 |
| $\dot{V}O_{2peak}$ (mL·kg$^{-1}$·min$^{-1}$) | W | 48.86 ± 5.82 | 36.92 ± 4.11 | -11.93 | 2.36 | <0.001 |
| $\dot{V}O_{2peak}$ (mL·FFM·kg$^{-1}$·min$^{-1}$) | M | 60.7 ± 5.05 | 43.82 ± 3.89 | -16.88 | 3.74 | <0.001 |
| $\dot{V}O_{2peak}$ (mL·FFM·kg$^{-1}$·min$^{-1}$) | W | 63.8 ± 6.83 | 45.48 ± 4.99 | 18.32 | 3.04 | <0.001 |

$\dot{V}O_2$, oxygen uptake; FFM, Fat Free Mass.

## Submaximal exercise

$\dot{V}O_2$ and HR-responses plotted to relative exercise intensity (%$\dot{V}O_{2peak}$) are shown in Figure 8. At the group level, wearing CB induced a lower exercise intensity for the same % of $\dot{V}O_{2peak}$ compared to NL (load*levels, $p<0.01$). No significant difference between sexes was found in NL or CB condition. This indicates that soldiers worked at a higher % of their $\dot{V}O_{2peak}$ while wearing CB at any submaximal exercise intensity (GXT stages).

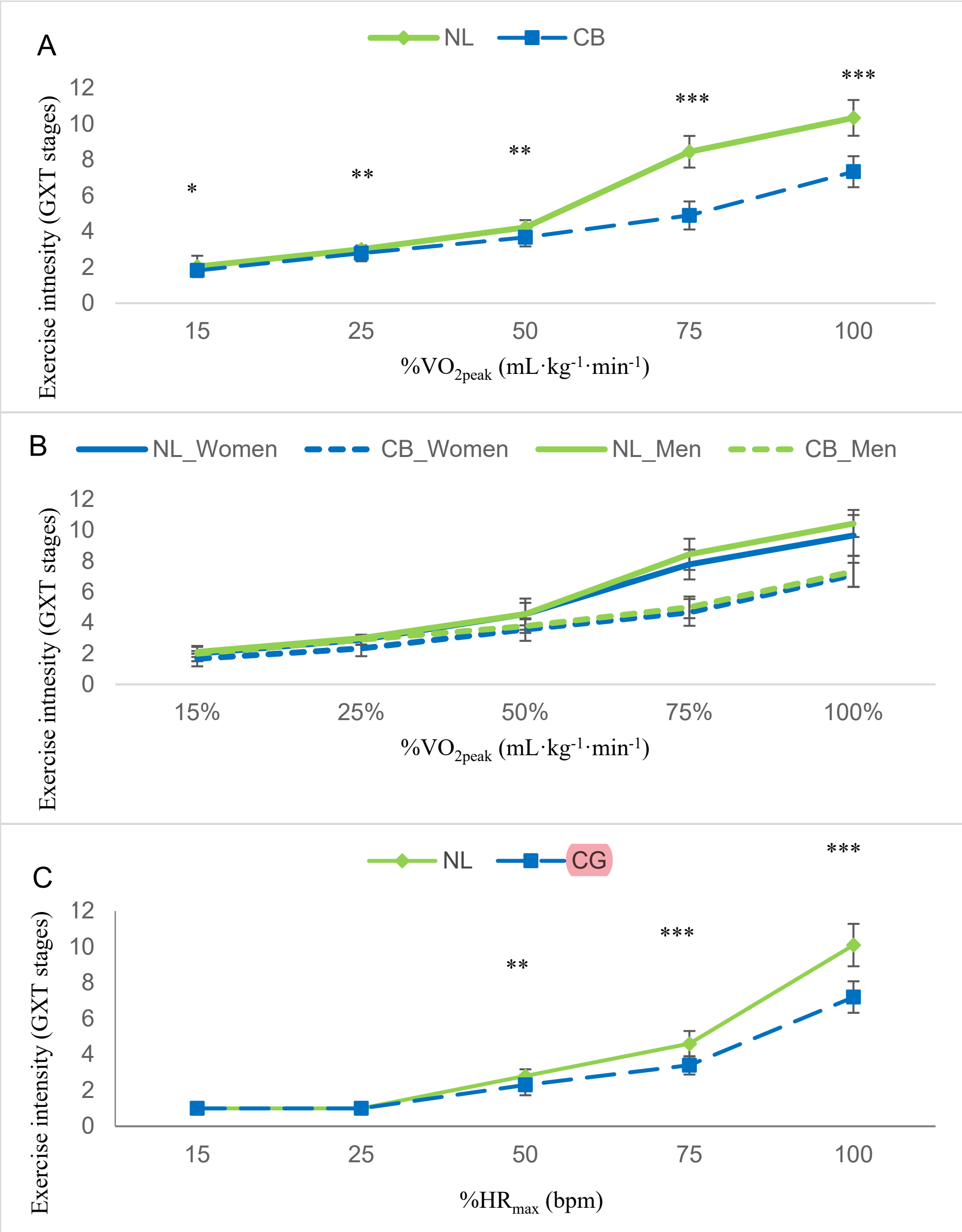


**Figure 8.** Oxygen uptake and cardiorespiratory responses to exercise intensity (Graded exercise test [GXT] stages) as a function of relative intensity of $\dot{V}O_{2peak}$ (peak oxygen uptake) 15-100 % of $\dot{V}O_{2peak}$, mean, standard deviations (SD) Group level. A. Sex differences. B. Heart rate 15-100 % of $HR_{max}$, (maximal heart rate); bpm, beats per minute, C. NL (diamonds) denotes no load test situation and CB (squares) denotes combat gear test situation. Exercise intensity presented as GXT stages, from stage 1 (supine), 2 (standing), 3 (5.4 km·h$^{-1}$ 0 grade) 4 (8 km·h$^{-1}$ 0 grade) 5 (8 km·h$^{-1}$ 2% grade) with 2% grade increase until stage 12 (8 km·h$^{-1}$ at 16 % grade). ANOVA, (Figure A, B) main effect of load $p < 0.001$ Interaction $p < 0.001$. Post hoc analyses significantly different from no load at *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

## Gas exchange

In the CB condition, minute ventilation ($V_E$) was approximately 30% higher compared to the unloaded condition at 5.4 km·h$^{-1}$. As expected, the difference became greater over time throughout the exercise trial and was 60% higher at 8 km·h$^{-1}$ 6% grade ($p<0.001$); no sex difference was found, except for stage 4 (Table 5) for both load conditions ($p<0.05$) (Figure 9). Similar to minute ventilation, the difference between conditions became greater for breathing frequency ($f_b$) over time throughout the exercise trial, ranging from 14% to 44% ($p<0.001$) (Figure 9). A small but not significant difference, ranging from 3-16%, was found for tidal volume ($V_T$) over the exercise trial ($p=0.17$) (Figure 9). No sex differences (level *load * sex) were found for the change in $\dot{V}_{Epeak}$ ($p=0.35$), $V_{Tpeak}$ ($p=0.10$), or $f_{bpeak}$ ($p=0.85$) between conditions. In contrast, at peak exercise, wearing CB, both minute ventilation and tidal volume decreased with a significant sex difference in both conditions ($p<0.05$), whereas breathing frequency increased as shown in Table 9.

Studying the change in peak values for $\dot{V}_E$ from NL to CB, revealed a small to moderate but non-significant difference between sexes, $\dot{V}_E$ (ES=0.46, p=0.34), $V_T$ (ES=0.54, p=0.26) or $f_b$ (ES 0.18, p=0.70).

**Table 9.** Mean, standard deviations (SD), effect size (ES) and p-value results for 9 men and 9 women, cardiorespiratory data at peak exercise, unloaded (NL) and loaded (CB) condition.

| | Sex Men, women | NL Mean ± SD | CB Mean ± SD | Change CB– NL | ES | t-test p-value |
|---|---|---|---|---|---|---|
| $\dot{V}_{Epeak}$ (L·min$^{-1}$) | M | 150.7 ± 25.2 | 138.4 ± 23.9 | -9.8 | 0.42 | 0.020 |
| $\dot{V}_{Epeak}$ (L·min$^{-1}$) | W | 113.3 ± 10.2 | 106.6 ± 12 | -8.8 | 0.61 | 0.036 |
| $V_{Tpeak}$ (mL·kg$^{-1}$) | M | 2.99 ± 0.4 | 2.56 ± 0.3 | -0.43 | 1.21 | <0.001 |
| $V_{Tpeak}$ (mL·kg$^{-1}$) | W | 2.33 ± 0.3 | 2.01 ± 0.3 | -0.32 | 0.97 | 0.001 |
| $f_{bpeak}$ (breath/minute) | M | 50.3 ± 6.1 | 54.2 ± 8.7 | 4.9 | 0.58 | 0.053 |
| $f_{bpeak}$ (breath/minute) | W | 49.3 ± 7.1 | 54.2 ± 9.4 | 3.9 | 0.52 | 0.021 |

$\dot{V}O_2$, oxygen uptake; HR, heart rate; $\dot{V}_E$, respiratory minute volume; $f_b$, respiratory rate; $V_T$, tidal volume.

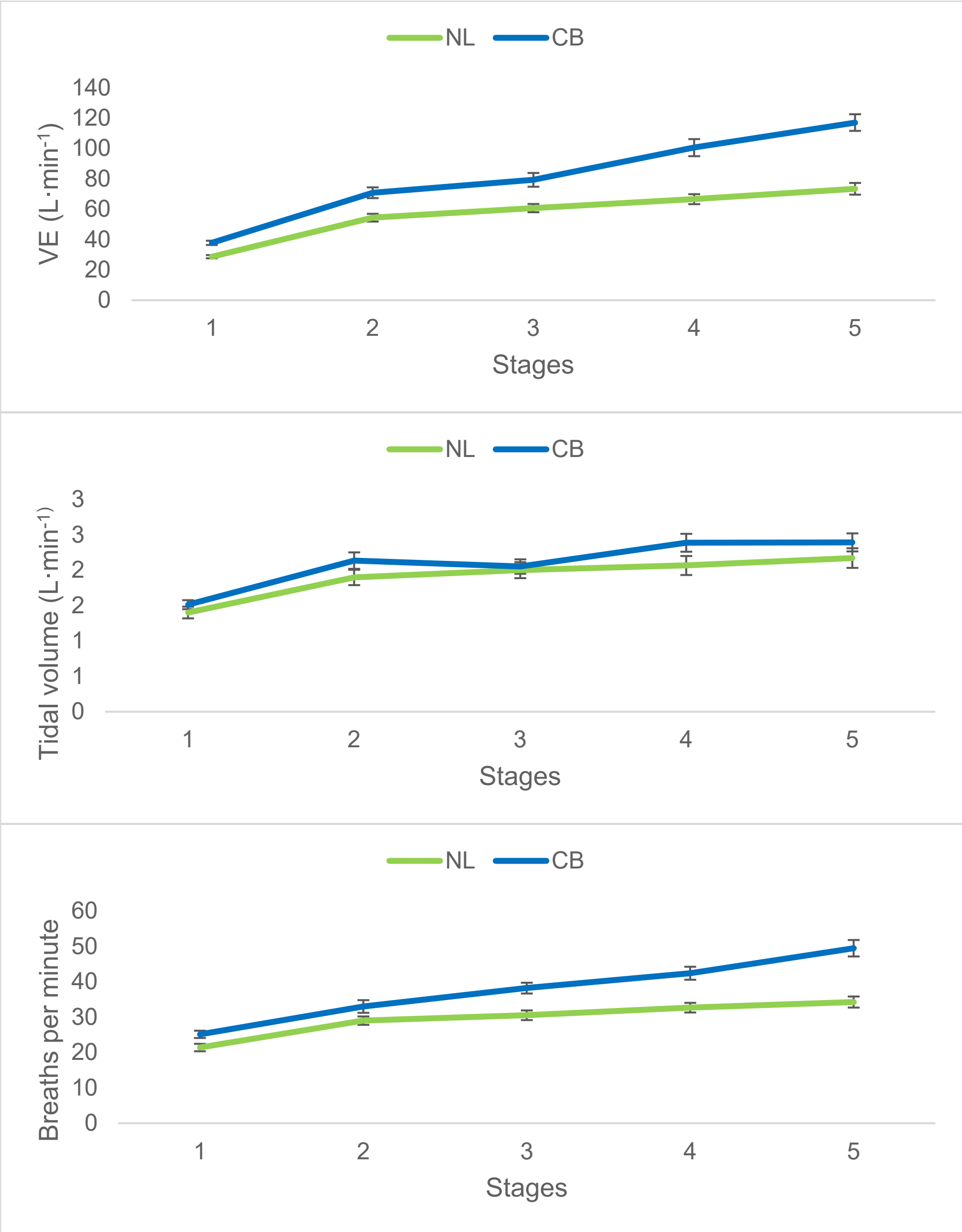


**Figure 9**. Graded exercise test [GXT], Minute ventilation stages ($\dot{V}_E$), at stages, standard deviations (SD) **A**. Tidal volume ($V_T$), at stages, standard deviations (SD) **B.** Respiratory rate ($f_b$) at stages, standard deviations (SD) **C**. NL (green) denotes no load test situation and CB (blue) denotes combat gear test situation. Exercise intensity presented as GXT stages from stage 1 (5.4 km·h$^{-1}$ 0 grade) 2 (8 km·h$^{-1}$ 0 grade) 3 (8 km·h$^{-1}$ 2% grade) 4 ((8 km·h$^{-1}$ 4% grade) ) 5 ((8 km·h$^{-1}$ 6% grade). ANOVA, (Figure A, B, C) main effect of load $p< 0.001$ Interaction $p<0.001$. Post hoc analyses significantly different from no load at *$p< 0.05$, **$p< 0.01$, ***$p< 0.001$.

## Ventilatory thresholds

There was no difference, neither for sex ($p=0.71$) nor load conditions, when VT1 occurred, in $\dot{V}O_2$ $L \cdot min^{-1}$, (women $\Delta$-0.02, $p=0.75$; men $\Delta$-0.06, $p= 0.65$) or percent of $VO_{2peak}$ (women $\Delta$3%, $p= 0.24$; men $\Delta$1%, $p= 0.69$), Table 10. Studying VT2 showed that there was a significant reduction in $\dot{V}O_2$ $L \cdot min^{-1}$ for the CB condition compared with the NL condition, and a sex difference in both conditions ($p<0.05$). However, studying VT2 as a percentage of peak values (women $\Delta$-1%, $p=0.64$; men $\Delta$1, $p=0.63$) showed no difference between load conditions, similar to VT1, and with no difference between sexes ($p=0.50$) (Table 10).

**Table 10.** Mean, standard deviations and Cohen´s d effect size results 9 men and 9 women, cardiorespiratory data at submaximal exercise, unloaded (NL) and loaded (CB) condition.

| | Sex Men, Women | NL Mean ± SD | CB Mean ± SD | Change NL-CB | Cohen'sES | t-test p-value |
|---|---|---|---|---|---|---|
| VT1 ($\dot{V}O_2$ $L \cdot min^{-1}$) | M | 2.78 ± 0.50 | 2.72 ± 0.62 | 0.06 | 0.11 | 0.648 |
| VT1 ($\dot{V}O_2$ $L \cdot min^{-1}$) | W | 2.24 ± 0.19 | 2.22 ± 0.08 | 0.02 | 0.14 | 0.753 |
| VT1 (% of $\dot{V}O_{2peak}$) | M | 67 ± 6 | 68 ± 10 | -1 | 0.12 | 0.686 |
| VT1 (% of $\dot{V}O_{2peak}$) | W | 70 ± 8 | 73 ±7 | -3 | 0.40 | 0.237 |
| VT2 ($\dot{V}O_2$ $L \cdot min^{-1}$) | M | 3.49 ± 0.43 | 3.30 ± 0.47 | 0.19 | 0.42 | 0.136 |
| VT2 ($\dot{V}O_2$ $L \cdot min^{-1}$) | W | 2.79 ± 0.38 | 2.66 ± 0.29 | 0.13 | 0.39 | 0.069 |
| VT2 (% of $\dot{V}O_{2peak}$) | M | 84 ± 7 | 83 ± 9 | 1 | 0.12 | 0.631 |
| VT2 (% of $\dot{V}O_{2peak}$) | W | 86 ± 4 | 87 ± 4 | -1 | 0.25 | 0.640 |

NL, no load; CB combat gear (body weight + added load); VT1, first ventilatory threshold; VT2, second ventilatory threshold.

## Power

At VT1, all participants, except 1 woman and 3 men, had higher power output with load, when compared to the unloaded condition, whereas all the participants had lower power output wearing CB at VT2. At peak exercise, all participants generated lower power output in CB condition when compared to the NL condition (Figure 10).

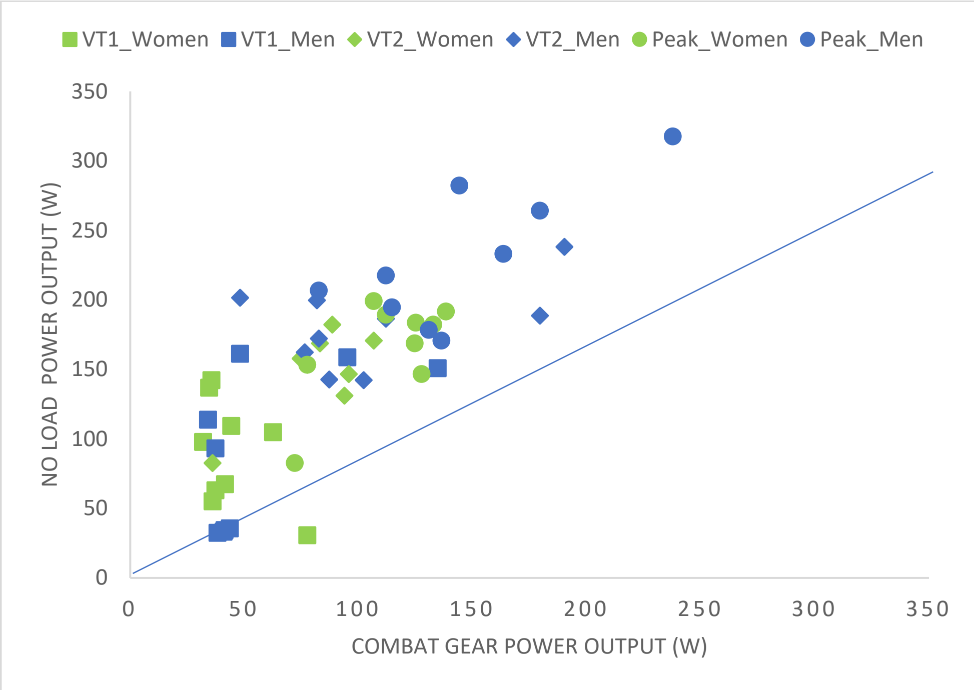


**Figure 10.** Power output during no load (NL) vs. combat gear (CB) during a graded treadmill test. Green denotes women, blue denotes men. First ventilatory threshold (VT1; squares), second ventilatory threshold (VT2; diamonds) and peak exercise (peak; circles) for the 18 participants.

## Muscle oxygen

There was no significant difference in $SmO_{2low}$ between men and women in NL conditions (p=0.17), whereas in CB condition, men's value was 51% lower than women's (p=0.003). Studying $\Delta SmO_{2Ex}$ showed a sex difference in CB condition (p=0.032), whereas no difference was found in NL condition (p=0.11). $SmO_2$ downslope showed a small difference between sexes in both conditions, demonstrating a higher oxygenation rate in m. vastus lateralis for men. A similar pattern appeared for recovery: men recovered 64% faster in NL condition (p=0.041) and 33% faster in CB (P=0.33) during muscle oxygen recovery (Table 11).

**Table 11.** Mean, standard deviations and Cohen´s d effect size results 9 men and 9 women, cardiorespiratory data at submaximal and peak exercise, unloaded (NL) and loaded (CB) condition.

| | Sex Men, Women | NL Mean ± SD | CB Mean ± SD | Change NL-CB | Cohen's ES | t-test p-value |
|---|---|---|---|---|---|---|
| $SmO_{2\ baseline}$ % | M | 72.4 ± 10.3 | 70.0 ± 17.1 | 2.4 | 0.17 | 0.650 |
| $SmO_{2\ baseline}$ % | W | 74.2 ±14.9 | 79.9 ± 19.1 | -5.7 | 0.33 | 0.400 |
| $SmO_{2\ low}$ (%) | M | 41.7 ± 19.8 | 31.0 ± 23.5 | 10.7 | 0.49 | 0.185 |
| $SmO_{2\ low}$ (%) | W | 56.4 ± 24.1 | 62.8 ± 14.8 | -6.4 | 0.32 | 0.571 |
| $\Delta SmO_{2\ Ex}$ (%) | M | 30.8 ± 17.6 | 39.0 ± 23.9 | -8.2 | 0.39 | 0.493 |
| $\Delta SmO_{2\ Ex}$ (%) | W | 17.8 ± 14.7 | 17.1 ± 14.5 | 0.7 | 0.00 | 0.924 |
| $SmO_{2\ down}$ ($\%\cdot min^{-1}$) | M | 0.87 ± 0.55 | 1.39 ± 0.83 | -0.52 | 0.74 | 0.242 |
| $SmO_{2\ down}$ ($\%\cdot min^{-1}$) | W | 0.49 ± 0.04 | 0.69 ± 0.06 | -0.20 | 3.92 | 0.429 |
| $SmO_{2\ up}$ $\%\cdot s^{-1}$) | M | 1.48 ± 1.15 | 0.83 ± 0.69 | 0.65 | 0.68 | 0.075 |
| $SmO_{2\ up}$ ($\%\cdot s^{-1}$) | W | 0.53 ± 0.55 | 0.55 ± 0.48 | -0.02 | 0.04 | 0.899 |

NL, no load; CB combat gear (body weight + added load); $SmO_2$, muscle oxygen saturation; ΔSmO2 Ex = magnitude of oxygen desaturation; $SmO_{2\ down}$ = $O_2$ desaturation rate; $SmO_{2\ up}$ = oxygen resaturation rate.

## Heart rate and $\dot{V}O_2$ relationship

We performed a mixed effect linear regression analysis for $\dot{V}O_2$ against HR to investigate whether the relationship between the HR and relative $\dot{V}O_2$ response are independent of load condition. The result revealed a significant association between HR, load and change in $\dot{V}O_2$ for women and men (Table 12), with no difference between sex. This finding implies that wearing NL, 1 beat per minute increase in HR resulted in an increase in $\dot{V}O_2$ for men of 0.337 $mL\cdot kg^{-1}\cdot min^{-1}$ ($p<0.001$), and in women of 0.315 $mL\cdot kg^{-1}\cdot min^{-1}$ ($p<0.001$). In addition, a significant association between CB and $\dot{V}O_2$ showed a lower increase in $\dot{V}O_2$ for every bpm increase in HR, for both women (0.271 $mL\cdot kg^{-1}\cdot min^{-1}$, $p\leq0.001$) and men (0.292 $mL\cdot kg^{-1}\cdot min^{-1}$, $p<0.001$) wearing CB compared to NL (Table 12, Figure 11).

**Table 12.** Association of changes in V̇O2 with HR and load.

| parameters | *β* | (95% CI) | p-value |
|---|---|---|---|
| Men NL $\dot{V}O_2$ ($mL\cdot kg^{-1}\cdot min^{-1}$) | 0.337 | (0.31, 0.36) | <0.001 |
| Women NL $\dot{V}O_2$ ($mL\cdot kg^{-1}\cdot min^{-1}$) | 0.315 | (0.29, 0.34) | <0.001 |
| Men CB $\dot{V}O_2$ ($mL\cdot kg^{-1}\cdot min^{-1}$) | 0.292 | (0.26, 0.32) | <0.001 |
| Women CB $\dot{V}O_2$ ($mL\cdot kg^{-1}\cdot min^{-1}$) | 0.271 | (0.24, 0.30) | <0.001 |
| intercept | -20.04 | (-24.1, -15.9) | <0.001 |

Results of mixed effect linear regression analyses for $\dot{V}O_2$ as dependent variable against heart rate. *β* regression coefficient. CI, confidence interval (95%); NL, no load condition; CB, combat gear condition (body mass + added load), $\dot{V}O_2$, oxygen uptake.

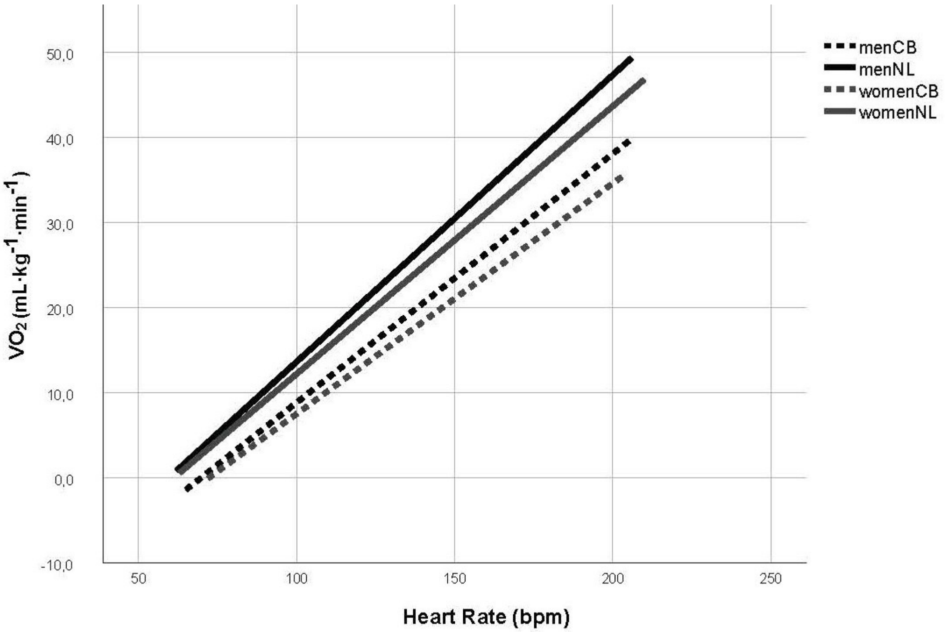


**FIGURE 11.** A mixed-effect linear regression model for oxygen uptake ($\dot{V}O2$) in mL·kg$^{-1}$·min$^{-1}$and increase in heart rate bpm (beats/min). Each line depicts the fitted regression line for a different load, NL (solid line) denotes no load test situation and CB (dashed line) denotes combat gear test situation, with a fixed slope and random intercepts. Effect of load $p< 0.001$ and heart rate (HR) $p<0.001$.

# Physiological combat demands (Study IV)

## Study design

After having conducted an exploratory qualitative study concerning soldiers' perceptions of physically demanding tasks (Study I), followed by a study that examined whether $\dot{V}O_2$ and HR measurements from unloaded tests can be used to predict energy expenditure with heavier load carriage, a study objectively describing the cardiorespiratory response and movements (e.g., distance covered, number of sprints, time in different heart-rate zones, speed, and direction of movement) of ground combat was conducted. This study contained four different parts: one urban operation task (Task 1) and three different retrograde operations with delay tasks (Task 2-4). The different tasks are described in Appendix 2.

The goal of this study was to provide an objective understanding of the physiological demands of soldiers' work performed while solving urban operations and retrograde in rough terrain. An additional goal was that the findings also could be used to develop a model for classifying work demands for ground combat forces.

### Setting and recruitment

The participating combat engineering soldiers were recruited from two different platoons: one in year 2019 and one in year 2020. A total of 42 (3 women) soldiers volunteered, aged 19 to 23 years, in different posts: squad leaders (14), gunners (11), combat engineers (12) and drivers (5).

We did not constrain platoon or squad commanders during the different tasks to mimic a more valid representation of active combat, i.e., they used the combat strategy they deemed appropriate to each enemy action. However, the enemy party behavior was controlled to ensure parity between engagement distance, aggression shown, and enemy activity cessation during each task. Both sides used blank ammunition in all exercises. The soldiers wore fighting order, which was comprised of webbing, body armor, and helmet. Mean fighting order load (weapon excluded) was 17.3 ± 2.6 kg, which was approximately 22.9 ± 4.5% of body mass (BM) (Table 13)

## Data collection and analysis

All the soldiers carried out anthropometrical and body composition measurements. We measured peak oxygen uptake ($\dot{V}O_{2peak}$) and maximal heart rate ($HR_{max}$) of the participants in a GXT, wearing combat gear and body armor, in a laboratory prior to the field exercise. The GXT protocol was executed on a motor-driven treadmill and consisted of marching 3 minutes at the speed of 5.4 km·h$^{-1}$ at 0% grade, followed by rapid marching/jogging for 3 minutes at 8 km·h$^{-1}$ at 0% grade, then continuing with marching or jogging at 8 km h$^{-1}$ with the incline increasing with 2% every third minute until volitional exhaustion. $\dot{V}O_2$ was measured by indirect calorimetry (*Oxycon Pro*™, Jaeger Oxycon, Intermedic, Sweden). HR was measured with Polar HR monitor (FT4, Polar Electro Oy, Kempele, Finland) placed on the chest of the participants, and synchronized with the Oxycon Pro system. Equipment was calibrated according to the manufacturer's instructions before each test. The highest 30 seconds average of $O_2$ uptake was determined as $\dot{V}O_{2peak}$.

During the time the soldiers conducted their tasks in the field exercise, we continuously assessed movement and metabolic demands through worn body sensors, and HR was continuously measured with a heart rate monitor with GPS (Polar Team Pro, Polar Electro Oy, Kempele, Finland). To classify the level of physical activity intensities, we used these levels of relative cardiovascular strain: HR < 50% $HR_{max}$ very light, 50-63% $HR_{max}$ light, 64-76% $HR_{max}$ moderate, 77-93% $HR_{max}$ hard, >94% $HR_{max}$ very hard, and 100%; $HR_{max}$ maximal work intensity. [9, 89]

*Statistical analyses*

We investigated correlations between KPI:s (accelerations·min$^{-1}$, decelerations ·min$^{-1}$, meters ·min$^{-1}$) and cardiorespiratory responses (percentage of time over 40% or 50% of $VO_{2max}$, and 76% over $HR_{max}$), using Spearman's product moment correlation coefficients and interpreted according to the following threshold: 0-0.2 negligible, 0.21-0.4 weak, 0.41-0.6 moderate, 0.61-0.8 strong, 0.81-1.0 very strong. [90] To determine potential difference between groups, platoon commanders (n = 14), combat engineers (n = 12), gunners and antitank (n = 11) and drivers (n = 5) a Kruskal-Wallis one-way ANOVA was conducted. Outliers were assessed with boxplot and Wilcoxon signed rank tests were used to compare data between Task 1 and Task 2. All statistical analyses were performed using SPSS software (SPSS Statistics, Version 25, IBM Corporation, New York). Statistical significance level was set at $p < 0.05$.

# Physical strains in combat

During the urban operation task, the platoon advanced from the assembly area and assaulted and cleared buildings, and thereafter set perimeter defences. During the retrograde tasks, they prepared delaying actions and counter mobility actions. Anthropometrical data and body composition are presented for the soldiers in Table 13.

**Table 13**. Descriptive statistics and main findings of the graded exercise test (N=42, 39 men, 3 women).

| Subject characteristics | Mean ± SD |
|---|---|
| Age (years) | 20.9 ± 1.4 |
| Body height (cm) | 182.1 ± 7.4 |
| Body mass unloaded (kg) | 77.3 ± 10.3 |
| Body mass, personal combat equipment (kg) | 94.6 ± 10.4 |
| BMI ($kg/m^2$) | 23.2 ± 2.0 |
| $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) | 4.2 ± 0.7 |
| $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 44.8 ± 4.9 |
| HRmax ($beats \cdot min^{-1}$) | 196 ± 8 |
| Time to exhaustion (min) | 17.7 ± 2.4 |

Values are means ± standard deviation. $VO_2$, oxygen uptake; HR, heart rate; BMI, body mass index

### *Movements during military tasks*

There was a difference in movement, total distance, between the different tasks due to the nature of the tasks. The urban operation (Task 1) consisted of less accelerations, decelerations, meters per minute compared to Tasks 2-4. Urban warfare is often more complex, challenging the commanders and is time-consuming. Table 14 displays the differences in the different tasks.

**Table 14.** Descriptive results for performance measures during different military tasks (n=42). Means, standard deviations

| Performance measures | Task 1 | Task 2 | Task 3 | Task 4 |
|---|---|---|---|---|
| Duration of task (min) | 482 | 423 | 448 | 501 |
| Total distance (m) | 4537 ± 8982 | 4235 ± 2938 | 9182 ± 1785 | 7669 ± 2650 |
| No of accelerations | 1369 ± 400 | 1439 ± 787 | 2206 ± 553 | 1914 ± 326 |
| $Accelerations \cdot min^{-1}$ | $2.84 \pm 0.83^{b}$ | $3.05 \pm 1.63^{d}$ | $4.90 \pm 1.16^{b,d,f}$ | $3.42 \pm 0.55^{f}$ |
| No of decelerations | 1507 ± 426 | 1562 ± 794 | 2295 ± 547 | 2040 ± 298 |
| $Decelerations \cdot min^{-1}$ | $3.12 \pm 0.87^{b}$ | $3.31 \pm 1.64^{d}$ | $5.10 \pm 1.14^{b,d,f}$ | $3.61 \pm 0.49^{f}$ |
| $M \cdot min^{-1}$ | $9.41 \pm 1.78^{b}$ | $9.99 \pm 5.78^{d}$ | $20.46 \pm 4.01^{b,d,f}$ | $13.66 \pm 4.64^{f}$ |

Results for individual task types. Data in the same row sharing the same symbol, (“a” Task 1 and Task 2; “b” Task 1 and Task 3; “c” Task 1 and Task 4; “d” Task 2 and Task 3, “e” Task 2 and Task 4, “f” Task 3 and Task 4), are significantly different from one another ($p < 0.05$).

*Physical activity during military tasks*

During the urban operations, the soldiers spent approximately 2 hours over 40% of their $\dot{V}O_{2max}$, with 22 ± 19 minutes of them on hard to maximal work intensity. Total amount of work intensity during the entire task was characterised as light work.

Whereas Task 2 resulted in less time over 40% of $\dot{V}O_{2max}$ compared to Task 1, although total work time represented light work. The highest percentage (33%) of time over 40% of $\dot{V}O_{2max}$ was found in Task 3 and 4. Similar to Task 1 and 2, Task 3 and 4 total work time corresponded to light intensity (Table 15).

There were no differences ($p>0.05$) between the studied posts (platoon commander, combat engineer, gunner, or driver) except for Task 1, on the amount of time they spent 40% and 50% over their $VO_{2max}$, nor for the time spent 76% over their $HR_{max}$. This may be because of the limited number of subjects. Figure 23 displays the differences in variables.

**Table 15.** Descriptive results for performance measures during different military tasks (n=42). Means, standard deviations.

| Performance measures | Task 1 | Task 2 | Task 3 | Task 4 |
|---|---|---|---|---|
| HR mean (beats·min$^{-1}$) | 105 ± 8 | 98 ± 14 | 111 ± 8 | 108 ± 10 |
| % $HR_{max}$ (%) | 54 ± 5 | 50 ± 7$^{d}$ | 56 ± 3$^{d}$ | 54 ± 5 |
| Percent of time over 40% of $\dot{V}O_{2peak}$ (%) | 21 ± 13$^{b,c}$ | 15 ± 8$^{d,e}$ | 33 ± 13$^{b,d}$ | 33 ± 10$^{c,e}$ |
| Percent of time over 50% of $\dot{V}O_{2peak}$ (%) | 10 ± 7$^{b}$ | 8 ± 5$^{d,e}$ | 19 ± 8$^{b,d}$ | 15 ± 11$^{e}$ |
| Percent of time over 76% of $HR_{max}$ (%) | 5 ± 4 | 2 ± 2$^{d,e}$ | 7 ± 4$^{d}$ | 7 ± 6$^{e}$ |

Results for individual task types. $\dot{V}O_2$, oxygen uptake; HR, heart rate. Data in the same row sharing the same symbol, (“a” Task 1 and Task 2; “b” Task 1 and Task 3; “c” Task 1 and Task 4; “d” Task 2 and Task 3, “e” Task 2 and Task 4, “f” Task 3 and Task 4), are significantly different from one another ($p < 0.05$).

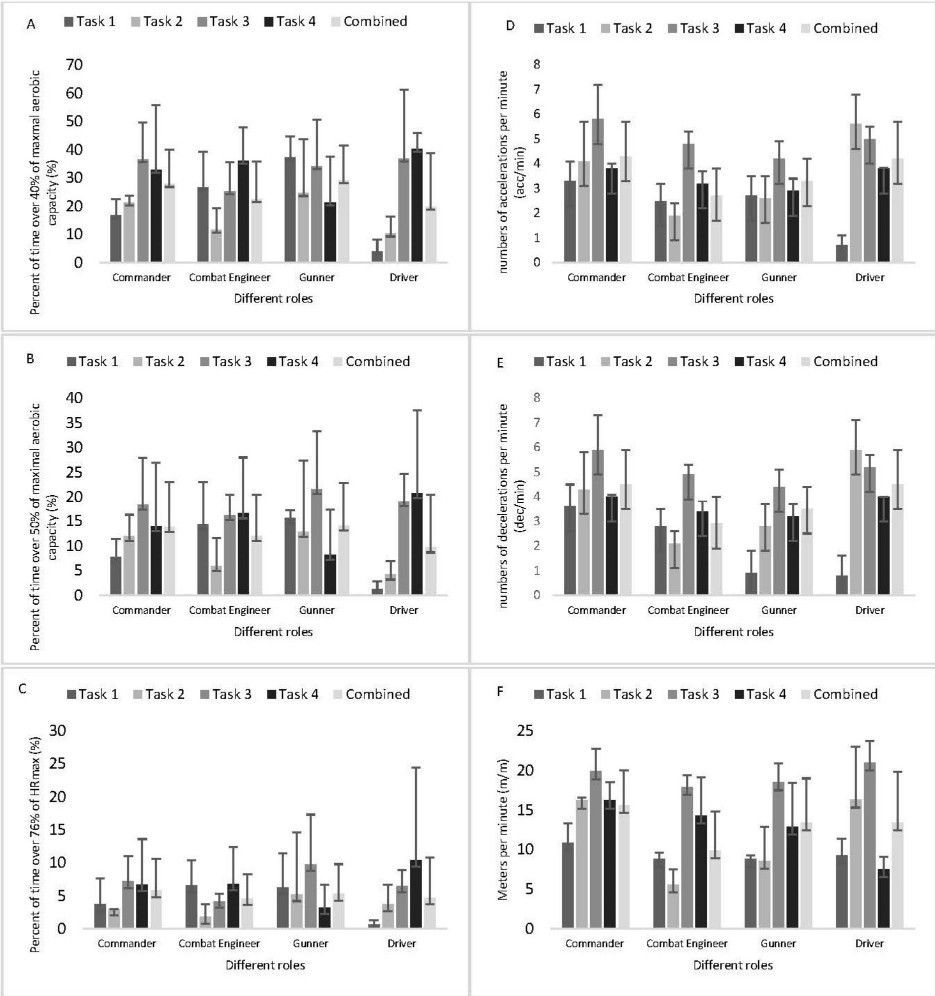


**Figure 12.** Cardiorespiratory responses and performance measures of each platoon role during four military task types (1, Urban operations; 2, 3 and 4 Delaying actions) and the four tasks combined. **A**. Percentage of time spent over 40% of maximal aerobic capacity. **B**. Percentage of time spent over 50% of maximal aerobic capacity. **C**. Percentage of time spent over 76% of $HR_{max}$. **D**. Numbers of accelerations/min. **E**. Number of decelerations/min. **F**. $m \cdot min^{-1}$. Results are presented as mean numbers of accelerations with error bars indicating the SD of the means. Statistical analysis was only conducted on the combined task. Bars sharing the same symbol are significantly different from one another ($p < 0.05$). Commander, n=14, Combat engineer, n=12, Gunners, n=11, Drivers n=5.

# Ethical considerations

The primary purpose of medical research is to generate new knowledge. When this research involves human subjects, this purpose can never surpass the rights and interests of individual research subjects. Medical research is, therefore, subject to ethical standards, which should ensure and promote respect for all human research subjects. Hence, it is the medical researcher's duty to protect the integrity, dignity, privacy, confidentiality and health of human research subjects. [91] These conditions have been considered in this project.

The Swedish Soldiers Physical Demands Study was approved by the Regional Ethical Review Board in Lund, Sweden (Dnr 2016/400), (Dnr 2017/78) and (2018/241). The project follows the World Medical Association's (WMA) Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects. Participation in the studies was voluntary, and informed consent was obtained from all participants for Studies I, II, III and IV. The participants were informed about their right to withdraw from participation at any time without giving a reason. All collected data were handled to ensure the participants' integrity and privacy. The overall impression was that the soldiers were eager to participate and regarded participation in the study as beneficial.

# Discussion

## General discussion

The studies in this thesis were conducted to describe and understand aspects of the physiological demands for soldiers performing their tasks in different environments.

The results of this project demonstrate that the process and methodology used was successful in identifying the critical physically demanding tasks performed by ground combat soldiers. This chapter begins with a discussion of the main findings of the study in the context of existing studies. Thereafter, methodological considerations are discussed, followed by conclusion, implications of the study and future study perspectives.

### Identifying physically demanding tasks (Paper I)

Physical demands are referred to as the duration and intensity of tasks and physical exertion in job functions. The research regarding physical demands in different operational environments in the military have been identified as important priority research areas, particularly physical performance and fitness. [12] It is a challenge to study military demanding tasks since they often are complex and do not consist of single activities. For instance, during an assault, the soldiers perform an approach march, different combat movements and casualty evacuations. Hence, the different tasks in this study contains both complex and single military activities.

Our analysis of the questionnaire showed that the soldiers reported that the most strenuous task was casualty evacuation, both for aerobic capacity (67% men and 52% women) and muscle strength (48-52% men and 48-68% women). Although transport of a wounded soldier is not the most frequent task for a soldier, dragging a casualty out of the line of fire is critical to saving lives. The result is similar to the armies of the United Kingdom, [55] United States, [92] Canada [93] and Australia, [43] which also have identified evacuating casualties as one of the most demanding tasks. However, although similar to results from other countries, there is a need for additional studies as the definition of tasks differ between armies, i.e., casualty evacuation. In the Royal Australian Army, a casualty drag consist of a four-person team whose task is to drag a casualty weighing 110-kg for a distance of 100 m followed by a 200-m fireman's carry. [42] In the British Army, a combat arms casualty drag is the task of one or two soldiers, dragging a 120-kg casualty for a distance of 40 m. In the Canadian Forces, a casualty evacuation task consists of lifting and carrying an equally sized soldier for 100 m in less than 60 seconds. [94] In the Swedish Armed Forces, a casualty evacuation is dragging one wounded person to cover, applying first aid and seeking assistance.

A soldier's work is physically demanding, and the environment has a large impact on a soldier's perceived workload. Soldiers work in different intensities during military operations with bursts of high-intensity activities. [11, 95] This may explain our findings that the next aerobic demanding task identified was movement in combat followed by dismounted attack in various types of terrain (reported by 20-40% of the participants) since assault in different terrain types were reported to involve high-intensity activities. That these tasks are rated this high is interesting since compared with studies from NATO, marching (loaded march, road march and running) has been identified as one of the most physically demanding tasks. [92, 94] This is in contrast to our study where loaded march was not ranked as one of the ten most demanding tasks (88% of female soldiers ranked it as somewhat strenuous or strenuous compared with 77% of the male soldiers). This discrepancy could be due to different interpretations of what the task entails. In the U.S. Army, it is a march of 24 km in less than 24 h with a load of approximately 47 kg. In the British Army, a similar task for ground combat soldiers is a 1–3 $km \cdot h^{-1}$ march for a duration of 4–8 h carrying ≥40 kg, and for Australian soldiers it is a 10-km march at 5.5 $km \cdot h^{-1}$ with a load of 38 kg.

Similar to the findings from countries within the NATO group: United States, [46] United Kingdom, [24, 47, 48 24, 47, 48] Netherlands [49] and Canada [50, 51] which concluded in 2009 [52] that 1) manual material handling (lifting and carrying), 2) marching (loaded march, road march and running) and 3) digging (entrenchment dig, trench dig) were the most physically demanding tasks, Swedish soldiers ranked carrying heavy loads, dismounted attack in urban terrain and digging foxholes as the most demanding tasks.

From World War II to the present time, the load carried by soldier has steadily increased and is now between 50-60 kg of extra weight. [2] To avoid fatigue, the recommended load should not exceed 30-50% of the soldiers' body mass, [96] where previous research has shown that the risk of injury increases fivefold for women if the load carried is > 25% of body weight, and there is an increased risk of fatigue even when the load is 15-20 kg. [96, 97] In comparison with these studies, it is interesting that in the present study, there were no differences in the ranking of physical requirements between female and male soldiers although they sometimes ranked the tasks in different order.

Based on the answers in the questionnaire, we excluded Riot Control from further studies of physically demanding tasks. Although the Swedish battalion in Kosovo 2004 was involved in the incident in Caglavica, [98] it is not a domestic duty of the

Swedish Army. Therefore, not surprisingly, most of the soldiers answered "I do not know" while ranking this task. It is important to not select low frequency, low critical tasks with a high physical demand so that the physical demands of the occupation are not unnecessarily elevated and have a negative impact on recruitment or employees. [75]

## Investigating cardiorespiratory responses of load carriage (Paper II and III)

Paper II and III presented data on cardiovascular response, pulmonary ventilation, and muscle oxygen consumption. The impact of load carriage on $\dot{V}O_{2peak}$ does not only depend on weight or tightening the load causing pressure on chest wall. [99] It may also depend on biomechanical factors, i.e., compensation in muscle activation (abdominals, lower back, hip, knee and ankle). [62]

*Submaximal exercise*

During submaximal GXT wearing CB, we observed a disproportional increase compared to NL exercise intensity (Figure 9). During the GXT, at low exercise intensity, there was a smaller, although significant difference between conditions. However, as the exercise intensity increased, there was an additional increase in the oxygen uptake required to carry the added weight (Figure 9A). No differences between sexes were observed, neither in NL nor CB conditions (Figure 9B). This is similar to findings of Phillips et al., [62] who studied the effect of wearing a 25 kg backpack during graded exercise and found a disproportional increase with increased grades. Similarly, HR was up to 25% higher with CB compared to NL at submaximal intensities with no sex differences (Figure 9C), indicating the increased demands of CB placed on the heart to maintain cardiac output. This is supported by previous studies on male soldiers [59] and female and male soldiers [57] whom observed a greater increase in HR while wearing body armor.

The added demands of $\dot{V}O_2$ wearing CB were met by an increase in $\dot{V}_E$ at submaximal exercise intensities (Figure 9A), supported with an increase in $f_b$ together with a lower $V_T$ from approximately 70% of $V_{Tpeak}$. This breathing pattern, a compensation breathing strategy, with a shift to a more shallow and frequent breathing pattern has previously been shown in a study of Phillips et al. [100] This sub-optimal breathing pattern has in previous studies been shown to lead to decreased upper extremity function, restricted chest wall motion, possibly resulting in respiratory muscle fatigue and a subsequent reduction of time that soldiers could operate wearing body armor. [58, 59, 101, 102] This possibly explains the lower $\dot{V}_{Epeak}$, lower $\dot{V}O_{2peak}$ and reduced time to exhaustion in the present study while wearing CB.

*Ventilatory thresholds*

In the CB condition $\dot{V}O2$ ($L \cdot min^{-1}$) was only slightly decreased (women, 0.9% and men 2.1 %) at VT1, similar to Phillips et al. [62], who studied men wearing 25 kg backpack on a treadmill with a reduction in $\dot{V}O_2$ with 3.9%. Our reductions in the power output, women (50%), men (36.7 %) were greater than the reduction (23.9%) in the study by Phillips et al. [62] When studying the reduction in $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$), it tends to be greater (19.8%) at VT1. At VT2, the reduction in $\dot{V}O2$ was similar to VT1, women (4.7%) and for men (5.4%), whereas the difference in $\dot{V}O2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) was larger (22%). The reduction in power was less compared to VT1, men -15% and women -18% with no difference between sexes. The soldiers were considered aerobically well-trained [103] since VT2 were in the range of 84–87% of $\dot{V}O_{2peak}$.

The slight decrease in $\dot{V}O_2$ at the different threshold explains only some parts of the larger decrease in power output (Figure 10). The total $\dot{V}O_2$ distribution to both external and internal work could explain most of the decrease in power wearing CB. A greater amount of $\dot{V}O_2$ is required for load carriage when treadmill grade increases, possibly explaining why VT1 and VT2 appeared at earlier stages in the CB condition. Taylor et al. [104] reported a decrease in the available energy for locomotion during steady-state exercise while wearing load carriage (firefighter personnel protective ensemble)

*Maximal exercise*

With CB, absolute $\dot{V}O_{2peak}$ was decreased by 6.6% for women and 12.4% for men (Table 8), whereas, studying relative $\dot{V}O_{2peak}$, the reduction for both men and women was ~24%. This reduction was also reflected in time to exhaustion, where the CB condition led to a significantly shorter time (Table 7). Similar results were found in previous research, where an increase in load resulted in a decrease in time to exhaustion, $\dot{V}O_{2peak}$ and $\dot{V}_{Epeak}$, in male military personnel, [60, 105] and in soldiers and university students of both sexes. [70, 106] This decrease in $\dot{V}O_{2peak}$ is likely connected to the similar decrease found in $\dot{V}_{Epeak}$ in our study, wearing CB, similar to a study of men wearing body armor. [59] There was no difference between women's (~6%) and men's (~8%) reduction (p=0.06). This is contrary to a study of Walker et al. [106] who found a greater reduction for women using a 10 kg weighted vest to simulate body armor and then added another 10 kg in a backpack.

Although women's reduction in absolute $\dot{V}O_{2peak}$ was only slightly lower compared to men, there is a difference between sexes both in NL (~25%) and in the CB (~17%) condition. These sex differences in the NL condition are in line with a study of Ogawa et al. [107] who found a difference between sexes, both for trained individuals (22%) and untrained (24%). There is a scarcity in studies examining sex differences wearing CB and body armor. One study by Walker et al. [106] assessed the effect of simulated body armor (20 kg, weighted west) in both men and women. The study did not examine sex differences per se, but found a ~20% sex difference similar to our study where wearing CB resulted in 17% lower $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$).

Interestingly, when $\dot{V}O_{2peak}$ is expressed in $mL \cdot kg\ FFM^{-1} \cdot min^{-1}$ the sex differences were altered, and women values were ~5% higher compared to men. These findings are opposed to previous findings of Ogawa et al. [107], who still had ~10% higher $\dot{V}O_{2peak}$ for trained men compared with women, and Peltonen et al. [108] who had a 4% reduction in $\dot{V}O_{2peak}$ for women compared to men during incremental cycling. One possible explanation for the altered reduction could be that the female soldiers in our study had a long experience of wearing combat gear. No difference was found in HR at peak exercise being in line with most previous studies. [62, 104, 109]

*Muscle oxygen*

To fully evaluate tissue oxygenation in both sexes, it is important to consider that women have several anatomic and physiologic characteristics that distinguish their acute exercise responses from those of men: women have more fat mass and less muscle mass for a given body size. [110] Male soldiers showed a greater decrease in $SmO_2$-m. vastus lateralis in both conditions, similar to a study of Espinosa-Ramirez et al. [74], who assessed sex differences in m. vastus lateralis and m. intercostales during incremental cycling. Contradictory to men, leg muscle oxygenation increased only modestly during GXT for women, particularly in the CB condition. At peak exercise, deoxygenation was similar between sexes, although the rate of muscle oxygenation declines was steeper for men. This is similar to Peltonen et al., [108], who studied unloaded cycling and found a greater deoxygenation for men, but in contrast to a study of Bhambhani et al. [72], who found that muscle deoxygenation during incremental exercise was similar in men and women. One possible explanation for the differences between these studies could be the use of different devices; McManus et al. [111] investigated different devices and found that the values are not generally comparable between devices. The initial increase in muscle oxygenation followed by an increase in deoxygenation to the lowest value at peak exercise found in this study is supported by other studies that examined incremental treadmill exercise. [112-114] Our results suggest that there may exist a sex difference in tissue deoxygenation during dynamic exercise.

The sensitivity of muscle $\dot{V}O_2$ recovery kinetics to athletic capacity have been demonstrated by several studies. [115, 116] The resaturation rate is shown to be faster, measured with NIRS, in trained individuals compared with non-trained. [117] $\dot{V}O_2$ recovery time of m. vastus lateralis has been shown as nearly twice as fast in well trained individuals. [115] The calculated values for recovery ($SmO_{2up}$), displayed a slower resaturation rate for women with 36% compared to men (Table 11) in the NL condition, whereas no difference was found in the CB condition. Studying men shows that their resaturation rate was somewhat slower in the CB condition (Table 11). The difference implies a greater load to the cardiorespiratory demands wearing

CB. However, regarding the widespread variation, the data must be interpreted with caution, and further studies are necessary.

*Heart rate and oxygen uptake relationship*

We intended to clarify whether measures of HR/$\dot{V}O_2$ during unloaded GXT could be used to estimate energy expenditure from HR measured in soldiers wearing CB performing exercises in the field. Our findings suggest that this should not be done. Wearing CB led to a larger increase in HR for any given $\dot{V}O_2$. Therefore, the HR/$\dot{V}O_2$ relationships wearing CB and NL are not similar and should not be used interchangeably. The presented data showed no differences between sexes.

The intensity of work wearing CB in field exercises will probably be underestimated if HR measured wearing CB is cited relative to the HR for unloaded running. The HR/$\dot{V}O_2$ relationship found in this study is similar to those of Gordon et al. and Rayson et al., [69, 70] although they used a slightly different protocol. Our study had the same protocol for both NL and CB condition, while their protocol had a constant speed while load for the marching and gradient for the running were varied. Other studies found comparable heart rate elevations during treadmill walking [101, 118, 119] with an added load of ~15%. In addition, they also found that placement and support of the load had an effect, whereas other studies found a linear relationship between external load and heart rate. [105, 120] The reason for the substantially larger increases in HR for a given $\dot{V}O_2$ during loaded marching has been suggested to relate to biomechanical factors and muscular fatigue. [69, 121] Other studies suggest that a greater postural control is demanded wearing added load. [70] In conclusion, the relationship of $\dot{V}O_2$ and HR for unloaded exercise cannot be directly applied to exercise wearing CB.

## Physiological combat demands (Paper IV)

This study demonstrated that the cardiorespiratory system of the soldier is highly affected by military tasks in urban operations and retrograde operations in rough terrain. The soldiers worked between 15-33% of the mission time close to 40% of their $\dot{V}O_{2max.}$ Oxygen consumption is directly correlated with workload, thus, working on a higher percentage of $\dot{V}O_{2max}$ could result in earlier fatigue and lower tolerance time. [96]

*Cardiorespiratory characteristics*

The results from the GXT in this study were similar to the data found in study II, i.e., $\dot{V}O_{2peak}$ (L·min$^{-1}$) and time to exhaustion. Directly measured $\dot{V}O_{2peak}$ data from the GXT was used as the reference measurement to estimate the HR values at 40% and 50% of $\dot{V}O_{2max}$, corresponding to 17.9 ± 1.9 and 22.4 ± 2.5 mL·kg$^{-1}$·min$^{-1}$, respectively. Our data corresponds with the findings from Santee et al., [10] who tested U.S. army soldiers wearing a load of 27.2 kg (34% of BM). Their $\dot{V}O_2$ at 36% of

$\dot{V}O_{2peak}$ was 18.8 $mL \cdot kg^{-1} \cdot min^{-1}$. Their data was somewhat higher than ours, possibly due to higher load compared to BM in their study [10] (34% vs, 23% in the present study). The average data corresponded to 54 ± 5% of the soldiers HRmax indicating that the soldiers' mean work time should be classified as light work. However, we found a great variance in HR responses between the different posts. There were soldiers who spent almost 5 hours (57%) of their time over 40% of $\dot{V}O_{2max}$, particularly gunners, who carry an additional load of up to 15 kg besides their CB. There are few available studies directly commensurable with ours. The closest comparable study is Pihlainen et al. [11], who studied 15 Finnish male conscripts during a military field exercise, examining energy expenditure of load carriage, digging and lifting loads. Our results are similar to their findings: their mean work intensity was close to 50% of soldiers' $\dot{V}O_{2max}$ and varied between 18 and 24 $mL \cdot kg^{-1} \cdot min^{-1}$.

Wu and Wang [39] stated that maximal acceptable work time is correlated to aerobic strain (%$\dot{V}O_{2max}$). Their prediction model determining the upper limits of %$\dot{V}O_{2max}$ for dynamic work lasting 12, 10, 8, and 4 hours are 28.5%, 31%, 34% and 43.5%, respectively. [39] Compared with the data from our study, it would indicate that some soldiers could be at risk for developing fatigue while solving urban operations and delaying actions. There was no difference in mean time over 40% of $\dot{V}O_{2max}$ between the different posts. We conclude that the soldiers spent ~25% of their time over 40% of their $\dot{V}O_{2max}$, which is below the limits described by Wu and Wang [39].

Our data suggests that an increase in load increases cardiorespiratory demands for lighter personnel, i.e., that higher load in percent of BM mass was positively correlated with time spent over 50% of $\dot{V}O_{2max}$ at intensities of hard to maximal work. This corresponds with a study of Lyons et al. [122] and Taylor et al. [123], who found that increased body mass (BM) is advantageous when carrying heavy loads despite lower $\dot{V}O_{2peak}$ relative to BM. Hence, measuring soldiers work capacity accounting only for the person's own body weight ($\dot{V}O_{2peak}$ as $mL \cdot kg^{-1} \cdot min^{-1}$) would not be optimal for soldiers who typically work with external loads. [54] $\dot{V}O_{2peak}$ expressed in more absolute terms will correlate better with performance in the actual work as more external weight is carried.

*Movement characteristics*

Although previous studies have investigated acceleration patterns for soldiers e.g., 15m sprint, 15 m slalom run, shuttle run 3x5 m, 15 squat, [124] and mock assault. [95] Our study extends current knowledge by evaluating these patterns during approximately 8 hours of simulated combat. Mean accelerations performed by the soldiers was ~4.9 accelerations/min; only a few were classified as high intensity sprints (>2 $m \cdot s^{-1}$). Acceleration is metabolically demanding and increases both energy expenditure and muscle activity, which could cause muscle. [125] Therefore, it is necessary, to assess acceleration patterns during missions. The acceleration pattern in this study was comparable to a 90-minute game of soccer, although the number of accelerations over 2 $m \cdot s^{-1}$ is greater in soccer. [126] In addition, meters per minute and total meters during this simulated combat corresponded with the numbers reached in a 90-minute soccer game. [127] $\dot{V}O_{2peak}$, accelerations and $m \cdot min^{-1}$ were a significant positively correlated indication that acceleration puts a metabolic demand on the soldiers.

# Methodological considerations, strength and limitations

This thesis is based on data from three separate studies. For the initial part in this thesis, great efforts were made to recruit a large and representative study sample of Swedish ground combat soldiers. Despite these efforts there is a possibility that those soldiers who are more well motivated and with stronger psychological resources were more likely to participate. Nevertheless, the 165 participants did not differ from soldiers' sociodemographic characteristics, thus the sample is likely to represent Swedish ground combat soldiers. A strength of the data collection is that the questionnaire was adapted for soldiers.

A possible limitation in the data collection for the first study was the wide range in age (19-44 years), which could be a confounder related both to years of military service experience and to level of exertion. However, since most of the soldiers were young, stratification based on median age did not seem relevant. In addition, lack of experience with short-service time may have affected the soldier's ability to assess the tasks in the questionnaire correctly. Furthermore, the initial study would have been further strengthened with a higher response rate (71% in the study), a greater number of women respondents (15% in the study), corresponding to the actual rate of women serving in the Swedish Armed Forces (18%). [128]

The questionnaire was developed and validated in several steps to give the survey content and face validity. Reliability of the questionnaire was studied with the interrelatedness among the items determined by Chronbach's alpha in accordance with the COSMIN manual, [129] and was supported with a high alpha coefficient. Some of the tasks may have been interpreted differently among the respondents since they involve a number of sub-tasks that may vary depending on the actual situation in which they occur. [130] Conducting questionnaire research stresses the importance of a specific and accurate description of the job requirements since the different components can determine the performance outcome. [47] The number of task should also not be too small so the demands and the wide variety of movement patterns and muscle groups employed in task execution are captured. [75] Studying psychometric properties of a questionnaire is an ongoing process and further studies are needed.

Research can be divided into observational and experimental studies, [131] where experimental studies, particularly randomised control trials, are typically considered to produce stronger evidence than observational studies in medical research. [132] However, the aim of the succeeding studies was not to study the effect of an intervention but to observe how different methods compare, and then to report on the descriptive cross-sectional data. Hence, the observational design in study II-IV should be appropriate to answer the given research questions.

A limitation in study II and III is the relatively small study sample. In addition, in previous studies, height has been shown to affect ventilatory responses and pulmonary gas exchange because women tend to have smaller lungs compared to men, hence, they have increased work breathing during exercise and decreased aerobic power. [133, 134] Therefore, larger physiological differences would be expected in our study compared with studies where height is controlled for. Moreover, standardised equipment (weight and bulk), was not used and tightness of body armor not controlled for. This could imply that our findings might be more difficult to compare to previous studies using identical equipment, standardised load and tightness.

In study IV, one of the limitations was that muscular strength and lifting ability were not tested for since it is an important component required to complete the tasks in urban operations and retrograde. A strength of this project is that the soldiers were tested in their actual environment solving real tasks, although it may also be a limitation since it entails that the data could not be directly comparable to other studies.

# Conclusions

This thesis has provided new knowledge and understanding about physical strain among Swedish ground combat soldiers, and the methodology used can be applied to the development and implementation of physical employment standards.

- Almost all the physically demanding tasks found in the present study contain elements of lifting and carrying, which demand muscular strength and muscular endurance capabilities. These findings could be used as a foundation in the development of adequate physical recruitment standards for Swedish soldiers.
- Body armor reduces cardiorespiratory capacity in men and women, even at lower intensities, and shortened time to exhaustion in both women and men with ~56%. No apparent sex-differences exist in relative cardiorespiratory response either at submaximal or maximal exercise intensities.
- The $\dot{V}O_2$ and HR relationships for unloaded and loaded marching were different with no difference between sexes, which make HR measurements from unloaded exercise less reliable to use for prediction of energy expenditure at heavier load carriage. Hence, it is important to use relevant occupational clothing and load both when determining physical employment standards used for admissions testing and during yearly fitness tests.
- Deoxygenation in m. vastus lateralis increased with CB in men and women, whereas men had a greater decrease in $\%SmO_2$ m. vastus lateralis in both conditions, indicating a higher peripheral workload
- CB induced a small decrease in $\dot{V}O_2$ ($L \cdot min^{-1}$) at VT1 and VT2 for both men and women, whereas power was substantially reduced. Men had ~20% higher $\dot{V}O_2$ at VT1/VT2 and peak exercise in both load conditions. No difference was found at which percentage of $\dot{V}O_{2peak}$ VT1 or VT2 occurred.
- It is feasible to use the assessment method in this study to identify physically demanding soldier tasks and provide an objective base for any conclusions or inferences made concerning the physiological demands of soldier’s work. Developing entry test and physical employment standards for soldiers should be based on input from actual training field exercises.

# Practical implications

The knowledge generated from this thesis can be used by officers, staff members and athletes themselves to plan and manage tasks. Ultimately, the practical relevance of this thesis is to develop valid and reliable measures to assess physical employment standards.

- There are often very short timeframes for military commanders to plan missions and deploy personnel. Therefore, it is not conceivable that well-controlled research could be conducted and understand the physiological burden of each specific operation prior to these activities.
- There is a need to further study military tasks in field conditions with direct measurements to reliably define the physical requirements in different army branches.
- The results of this thesis show that the process and methodology can be used to identify the most physically demanding tasks performed by soldiers in the Swedish army.
- Certain physical characteristics, such as height, body mass, fat free mass, muscular strength and $\dot{V}O_{2peak}$ may impact load carriage performance, and therefore, must be considered in the development of physical assessment models.
- To prevent fatigue on the battlefield, education is suggested concerning the benefits of physical training.

# Future perspectives

- Future studies are needed to assess full validity and reliability of the questionnaire.
- It could be suggested that future studies should evaluate potential sex differences to better understand women's physiological responses to load carriage during field work.
- Future studies emerging from this project also will focus on evaluating specific types of branches such as Engineering and Artillery.
- More in-depth analyses of biomechanical mechanisms also are needed to evaluate compensatory changes in muscle activation and their effect on load carriage.
- Future studies should also focus on evaluating resaturation rate, i.e., muscle recovery and potential sex differences to obtain more specific data.
- Further research also is needed to compare NIRS thresholds in soldiers wearing CB to other concepts determining thresholds.

# Populärvetenskaplig sammanfattning

Att vara soldat är väldigt fysiskt krävande, det viktigt att upprätthålla en god fysisk kapacitetsnivå för att klara sin tjänst. Vid militära operationer arbetar soldater på lägre fysiska kravnivåer under lång tid för att ibland gå upp på intensiva kravnivåer. Framgång vid militära operationer är ofta beroende på soldaternas fysiska kapacitet, rörlighet och förmågan att bära sin utrustning. Det är därmed nödvändigt att soldater har tillräcklig arbetskapacitet att utföra sina arbetsuppgifter på ett både snabbt och säkert sätt och minska risken för skador. Fysiska urvalskrav har funnit länge och utvecklats över tiden, men vissa av dessa kravbilder är inte validerad på militär personal, därför är denna typ av metodologiska studier nödvändig.

Det övergripande syftet med detta projekt var därför att få en fördjupad förståelse och kunskap om fysiska belastningar inom markstridsområdet för att kunna främja utvecklingen av evidensbaserade urvals och uppföljningstester. Även utveckla en modell för arbetskrav analys för att i förlängningen kunna fastställa kravgränser vid fysiska rekryteringstester av soldater. Data samlades in genom enkäter och kliniska tester och undersökningar för att få en holistisk och systematisk kunskap om ämnet.

I en första studie utvecklades en enkät som distribuerades till 251 soldater på olika regementen i Sverige för att få en bättre förståelse om soldaterna egna uppfattningar och erfarenheter kring vilka av deras uppgifter de anser är de mest fysiskt krävande. Resultaten från detta användes för att utveckla en observationsstudie för att mäta den fysiska påfrestningen för de olika uppgifterna som framkom i enkätstudien. Därefter genomförde vi tester med 18 soldater, varav 9 kvinnor, där vi mätte den maximala syreupptagningsförmågan, både i träningskläder och med soldaternas utrustning som de bär i fält, inklusive skyddsväst/kroppsskydd, för att se vilken skillnad det kan vara mellan dessa alternativ. Slutligen följde vi 42 soldater (3 kvinnor) vid 4 olika tillfällen då de genomförde olika övningar i fält. Soldaterna genomförde strid i bebyggelse samt fördröjning strid med fördröjande fältarbeten. De vid undersökte var den fysiska belastningen under dessa övningar.

Resultaten av enkätundersökningen visar att soldaternas uppfattning är att omhändertagande och transport av skadade kamrater är de uppgifter som är mest ansträngande tillsammans med olika stridsförflyttningssätt och bära tung materiel. Strid i bebyggelse och olika terrängtyper uppfattades också som ansträngande. Nästan alla uppgifterna som soldaterna uppfattade som mest ansträngande, innehöll moment av att lyfta och bära tungt. Detta ställer krav på både styrke- och aerob förmåga. Inga könsskillnader identifierades bland svaren, män och kvinnor hade samma uppfattning om vilka moment som var mest fysiskt ansträngande.

Testerna av den kardiorespiratoriska kapaciteten på löpband, visade att kvinnor och män orkade genomföra testerna på löpbandet under lika lång tid, trots att kvinnor hade en procentuellt högre extra belastning med stridsutrustning och kroppsskydd i jämförelse med männen. Att bära stridsutrustning förkortade tiden till utmattning med cirka 56 %. Den maximala syreupptagningsförmågan sänktes med ungefär 17 % av att bära utrustning, dock med lite större påverkan på männen. Under sub-maximal löpning arbetade både män och kvinnor på en högre procentsats av sin maximala kapacitet i jämförelse med när de bar utrustning. Vilket också bekräftades när vi analyserade det linjära sambandet mellan hjärtfrekvens och syreupp-tagningsförmåga, det skiljer mellan utrustningsalternativen, vilket innebär att HR-mätning som genomförs med träningskläder inte är direkt överförbar till att bära stridsutrustning. Syresättningen i musklerna minskade mer för männen än kvinnorna, när soldaterna hade stridsutrustning sjönk syresättning snabbare och männen hade ungefär 50 % lägre värden än kvinnorna. Även ventilationen påverkades, minutvolymen minskade vid bärande av stridsutrustning samtidigt som andningsfrekvensen ökade, detta innebar att andningsmönstret förändrades med minskad vitalkapacitet som följd. Inga könsskillnader upptäckte i relativa kardiorespiratoriska svaret på att bära stridsutrustning. Kvinnliga soldater i studien vägde mindre men bar tyngre utrustning dock hade de lägre absolut $VO_2$ jämfört med männen på samma nivå, skillnaden försvann för relativ $VO_2$. När vi följde soldaterna i fält vid ett antal olika övningar fann vi att de genomför relativt mycket acceleration och de-accelerationer, de flesta av dem i relativt låg hastighet. Under de 8 timmarna vi följde soldaterna vid respektive övning tillbringade de ungefär 2 timmar över 40 % av deras maximala aerobiska kapacitet, för lång tid över denna nivå kan innebära utmattning och soldaterna löser sina uppgifter på ett sämre sätt. Soldater med en god aerobisk kapacitet har bättre möjligheter att lösa sina uppgifter i den fysiskt påfrestande miljö som de verkar i.

Sammanfattningsvis är det viktigt att ha en objektiv och validerad kravbild när man genomför mönstringstester, detta minskar risken för att lämpliga personer inte blir antagna, men även en mindre risk för könsdiskriminering och felaktiga uttagningar. Eftersom den burna utrustningen påverkar soldaternas fysiska förmåga är det viktigt att ta hänsyn till detta vid tester av deras fysiska tjänstgöringsförmåga och man bör använda relevanta utrustningsalternativ

# Acknowledgements

First of all, a warm thank you to colonel **Micael Ginér** and colonel **Patrik Ahlgren** who made it possible for me to go through with this project. And also, a warm thank you to my **colleagues** who supported me on this journey. I would also thank all the **Soldiers** who participated in this study. Thank you for taking the time to fill in the questionnaires and sharing your experiences and opinions. Your contribution is extremely valuable to this field of research. Great thank you also to the **Swedish Armed Forces and Halmstad University** for funding this PhD-project.

I would also like to express my sincere gratitude to the following persons:

**Magnus Dencker,** my main supervisor. Thank you for accepting me as a PhD-student and for sharing your knowledge. It is not easy to complete a PhD, but with your support I reached the goal.

**Charlotte "Lottie" Olsson,** my co-supervisor. First of all, thank you for accepting to be my supervisor. Thank you for sharing all your knowledge and experience. Your experience in research has led to great learning experiences through our discussions and ultimately strengthened my project.

**Ann Bremander,** my co-supervisor. Even though you were not a part of the whole journey, thank you for your support with statistics. Also, thank you for providing relevant and creative scientific feedback and ideas to all the studies in this project.

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# Appendix

# Questions about physical requirements at various tasks

## The information collected is intended for research purposes

## Background

Being a soldier is very physically demanding, so it is important to maintain a good level of physical capacity to cope with service. Success in military operations often depends on the soldiers' physical ability, mobility and ability to carry their equipment. It is therefore important both for the Armed Forces and for the security of the soldier to establish relevant limit values for physical work capacity in both recruitment and follow-up tests.

If the requirements are too low, soldiers with too low physical capacity can be recruited, which can mean that the ability to carry out tasks is impaired as well as an increased risk of individual overload with work injuries as a result. If the requirements are instead too high, it can mean that individuals who have relevant and desirable traits for the profession are eliminated during recruitment.

## Purpose

To map physical load in the ground combat area and, by extension, be able to set requirements limits for physical recruitment tests of soldiers.
It is important for the Armed Forces to gain more knowledge about the stresses that soldiers face during various types of operations. It is also part of developing relevant selection and follow-up tests. This questionnaire is part of a series of other surveys. The purpose of the survey is to identify:

- how strenuous different work tasks are considered to be, in order to assess what type of efforts can be borderline.
- how common different work tasks are
- what requirements soldiers perceive different tasks

## Questions about projects and questionnaires

We ask you to answer all questions as best you can.

Your answers will not be available to anyone who is not working on the project. The responses from the questionnaires will be recorded and coded by the responsible researcher and only the researchers included in the study and who need access to decoded information will receive it. All data handling will be done in accordance with the Personal Data Act (1998: 204)

The results of the survey will be published at group level in an article in an English-language journal, the answers for the individual will not be readable. The study is also part of a doctoral dissertation that deals with the physical capacity of soldiers.

If you have any questions about the form, please contact Captain Jonas Larsson, Swedish Armed Forces.
Tel: 0381-18762 or mobile 070-698 41 66. Email: jonas.a.larsson@mil.se

## Background questions

*In the case of cross-questions, click on the box that indicates your answer. Otherwise, write your answer.*

A1. Unit: ☐

A2. Age (years): ☐

A3. Sex: Male ☐
Female ☐

A4. I work; Fulltime ☐ /K
Parttime ☐ /T

A5. I work as: Soldier ☐
Officer ☐

A6. What is your rank (I.e. OR1)? ☐

A7. How many years employed? ☐

A8. Height: ☐

A9. Weight: ☐

A10. Position (I.e. rifleman)? ☐

A11. Have you done international service, if so what position and year?

Yes ☐ Position

No ☐

Year ☐

**Definition of ground combat**

Ground combat ability can be divided into sub-abilities. A sub-ability represents the most important components of the ability. For ground combat ability, there is ground operative control, combat with combined weapons and occupying and holding terrain.

The Armed Forces defines the following positions as ground combat soldiers: base guard soldier, air base security soldier, grenade launcher / group commander, dog guard home guard, high guard soldier, ground combat officer army / air force soldier, ranged soldier, battalion soldier, battalion / light mechanized , tank driver / shooter and wagon manager on tank 90 / tank 122.
Markstridsförmågan kan delas in i delförmågor.

B1. **What is your main daily task (more than 50 % of your daily worktime)**

*Click on the box that indicates your answer for each question (only one answer per question)*

| | |
|---|---|
| **1)** Desk duty (administration) | ☐ |
| **2)** Easy work (standing/walking/sitting) | ☐ |
| **3)** Moderately strenuous work | ☐ |
| **4)** Heavy strenuous work | ☐ |

On how many occasions do you, on average, perform the following tasks in the service during a normal work week? Think about it, because you may have done several tasks at the same time.

| | **Never** | **1-2** | **3-5** | **6-10** | **over10** |
|---|---|---|---|---|---|
| **5)** Combat Training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **6)** Aerobic training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** Strength training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** Other physical training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **9)** Loaded march | ☐ | ☐ | ☐ | ☐ | ☐ |
| **10)** Orienteering with map and compass | ☐ | ☐ | ☐ | ☐ | ☐ |
| **11)** Position specific training | ☐ | ☐ | ☐ | ☐ | ☐ |

What kind of position specific training?

B2a. **Physical training, how many hours do you do physical training in the service per week on average over a month?**

*Click on the box that indicates your answer for each question (only one answer per question)*

| | Never | 1-2 | 3-5 | 6-10 | over 10 |
|---|---|---|---|---|---|
| **1)** Aerobic training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **2)** Strength training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **3)** Mobility training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **4)** other type of training | ☐ | ☐ | ☐ | ☐ | ☐ |

Specify the type of other workout

B2b. **Physical exercise, how many hours do you do physical exercise in your spare time per week on average over a month?**

*Click on the box that indicates your answer for each question (only one answer per question)*

| | Never | 1-2 | 3-5 | 6-10 | over 10 |
|---|---|---|---|---|---|
| **5)** Aerobic training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **6)** Strength training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** Mobility training | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** other type of training | ☐ | ☐ | ☐ | ☐ | ☐ |

Specify the type of other workout

B3. **Physical requirements in your current position, is it physically demanding?**
**Are your tasks / tasks physically demanding?**

*Click on the box that indicates your answer for each question (only one answer per question)*

| | Yes | No |
|---|---|---|
| **1)** Endurance requirements (you get sweaty and or out of breath) | ☐ | ☐ |
| **2)** Strength requirements (eg lifting or carrying heavy equipment) | ☐ | ☐ |
| **3)** Mobility requirements | ☐ | ☐ |
| **4)** Requirements for coordination | ☐ | ☐ |
| **5)** Different type of requirements | ☐ | ☐ |

Specify the type of requirement

| | Not Important | Less | Indifferent | Some | Very Important |
|---|---|---|---|---|---|
| **6)** How important is endurance in your current job | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** How important is strength in your current job | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** How important is mobility in your current job | ☐ | ☐ | ☐ | ☐ | ☐ |
| **9)** How important is coordination in your current job | ☐ | ☐ | ☐ | ☐ | ☐ |
| **10)** How important is other requirements in your current job | ☐ | ☐ | ☐ | ☐ | ☐ |

Specify the type of requirement

| Level of agreement | Totally Disagree | Partly | Partly Agree | Totally Agree | Do not Know |
|---|---|---|---|---|---|
| **11)** I experience the physical requirements of training exceeding the requirements of my position | ☐ | ☐ | ☐ | ☐ | ☐ |
| **12)** I experience international service as more physically demanding than the demands of my position | ☐ | ☐ | ☐ | ☐ | ☐ |

What is more demanding, what position did you have

For question B4-B8:
**Click on the box that indicates your answer for each question.**
**If you have not completed the work, click do not know.**

**B4. How strenuous do you feel that the following work tasks are in your current position conditionally (oxygen-absorbing ability)?**

| | Very Light (9) | Light (11) | Somewhat Hard (13) | Hard (15) | Very Hard. (17) | Do not know |
|---|---|---|---|---|---|---|
| **1)** Loaded march With combat equipment | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **2)** Defence against ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **3)** Movement in combat (low crawl, high crawl, dodge, rush.) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **4)** Digging trenches/foxholes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **5)** Laying mines | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **6)** Loading equipment on vehicle | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** Carrying heavy loads | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** Camouflage (vehicels, tent) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **9)** Patroling | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **10)** Combat mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **11)** Reconnaissance patrol | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **12)** Attack in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **13)** Defence in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **14)** Delaying action in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **15)** Attack in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **16)** Defence in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **17)** Delaying action in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **18)** Attack in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **19)** Defence in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**20)** Delaying action in rough terrain
**21)** Ambush
**22)** Defence against air attack
**23)** Delaying fieldwork (demolition, interception)
**24)** Minesweeping and mineclearing
**25)** Setting up base camp
**26)** Care of wounded
**27)** Transport of wounded
**28)** Monitoring mission
**29)** Crowd control
**30)** Search operation
**31)** Guarding object or person

**32)Other task, what task?**

*B.5*

**Grade the strength of the hand you need to pass the following work task**

*Click on the box that indicates your answer for each question.*

| | Very Weak (1) | Weak (2) | Somewhat strong (3) | strong (5) | Very strong (7) | Do not know |
|---|---|---|---|---|---|---|
| **1)** Defence against ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **2)** Movement in combat (low crawl, high crawl, dodge, rush) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **3)** Digging trenches/foxholes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **4)** Laying mines | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **5)** Loading equipment on vehicle | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **6)** Carrying heavy loads | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** Camouflage (vehicels, tent) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** Patroling | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **9)** Combat mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **10)** Reconnaissance patrol | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **11)** Attack in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **12)** Defence in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **13)** Delaying action in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **14)** Attack in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **15)** Defence in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **16)** Delaying action in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **17)** Attack in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **18)** Defence in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **19)** Delaying action in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **20)** Ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **21)** Defence against air attack | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **22)** Delaying fieldwork (demolition, interception) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **23)** Minesweeping and mineclearing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **24)** Setting up base camp | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **25)** Care of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **26)** Transport of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **27)** Monitoring mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **28)** Crowd control | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **29)** Search operation | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **30)** Guarding object or person | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **31)Other task, what task?** | | | | | | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

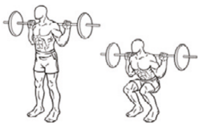
B6. **Grade the strength of the arm you need to pass the following work task**

*Click on the box that indicates your answer for each question.*

| | Very Weak (1) | Weak (2) | Somewhat strong (3) | strong (5) | Very strong (7) | Do not know |
|---|---|---|---|---|---|---|
| **1)** Defence against ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **2)** Movement in combat (low crawl, high crawl, dodge, rush) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **3)** Digging trenches/foxholes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **4)** Laying mines | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **5)** Loading equipment on vehicle | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **6)** Carrying heavy loads | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** Camouflage (vehicels, tent) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** Patroling | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **9)** Combat mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **10)** Reconnaissance patrol | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **11)** Attack in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **12)** Defence in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **13)** Delaying action in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **14)** Attack in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **15)** Defence in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **16)** Delaying action in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **17)** Attack in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **18)** Defence in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **19)** Delaying action in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **20)** Ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **21)** Defence against air attack | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **22)** Delaying fieldwork (demolition, interception) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **23)** Minesweeping and mineclearing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **24)** Setting up base camp | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **25)** Care of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **26)** Transport of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **27)** Monitoring mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **28)** Crowd control | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **29)** Search operation | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **30)** Guarding object or person | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **31)Other task, what task?** | | | | | | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

B7. **Grade the strength of the legs you need to pass the following work task**

*Click on the box that indicates your answer for each question.*



| | **Very Weak (1)** | **Weak (2)** | **Somewhat strong (3)** | **strong (5)** | **Very strong (7)** | **Do not know** |
|---|---|---|---|---|---|---|
| **1)** Defence against ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **2)** Movement in combat (low crawl, high crawl, dodge, rush.) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **3)** Digging trenches/foxholes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **4)** Laying mines | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **5)** Loading equipment on vehicle | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **6)** Carrying heavy loads | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **7)** Camouflage (vehicels, tent) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **8)** Patroling | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **9)** Combat mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **10)** Reconnaissance patrol | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **11)** Attack in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **12)** Defence in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **13)** Delaying action in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **14)** Attack in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **15)** Defence in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **16)** Delaying action in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **17)** Attack in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **18)** Defence in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **19)** Delaying action in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **20)** Ambush | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **21)** Defence against air attack | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **22)** Delaying fieldwork (demolition, interception) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **23)** Minesweeping and mineclearing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **24)** Setting up base camp | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **25)** Care of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **26)** Transport of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **27)** Monitoring mission | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **28)** Crowd control | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **29)** Search operation | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **30)** Guarding object or person | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **31)Other task, what task?** ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

B8. **Grade the strength of the core you need to pass the following work task**

*Click on the box that indicates your answer for each question.*

| | Very Weak | Weak | Somewhat strong | strong | Very strong | Do not know |
|---|---|---|---|---|---|---|
| **1)** Defence against ambush | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **2)** Movement in combat (low crawl, high crawl, dodge, rush) | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **3)** Digging trenches/foxholes | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **4)** Laying mines | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **5)** Loading equipment on vehicle | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **6)** Carrying heavy loads | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **7)** Camouflage (vehicels, tent) | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **8)** Patroling | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **9)** Combat mission | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **10)** Reconnaissance patrol | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **11)** Attack in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **12)** Defence in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **13)** Delaying action in urban terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **14)** Attack in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **15)** Defence in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **16)** Delaying action in close terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **17)** Attack in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **18)** Defence in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **19)** Delaying action in rough terrain | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **20)** Ambush | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **21)** Defence against air attack | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **22)** Delaying fieldwork (demolition, interception) | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **23)** Minesweeping and mineclearing | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **24)** Setting up base camp | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **25)** Care of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **26)** Transport of wounded | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **27)** Monitoring mission | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **28)** Crowd control | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **29)** Search operation | ☐ | ☐ | ☐ | ☐ | ☐ | |
| **30)** Guarding object or person | ☐ | ☐ | ☐ | ☐ | ☐ | |

**31)Other task, what task?**

B9. Physical test (mandatory tests FM FysS)

*Click on the box that indicates your answer for each question.*

| Importance of mandatory tests | not Important | Less | somewhat | Very | No idea |
|---|---|---|---|---|---|
| **1)** How important is it to physical tests in your position? | ☐ | ☐ | ☐ | ☐ | ☐ |
| **2)** How do you perceive today's tests, the additional requirements FM FySS? | ☐ | ☐ | ☐ | ☐ | ☐ |

**3)** Do the tests have any effect on your amount of workout? Yes☐ No ☐

**4)** Should everyone have the same type of physical tests? Yes☐ No ☐

**5)** Are the tests gender neutral, does everyone have the same conditions? Yes☐ No ☐

**6)** Should the tests be age differentiated Yes☐ No ☐

**7)** Do you experience physical tests as stressful? Yes☐ No ☐

What physical tests do you experience as stressful?________________________________

**B10. If you have comments, write these here, thank you!**

***Please make sure you answered all the questions!***

***Thank you for your participation.***

## Appendix 2. Task descriptions

*Military urban operations description*

Military operations in urban terrain or urban operations are usually fragmented and difficult to oversee. Within the company's area of operations, a single platoon will attack along 1-2 streets. Battle positions are sometimes taken in cleared civilian houses in areas that have been controlled. While operating in urban areas, the major offensive tasks at platoon and squad level are attacking and clearing buildings. This involves close-quarters battle, isolating the objective, suppressing the threat, advancing the assault element, assaulting, and clearing buildings. The platoon leader will normally organize his platoon into two assault squads: a support squad and a breaching squad.

*Military urban operations field exercise description (Task 1)*

The urban operations field exercise lasted 4 days, during which time the platoon performed an attacking and clearing building task. Task 1 the platoons' mission within the company's urban operations consisted of advancing and assaulting buildings via penetration attacks, seize control and clearing buildings. Thereafter consolidating, reorganizing, and setting up perimeter defenses. Task 1 lasted approximately 8 hours.

*Military retrograde description*

A delaying action is a form of retrograde operation in which a force under pressure trades space for time by slowing down the enemy's momentum and inflicting maximum damage on the enemy without, in principle, becoming decisively engaged. A delay wears down the enemy so that own forces can regain the initiative through offensive action, buy time to establish an effective defense, or determine enemy intentions as part of a security operation. A company usually delays within an area of between 3x5 km up to 5x10 km. The size of the area depends mainly on terrain and time conditions.

*Military delay field exercise description (Task 2)*

The task for the company was to delay the enemy at least 4 hours, enable a mechanized battalion the defeat the enemy. The platoon was assigned an area of operation where they conducted delaying field work with plenty of time for defense preparations in the actual covered terrain. Thereafter they executed the delay with different ambushes, in combination with mines and indirect fire.

*Military delay field exercise description (Task 3)*

Task 3 was similar to task 2 but with a little less time for preparation of the counter mobility actions. Hence the delaying action was executed with more ambush moving to different battle positions.

*Military delay field exercise description (Task 4)*

Task 4 was simulated combat for the company with delaying action (described prior). The force was assigned an area of operation within which the commander creates a battle plan based on defense and attack in combination with mines and indirect fire. The company had plenty of time for defense preparations in the actual terrain, so the battle was carried out over great depths with a large element of attacks and delaying field work. Delaying backwards to enable the counterattack from another mechanized battalion.

# Paper I

Applied Ergonomics 83 (2020) 103002

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: http://www.elsevier.com/locate/apergo

# Development and application of a questionnaire to self-rate physical work demands for ground combat soldiers☆

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ARTICLE INFO

*Keywords:*
Ground combat soldiers
Work-demands
Physical demand
Aerobic capacity

ABSTRACT

*Purpose:* The aim of the present study was to identify the most physically demanding work tasks for Swedish ground combat soldiers through the development and application of a questionnaire survey. This is the first in a series of studies aiming to describe the development process and validation of physical selection standards in the Swedish armed forces.
*Methods:* Based on procedural documentation, combat manuals and job analyses, a questionnaire was developed that defined and rated the perceived physical strain of 30 work tasks for ground combat soldiers. To assess validity, an expert focus group was used and psychometric analysis performed. The questionnaire was then distributed to 231 ground combat soldiers, of whom 165 responded (71%).
*Results:* The questionnaire was validated in three steps to achieve face and content validity, and internal consistency was acceptable (Chronbach's alpha ≥0.95). Of the 30 work tasks included in the survey, transport of wounded was rated as the most demanding task for both aerobic capacity and strength. Other highly demanding tasks for aerobic capacity included combat movement (low/high crawl), dismounted attack in close country, urban and rough terrain and carrying heavy loads. There were no gender differences for either aerobic or strength demands in the top five most challenging tasks based on proportions.
*Conclusions:* This study identified the most physically demanding tasks performed in the Swedish ground combat forces. Almost all the physically demanding tasks found in the present study contain elements of lifting and carrying, which require muscular strength and muscular endurance, with no gender differences.

## 1. Introduction

Many military tasks are physically demanding, and the ability to achieve and maintain the physical capacity required to perform all military tasks is important (Knapik et al., 2005; Heinrich et al., 2012). The most physically demanding work tasks for soldiers include carrying, lifting heavy loads and digging (Rayson, 1998). In military operations, soldiers often work at submaximal intensities during long periods of time interspersed with shorter high-intensity activities (Pihlainen et al., 2014). The success of military operations is often dependent on the soldiers' mobility and their ability to carry equipment. Soldiers with inadequate physical capacity increase their susceptibility to fatigue or injury, which can jeopardise the success of the mission (Nindl et al., 2013).

To select recruits able to meet the physical requirements of military operations, valid and reliable entry tests are important as are complementary tests for specific posts. Applying for basic military service in Sweden takes approximately 16–24 weeks from application to admission. If the applicant meets the initial requirements, he/she will perform an admission test at the Swedish Defence Recruitment Administration consisting of a physical, theoretical and medical examination, and all tests are the same irrespective of gender. The physical examination includes measures of isokinetic muscular strength during a simulated work-related heavy lift and a physical test on a test cycle (Larsson et al., 2011). Other criteria for admission selection include medical fitness and psychological capacity tests (Larsson et al., 2013). Validation of old as

☆ This work was supported by Swedish Armed Forces, Eksjö Sweden.
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https://doi.org/10.1016/j.apergo.2019.103002
Received 5 February 2019; Received in revised form 28 October 2019; Accepted 12 November 2019
Available online 17 November 2019

well as new tests to accurately reflect the requirements of different military tasks is important (Larsson et al., 2011). Since no work demand analyses have been performed in the Swedish armed forces, it is difficult to determine how valid the physiological admissions criteria are. Another question is whether there are gender differences in the perception of physically demanding tasks in the Swedish armed forces since male soldiers often have an advantage in physically demanding tasks due to anthropometric and physiological factors (Epstein et al., 2013; Roberts et al., 2016). Unlike other international armed forces, Sweden does not have gender-specific admission criteria. Some countries, however, are starting to initiate gender- and age-neutral admission standards, e.g., the United Kingdom (British army, 2018), which will introduce a gender and age-neutral fitness test in 2019.

Previous work task analyses have used physical loads to characterise the tasks performed by correctional officers (Hughes et al., 1989), firefighters (Phillips et al., 2011; Lindberg et al., 2014) and Australian State Emergency Services personnel (Larsen et al., 2013). Other studies have assessed the most physically demanding tasks. For example, the British army identified four key activities in the job analysis: single lift, carry, repetitive lift and loaded march (Rayson, 1998), and Canadian forces identified digging, marching and manual materials handling as the most physically demanding tasks (Jaenen, 2009). Using questionnaires, 70% of recruits in the Norwegian armed forces reported that their service was rarely endurance or strength demanding (lifting or carrying heavy loads) (Stornæs et al., 2014), while smoke diving and victim rescue were the most strenuous tasks reported by firefighters (Lindberg et al., 2014). Lastly, Australian State Emergency Service personnel identified twelve tasks as the most physically demanding, with carrying sandbags, lifting sandbags and shoveling sand (with hands) ranking as the top three physically demanding tasks (Larsen et al., 2013). In Sweden, studies have examined training optimisation and injury prevention for recruits during military training (Larsson, 2009) but not the physical demands of tasks for ground combat forces.

The aim of the present study, therefore, was to identify the most physically demanding work tasks for Swedish ground combat soldiers through the development and application of a questionnaire pertinent to the Swedish army, and to study possible gender differences in perceived difficulty of the tasks. This is the first in a series of studies and intends to serve as a foundation for the development of a valid admission and physical work capacity test applicable to the Swedish army.

## 2. Methods

### 2.1. Development of a work task analysis questionnaire

Questionnaires from other countries and from other physically demanding professions (Lindberg et al., 2014; Stornæs et al., 2014) were studied since none existed for the Swedish armed forces. The sections that were in agreement with and adaptable to a Swedish context and suitable for ground combat soldiers were used in the questionnaire development. An initial inventory of the tasks for ground combat soldiers was performed using combat manuals and procedural documentation from the Swedish armed forces (Hemvärnet, 2018).

The research group included a military officer, exercise physiologist, physiotherapist and physician specialised in physiology who examined the relevance of the items selected in the first version of the questionnaire. The questionnaire came to consist of six different sections: the first included questions related to the soldier's age, sex, anthropometric data and the nature of his/her job. The next four sections included questions regarding work demands for different tasks. The sixth section included questions regarding mandatory physical tests.

During development of the questionnaire, difficulty of the tasks requiring aerobic capacity were based on the Borg rating of perceived exertion (RPE) scale 6–20 (Borg, 1985, 1990, 1998) and were rated as very light (RPE 9), light (RPE 11), somewhat hard (RPE 13), hard (RPE 15), very hard (RPE 17) or I do not know. The questions regarding requirements for muscle strength in the hands, arms, trunk and legs were based on Borg category-ratio (CR 10 scale) (Borg, 1982) and were rated as very weak (1), weak (2), somewhat strong (3), strong (5), very strong (7) or I do not know. In the final version of the questionnaire, the intensity descriptions used the text answers, not the numerical values.

### 2.2. Validity and feasibility of the questionnaire

An expert focus group consisting of both male ($n = 7$) and female ($n = 1$) officers was used to establish interpretation, cultural relevance, face validity (the degree to which a test is subjectively viewed as adequately covering the measured construct) and content validity (the degree to which the content of the questionnaire adequately reflects the construct to be measured) according to recommended guidelines in COSMIN checklist (Mokkink et al., 2010). The focus group had some concerns regarding the information text and the interpretation of tasks, which we clarified. The focus group also suggested adding questions pertaining to international duty, which we included. In addition, the focus group rated the tasks based on importance, which resulted in some tasks being removed from the first version. After adjustment, the questionnaire was tested once more by 4 soldiers (2 men and 2 women). The adjusted questionnaire was then digitalised and tested on 2 new soldiers (2 men). The final version of the questionnaire, "Questions regarding physical demands during different moments of duty," was reviewed by a total of 14 combat soldiers before it was administrated to the larger group of combat soldiers and included questions concerning employment data, physical capacity clusters (Table 1), ranking of daily work tasks (Table 2) and mandatory physical tests.

To study application and psychometric properties (internal consistency, missing items and general design issues) of the questionnaire, soldiers from all five regiments in Sweden where ground combat soldiers are stationed were invited to participate in the study. Ground combat soldiers from three out of the five regiments participated. The questionnaire was distributed from the period of late 2016 to spring 2017 to 231 ground combat soldiers, aged 18–50 years.

The study was approved by the Regional Ethical Review Board in Lund (Dnr, 2016/400). After a first verbal study briefing, participating soldiers gave their informed consent and were later sent a survey link to the questionnaire, which also included written information about the study. Individual responses to the questionnaire could not be traced by the researchers since the survey was designed to be non-identifiable.

### 2.3. Data analysis

#### 2.3.1. Statistics

Descriptive data were expressed as mean and standard deviation (SD). Missing items were reported for each subscale, and Chronbach's

**Table 1**
Structure of the survey.

| Area of interest | Question | Number of tasks |
|---|---|---|
| Background | Soldier's age, sex, anthropometric data, and the nature of his/her job | |
| Aerobic capacity | How strenuous do you experience the following work tasks in your current post (exercise and service) to be in terms of your aerobic fitness (oxygen uptake, aerobic capacity) | 31 |
| Hand strength | Rate how strong you need to be in your hands to solve the following work tasks | 30 |
| Arm strength | Rate how strong you need to be in your arms to solve the following work tasks | 30 |
| Core strength | Rate how strong you need to be in your core to solve the following work tasks | 30 |
| Leg strength | Rate how strong you need to be in your legs to solve the following work tasks | 30 |
| Physical tests | Opinion regarding mandatory physical tests | |

**Table 2**
Work task description.

| Task number | Task description | Task number | Task description |
|---|---|---|---|
| 1 | Defence against ambush | 17 | Attack in rough terrain |
| 2 | Movement in combat (low crawl, high crawl, dodge, rush) | 18 | Defence in rough terrain |
| 3 | Digging trenches/foxholes | 19 | Delaying action in rough terrain |
| 4 | Laying mines | 20 | Ambush |
| 5 | Loading equipment on vehicle | 21 | Defence against air attack |
| 6 | Carrying heavy loads | 22 | Delaying fieldwork (demolition, interception) |
| 7 | Camouflage | 23 | Minesweeping and mineclearing |
| 8 | Patroling | 24 | Setting up base camp |
| 9 | Combat mission | 25 | Care of wounded |
| 10 | Reconnaissance patrol | 26 | Transport of wounded |
| 11 | Attack in urban terrain | 27 | Monitoring mission |
| 12 | Defence in urban terrain | 28 | Crowd control |
| 13 | Delaying action in urban terrain | 29 | Search operation |
| 14 | Attack in close terrain | 30 | Guarding object or person |
| 15 | Defence in close terrain | 31 | Other tasks |
| 16 | Delaying action in close terrain | | |

alpha was used to analyse internal consistency (the degree of the interrelatedness among the items to support the reliability of the questionnaire) in the subscales measuring aerobic capacity and strength. An acceptable internal consistency is a Chronbach's alpha between 0.7 and 0.9 (Tavakol and Dennick, 2011). Results from aerobic capacity, hand strength, arm strength, core strength and leg strength were analysed separately. The proportion of subjects were noted based on their work tasks ratings for aerobic demands (very light, light, somewhat hard, hard, very hard or I do not know) and for strength demands (very weak, weak, somewhat strong, strong, very strong or I do not know).

The five work tasks with the highest proportion of subjects responding very hard for aerobic capacity, strong and very strong for muscle force within each area of interest were chosen for gender analysis. Differences in the distribution of answers between men and women within each rated work task were analysed with the Mann-Whitney test. The probability level of acceptable significance was set to 0.05. SPSS version 23 was used for statistical calculations (IBM SPSS Statistics for Windows, Version 23.0. IBM Corp., Armonk, NY).

## 3. Result

### 3.1. Participant information

Out of 231 soldiers invited to participate in the study, 165 soldiers (71%) accepted the invitation (25 women and 140 men). Of these, 16 individuals did not complete the survey, but data from the completed sections were analysed. The age of the respondents ranged from 19 to 44 years (mean 24, SD 5 years). The number of years in military service ranged from 0.5 to 16 years (mean 3, SD 3 years).

### 3.2. Psychometric properties of the questionnaire

The time it took for the respondents to complete the survey was approximately 35–40 min. The first section of the survey regarding demographic data had a higher response rate than the later sections of the survey. Aerobic demands were answered by 160 soldiers (135 men and 25 women), hand strength demands by 159 soldiers (134/25), arm strength by 154 soldiers (129/25), leg strength by 152 soldiers (127/25) and core strength by 149 soldiers (124/25). Chronbach's alpha was used to analyse internal consistency in the subscales measuring aerobic capacity and strength and showed an alpha coefficient between 0.95 and 0.99.

### 3.3. Physical domain findings

#### 3.3.1. Aerobic demands

The tasks perceived as the most aerobically demanding were 1) transport of a wounded soldier, 2) movement in combat, 3) attack in close terrain, 4) attack in urban terrain and 5) attack in rough terrain (Fig. 1). There were no differences between male and female soldiers in the ratings for aerobic demands ($p \geq 0.09$, Mann-Whitney test).

#### 3.3.2. Muscle strength demands

For hand, arm, leg and core strength, 11 work tasks out of 30 (see Table 2) were ranked as demanding (strong) or very demanding (very strong) although many of them only in one of the strength areas. To summarise the findings and to enhance understanding, the top five most strenuous tasks (ranking from 1 most demanding to 5 least demanding) based on proportions are described in Table 3. Both male and female soldiers considered transport of wounded as the most challenging task for hand strength (80% men and 68% women), arm strength (81% men and 84% women), leg strength (82% men and 84% women) and core strength (81% men and 84% women). The second most demanding task for hand and arm strength was carrying heavy loads, which also ranked third for leg and core strength (Table 3). There were no significant differences between male and female soldiers although they sometimes ranked the tasks in different order ($p \geq 0.3$, Mann-Whitney test) (Table 3).

Tasks included in the soldiers' job requirements pertaining to foreign service (monitoring mission, search operation and riot control) were marked I do not know for most of the respondents.

## 4. Discussion

The results from the final questionnaire "Questions regarding physical demands during different moments of duty" show that transport of wounded, carrying heavy loads, care of wounded, movement in combat and attack in urban terrain are the most physically demanding work tasks in the Swedish army. Among Swedish soldiers, there were no differences in the ranking of physical requirements between men and women. Military mission demands are complex and cannot solely be described in single activities such as marching or digging. This means that complex tasks can be interpreted slightly different by each person completing the questionnaire, which could bias the result. For example, the task attack in urban terrain contains many different military activities. The tasks selected for this survey are a mixture of both complex and single military activities.

To the authors' knowledge, no previous study has identified and ranked the most physically demanding tasks for ground combat forces in the Swedish army. The present study gives insight into the perceived physical demands of ground combat soldiers in the Swedish armed forces.

### 4.1. Physical demands

Ground combat soldiers' work is physically demanding, and the ability to perform different duties depends on the duration and intensity of the work task. The terrain also has a large impact on a soldier's perceived workload. During military operations, soldiers often work long periods at low to moderate intensities. However, several tasks important to the success of the mission involve bursts of high-intensity activities (Pihlainen et al., 2014). In the present study, assault in different terrain and transport of wounded were reported to involve high-intensity activities. Transport of a wounded soldier was ranked as

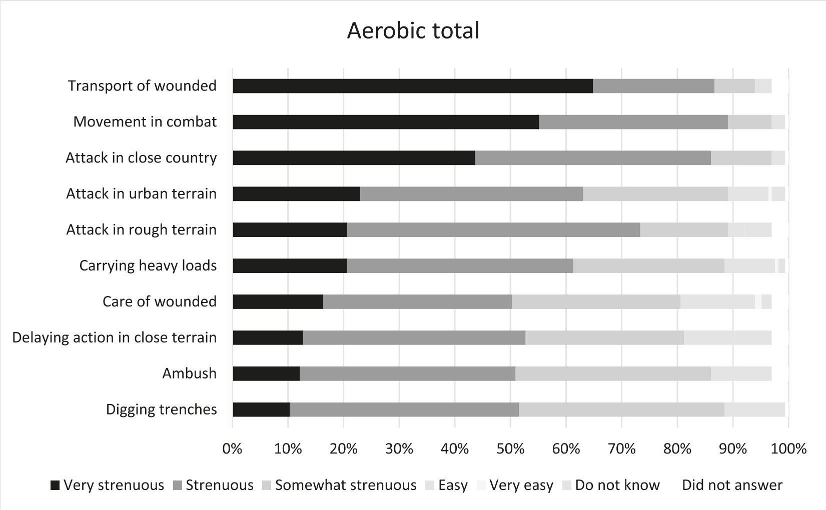


**Fig. 1.** The 10 most demanding work tasks regarding aerobic capacity for all soldiers, N = 165.

**Table 3**
Ranking of the top five (1–5, 1 = most demanding task) muscle strength demanding tasks: total (T), men (M) and women (W). The ratings are based on proportions of subjects who have rated the demands of the tasks. Blank space indicates that the tasks were ranked lower than top five.

| Work tasks | Hand strength | | | Arm strength | | | Leg strength | | | Core strength | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | M | W | T | M | W | T | M | W | T | M | W |
| Transport of wounded | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Carrying heavy loads | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | | 3 | 3 | 2 |
| Care of wounded | 3 | 3 | 3 | | | 3 | 4 | 4 | 3 | 5 | | 4 |
| Attack in urban terrain | 4 | 4 | 5 | 3 | 3 | | | | | | 4 | |
| Digging foxholes | 5 | | 4 | 5 | | 5 | | | | 4 | 5 | 5 |
| Delaying fieldwork | | 5 | | | | | | | | | | |
| Movement in combat | | | | 4 | 5 | | 2 | 3 | 2 | 2 | 2 | 3 |
| Delaying action in urban terrain | | | | | 4 | | | | | | | |
| Loading equipment | | | | | | 4 | | | | | | |
| Attack in close terrain | | | | | | | 5 | 5 | 5 | | | |
| Executing ambush | | | | | | | | | 4 | | | |

the most strenuous task both for aerobic capacity (67% men, 52% women) and muscle strength (48–52% men, 48–68% women) by the ground combat soldiers. The second to fourth most aerobically demanding task (reported by 20–40% of the participants) involved dismounted attack in different types of terrain, carrying heavy loads and movement in combat. For most of the different strength components, similarly, carrying heavy loads ranked second before dismounted attack in different types of terrain, and low crawl/high crawl was ranked the most strenuous task. The results are in line with those found in the US army (Sharp et al., 2017), British army (Rayson, 1998; Rayson et al., 2000), Canadian army (Force operations manual, 2016), and Australian army (Doyle et al., 2015), which ranked similar tasks as being the most demanding: load carriage, lifting and carrying, evacuating casualties and moving under fire. However, the definition of the tasks can differ between countries, supporting the need for the current study. In Sweden, a casualty drag is one person dragging a wounded person to cover, applying first aid and seeking assistance. In other armies, e.g., the Royal Australian army, a casualty drag is a four-person team task to drag a 110-kg casualty for 100 m followed by a 200-m fireman's carry. The United Kingdom defines the combat arms casualty drag task as one or two soldiers dragging a ~120-kg casualty 40 m (Sharp et al., 2017).

Loaded march has previously been identified as one of the most demanding tasks in the Canadian, Dutch, British, and US armies (Jaenen, 2009). However, in the present study, loaded march was not ranked as one of the ten most demanding tasks by Swedish ground combat soldiers. Eighty-eight percent of the female soldiers ranked loaded march as somewhat strenuous or strenuous compared with 77% of the male soldiers. Soldiers' load carriage has steadily increased since World War II and is now between 50 and 60 kg of extra weight (Knapik et al., 2004). The recommended load to be carried by soldiers is 30–50% of body mass (Epstein et al., 2013). Research has shown that injury risk for women increases fivefold if the load carried is >25% of body weight, and women are more likely to be fatigued even when carrying loads of 15–20 kg (Epstein et al., 2013; United Kingdom Ministry of Defence, 2014). In our study, we did not find any difference between how men and women interpreted load carriage. A study of Sharp et al. (2017) states that foot marching is a critical, physically demanding task for combat arms soldiers in each nation studied, and it is intriguing that load carriage did not rank in the top 10 of most demanding job tasks among Swedish ground combat soldiers. This discrepancy could be due to the soldiers' individual interpretation of the described task, and, therefore, needs to be further investigated.

Most soldiers chose to answer I do not know when rating riot control as being a demanding task, despite the reported experience of the Swedish battalion in Kosovo 2004 involved in the incident in Caglavica (Human Rights Watch, 2004). Most soldiers who answered the questionnaire had not participated in international duty, and riot control is not a domestic duty of the Swedish army. Since it is not a common task, it will not be selected for further studies in this research because it is a low frequency, low critical task, albeit with high physical demand that may have a negative impact on recruitment or maintenance of soldiers (Beck et al., 2016).

In each area (aerobic and hand, arm, leg, and core strength demands), the five tasks ranked most demanding were studied further to determine whether any gender differences existed. There were no significant differences in ranked physical requirements between male and female soldiers although they sometimes ranked the tasks in different order.

### 4.2. Methodical considerations

The questionnaire was developed in collaboration with an expert focus group of military officers and soldiers and analysis of combat troop manuals and regulations, and it has been validated with soldiers in three steps to give the survey content and face validity. Only the most relevant tasks were included in the final questionnaire since too many questions can mean that the respondents do not pay attention to the answers at the end of the questionnaire (Lindberg et al., 2014). The length of the questionnaire became an actual problem in the current study as 16 of the respondents did not complete the questionnaire. To study reliability of the questionnaire, the interrelatedness among the items was determined by Chronbach's alpha in accordance with the COSMIN manual (Mokkink et al., 2010). The findings from the analysis showed a high alpha coefficient, supporting the reliability of the questionnaire. An alpha $>0.95$ might indicate redundancy of some questions within the separate scales. However, all included questions were rated as important by the expert group while removing items may affect the validity of the questionnaire. Some of the tasks in the questionnaire involve a number of sub-tasks that vary depending on the actual situation in which they occur, leading to different interpretations by respondents (Tavakol and Dennick, 2011). It is important to have as specific and accurate description of the job requirements as possible since the different components can determine the performance outcome (Rayson, 1998). It is also important that the number of tasks are not too small to capture the demands of the wide variety of movement patterns and muscle groups employed in task execution (Beck et al., 2016), challenging a shortening of the questionnaire. Studying psychometric properties of a questionnaire is an ongoing process and further studies are needed.

The demographic data indicated a wide range in age (19–44 years). This variance in age might be a confounder related both to years of military service experience and to level of exertion. However, most soldiers were young (mean age 24 years, SD 5 years, median age 23 years), and stratification based on median age did not seem relevant. The lack of experience in some of the tasks for soldiers with short service time could have affected their ability to assess these tasks correctly, although soldiers with short military service time mostly replied I do not know for low frequency tasks.

A total of 165 soldiers from three different regiments took part in this study. The response rate was 71%, although the study would be further strengthened by more respondents. Also, with only 15% women in the study, the actual number of female respondents is low. Although a higher number of women's responses would be desired to strengthen the results, the actual ratio of men to women is representative of the Swedish armed forces (18% women) (Fitriani et al., 2016).

The present study constitutes the first step in the development of work task analysis and aerobic evaluation for soldiers. All tasks included in a job analysis to evaluate physical capacity must be valid in each stage of the process (Payne and Harvey, 2010), and the next step will be measuring aerobic capacity with a special focus on the domains found in this study. This will be to find adequate physical capacity tasks for military service admission tests as well as fitness tests for those already serving.

## 5. Conclusion

The questionnaire was found to have acceptable face and content validity together with an acceptable internal consistency. However, validity is an ongoing process and more studies are needed to assess full validity and reliability of the questionnaire. The results of this study show that the process and methodology can be used to identify the most physically demanding tasks performed by soldiers in the Swedish army. Five tasks were identified as the most physically demanding for Swedish ground combat soldiers. Almost all the physically demanding tasks found in the present study contain elements of lifting and carrying, which demand muscular strength and muscular endurance capabilities. The five physically demanding tasks as described in this study will be a step in forming the basis for developing adequate physical recruitment standards for Swedish soldiers.


## Funding

No funding to declare.


## Declaration of competing interest

The authors have no competing interests to declare.

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# Paper II

Applied Ergonomics 101 (2022) 103710

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

# Cardiorespiratory responses of load carriage in female and male soldiers

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ARTICLE INFO

*Keywords:*
Aerobic capacity
Ventilation
$VO_{2peak}$
Graded exercise test

ABSTRACT

*Purpose:* To investigate the effect of sex and load carriage on cardiorespiratory responses to high intensity exercise in male and female soldiers.
*Methods:* Soldiers (9 women, 9 men) performed a graded treadmill test until exhaustion with no load (NL) and combat-gear with body armor (CG). Cohen's d effect sizes, paired t-tests and ANOVA were used to study differences between conditions. A mixed linear regression model analyzed the relationship between heart rate (HR) and oxygen uptake ($VO_2$) with load and between sexes.
*Results:* Wearing CG resulted in, for both sexes, a decreased time to exhaustion (−11 min), lower $VO_{2peak}$ (L/min) ES = 0.56; $VO_{2peak}$ (mL//kg/min) ES = 2.44, both $p < 0.001$, a net decrease in minute ventilation (ES = 3.53) and no change in $HR_{max}$. No sex-difference were present except for absolute $VO_{2peak}$. The $VO_2$ and HR relationship showed a cardiorespiratory reduction wearing CG vs. NL. Added load was equal between sexes, although female soldiers' CG relative to body mass was higher (25%) than male soldiers' (20%), $p < 0.01$.
*Conclusion:* Wearing CG reduces soldiers' cardiorespiratory capacity and exercise performance level, although the reduction cannot be explained solely based on the added load of CG, instead CG seems to restrict the capacity to fully ventilate. No sex differences were found in relative cardiorespiratory responses to wearing CG compared to NL.

## 1. Introduction

The ability to carry load for a soldier is a core requirement, often including body armor, helmet, and combat equipment along with sustainment stores (food, water etc.). For dismounted personnel, the load can also include mission specific equipment. The total amount of carried equipment can be as high as 60% of a soldier's body mass (Birrell et al., 2007, Dean and Dupont, 2003), making the soldier more susceptible to fatigue, and this can have a negative impact on work performance, especially when the intensity is greater than 50% of maximal work capacity (Epstein et al., 1988). Previous studies of load carriage up to 40% of body mass, where the load was in the form of a backpack have shown that the added load put a stressor to the cardiorespiratory system. This resulted in lowered time to exhaustion, whereas the peak physiological responses were not necessarily significantly affected, neither in men nor women (Phillips et al., 2016a, 2016b; Taylor et al., 2016). Studying sex differences in load carriage, showed that women had lower $VO_{2peak}$ and peak minute ventilation, but the submaximal ventilatory responses to exercise carrying a backpack were similar in men and women (Phillips et al., 2019).

Besides the load of a backpack, personal protective equipment such as a body armor has been shown to restrict the thoracic cavity, resulting in further volume and movement limitation of the chest in men (Peoples et al., 2016; Armstrong et al., 2019). Soldiers are frequently required to undertake load carriage with combat gear (CG) i.e., webbing, rifle, helmet, and body armor during both training and operations. Additional load of a backpack is added mainly during road marching and approach march. Therefore, conducting studies with backpack loads only, could misrepresent the load carried by soldiers, and is not likely to correctly measure the energy demands of wearing body armor (De Maio et al., 2009; Armstrong et al., 2019).

Only a few studies have investigated the effects of CG on ventilatory responses in a military population (Crowder et al., 2007; Armstrong

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https://doi.org/10.1016/j.apergo.2022.103710
Received 15 September 2021; Received in revised form 1 February 2022; Accepted 2 February 2022

**Abbreviations**

| | |
|---|---|
| 95% CI | 95% Of confidence interval |
| ANOVA | Analysis of variance |
| $\beta$ | Regression coefficient |
| BM | Body mass |
| BMI | Body mass index |
| Bpm | Beats per minute |
| CG | Combat gear + body armor |
| cm | Centimeters |
| ES | Effect size (Cohens) |
| $f_b$ | Respiratory rate |
| $f_{bpeak}$ | Peak respiratory rate |
| GXT | Graded exercise test |
| HR | Heart rate |
| $HR_{max}$ | Maximal heart rate |
| Kg | Kilogram |
| L | Liter |
| min | Minute |
| mL | milliliter |
| mmol/L | Millimoles per liter |
| NL | No Load (light training clothes) |
| RER | Respiratory exchange ratio |
| RPE | Ratings of perceived exertion |
| SD | Standard deviation |
| $VCO_2$ | Carbon dioxide output |
| $V_E$ | Minute ventilation |
| $V_{Epeak}$ | Peak minute ventilation |
| $VO_2$ | Oxygen uptake |
| $VO_{2peak}$ | Peak oxygen uptake |
| $V_T$ | Tidal volume |
| $V_{Tpeak}$ | Peak tidal volume |

et al., 2019). Armstrong et al. (2019) showed depressed ventilation parameters during simulated military load carriage, increased $V_E$ and $f_b$ with load and time, and a greater increase in $V_E$ and $f_b$ with heavier loads. However, these studies did not investigate sex-differences of the different loads, and only one studied the effect of load, i.e. CG, on peak exercise (De Maio et al., 2009). A greater understanding of sex differences associated with load carriage and ventilatory restriction is needed since there has been an increase in occupational specialties open to women, including direct combat roles in the soldier profession.

To determine work intensity, $VO_2$ or some equivalent index must be measured. Maximal oxygen consumption ($VO_{2peak}$) is generally recognized as the functional limit of the cardiorespiratory system to transport oxygen to tissues to meet the aerobic requirements of the body (Bruce et al., 1973), and it is the best physiological indicator of muscular capacity for sustained work (Noakes, 1988). Since heart rate (HR) is linearly related to $VO_2$ and is easy to measure, working HR has often been used to monitor aerobic work intensity (Almeida et al., 2019). Previous studies have not shown conclusively if the HR and $VO_2$ relationship during load carriage follow the same slope as unloaded work in soldiers. Keren et al. (1981) found similarities for the rate of oxygen consumption with incrementing speed between loaded marching and treadmill running. While other studies found a larger increase in HR at a given $VO_2$ in loaded marching compared to unloaded marching or running (Gordon et al., 1983; Rayson et al., 1995). These studies investigated either men or women using different protocols, but direct sex-comparisons have not been investigated.

The armed forces in many countries require some type of cardiorespiratory admissions test or yearly fitness test, normally performed in light gym clothing gear, even though soldiers wear combat gear and body armor while conducting military tasks. Therefore, using results from cardiorespiratory fitness tests with light clothes and no load (NL) could overestimate actual cardiorespiratory capacity, and thus increase the risk of load carriage-related fatigue for soldiers (Bilzon et al., 2001; Vanderburgh, 2007). The cardiovascular response to load carriage during simulated road marching has been investigated thoroughly in male soldiers at various load and speed (Quesada et al., 2000; Crowder et al., 2007; Beekley et al., 2007). However, knowledge about the cardiorespiratory responses during work until exhaustion wearing CG is limited (De Maio et al., 2009), especially in female soldiers. Thus, this study aimed to investigate cardiorespiratory responses in female and male soldiers, for 1) both CG and no load during a graded treadmill exercise test to exhaustion and 2) sex-differences in the physiological response to load carriage, and 3) if the relationship between HR and $VO_2$ differ between the two load conditions, or between women and men.

## 2. Material and methods

### 2.1. Participants

Healthy, non-smoking soldiers (9 women and 9 men) volunteered for the study. Group characteristics are summarized in Table 1. All participants were free from musculoskeletal injury. The soldiers were informed about the study in both writing and orally and were given the opportunity to pose questions before signing a written informed consent. The study was approved by the Regional Ethical Review Board in Lund, Sweden (Dnr, 2016/400).

### 2.2. Load configuration

The soldiers wore top and shorts/tights and running shoes in the NL condition, but no additional load. In the CG condition the soldiers used their own equipment since they were familiarized to it, and it was adjusted for an optimal fit. It consisted of statutory combat gear: army boots, uniform (M90), helmet and depending on post; body armor; Kroppskydd 90 A (Stormark K Konfeksjonsfabrikk A/S, Norge, size small to large, weight 3.3–3.5 kg), webbing with armored plates, Kroppsskydd 12 (Mehler Vario Systems Gmbh, size 1–7, weight 6–14 kg) or Kroppsskydd 94 (Åkers Krutbruk Protection AB, size small to large, weight 4.5–10.5 kg), and a dummy weapon designed to simulate the Swedish Army standard weapon AK5 (weight 4.5 kg). There was no difference in added load (CG) between women 16.3 ± 2.5 kg and men 15.7 ± 2.0 kg ($p = 0.56$) (Table 1), whereas the load added expressed as a percentage of body mass was greater for women compared to men (24.8 ± 0.4% and 20 ± 0.1% respectively, $p < 0.01$).

### 2.3. Experimental design

We used the standardized marching speeds of the Swedish Armed Forces for treadmill speeds to simulate real-life work recommendations in a laboratory setting with a highly standardized protocol. The soldiers who volunteered for the study were all ground combat soldiers but with

**Table 1**
Physical characteristics of female and male soldiers.

| | Women (n = 9) | Men (n = 9) | p-value |
|---|---|---|---|
| Age (years) | 26.2 ± 4.8 | 22.6 ± 2.4 | 0.056 |
| Height (cm) | 167.0 ± 6.0 | 181.3 ± 5.2 | <0.001 |
| Body mass (kg) | 66.5 ± 8.6 | 78.3 ± 8.9 | 0.012 |
| Added load (kg) | 16.3 ± 2.5 | 15.7 ± 2.0 | 0.559 |
| BMI (kg/m$^2$) | 23.7 ± 2.2 | 23.7 ± 2.2 | 0.950 |

Values are means ± standard deviation. BMI, body mass index.

different posts, employment time ranged between 1 and 6 years with an extensive experience of load carriage. During the load session with CG they were all equipped with their personal duty combat gear and carried a dummy weapon.

Participants were tested at the laboratory twice with 2–14 days between sessions. During their first visit they were informed about the study, signed the consent form, had their height and body mass measured and their BMI calculated as the body mass (kg) divided by the height (m) squared. After that they continued with a graded exercise test (GXT). Participants performed the same GXT protocol at both sessions with a cross-over design starting with either NL or CG in randomized order. The participants were asked to refrain from smoking, drinking caffeinated drinks, and the use of nicotine 3 h prior to the tests. Data from the NL-test served as a reference for comparison with the values from the CG-test. The primary outcome measures were HR, minute ventilation ($V_E$) and $VO_2$.

### 2.4. Assessment of cardiorespiratory capacity

All GXTs were conducted on a motorized treadmill (Rodby Innovation AB, Vänge, Sweden) indoors in a laboratory setting. Values for $VO_2$, carbon dioxide output ($VCO_2$), and $V_E$ were obtained with indirect calorimetry (Oxycon Pro, Jaeger, Hoechberg, Germany), and equipment was calibrated according to the manufacturer's instructions before each test. HR measurements were obtained with a Polar HR monitor (FT4, Polar Electro Oy, Kempele, Finland) placed on the chest of the participants and synchronized with the Oxycon Pro system. Blood lactate concentration was measured from the fingertip, immediately after cessation of GXT (Lactate Pro 2, Arkray Inc, Kyoto, Japan). Prior to the GXT, resting values for blood pressure, HR, $VO_2$, $VCO_2$, $V_E$ including respiratory rate ($f_b$) and tidal volume ($V_T$) were collected with the subject lying supine approximately 15 min until the HR had decreased to resting heart rate level, estimated based on the minimum heart rate recorded at rest prior to loading (normal range for resting level 60–100 bpm) and remained constant for 5 min, and thereafter while standing quietly for 5 min with minimal movement. The GXT protocol continued until volitional exhaustion.

The GXT protocol was adapted from Bruce graded treadmill protocol (Bruce et al., 1963) with the use of speed 5.4 km/h since it matched the regulated speed during loaded marches determined by the Swedish Armed Forces and represents approximately 50% of the soldiers maximal work capacity marching on gravel road (Danielsson and säkerhet, 2008), and 8 km/h was used as it corresponds with the regulated speed used for rapid march (jogging) (Danielsson and säkerhet, 2008) as shown in Table 2.

The soldiers were considered to have reached their maximal effort when the following criteria were fulfilled: HR reaching ±10 beats of the subjects age predicted maximum HR (220-age), respiratory exchange ratio (RER) exceeded 1.05, ratings of perceived exertion (RPE) ≥18 for the sensation in leg muscles and breathing on the Borg 6-to-20 RPE-scale, and blood lactate concentration immediately post-exercise (≥9.0 mmol/L) (Edvardsen et al., 2014). During rest and the GXT, continuous measurements of $VO_2$, $VCO_2$, $V_E$, $V_T$, $f_b$, and HR were made. The last 30 s of each 5- or 3-min stage were used for determining HR, $V_E$ components, and gas exchange data.

**Table 2**
Graded exercise test, treadmill protocol. (Adopted from Bruce graded treadmill protocol).

| Stage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration (min) | 5 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Speed (km/h) | 5.4 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Grade (%) | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |

### 2.5. Data presentation and statistical analyses

Values are presented as mean and standard deviation (SD). In this study, we calculated individual responses for $VO_2$, HR, $V_E$, $V_T$ and $f_b$ as a percentage at 5 levels (15, 25, 50, 75, 100%) of peak values (called exercise intensity) to analyze these cardiorespiratory sex difference responses to load carriage during a GXT. A two-way repeated measures ANOVA was performed for exercise intensity (5 levels) and effect of load (NL/CG). Similarly, for sex-specific analyses the difference between NL and CG, a three-way mixed ANOVA was run to understand the effect of load (NL/CG) and exercise intensity (5 levels) on sex (woman/man). When the assumption of sphericity determined by Mauchly's test was violated, Greenhouse-Geisser adjustment was applied. Tukey's post-hoc test was used to identify any significant differences between load or sex.

To compare effect of load on peak values for $VO_2$, HR, $V_E$, $V_T$, $f_b$, and time to exhaustion, two-sided paired t-tests were used, and to compare effect of load between sexes at peak exercise intensity, independent sample t-tests were used. To study the magnitudes of change between NL and CG and between women and men for peak values, effect sizes (ES) were calculated using Cohen's D, effect statistic (Cohen, 1988), and interpreted according to the following thresholds for ES: <0.2 (trivial), 0.20–0.59 (small), 0.60–1.19 (moderate), 1.20–1.99 (large), 2.00–3.99 (very large), and >4.00 (extremely large) (Hopkins et al., 2009). Generalized mixed effect linear regression models were used to compare the change in HR and $VO_2$ (dependent variable) between NL and CG over the time course of the GXT and between sex. All statistical analyses were performed using SPSS software (SPSS Statistics, Version 25, IBM Corporation, New York). Statistical significance level was set at $p < 0.05$.

## 3. Results

### 3.1. Oxygen consumption and heart rate

When the soldiers performed a GXT, the group mean of time to exhaustion was 19.4 ± 3.4 min for NL and 8.5 ± 2.6 min for CG, showing a very large, decrease between the two load conditions (ES = 3.60, $p < 0.001$). Based on these results, it was estimated that time to exhaustion decreased by approximately 40 s for every 1 kg of additional external mass in CG condition (−660 s divided by 16 kg added load) (Table 3). The difference between the NL and CG condition for women was −11.1 min (ES = 3.41, $p < 0.001$) and for men −9.6 min (ES = 3.56, $p < 0.001$), with no difference between sexes in the same conditions (NL, p = 0.34 and CG, p = 0.79) (Table 3).

Analysis of absolute $VO_{2peak}$ (L/min) revealed that wearing CG vs. NL led to a small decrease for women (ES = 0.55, $p < 0.05$), but a moderate decrease (ES = 0.93, $p < 0.01$) for men (Table 3). The change in $VO_{2peak}$ from the NL to the CG-test was evaluated for sex-differences where men had a moderately larger decrease in absolute $VO_{2peak}$ (ES = 1.04, p = 0.05) compared to women.

However, in relative $VO_{2peak}$ (mL/kg/min), CG resulted in very large decreases, for both women (ES = 2.46, $p < 0.001$) and men (ES = 3.43, $p < 0.001$), as shown in Table 3, and the sex-difference was eliminated for relative $VO_{2peak}$ (ES = 0.25, p = 0.60).

Fig. 1 shows the GXT levels vs. relative exercise intensity (% of relative $VO_{2peak}$) for both NL and CG. From 15% of $VO_{2peak}$ and onwards, CG yielded a lower exercise intensity for the same % of $VO_{2peak}$ compared to NL (load*levels, $p < 0.01$), with no difference between sexes (level *load*sex, p = 0.18). This indicates that while wearing CG at any submaximal exercise intensity (GXT stages), the soldiers worked at a higher % of their $VO_{2peak}$ compared to when they wore NL. At 100% $VO_{2peak}$, the actual $VO_{2peak}$ is lower with CG compared to NL.

Similarly, Fig. 1 shows the GXT levels vs. relative heart rate response (% of $HR_{max}$) and from approximately 50% of $HR_{max}$ onwards, wearing CG resulted in a lower exercise intensity for the same % of HRmax compared to NL (load*levels, $p < 0.01$). In absolute numbers, this means

**Table 3**
Mean, standard deviations (SD), effect size (ES) and p-value, results for 9 men and 9 women, cardiorespiratory data at peak exercise, unloaded (NL) and loaded (CG) condition.

| | Sex Men, women | NL Mean ± SD | CG Mean ± SD | Change NL – CG | ES | *t*-test p-value |
|---|---|---|---|---|---|---|
| Time to exhaustion (min) | M | 20.3 ± 2.79 | 10.7 ± 2.59 | −9.63 | 3.56 | <0.001 |
| Time to exhaustion (min) | W | 20.1 ± 3.81 | 9.0 ± 2.56 | −11.10 | 3.41 | <0.001 |
| $VO_{2peak}$ (L/min) | M | 4.16 ± 0.47 | 3.70 ± 0.51 | −0.46 | 0.93 | 0.002 |
| $VO_{2peak}$ (L/min) | W | 3.23 ± 0.39 | 3.03 ± 0.33 | −0.19 | 0.55 | 0.026 |
| $VO_{2peak}$ (mL/kg/min) | M | 53.33 ± 3.92 | 40.55 ± 3.52 | −12.78 | 3.43 | <0.001 |
| $VO_{2peak}$ (mL/kg/min) | W | 48.86 ± 5.82 | 36.92 ± 4.11 | −11.93 | 2.36 | <0.001 |
| $HR_{max}$ (bpm) | M | 196 ± 9 | 195 ± 7 | −1 | 0.12 | 0.75 |
| $HR_{max}$ (bpm) | W | 198 ± 8 | 196 ± 6 | −2 | 0.29 | 0.31 |
| $V_{Epeak}$ (L/min) | M | 150.7 ± 25.2 | 138.4 ± 23.9 | −9.8 | 0.42 | 0.020 |
| $V_{Epeak}$ (L/min) | W | 113.3 ± 10.2 | 106.6 ± 12 | −8.8 | 0.61 | 0.036 |
| $V_{Tpeak}$ (mL/kg) | M | 2.99 ± 0.4 | 2.56 ± 0.3 | −0.43 | 1.21 | <0.001 |
| $V_{Tpeak}$ (mL/kg) | W | 2.33 ± 0.3 | 2.01 ± 0.3 | −0.32 | 0.97 | 0.001 |
| $f_{bpeak}$ (breath/minute) | M | 50.3 ± 6.1 | 54.2 ± 8.7 | 4.9 | 0.58 | 0.053 |
| $f_{bpeak}$ (breath/minute) | W | 49.3 ± 7.1 | 54.2 ± 9.4 | 3.9 | 0.52 | 0.021 |
| Lactate at $VO_{2peak}$ (mmol/L) | M | 13.74 ± 4.01 | 11.18 ± 3.89 | −2.56 | 0.65 | 0.08 |
| Lactate at $VO_{2peak}$ (mmol/L) | W | 11.99 ± 2.79 | 11.15 ± 2.43 | −0.84 | 0.32 | 0.41 |
| RER at exhaustion | M | 1.10 ± 0.03 | 1.10 ± 0.04 | 0 | 0 | 0.94 |
| RER at exhaustion | W | 1.10 ± 0.02 | 1.08 ± 0.04 | −0.02 | 0.63 | 0.24 |

$VO_2$, oxygen uptake; HR, heart rate; $V_E$, respiratory minute volume; $f_b$, respiratory rate; $V_T$, tidal volume; RER, respiratory exchange ratio; bpm, beats per minute.

that for the same submaximal loads, HR was between 17 and 29 beats per minute (bpm) higher for soldiers wearing CG compared to NL ($p < 0.001$), with no sex difference (level*load*sex, $p = 0.22$). At $HR_{max}$ no differences in bpm existed between the two load conditions (Table 3).

A mixed effect linear regression analysis, investigating whether the relationship between relative$VO_2$ and HR differ if a soldier wore NL or CG, showed a significant association between load, HR and change in $VO_2$ for women and men (Table 4), with no sex differences. This suggest that wearing NL, 1 beat per minute increase in HR resulted in an increase in $VO_2$ for men of 0.337 mL/kg/min ($p < 0.001$), and in women of 0.315 mL/kg/min ($p < 0.001$). Furthermore, a significant association between CG and $VO_2$ showed a lower increase in $VO_2$ for every bpm increase in HR, for both women (0.271 mL/kg/min, $p \leq 0.001$) and men (0.292 mL/kg/min, $p < 0.001$) wearing CG compared to NL (Table 4, Fig. 2).

### 3.2. Pulmonary ventilation

To investigate possible reasons for a difference in cardiorespiratory response wearing CG that could not be explained only by the increase in load *per se*, we studied $V_E$ and its components ($V_T$ and $f_b$) during GXT wearing CG or NL in male and female soldiers. At peak intensity, $V_E$ showed a moderate decrease for women (−8.8 L/min, ES = 0.61, $p < 0.05$) and a small decrease for men(-9.8 L/min, ES = 0 0.42, $p < 0.05$) wearing CG (Table 3). $V_T$ was moderately to largely decreased with CG for women (−0.32 mL/kg, ES = 0.97, $p < 0.01$) and men (−0.43 mL/kg, ES = 1.21, $p < 0.001$) respectively, whereas $f_b$ showed a small increase for both women (3.9 breaths/min, ES = 0.52, $p < 0.05$) and men (4.9 breaths/min, ES = 0.58, $p = 0.053$) (Table 3). In addition, evaluation of the change in peak values for $V_E$ from NL to CG, revealed a small to moderate, but non-significant difference between sexes, $V_E$ (ES = 0.46, $p = 0.34$), $V_T$ (ES = 0.54, $p = 0.26$) or $f_b$ (ES 0.18, $p = 0.70$). Fig. 3 shows how wearing CG resulted in a lower exercise intensity workload (GXT stages) for the same % of $V_{Epeak}$, $V_{Tpeak}$, and $f_{bpeak}$ (load*levels, $p < 0.001$), with no sex differences (level *load * sex) for, $V_{Epeak}$ ($p = 0.35$), $V_{Tpeak}$ ($p = 0.10$), or $f_{bpeak}$ ($p = 0.85$).

## 4. Discussion

To our knowledge this is the first study to investigate sex differences, with and without CG, in cardiorespiratory responses to graded treadmill exercise. Overall, no sex differences were found in relative cardiorespiratory responses to wearing combat gear and body armor. The one exception to this was that despite women having lower absolute $VO_{2peak}$ and carrying a heavier load relative to their body mass, time to exhaustion was similar to the men's time. Increased energy cost due to increased load and velocity is a well-known occurrence. Hence, it is not surprising we found an increase in submaximal $VO_2$, HR and $V_E$ with added load in the present study. Though, our results also show that wearing CG led to a larger increase in HR for a given $VO_2$ compared to NL for both male and female soldiers, reducing their cardiorespiratory capacity and exercise performance level.

### 4.1. Oxygen consumption and heart rate during load carriage

When the soldiers wore CG, at any given submaximal exercise intensity (GXT stages) beyond standing, both male and female soldiers showed a progressively greater $VO_2$ compared with NL. Relative $VO_{2peak}$ decreased approximately 24% for both women and men wearing CG compared to NL, and this was reflected in a shorter time to exhaustion with CG. These results are similar to previous research on military personnel and university students of both sexes (Rayson et al., 1995; Walker et al., 2015), and on male military personnel (Beekley et al., 2007; Crowder et al., 2007) where an increased load was found to result in a decrease in time to exhaustion, $VO_{2peak}$ and $V_{Epeak}$.

For the women in this study $VO_{2peak}$ (L/min) at no load, was 22% lower compared to the men, and at CG 18% lower. This is in line with previous studies, where the difference between men and women's $VO_{2peak}$ was 25% with no load (Patton et al., 1980), and 18% wearing backpacks during a treadmill test (Phillips et al., 2016b). Once expressed per kg body mass, the difference in $VO_{2peak}$ between women and men in the present study was reduced to 9% for both load conditions. This sex difference is less compared to the aforementioned studies (Patton et al., 1980; Phillips et al., 2016b). One explanation for this finding could be that a majority of the female soldiers in this study had posts requiring wearing protective webbing, hence, well experienced in wearing CG and were moderately well-trained (Heyward, 1998).

HR at submaximal intensities was up to 25% higher with CG compared to NL, both for men and women, which shows that load carriage in soldiers places an increased demand on the heart to maintain cardiac output. Our findings are similar to previous studies performed on men and women military personnel (Ricciardi et al., 2008) and male soldiers (Armstrong et al., 2019) where a greater increase in HR was found at submaximal intensities wearing body armor. At maximal exercise effort the soldiers' $HR_{max}$ was similar irrespective of condition, in line with most previous studies (Taylor et al., 2012; Peoples et al., 2016; Phillips et al., 2016a).

The mixed effect linear regression model on $VO_2$ and HR from this

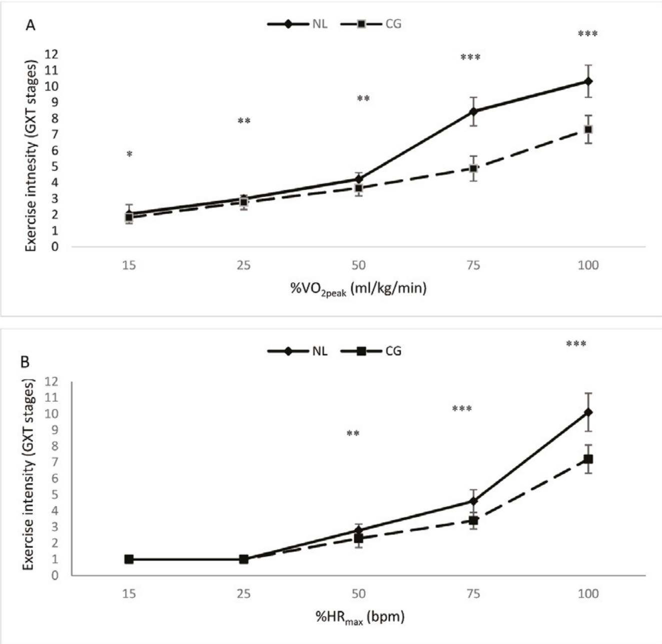


**Fig. 1.** Oxygen uptake and cardiorespiratory responses to exercise intensity (Graded exercise test [GXT] stages) as a function of relative intensity of $VO_{2peak}$ (peak oxygen uptake) 15–100% of $VO_{2peak}$, mean, standard deviations (SD). **A.** Heart rate 15–100% of $HR_{max}$, (maximal heart rate); bpm, beats per minute, **B.** NL (diamonds) denotes no load test situation and CG (squares) denotes combat gear test situation. Exercise intensity presented as GXT stages, from stage 1 (supine), 2 (standing), 3 (5.4 km/h 0 grade) 4 (8 km/h 0 grade) 5 (8 km/h 2% grade) with 2% grade increase until stage 12 (8 km/h at 16% grade). ANOVA, (figure A, B) main effect of load $p < 0.001$ Interaction $p < 0.001$. Post hoc analyses significantly different from no load at *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

**Table 4**
Association of changes in $VO_2$ with HR and load.

| parameters | $\beta$ | (95% CI) | p-value |
|---|---|---|---|
| Men NL $VO_2$ (mL/kg/min) | 0.337 | (0.31, 0.36) | <0.001 |
| Women NL $VO_2$ (mL/kg/min) | 0.315 | (0.29, 0.34) | <0.001 |
| Men CG $VO_2$ (mL/kg/min) | 0.292 | (0.26, 0.32) | <0.001 |
| Women CG $VO_2$ (mL/kg/min) | 0.271 | (0.24, 0.30) | <0.001 |
| Intercept | −20.04 | (-24.1, −15.9) | <0.001 |

Results of mixed effect linear regression analyses for $VO_2$ as dependent variable against heart rate. $\beta$ regression coefficient. CI, confidence interval (95%); NL, no load condition; CG, combat gear condition (body mass + added load), $VO_2$, oxygen uptake.

study found that wearing CG compared to NL led to a larger increase in HR for a given $VO_2$, and no difference between sexes was found. The reason for larger increase in HR at a given $VO_2$ wearing CG may be related to biomechanical factors (stride pattern, stride length and speed) and/or muscular fatigue, but also restriction in the movement of the chest (Gordon et al., 1983; Rayson et al., 1995). An additional explanation could be that added load requires a greater postural control during loaded marching compared to NL and the HR response may be a result of extra static postural components (Rayson et al., 1995). Therefore, energy expenditure during loaded running/marching could be underestimated if submaximal HR determined during unloaded conditions are used as an estimation of $VO_2$. Previous studies have found comparable heart rate elevations during treadmill walking with load weighing ~15% body mass but also an effect of the position and type of support for the backpack (Holewijn, 1990, Faghy and Brown, 2014, Joseph and Sengupta, 2014). Others have shown a linear relationship between external load and heart rate (Quesada et al., 2000; Beekley et al., 2007). Consequently, the relationship of $VO_2$ and HR for unloaded exercise cannot be directly applied to loaded exercise.

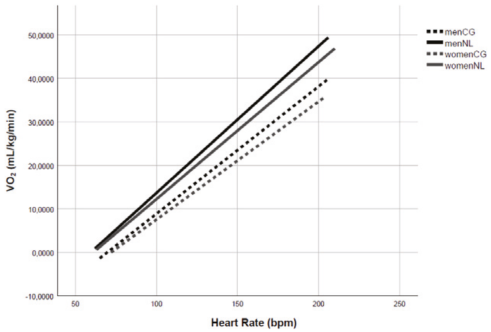


**Fig. 2.** A mixed-effect linear regression model for oxygen uptake ($VO_2$) in mL/kg/min and increase in heart rate bpm (beats/min). Each line depicts the fitted regression line for a different load, NL (solid line) denotes no load test situation and CG (dashed line) denotes combat gear test situation, with a fixed slope and random intercepts. Effect of load $p < 0.001$ and heart rate (HR) $p < 0.001$.

## 4.2. Pulmonary ventilation and load carriage

In the present study, $V_E$ increased with CG at submaximal exercise intensities, and this was met by increased $f_b$ together with a lower $V_T$ from approximately 70% of $V_{Tpeak}$ compared to NL. This sub-optimal breathing pattern could influence the capacity of the respiratory

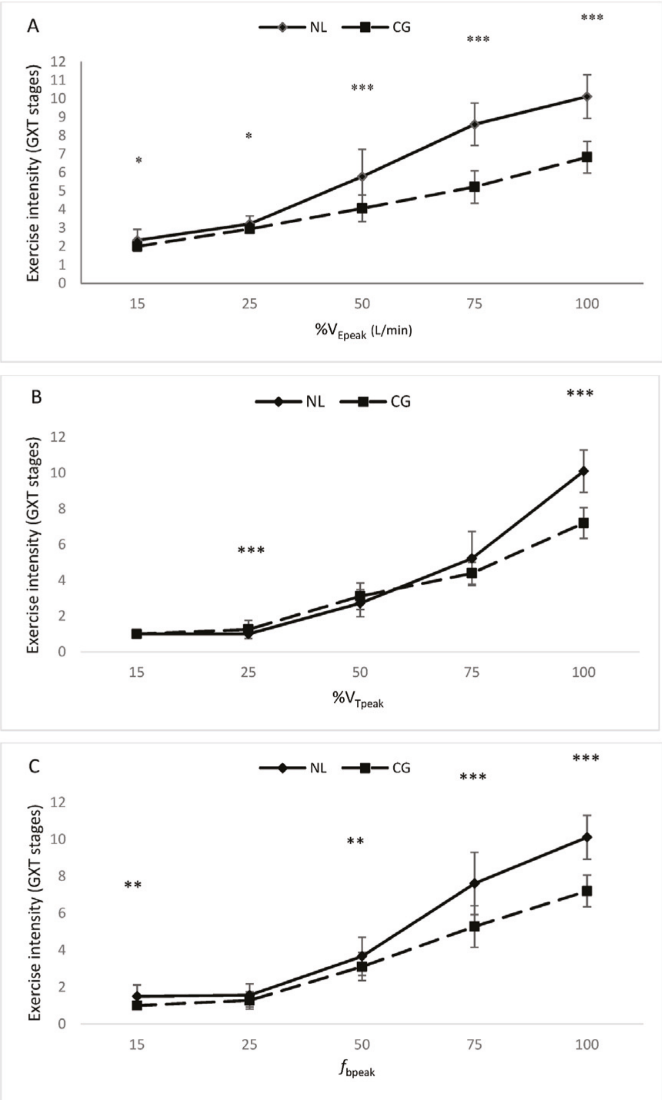


**Fig. 3.** Exercise intensity (Graded exercise test [GXT] stages) as a function of relative expired ventilation ($V_E$), 15–100% of $V_{Epeak}$, mean, standard deviations (SD) **A.** Tidal volume ($V_T$), 15–100% of $V_{Tpeak}$, **B.** Respiratory rate ($f_b$) 15–100% of $f_{bpeak}$, **C.** NL (diamonds) denotes no load test situation and CG (squares) denotes combat gear test situation. Exercise intensity presented as GXT stages from stage 1 (supine), 2 (standing), 3 (5.4 km/h 0 grade) 4 (8 km/h 0 grade) 5 (8 km/h 2% grade) with 2% grade increase until stage 12 (8 km/h at 16% grade). ANOVA, (figure A, B) main effect of load $p < 0.001$ Interaction $p < 0.001$. Post hoc analyses significantly different from no load at $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

muscles, leading to a lower $V_{Epeak}$ while wearing CG, and thus a lower $VO_{2peak}$ and reduced time to exhaustion. Similar results were revealed in previous studies who found that wearing combat gear and specifically body-armor decreased upper extremity function and restricted chest wall motion, leading to respiratory muscle fatigue and a subsequent reduction of time that soldiers could operate wearing body armor (De Maio et al., 2009; Faghy and Brown, 2014; Shei et al., 2018; Armstrong et al., 2019). Limiting respiratory muscle movements can impair ventilation, which could be a problem during high-intensity work when ventilation increases disproportionately (Louhevaara et al., 1995; De Maio et al., 2009; Taylor et al., 2012; Peoples et al., 2016; Phillips et al., 2016a). The present study found a small decrease in $VO_{2peak}$ with load carriage, which most likely is secondary to a similar decrease in $V_E$, with no difference ($p = 0.06$) between sexes (women approx. 6% reduction, men approx. 8%), which reflects a previous study in men (Armstrong et al., 2019). Walker et al. (2015) used a 10 kg weighted vest to simulate body armor then added another 10 kg in a backpack and found a greater reduction for $V_E$ in men during 20 kg load carriage compared to women, in contrast to our results where the use of CG lowered $V_E$ in women and men similarly.

The effect of load carriage on $VO_{2peak}$ not only depends on the weight or tightening the fit of the load causing pressure on chest wall (Bygrave et al., 2004), but may also depend on biomechanical factors, i.e., compensatory changes in muscle activation (abdominals, lower back, hip, knee and ankle) (Phillips et al., 2016a). An interesting sex-specific finding in the present study is that women, despite lower aerobic capacity and pulmonary ventilation, had almost identical time to exhaustion as men in both the NL and CG conditions. One possible explanation for this could be running economy, but unfortunately, we did not collect biomechanical data, and cannot say if sex-specific changes in biomechanics might have contributed to the results in time to exhaustion.

The present study had some limitations that need to be acknowledged. Height has been shown to affect ventilatory responses and pulmonary gas exchange since women compared to men have smaller lungs, increased work of breathing during exercise and decreased aerobic power (Bouwsema et al., 2017; Dominelli et al., 2018). Hence, larger physiological differences would be expected in this convenience sample of active soldiers compared to studies where height is controlled for. Moreover, the soldiers used their own equipment since they were familiarized with it, and it was adjusted for an optimal fit. However, since standardized equipment (weight and bulk), was not used and tightness of body armor not controlled for, our findings might be more difficult to compare to previous studies using identical equipment, standardized load and tightness. Instead, the design of our study was to use a load carriage setup that matched the soldiers' real work context at the expense of a higher load standardization. Another limitation in our study was the GXT protocol adopted from the Bruce treadmill protocol to evaluate the cardiorespiratory responses during high-intensity exercise while wearing NL and CG. The Bruce protocol is designed to bring a subject to fatigue in a short amount of time (usually less than 20 min); in our study, all but one subject lasted at least 25 min wearing NL (including marching 5 min 5.4 km/h and jogging 5 min 8 km/h 0% incline).

Future research is required to expand the findings in this study, to better understand women's physiological responses to load carriage during field work and if potential sex differences exist that need to be considered when determining physical employment standards.

## 5. Conclusion

This study extends current knowledge on sex differences and the effect of CG and body armor in soldiers and shows that wearing body armor reduced cardiorespiratory capacity in men and women. Even at lower intensities, load carriage increased the demands on soldiers during marching with no apparent sex-differences in relative cardiorespiratory response either at submaximal or maximal exercise intensities. One of the main findings was that the combat gear and body armor decreased time to exhaustion in both women and men by approximately 56% (11 min) during GXT. Considering that in military operations soldiers are subjected to work during long hours interspersed with high intensity activities, the reduction in time to exhaustion with CG is of importance in a real-life operation.

In addition, the $VO_2$ and HR relationships for unloaded and loaded marching were different with no difference between sexes, which make HR measurements from unloaded exercise less reliable to use for prediction of energy expenditure at heavier load carriage. It could also be inappropriate to assume that the load carriage implications from one occupation can be applied to another. Therefore, it is important to use relevant occupational clothing and load both when determining physical employment standards used for admissions testing and during yearly fitness tests. These results could also be used in forming work guidelines for both female and male military personnel.

## Author's contribution

The study was designed by JL, MCO; MD and AB; data were collected by JL and MCO; Data was analyzed by JL and MCO, data interpretation and manuscript preparation were undertaken by JL, MCO, MD and AB. All authors read and approved the manuscript.

## Funding

The study was funded by Halmstad University and Swedish Armed Forces.

## Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## Ethics approval and consent to participate

This investigation was performed in accordance with the Declaration of Helsinki and was approved by the Regional Ethical Review Board in Lund, Sweden (Dr, 2016/400).

## Consent for publication

Not applicable.

## Conflicts of interest

The authors declare that they have no competing interests.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

The authors would like to thank all subjects who volunteered to participate in this study and demonstrated great motivation and commitment. A special thanks to Lars Jehpsson for statistical support, and to Amanda Engberg & Max Turnstedt for the support with the data collection in this study.

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