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## Tongue articulation dynamics of /i:/, y:/, ʉ:/ in Stockholm, Gothenburg and Malmöhus Swedish

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### Abstract

Articulatory data were collected for the Swedish vowels /i:/, y:/, ʉ:/ from nine speakers each of Stockholm, Gothenburg, and Malmöhus Swedish, and the tongue positions and their dynamics analysed using Functional Data Analysis (FDA). Results showed that the general tongue positions for /i:/ and /y:/ are similar and clearly different from /ʉ:/ in all three dialects. Variation within the Stockholm and Gothenburg groups led to a subdivision into two types, where the tongue positions of type 1 resembled Malmöhus Swedish more. Several differences in tongue articulation between types 1 and 2 were observed, possibly explained by the presence of Viby-coloured /i:/ and /y:/ in type 2.

### Introduction

In the Swedish vowel system, there are three contrastive long front, close vowels /i:/, y:/, ʉ:/, characterised by a relatively small acoustic and perceptual distance. The magnitude of the lip opening is regarded as the major distinctive feature: unrounded /i:/, out-rounded /y:/, and inrounded /ʉ:/ (Fant, 1959; Ladefoged & Maddieson, 1996). Specifically the contrast between /y:/ and /ʉ:/ is considered highly unusual among the world's languages. The tongue articulation is assumed to be basically identical, but the documentation of this is incomplete, especially for the articulatory dynamics (Ladefoged & Maddieson: 295–6). To maintain the distinctions between these vowels, they are often characterised by a slight diphthongisation or consonantal off-glide at

the end. In many dialects, including Stockholm and Gothenburg, the gesture for /i:/ and /y:/ is achieved by the tongue dorsum as [ij] and [yj], while the lips are used for /ʉ:/ as [ʉβ] (McAllister et al., 1996; Hadding et al., 1974). A different tongue gesture is used in Malmöhus Swedish. Here /i:/, y:/, ʉ:/ are realised as [ei], [ø̥y], [ø̥ʉ] (Bruce, 2010).

Another fairly common realisation of /i:/ and /y:/ in Swedish is as [i:] and [y:]. i.e. with a “damped” quality often referred to as Viby-colouring (Bruce, 2010; Ladefoged & Maddieson, 1996). There is disagreement in the Swedish phonetics literature if the major constriction for the damped /i:/ and /y:/ is further front compared to their regular counterparts, and basically alveolar, or instead further back and rather central (Björsten et al., 1999; Engstrand et al., 2000). However, as adequate articulatory data seem to be lacking, these views are at best intelligent speculations.

In Schötz et al. (2013) we investigated the articulatory dynamics of /i:/, y:/, ʉ:/ in Gothenburg Swedish (GS) and Malmöhus Swedish (MS), spoken in and near Gothenburg and Malmö, respectively, using Functional Data Analysis. In MS, we found that the position of the tongue body was significantly lower for /ʉ:/ than for /i:/ and /y:/ . In GS, the speakers could be subdivided into two different types according to their articulation patterns; type GS1 resembled MS, while type GS2 had higher tongue body for /ʉ:/.

The purpose of this study was to extend our findings by including Stockholm Swedish (SS), spoken in and near Stockholm, and compare the tongue

articulation of /i:/, /y:/, /ɥ:/ of this dialect to those of GS and MS. Our aim was to find out how SS relates to our findings for MS and GS. Based on the results of Schötz et al. (2013), we expected the tongue positions in the dimensions open–close and front–back to be different for /ɥ:/ than for /i:/, /y:/ in all three dialects. Furthermore, we expected to find regional differences in the articulation of /i:/ and /y:/, as Vibry-colouring is more common in SS and GS than in MS (Bruce, 2010). We also expected to find a subdivision into two types in both GS and SS.

### Material and method

Nine speakers each of SS (3 females, 6 males, age: 21 – 63, mean = 42, sd = 15.2), GS (5 females, 4 males, age: 20 – 47, mean = 29, sd = 10.0), and MS (4 females, 5 males, age: 23 – 62, mean = 43, sd = 11.7) were recorded by means of electromagnetic articulography along with a microphone signal using an AG 500 (Carstens Medizinelektronik). Twelve sensors were placed on the lips, jaw and tongue, and also on the nose ridge and behind the ear to correct for head movements. Figure 1 shows the sensor positions and one subject with sensors attached.



Figure 1. The twelve sensor positions and a speaker with the sensors attached.

In this study we focused on the tongue tip (sensor 1) and body (sensor 2). The speech material consisted of 15–20 repetitions by each speaker of /i:/, /y:/, /ɥ:/ in carrier sentences of the type “De va inte hVt utan hVt ja sa” (It was not hVt, but hVt I said), where the target words containing the vowels were stressed and produced with contrastive focus. The sentences were displayed in random order on a computer screen, and the

speakers were instructed to read each sentence in their own dialect at a comfortable speech rate. A contour of the palate was obtained as the speakers moved their tongue tips back and forth along the midline of their palate.

### Error detection and speaker normalisation

Noise and measurement errors in articulatory data are fairly common due to quick head movements, sensors moving too close to each other, sensors breaking or falling off, or calculation errors. In order to detect and exclude such errors, we used the same two-step process, described in Schötz et al. (2013). The vowels were segmented manually in Praat (Boersma & Weenink, 2013) and used as acoustic landmarks to trim the data set. Plots for sensors traces 1–3 were used to visually identify and exclude vowels with errors. The remaining errors and outliers were removed with the package ‘robustbase’ (Rousseeuw et al., 2012) in the R statistical environment (R Development Core Team, 2013). In order to compensate for differences in oral anatomy between speakers, data was normalized using z-score transformation.

### FDA smoothing and aligning

Functional Data Analysis (FDA) is a technique for timewarping and aligning a set of signals to examine differences between them. FDA techniques and applications to speech analysis were first introduced by Ramsay et al. (1996), and further developed by Lucero et al. (1997), Lucero and Löfqvist (2005) and Gubian et al. (2011). In FDA, a function or function system is fitted to the data, and the fitting coefficients are examined instead of the original data. A commonly used function form are B-spline functions (Ramsey et al. 2009), which are flexible building blocks for fitting curves to approximate a large number of different shapes. By selecting weights for each spline, the overall shape becomes similar to the actual sensor trace. The details

are described in Schötz et al. (2013). In this study, FDA was used to smooth the sensor traces, and to standardise the time to facilitate comparisons between repetitions. All FDA processing was done using the R package 'fda' (see Schötz et al., 2013 for details).

#### Analysis of tongue articulation

Sensors 1 and 2 were selected to represent the tongue tip and body (see Figure 1). FDA processed contours were plotted for the tongue body and tip dynamics in height and frontness, and the positions and dynamics compared within as well as across the regional varieties. Statistical analysis was done with functional t-tests (see Ramsey et al. 2009 for details), where the t-statistic is a function of time, using the function *tperm.fd* in the 'fda' package.

#### Results

Generally, the vowel /ɘ:/ displays distinct patterns from /i:/ and /y:/, and /ɘ:/ also varies the most between regions. Among the SS and GS speakers we found a subdivision between speakers (5 type SS1, 4 type GS1) who articulate the three vowels with similar tongue positions as the MS speakers, and speakers (4 type SS2, 5 type GS2) who generally have different tongue positions compared to the MS speakers.

#### Tongue body height

Tongue body height is shown in Figure 2. In MS, GS1 and SS1 the position of the tongue body is lower for /ɘ:/ than for /i:/ and /y:/, while in GS2 and SS2 the position is higher for /ɘ:/. We found significant differences between varieties (pairwise functional t-tests,  $p < 0.05$ ) throughout the vowel in /ɘ:/ for MS-GS2, MS-SS2, GS1-GS2 and SS1-SS2. For MS-GS1 and MS-SS1 the difference is not significant throughout the whole vowel. The main difference between SS2 and GS2 is that /i:/ has the lowest tongue body in SS2 while /y:/ is lower in GS2. SS1 displays slightly more arched contours for all vowels compared to the other varieties, sug-

gesting a higher degree of diphthongisation or coarticulation.

#### Tongue tip height

Figure 3 shows that the tongue tip height for /y:/ is higher than for /i:/ and /ɘ:/ in all varieties except MS, where /ɘ:/ has the highest contour. Between varieties there are significant differences (pairwise functional t-tests,  $p < 0.05$ ) in the central part of /ɘ:/ between MS and all others varieties. For GS1-GS2 and SS1-SS2 the difference is not significant. The dynamics for all the vowels in all the varieties is represented by slightly rising contours, suggesting closing diphthongisations, although some individual variation can be observed.

#### Tongue body frontness

As shown in Figure 4, the tongue body is more protruded in /i:/ and /y:/ than in /ɘ:/ in all varieties except GS2, which displays an opposite pattern except in the final part of the vowel. /i:/ and /y:/ have similar contours in all varieties, with the clearest overlap in SS2. The vowel contours are either rising slightly (GS1, MS), arch-shaped (e.g. SS1, SS2) or slightly falling (GS2), suggesting different diphthongisation strategies.

#### Tongue tip frontness

Tongue tip frontness is shown in Figure 5. In MS the tongue tip is further back in /i:/ and /y:/ compared to /ɘ:/, while the opposite pattern is found for all the other varieties. Between varieties, we found significant differences (pairwise functional t-tests,  $p < 0.05$ ) in the middle of /ɘ:/ for MS vs. all the others. We also note somewhat different vowel dynamics in the different vowels and varieties, suggesting different types of diphthongisation gestures. In SS1 all vowels show slight forward-backward movements, but with an earlier timing for /ɘ:/ than for /i:/ and /y:/. All vowels in GS1 move lightly forward, while they move backward in GS2. In MS /i:/ and /y:/ show a forward motion, while the arch-shaped contour for /ɘ:/ suggests a forward-backward-movement.

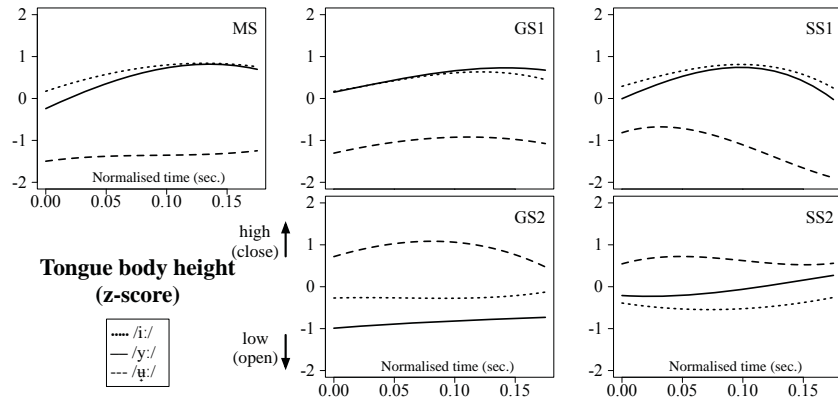


Figure 2. Mean tongue body height (z-score) as a function of normalised time for /i:/, /y:/, /ɥ:/ in Malmö (MS) and two types of Gothenburg (GS1, GS2) and Stockholm (SS1, SS2) Swedish.

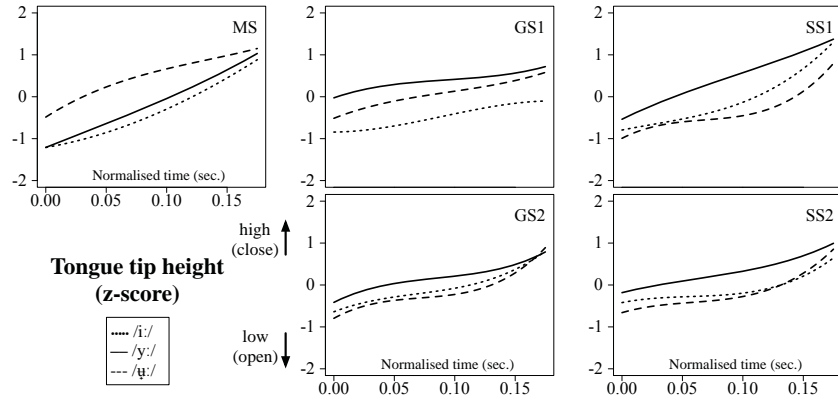


Figure 3. Mean tongue tip height (z-score) as a function of normalised time for /i:/, /y:/, /ɥ:/ in Malmö (MS) and two types of Gothenburg (GS1, GS2) and Stockholm (SS1, SS2) Swedish.

## Discussion

The results of this study indicate that the tongue articulation for /ɥ:/ is significantly different from /i:/ and /y:/ in both Stockholm, Gothenburg and Malmö Swedish. Our hypothesis of different tongue articulation for /ɥ:/ than for /i:/ and /y:/ was thus confirmed.

Considerable regional variation was observed in this study, not only for each vowel in the front-back and open-close dimensions, but also in the vowel dynamics (diphthongisation). MS often displayed different patterns than SS and GS, supporting our hypothesis of different articulation strategies in different regional varieties, at least in part.

The intra-regional variation found in SS and GS led to a subdivision into the four types SS1, SS2, GS1 and GS2. A closer look showed that the SS1 and GS1 speakers were more often from the outskirts of the Stockholm and Gothenburg areas than the SS2, GS2 speakers. Furthermore, most SS2 and GS2 speakers had clear Viby-coloured /i:/ and /y:/, which was not the case for most of the SS1 and GS1 speakers. No MS speakers used Viby-colouring. The Viby-colouring may offer one explanation for the differences in tongue articulation. In future studies, we will investigate this further by comparing articulatory data and acoustic data, e.g. formant frequencies.

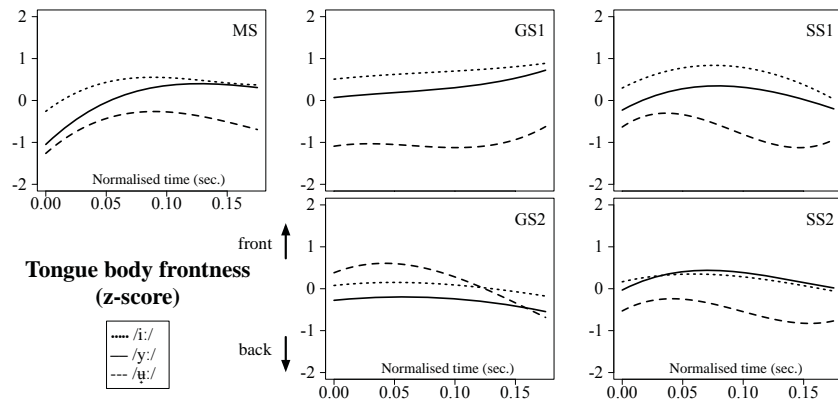


Figure 4. Mean tongue body frontness (z-score) as a function of normalised time for /i:/, /y:/, /ɥ:/ in Malmö (MS) and two types of Gothenburg (GS1, GS2) and Stockholm (SS1, SS2) Swedish.

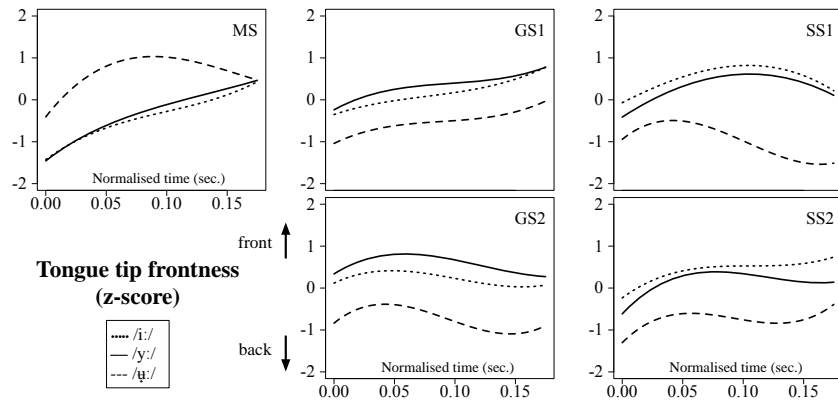


Figure 5. Mean tongue tip frontness (z-score) as a function of normalised time for /i:/, /y:/, /ɥ:/ in Malmö (MS) and two types of Gothenburg (GS1, GS2) and Stockholm (SS1, SS2) Swedish.

In this study we analysed only two discrete points and two dimensions of the tongue: tongue tip and body height and frontness, and used a standard z-score transformation for speaker normalisation. Although we did not look at lip rounding, traditionally regarded as the main difference between /i:/, /y:/ and /ɥ:/, our results clearly show differences between these vowels in tongue body height as well. In future studies, we will compare tongue articulation to lip rounding and we also include a larger number of vowels, e.g. /e:/ and /ø:/.

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