A physiological analysis of high front, tense-lax vowel pairs in Standard Austrian and Standard German

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The main aim in this study was to establish whether lax /ɪ/ was closer to tense /iː/ in Standard Austrian German (SA) compared with Standard German (SG) and to suggest some possible mechanisms that may have brought about the differences between /ɪ/ and /iː/ in these varieties. In order to do so, physiological movement data of vowels in three symmetrical consonant contexts were analyzed from four Standard Austrian and seven Standard German speakers. The results showed that the duration of /ɪ/ was less than /iː/ in both varieties but that the position of the tongue for /ɪ/ was closer to /iː/ in SA than in SG. Consonantal context was found to exert a greater influence on /ɪ/ than /iː/ only in Standard German and not in Standard Austrian: the coarticulatory differences in SG were such that /ɪ/ in the velar, but not the other two contexts, was perturbed towards the /iː/ vowel space. This perturbation is interpreted as being due to the raised dorsum position of /k/ which counteracts the tongue-dorsum lowering in /ɪ/. We suggest that the shift of /ɪ/ towards /iː/ in varieties such as Standard Austrian may come about when these coarticulatory tongue-dorsum raising effects are generalized to other contexts in which /ɪ/ occurs.[*]

1. Introduction

The present investigation is concerned with a theme that is central to many sociophonetic studies (e.g. Hay & Drager 2007, Foulkes 2010, Munson 2010, Docherty & Mendoza-Denton 2012, for recent reviews): quantifying phonetic differences between two varieties, in this case between Standard German (SG) and Standard Austrian (SA) based on experimental studies of group differences in vowel production. Our particular concern in this paper is with differences in vowel tensity and whether there is any evidence, as has been suggested in the literature (Moosmüller 2008, Wiesinger 2009), that the high front lax vowel in words like *bitten* ('to request') is tenser in SA than in SG. The overall aim of this study is to shed light both on some of the ways that tense and lax vowels can differ phonetically as well as to contribute to our understanding of diachronic tense-lax sound changes which – in contrast to monophthon-

gal vowel changes that have been shown to be involved in various types of chain shifts (Labov 1994, Watson et al. 2000, Labov et al. 2006, Maclagan & Hay 2007 – are not so well understood nor documented (but see Di Paolo & Faber 1990 and Faber & Di Paolo 1995 for details of tense/lax neutralizations in some varieties of American English).

In SG, almost all vowels stand in a tense/lax phonological opposition that can give rise to various minimal pairs such as /lɛːm/ vs. /lɛm/[1] (*lahm* vs. *Lamm*, 'lame' vs. 'lamb'), /miːtə/ vs. /mɪtə/ (*Miete* vs. *Mitte*, 'rent' vs. 'middle') and /oːfn̩/ vs. /ɔfn̩/ (*Ofen* vs. *offen*, 'oven' vs. 'open').[2] In both English and German, tense vowels have been shown to be more peripheral and longer (Lehiste & Peterson 1961, Hoole 1999) than their lax counterparts. The tensity distinction found in some Germanic languages is quite different from that of Niger-Congo languages that involves differences in pharyngeal volume as a result of tongue root advancement (Ladefoged 1964, Stewart 1967, see Tiede 1996 for an MRI study comparing vowel tensity differences in Akan and English). In English and German, tense and lax vowels are distinguished not only on static measurements of vowel peripherality at the target, but also on their dynamic structure including for English the proportional amount of time taken up by the vowel's closing transitions (Lehiste & Peterson 1961, Rakerd & Verbrugge 1985, Huang 1986). There is a long line of research to suggest that German tense and lax vowels differ dynamically (Sievers 1901, Jespersen 1913, Trubetzkoy 1939) and that lax vowels are cut off to a greater extent by a following consonant than are tense vowels (Vennemann 1991). Some evidence to support this view was found in a study of German vowels using electromagnetic articulometry by Hoole & Mooshammer (2002) who tested whether lax vowels were more truncated versions of their tense counterparts using some of the parameters in Harrington et al. (1995). Based on their analyses of the different ways that lax and tense vowels change physiologically under manipulations of speech rate, Hoole & Mooshammer (2002) proposed that the force required to move the articulators may be concentrated in a single peak for lax vowels but distributed as two separate peaks in the opening and closing movements for tense vowels: this hypothesis was also shown to be consistent with the results of an electromyographic study of the intrinsic laryngeal muscles in lax and tense vowel production in Hoole & Honda (2011).

Tense and lax vowels have been shown to differ in their compressibility when they occur in prosodic contexts that are likely to lead to vowel shortening. Thus whereas tense vowels have been shown

to shorten at faster rates or in unstressed contexts, lax vowel duration in German changes minimally (Mooshammer et al. 1999, Geng & Mooshammer 2000, Mooshammer & Fuchs 2002) and may be close to a threshold of incompressibility (Klatt 1973). Nevertheless, even though lax vowels scarcely shorten, they may nevertheless reduce spatially (Mooshammer & Fuchs 2002): that is, the extent of German lax vowel reduction in unstressed contexts is often far greater than can be predicted from durational shortening alone (Mooshammer & Geng 2008). Finally, Hoole & Mooshammer (2002) showed that lax vowels were more variable than their tense counterparts but principally because they were affected to a greater extent by the coarticulatory influences from flanking consonants: they found that the variation in lax vowels across labial, alveolar, and velar contexts was greater than that of their tense counterparts.

The variety of German to be investigated for differences in vowel tensity, SA, is spoken in lower and upper Austria, Vienna, parts of Salzburg, and parts of the Burgenland; it is characteristic of educated and non-working-class speakers (Wiesinger 2009, Moosmüller 2011); and, together with varieties spoken in lower and upper Bavaria, SA forms part of the Central Bavarian dialect. Impressionistically-based studies have suggested that, in comparison with SG, the tense-lax distinction in pairs like *bieten / bitten* is less marked in Central Bavarian varieties than in SG (Bannert 1976, Wiesinger 1990). In a recent, acoustically-based apparent-time study by Kleber (2011), one of the main bases for the tense-lax distinction for older Central Bavarian speakers from upper Bavaria was a lengthening of the tense vowel that was argued to be a by-product of the lenition of the following obstruent: thus, older Central Bavarian speakers tended to distinguish between [biːdn] (*bieten*) and [bitn] (*bitten*). As far as SA is concerned, Moosmüller (2007, 2008) has proposed, based on acoustic measurements of duration and the formant pattern at the vowel target, that pairs like *bieten/bitten* may well be in the process of merging, possibly under the influence of a predominantly working class variety spoken in Vienna.

The magnitude of both vowel tensity differences in Central Bavarian varieties and the possible causes of a tense-lax merger in SA are nevertheless not very well understood and the aim of the present study is to begin to shed some light on this matter through a comparison between SA and SG of /iː, ɪ/. Thus the aim is to make use of SG, in which the tense and lax vowels are distinct, as a baseline for assessing the direction and nature of the change that has taken place in SA. Our analysis is physiologically based because, as the various studies of SG

reviewed above have shown, the vowel tensity distinction depends on often quite subtle dynamic differences that cannot always easily be quantified using acoustic measures such as total duration or information based on single time slices at the vowel target. There is, it must be admitted, a further pragmatic reason why we have proceeded with a physiological analysis in this case which is to do with the availability of a corpus of speech movement data of seven speakers of SG who produced all the German vowels in three consonantal contexts that exists as a result of other studies (Hoole 1999, Harrington et al. 2011a). We do not apologise for this however: physiological speech corpora are extremely time-consuming to collect and opportunities should be exploited for their re-use when, as in the present case, they have the potential to provide an existing baseline against which vowel changes and differences in other varieties can be assessed.

The comparison between SA and SG is reported in three separate sections below. Firstly (section 2), two types of analyses were carried out to measure the relative proximity of /iː/ and /ɪ/ in the two varieties: these included calculating the (speaker-specific) distances between these vowels in a transformed space of the tongue; and calculating the size of the coarticulatory influence of the consonant on the lax vowel. The predictions here were that the tongue positions of /iː, ɪ/ should be closer together in SA than in SG; and that SA /ɪ/ should be perturbed less by consonantal context if it is tenser than its standard German counterpart. Then we considered whether any differences between the varieties found in section 2 could be explained in terms of duration (section 3): specifically whether the closer approximation between /iː, ɪ/ in SA than in SG could be predicted either from rate-dependent stylistic variation or from a longer /ɪ/ in the Austrian than in the SG variety. Finally, we tested whether any differences between the two varieties in the relative position of /ɪ/ to /iː/ could be explained in terms of perturbations due to consonant-on-vowel coarticulation (section 4).
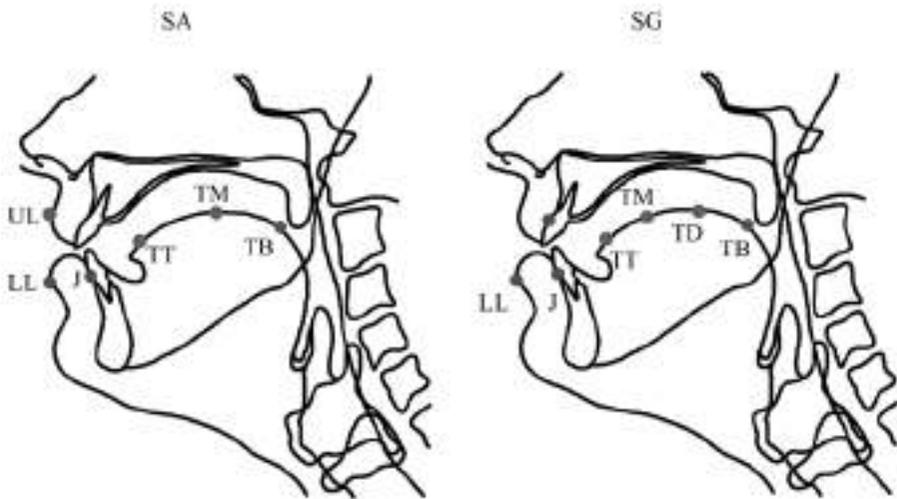
2. The tongue positions of /iː, ɪ/ in Standard Austrian and Standard German

2.1. Method
2.1.1. Data collection and speakers
Speech movement data of the motion of the jaw, lips, and surface of the tongue were collected at the IPS, Munich from 7 SG, and 4 SA speakers. The SG speakers were all staff or students of the Institute of

Phonetics and Speech Processing, University of Munich at the time of recording and included 6 male speakers and 1 female speaker spanning an age range between 26 and 58 years. Four of the SG speakers were born in Bavaria, two in the Rhineland, and one in Schleswig-Holstein. All seven SG speakers were judged to speak in a Standard German variety with minor regional colouring. The 4 SA speakers were recruited from a larger group of SA speakers for which acoustic data had been collected at the Acoustics Research Institute, Vienna. The 4 SA speakers were born in Vienna and were students in Vienna at the time of the recording.[3] Their age ranged between 19 and 23 years.

Figure 1. A cross-sectional view of the vocal tract showing the approximate positions of the sensors in the recordings from the Standard Austrian (left) and Standard German (right) speakers for the upper lip (UL), lower lip (LL), jaw (J), tongue tip (TT), tongue mid (TM), tongue dorsum (TD), and tongue back (TB).

The data for the SG speakers were collected between 1993 and 1995 and were taken from the same corpus described in Hoole (1999) and Hoole & Mooshammer (2002); they were acquired using electromagnetic midsagittal articulometry (EMMA; AG100 Carstens Medizinelektronik Göttingen) with four sensors attached to the surface of the tongue (Fig. 1), and one each on the jaw and lower lip (plus one sensor each on the upper incisors and bridge of nose to compensate for head movements). The jaw sensor was positioned in front of the lower incisors on the tissue just below the teeth. The lower lip (LL) sensor was positioned on the skin just below the lips. The tongue tip (TT) sensor was attached

approximately 1 cm behind the tip of the tongue; the tongue back (TB) sensor was positioned as far back as the subject could tolerate.

The 4 SA speakers were recorded at the IPS, Munich in 2011 using 5D electromagnetic articulometry (EMA) allowing the horizontal, vertical, and lateral positions of the articulators to be measured.[4] The movement data were recorded from sensors fixed as closely as possible to the same positions as they had been for the 7 SG speakers. One of the differences was that only three sensors were attached to the tongue for the SA speakers, whereas for the SG speakers there had been four. However, the relative positions of the TT and TB sensors (1 cm behind the tongue tip and as far back on the surface of the tongue as the subject could tolerate) were the same. A second difference was that sensors were attached to both the upper and lower lips for the SA speakers, whereas for the SG speakers only lower lip recordings had been made (however, this is of no consequence for the present paper which deals only with tongue movement). In addition, four reference sensors were used in obtaining data from the SA speakers to correct for head movements: one each on the left and right mastoid process, one high up on the bridge of the nose, and one in front of the upper incisors on the tissue just above the teeth. Apart from these differences the data from the two articulometry systems can be regarded as comparable since both acquire flesh-point data of the articulators using exactly the same kind of sensor (see Hoole & Zierdt 2010, for further comparison of the systems).

The physiological data in both corpora were sampled at a frequency of 200 Hz and band-pass filtered with a FIR filter (Kaiser window design, 60 dB at 40-50 Hz for the tongue tip, at 20-30 Hz for all other articulators, at 5-15 Hz for the reference sensors). The data for both SA and SG speakers were rotated so that they were parallel to the occlusal plane that was estimated by having a subject bite onto a bite-plate. The synchronized acoustic waveform was digitized at 16 kHz in both corpora. These procedures were carried out in Matlab and the output stored in self-documented Matlab files. The data from both corpora were converted into an Emu compatible format and analyzed in the R programming language (Harrington 2010, Ch. 5).

2.1.2. Materials and segmentation

The SG speakers produced symmetrical CVC sequences for C = /p, t, k/ and all the German monophthongs embedded in the target non-word and carrier phrase *ich habe* /gəCVCə/ *gesagt* (literally *I have* /gəCVCə/ *said*). In addition, the subjects produced separately

three steady-state versions each of all tense vowels except /ɛː/ (none of these steady-state vowels were analyzed in the present study). The carrier phrase was produced with a nuclear accent on the target /gəCVCə/ and in most cases with a falling intonational melody. The carrier phrases were repeated five times, randomised separately for each subject, and presented individually on a computer monitor in the corresponding orthography (e.g., for /pɐːp/ *ich habe gepaape gesagt*, for /kɪk/ *ich habe gekikke gesagt*, etc.). The entire corpus was produced twice on separate occasions, once at a slow speech rate, then once again at a fast speech-rate at which vowel duration of tense vowels most closely matched the duration of lax vowels spoken at the slow rate. The total number of presented sentences was 3 (places of articulation) × 15 (vowels) × 2 (rates) × 5 (repetitions) × 7 (speakers) = 3150. All of the analyses in this section are based only on the data from the self-selected slow rate (see section 3 for a comparison of the two rate conditions).

The SA speakers produced the same materials that had been produced by the SG speakers and as far as possible under the same conditions with two exceptions: firstly, they also produced symmetrical CVC sequences for the voiced stops, C = /b, d, g/ which were not analyzed in this paper; secondly, they produced the materials only at their normal rate of speech. The total number of presented sentences was 3 (places of articulation) × 15 (vowels) × 2 (stop voicing conditions) × 5 (repetitions) × 4 (speakers) = 1800.

The acoustic signals from both SA and SG speakers were automatically segmented using the Munich Automatic Segmentation tools (Schiel 2004). The acoustic boundaries were manually adjusted at the beginning and end of the acoustically periodic vowel signal in the target word: this is the interval over which the data were analyzed for both groups of speakers in this paper.

2.1.3. Data reduction

Following a procedure in Harrington et al. (2011b), our aim was to compress the data from the tongue sensors to a two-dimensional space that bears some relationship to the backness × height dimensions of the vowel quadrilateral that is often used for acoustic comparisons of vowel quality differences between groups of speakers in sociophonetic and sociolinguistic studies. In order to do so, we applied separately for each of the 11 speakers principal components analysis (PCA) to standard-normalized (*z*-score transformed) tongue positions extracted at the acoustic temporal midpoint only for the five tense vowels /iː, eː, ɐː, oː, uː/. For the SG speakers, there were

8 values per vowel token (one vertical and one horizontal position from each of the tongue tip, tongue mid, tongue dorsum, and tongue back) and only the vowels at the slow rate were input to PCA; for the SA speakers 6 values per vowel token (one vertical and one horizontal position from each of the tongue tip, tongue dorsum, and tongue back sensors) were input to PCA. The resulting speaker-specific eigenvectors (loadings on the tongue parameters) were then applied to (matrix-multiplied with) the standard-normalized vowel data between the acoustic onset and offset for the same speaker. All subsequent analyses for assessing the relative similarity between lax and tense vowels in the two varieties were carried in these first two PCA-transformed dimensions.

2.1.4. Relative distance measurements

We quantified separately for each speaker the relative distance of lax /ɪ/ to both tense /iː/ and to lax /ɛ/ in this two-dimensional, transformed PCA-space. The hypothesis to be tested was that /ɪ/ was proportionately closer to /iː/ than to /ɛ/ for SA compared with SG speakers. The quantification was based on calculating the average distance of the trajectory to the same speaker's /iː/ and /ɛ/ means in the same consonantal context. More specifically, where $(x_{t.C.S}, y_{t.C.S})$ are the x- and y-co-ordinates respectively in this transformed two-dimensional PCA-space of a vowel trajectory (between its acoustic onset and offset) of length N at time t in consonantal context C (C = /p, t, k/) produced by speaker S, and where $(\bar{x}_{I.C.S}, \bar{y}_{I.C.S})$ is the mean value at the acoustic vowel temporal midpoint averaged across all (tense) /iː/ tokens in the same consonantal context and by the same speaker, and where $(\bar{x}_{E.C.S}, \bar{y}_{E.C.S})$ is the mean value at the acoustic vowel temporal midpoint averaged across all (lax) /ɛ/ tokens in the same consonantal context and by the same speaker, we calculated (in the two-dimensional transformed PCA space) a given vowel trajectory's summed Euclidean distance to the mean of /iː/:

$$d_{I.C.S} = \sum_{t=0}^{N-1} \sqrt{(x_{t.C.S} - \bar{x}_{I.C.S})^2 + (y_{t.C.S} - \bar{y}_{I.C.S})^2} \qquad (1)$$

and the same vowel trajectory's summed Euclidean distance to the mean of /ɛ/:

$$d_{E.C.S} = \sum_{t=0}^{N-1} \sqrt{(x_{t.C.S} - \bar{x}_{E.C.S})^2 + (y_{t.C.S} - \bar{y}_{E.C.S})^2} \qquad (2)$$

Each of (1) and (2) produce a single value of the trajectory's summed distance to /iː/ and /ɛ/. The final calculation was the logarithmic ratio of these two distances which expresses the relative proximity of the trajectory to the means of /iː/ and /ɛ/:

$$r_{C.S} = \log(d_{i.C.S}/d_{\varepsilon.C.S}) = \log(d_{i.C.S}) - \log(d_{\varepsilon.C.S}) \tag{3}$$

When $r_{C.S}$ is zero, then the trajectory is, on average, equidistant between /iː/ and /ɛ/; if it is negative, then the trajectory is closer to /iː/ than to /ɛ/; and if it is positive, then it is closer to /ɛ/ than it is to /iː/. We calculated (3) for each speaker's /ɪ/ vowel trajectories. The hypothesis to be tested was that if /ɪ/ is closer to /iː/ for SA speakers, then /ɪ/ should have lower values on (3) for this group than for SG speakers.

2.1.5. Magnitude of coarticulation

We further quantified the extent to which the vowels were perturbed due to the coarticulatory influence of the consonantal context by measuring separately for each vowel and for each speaker the Euclidean distances to the vowel's mean: the greater the coarticulatory perturbation, the further a given trajectory is likely to deviate away from the group mean. Since lax vowels are influenced to a greater extent by coarticulation than are tense vowels (e.g., Hoole & Mooshammer 2002), then if SA-/ɪ/ is tenser than SG-/ɪ/, it should have lower distances than SG-/ɪ/ on this measure. Where $(x_{t.V.S}, y_{t.V.S})$ are the *x*- and *y*-co-ordinates respectively in the transformed two-dimensional PCA-space of a trajectory between the acoustic onset and offset of a given vowel, *V*, of length *N* at time *t* produced by speaker *S*, and where $(\bar{x}_{V.S}, \bar{y}_{V.S})$ is the mean value at the acoustic vowel temporal midpoint averaged across all tokens of the same vowel type produced by the same speaker, the mean Euclidean distance d_S, of a trajectory to the same speaker's vowel mean was calculated from:

$$d_S = \frac{1}{N}\sum_{t=0}^{N-1}\sqrt{(x_{t.V.S} - \bar{x}_{V.S})^2 + (y_{t.V.S} - \bar{y}_{V.S})^2} \tag{4}$$

for each speaker, *S*, and for the vowel-types *V* = /iː, ɪ, eː, ɛ/.

2.2. Results

The results in this section are based on comparisons between the SA-vowels and those of the SG speakers produced at the self-selected slow rate.
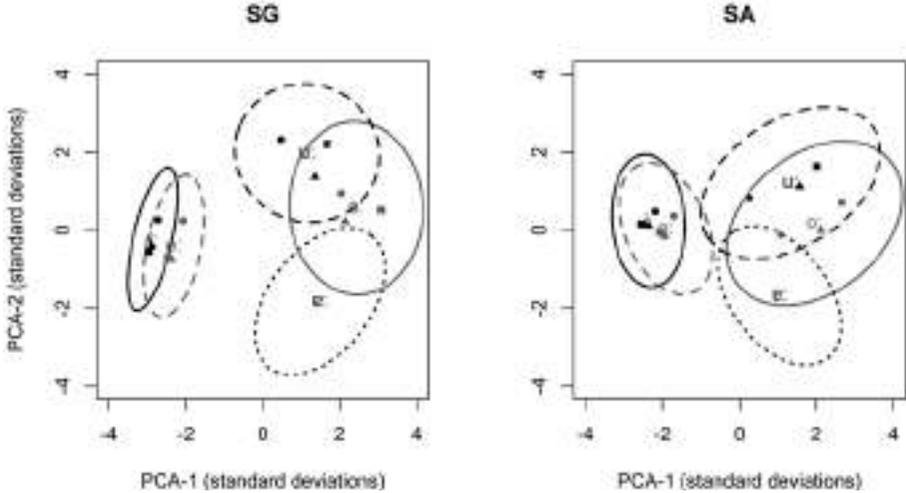

Figure 2. 95% confidence ellipses for PCA-transformed tongue data extracted at the acoustically temporal midpoint of /iː/ (solid black), /eː/ (dashed grey), /ɛː/ (dotted black), /oː/ (solid grey), and /uː/ (dashed black) for 7 speakers of Standard German (left) and 4 speakers of Standard Austrian (right). The squares, circles, and triangles denote respectively the mean positions per vowel category in /p_p/, /t_t/, and /k_k/ contexts. A colour version is online at: http://linguistica.sns.it/RdL/2012.htm

As Figure 2 shows, a quadrilateral-like shape emerged from the distribution of the five tense vowels in the first two dimensions of the PCA-transformed space, with /iː/ positioned above /ɛː/ and to the left of /uː, oː/. Given that these are physiology data with ellipses pooled across contexts and speakers, then the vowels show a fair degree of separation. Some of the expected effects of consonant-on-vowel coarticulation are in evidence in both varieties, such as the shift of /uː/ towards /iː/ in an alveolar context.

As far as the relative degree of tensity of /ɪ/ in the two varieties is concerned, the data in Figure 3, which shows linearly time-normalized trajectories averaged across the speakers in the three consonantal contexts for the four vowel types, suggests that /ɪ/ is relatively closer to /iː/ in SA than it is in SG: in particular, whereas SA-/ɪ/ in the labial (squares in Fig. 3) and alveolar (circles) contexts is quite close to /iː/ in the same contexts respectively, for SG these vowels are positioned at an approximately intermediate position between /iː/ and /ɛ/.
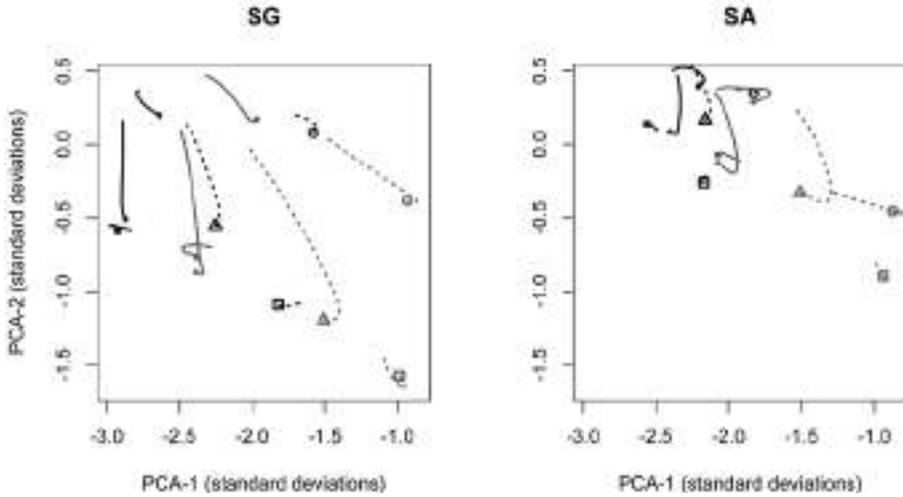
Figure 3. PCA-transformed tongue trajectories extending between the acoustic vowel onset and offset averaged after linear-normalization across 7 Standard German (left) and 4 Standard Austrian speakers (right). The symbols are positioned at the acoustic vowel onset and represent /pVp/ (square), /tVt/ (circle), and /kVk/ (triangle) contexts for V = /iː/ (black solid, filled symbol), /eː/ (grey solid, filled symbol), /ɪ/ (black dashed, open symbol), and /ɛ/ (grey dashed, open symbol). A colour version is online at: http://linguistica.sns.it/RdL/2012.htm
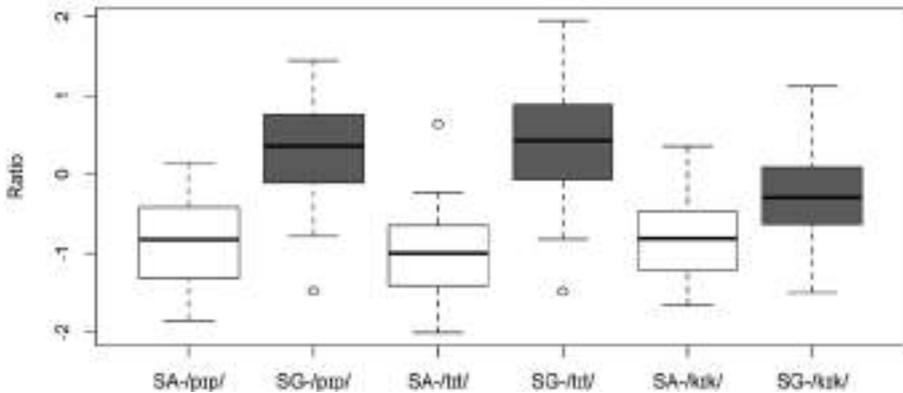
Figure 4. Boxplots of the log. Euclidean distance ratio for /ɪ/ in three contexts produced by 4 Standard Austrian (white) and 7 Standard German (grey) speakers. Negative values represent positions closer to /iː/, positive values are positions closer to /ɛ/, and the value of zero is a position intermediate between these two vowels. The boxes extend over the interquartile range and the solid horizontal line is the median value.

The quantification in Figure 4 of the relative position of /ɪ/ using the log. Euclidean distance ratio (3) discussed in section 2.1.4 shows that, in comparison with SG, SA-/ɪ/ is relatively closer to SA-/iː/ than it is to SA-/ɛ/ for all three consonantal contexts: thus for all three SA contexts, the boxplots are generally below zero (i.e., closer to /iː/), whereas for SG-/ɪ/ the values are above zero in both /p/ and /t/ contexts (i.e., they are closer to /ɛ/), and just below zero for SG-/ɪ/ in the /k/ context. These data are therefore consistent with those in Figure 3 in showing a relatively greater /ɪ/-/iː/ proximity for the SA than for the SG speakers. A mixed model with the log. Euclidean distance ratio (the values in Fig. 4) as the dependent variable, with independent factors Variety (two levels: SA, SG), and Context (three levels: /p, t, k/), and with the speaker as the random factor showed a significant interaction between Variety and Context ($\chi^2_2 = 15.0$, $p < 0.01$). Post-hoc Tukey-tests[5] showed, consistently with the results in Figure 4, that there were significant differences between the two varieties in the /p/ ($z = 5.1$, $p < 0.001$) and /t/ ($z = 5.7$, $p < 0.001$) contexts, but not in the /k/ context. Overall these results are strongly consistent with the hypothesis, that /ɪ/ is proportionately closer to /iː/ than it is to /ɛ/ for the SA than for the SG variety.
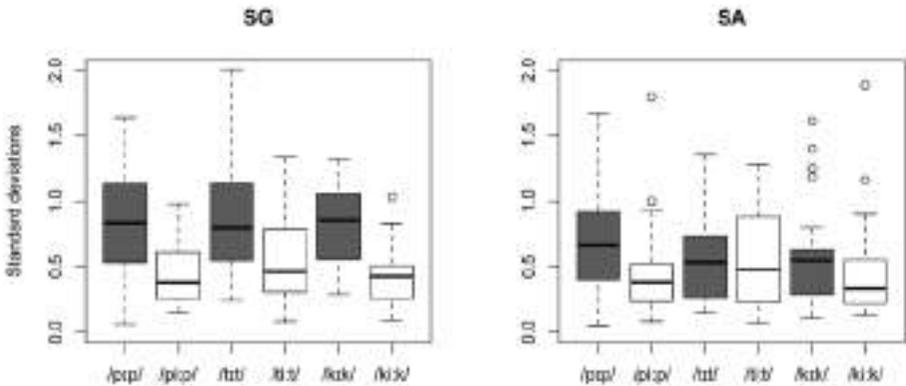
Figure 5. Boxplots of the Euclidean distances to the vowel mean for /ɪ/ (grey) and /iː/ (white) in three contexts produced by 7 Standard German (left) and 4 Standard Austrian (right) speakers.

The results in Figure 5 of quantifying the coarticulatory influences of consonantal context are to a certain extent consistent with the hypothesis that SA-/ɪ/ should be perturbed less by context if it is tenser. Recall from (4) in section 2.1.5 that the greater the values on this

measure, the more that tokens in a particular context are displaced from the speaker's vowel group mean (and by inference the greater the coarticulatory influence of consonantal context on the vowel). As the left panel of Figure 5 shows, consonantal coarticulation had a greater influence on /ɪ/ than on /iː/ for the Standard German variety (as shown by the values in the three /iː/ contexts which are closer to zero than those for /ɪ/), whereas for SA (right panel of Fig. 5), such differences were much less marked. To a certain extent, these data are consistent with those in Figure 3 in which the /ɪ-iː/ trajectories in the same context were further apart for SG than for SA speakers.

The results of a mixed model with dependent variable Euclidean distance (the parameter in Fig. 5) and independent factors Context (three levels: /p, t, k/), Tensity (two levels: /ɪ/, /iː/) and Variety (two levels: SA/SG) and with the speaker as a random factor showed a significant three-way interaction between the independent factors ($\chi^2_{11} = 83.7$ p < 0.001). The results of post-hoc Tukey tests showed significant differences only between SG-/ɪ/ and SG-/iː/ for all three places of articulation: (SG-/pɪp/ vs. SG-/piːp/: z = 5.8, p < 0.01; SG-/tɪt/ vs. SG-/tiːt/: z = 4.4, p < 0.01; SG-/kɪk/ vs. SG-/kiːk/: z = 5.3, p < 0.01) but there were no other significant differences, neither between the varieties, nor between /ɪ/ and /iː/ in SA.

Thus the general conclusion from these results is that whereas coarticulation perturbs /ɪ/ to a greater extent than /iː/ in SG, such differences are much less in evidence for the SA variety.

2.3. Discussion

The first part of this physiological study of tongue positions has provided some evidence for a greater overlap between /ɪ/ and /iː/ in SA compared with SG. The second part showed that there is also a difference in the extent of perturbation due to coarticulation: whereas SG-/ɪ/ is much more prone to coarticulatory influences than SG-/iː/, SA-/ɪ/ is shifted due to coarticulation to about the same extent as SA-/iː/.

There are, however, at least two ways in which these SA-SG differences could be an artefact of durational differences between the two speaker groups. Firstly, recall that SG speakers produced the materials at two rates (slow, fast) and that the above analysis was based on productions at the slow rate. It is possible therefore that the materials were produced by the SG speakers with greater hyperarticulation than those produced by the SA speakers who received no instruction about rate. Since the vowel space tends to expand in hyperarticulated speech (Moon & Lindblom 1994), then the greater /iː, ɪ/ separation in the SG than in the SA productions may be a conse-

quence not of phonetic, but of rate differences. We explored this issue further by comparing the SG speakers' slow and fast rate productions on the same measures that had been used for analysing the SA/SG differences in 2.2. The hypothesis to be tested in this case is that, if the SA/SG differences were an artefact of speaking rate, then SG-/ɪ/ should be closer to SG-/iː/ at the fast, than at the slow rate.

Secondly, we compared the durations of SA and SG vowels: the hypothesis to be tested in this case is that, if the greater centralisation of /ɪ/ relative to /iː/ in SG is conditioned by vowel-dependent undershoot (Cho 2004, Lindblom et al. 2009), then /ɪ/ can be expected to be shorter in SG than in SA.
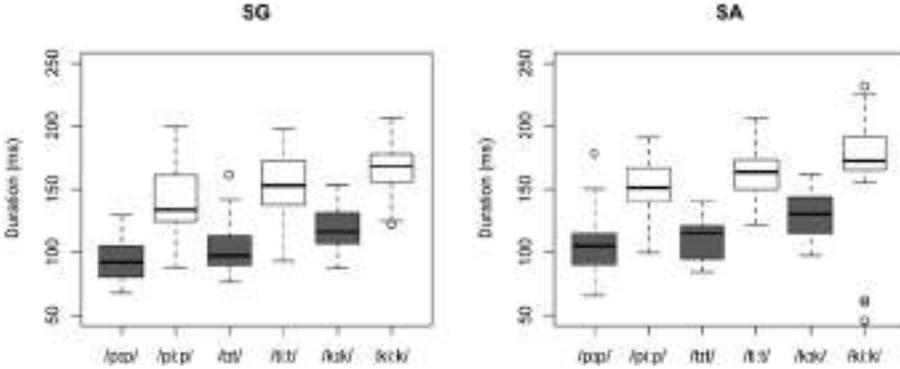
3. Vowel duration and rate in Standard German and Standard Austrian

3.1. Method

The speakers, materials, and procedures for processing the physiological data were the same as described in section 2.1. In addition, we calculated the log. Euclidean distance ratio from (3) and quantified the magnitude of coarticulation from (4) for the data produced at the fast rate of speech by the Standard German speakers. The aim was to assess whether there was any evidence of a greater approximation of /ɪ/ towards /iː/ at the fast compared with the slow rate. We also tested whether the durational difference between /ɪ/ and /iː/ was less in SA than in SG.

3.2. Results

The results for the SG speakers of a repeated measures ANOVA with the log. Euclidean distance ratio as the dependent variable calculated from (3) and independent factors rate (2 levels: slow, fast) and place of articulation (3 levels, /p, t, k/) showed no significant effects for rate: that is, the relative distance of /ɪ/ to /iː/ was no different in the slow or fast rates for the SG speaker productions.

Figure 6. Acoustic vowel duration (as measured between the periodic onset and offset of the vowel) for /ɪ, iː/ in three contexts in Standard German (left) and Standard Austrian (right).

Secondly, we compared the acoustic durations of /ɪ/ in the two varieties in order to determine whether it was longer (and more /iː/-like) in SA than in SG. This analysis was based on the vowels produced at the slow rate by the SG speakers that had been analysed in section 2. The data in Figure 6 show very little evidence in support of the idea that SA /ɪ/ is longer than its SG counterpart. Compatibly, the results of a mixed model with voiced vowel duration as the dependent variable, with independent factors Vowel (two levels: /ɪ, iː/), Consonant (three levels: /p, t, k/), and Variety (two levels: SA, SG) showed (predictably) a highly significant effect of Vowel ($\chi^2_1 = 232.5$, p < 0.001) but no effect of Variety and there were no significant interactions (as there should have been, if /ɪ/, but not /iː/, had been longer in SA than in SG).

3.3. Discussion

The analysis in this section was designed to investigate whether the closer /ɪ-iː/ proximity in SA compared with SG might be an artefact of duration. Firstly, the greater /ɪ-iː/ separation observed for SG compared with SA in section 2.2 may have come about because of vowel space expansion at the slow rate. But if this had been so, then we should have observed a shift of /ɪ/ towards /iː/ in SG speakers' self-selected faster rate: however, there was no evidence to support this hypothesis. Thus the greater /ɪ-iː/ approximation in SA compared with SG is unlikely to have been caused by different degrees of hyperarticulation in the two varieties.

Secondly, the greater /ɪ-iː/ similarity combined with the smaller perturbation of /ɪ/ due to coarticulation found in section 2.2 for SA compared with SG might have been associated with durational differences: if both /ɪ/ and /iː/ are long in SA and more similar to each other in duration than in SG, then there would be more time to produce SA-/ɪ/ than SG-/ɪ/, as a result of which target undershoot and coarticulatory perturbation would be less likely in the Austrian variety. Such an explanation is however unlikely in view of the results showing that the durational relationship between /ɪ/ and /iː/ was similar across the two varieties.

The conclusion from all the results so far is that there is a greater articulatory proximity between /ɪ/ and /iː/ in SA compared with SG that can be explained neither by style nor duration differences. The question remains therefore which mechanisms might bring about the differences between these two varieties such that /ɪ-iː/ in SA are spatially, but not durationally, more similar than in SG. On the one hand, the data for SG in the left panel of Figure 3 is possibly anomalous because it suggests that the tongue position for /ɪ/ was more centralised in /pɪp/ as shown by its greater proximity to the more central (and lower) vowel /ɛ/ than when it occurred in the other two contexts. The anomaly here is that a labial context should interfere minimally with tongue articulation of the vowel and therefore not induce any form of tongue centralisation, given that the consonant and vowel are produced with different sets of articulators in /pɪp/. But a different and more plausible way to interpret the left panel of Figure 3 is that the tongue position for /ɪ/ was perturbed not in /pɪp/ but in /kɪk/: that is, the coarticulatory influences of the velar stop shifted the tongue trajectory of /ɪ/ towards the space for /iː/. The basis for this idea is that, as van Bergem (1993, 1994) has shown in his detailed acoustic study of vowel shifts in prosodically weak contexts, "...vowel reduction is not a tendency of vowels to centralize, but rather the result of an increased contextual assimilation" (van Bergem 1993: 22). Thus if /ɪ/ assimilates to its consonantal context in /kɪk/, then the constricted tongue configuration during the stop is likely to restrict the magnitude of tongue-dorsum lowering in /ɪ/, with the consequence that it might be produced with a relatively high tongue configuration similar to that of /iː/. Thus context-induced undershoot may have caused /ɪ/ to shift into the /iː/ space in this context. We addressed this issue by comparing the two varieties on the influence of context on tongue dorsum lowering of /ɪ/. Our hypothesis was that the extent of tongue dorsum lowering would be greater in /p, t/ contexts than in a /k/-context but only in Standard German.

4. Tongue dorsum lowering in /ɪ/

4.1. Method

For each speaker separately, the physiological data were normalised by conversion to z-scores. In order to do so, the speaker-specific mean and standard deviation were calculated from all the frames of data and across all sensor positions between the acoustic onset and acoustic offset of the pooled tense /iː, eː, ɛː, oː, uː/ vowels produced by the same speaker. In this way, a z-score of zero is a value at the centre of the tongue space for tense vowels and increasing/decreasing values are standard deviations greater/less than this value. This z-score transformation was carried out separately for the horizontal and vertical positions of each speaker's tongue sensor positions.

4.2. Results

The mean positions of the tongue sensors averaged across the subjects separately by variety in Figure 7 shows that the tongue dorsum position (as judged from the 3rd sensor from left in the left panel) for /ɪ/ in the /k/ context was not as low as for the other two contexts for the SG speakers; and also that this same sensor position was evidently very close to those for /iː/. The tongue dorsum positions for /ɪ/ as judged from the 2nd sensor from the left in Standard Austrian were by contrast all very close to those of /iː/ and there was no evidence for the influence of context on tongue dorsum height as there was for the SG.

We applied a mixed model to test for an effect of consonantal context on the tongue dorsum position of /ɪ/. The dependent variable was the vertical tongue dorsum position (3rd sensor from the left for the SG data; 2nd sensor from the left for the SA data in Fig. 7) extracted at the temporal midpoint of the vowel in the z-score normalised space. The independent factors were Variety (two levels: SA, SG), and Consonantal context (three levels: /p, t, k/). Consistently with the data in Figure 7, the results showed a significant interaction between Variety and Consonantal context ($\chi^2[2] = 41.0$, $p < 0.001$). A post-hoc Tukey test showed that the tongue dorsum position for /ɪ/ differed significantly between the two varieties in the /p/ ($z = 4.3$, $p < 0.001$) and /t/ ($z = 5.0$, $p < 0.001$) but not in the /k/ contexts. Within each variety, consonant place of articulation had no significant effect on /ɪ/ in SA; as far as SG was concerned, the vertical position of the tongue dorsum for /ɪ/ in a /k/ context was significantly higher compared with the corresponding positions in the other two consonantal contexts (/k/ vs. /p/: $z = 12.1$, $p < 0.001$; /k/ vs. /t/: $z = 12.9$, $p < 0.001$) whereas the /p/-/t/ differences were not significant on this measure.

These data show, therefore, that the tongue dorsum position for SG-/ɪ/ in a /k/ context was higher than in the other two SG-contexts; and that SG-/ɪ/ in a /k/ context did not differ from the corresponding positions of Standard Austrian /ɪ/ (in any context).
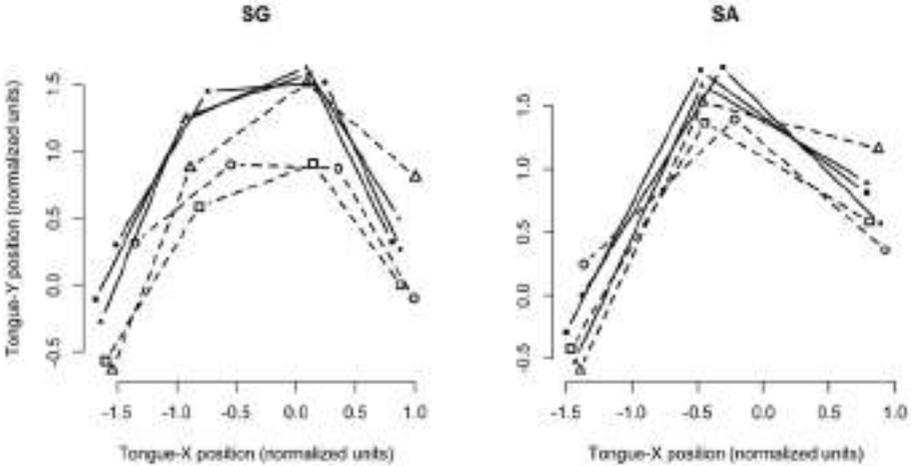
Figure 7. Mean positions of the sensors at the temporal midpoint of the vowel averaged across speakers in labial (squares), alveolar (circles), and velar (triangles) contexts for /iː/ (black, filled symbols) and /ɪ/ (dashed, open symbols) produced by Standard German (left) and Standard Austrian speakers (right). The direction is as in Figure 1 with positions to the left on the *x*-axis nearer the lips, and higher positions towards the palate.

5. Discussion

The main findings from this study are as follows. In section 2, it was shown that the tongue configuration for /ɪ/ at the temporal midpoint of the vowel was closer to /iː/ in SA than in SG. There was also evidence to show that the coarticulatory influence of consonantal context on SG-/ɪ/ was greater than on SA-/ɪ/. Taking into account the findings from Hoole & Mooshammer (2002) showing that tense vowels are less prone to coarticulatory-induced perturbation than lax vowels, the general conclusion from these results is that /ɪ/ in SA is tenser – that is, it is more peripheral in the vowel space – than in SG. In section 3, we considered two ways in which these findings might have been an artefact of vowel duration. The first was that the SG speakers' vowels might have been hyperarticulated since

they – in contrast to those of the SA speakers – had been produced at a self-selected slow rate. However, we ruled this out as a possible explanation for the differences between the two varieties found in section 2, in view of the findings in section 3 showing that speech rate differences for the SG speakers had no effect on the relative /ɪ-iː/ positions. Secondly, the duration of Standard Austrian /ɪ/ might have been longer and more similar to /iː/ than in SG – as a result of which, there would be more time for a more peripheral (and more /iː/-like) target configuration to be produced in the Austrian variety. However, this was also ruled out as a possible explanation for the results in section 2, given that the pattern of /ɪ-iː/ durations was found to be no different in the two varieties. The conclusion from these two sections together is therefore that /ɪ/ is phonetically tenser/more peripheral in SA than in SG.

Finally, we interpret the origin of the greater /ɪ-iː/ proximity in the velar compared with the other two contexts in SG as due to coarticulation. The tongue dorsum in /kɪk/ is high for the two dorsal consonants and must be lowered for the vowel; but if it is lowered insufficiently, then the position of the tongue dorsum in /ɪ/ may be no lower than it is for tense /iː/. Thus as observed in van Bergem (1994), coarticulation need not result in vowel centralisation but can instead push a lax vowel towards the periphery of the vowel space. Perhaps the tenser /ɪ/ in all contexts of SA has come about as a result of generalizing synchronic coarticulatory-induced raising of /ɪ/ when it is produced in velar or dorsal contexts: under this scenario, the close approximation of /ɪ-iː/ in SA may have developed out of the synchronic undershoot of /ɪ/ in dorsal contexts which causes the tongue positions of /ɪ/ and /iː/ to become more similar. This type of generalization could be accounted for in Ohala's (1993, 2005) model of sound change in which /ɪ/ is misperceived as /iː/ in a velar context not just because of F2-raising, but also because of the F2-F3 proximity in the formant transitions in velar contexts (see e.g., Harrington & Cassidy 1999, Fig. 4.17) which resemble the close F2-F3 frequencies of /iː/. The sound change would then, according to Ohala's (1993) model, be brought about by the generalization of this raised /ɪ/-variant in velar contexts to other (e.g., labial and alveolar) contexts in which tongue-dorsum raising would have no coarticulatory *raison d'être*. We are currently conducting various perception tests in varieties of German with and without /ɪ/-tensing in order to test further whether such a coarticulatory-based model of sound change can be applied to /ɪ/-tensing in these varieties.

6. Conclusion

In the present study as well as in the apparent time analysis in Harrington et al. (2011b) electromagnetic articulometry has been used to address questions that are relevant to sociophonetics. Both studies have also shown that a quadrilateral-like vowel space can be derived from tongue data (Fig. 2) which can be used to assess the phonetic similarity between vowels across different varieties: this procedure therefore establishes a methodological relationship to many formant-based analyses that are common in sociophonetics and sociolinguistics for comparing varieties and establishing on-going sound change (Labov 1994, Cox 2006, Maclagan & Hay 2007, Jacewicz et al. 2011). One of the very general differences between the two varieties of German examined here is that there is a slightly greater degree of overlap between the vowel categories in SA compared with SG (Fig. 2). The reason for such differences is not entirely clear. One possibility is that the SG speakers may have spoken more precisely at the slow rate than the Austrian speakers who were given no instructions about speaking tempo (other than to speak in their usual speaking style) – although the analysis in section 3 showed that if they did so, then there was a negligible effect on the relative positions of their /ɪ-iː/ vowels. Another possibility that cannot be discounted is that all of the SG speakers had advanced knowledge of phonetics, with the consequence that they may have produced more cardinal-like tense vowels than the SA speakers who were phonetically naïve. Yet another is that vowel quantification may have been more accurate in the Standard German corpus because the tongue was sampled with four sensors as opposed to the three that were used for SA speakers. A further consideration is that if one speaker represents an outlier in relation to the others, then this would have had a more dramatic effect on the degree of variability of the SA vowel space of Figure 2 because of the smaller number of SA than SG speakers. The solution to this and some of the other problems outlined above is to obtain data from many more speakers. Therein lies one of the current difficulties: recording and quantifying data using EMA is exceptionally time consuming as a result of which a single study can rarely accommodate more than 5-10 speakers. It remains to be seen whether technological developments in EMA will allow the kinds of subject sizes to be attained that are more typical of sociophonetic investigations.

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Notes

[1] In broad phonemic transcriptions of Standard German, these vowels are conventionally transcribed with a Cardinal Vowel 4 symbol. However, they are phonetically open central in both varieties.

[2] With the exception of /ɛ:/, German vowels that occur in rhythmically strong syllables can be grouped into four front (/i:, ɪ/, /y:, ʏ/ /e:, ɛ/, /ø:, œ/), one central (/ɐ:, ɐ/) and two back (/o:, ɔ/, /u:, ʊ/) tense-lax pairs. The phonetic qualities of the vowels denoted by these transcriptions correspond approximately to those of the international phonetic alphabet (thus /e:/ is phonetically close to a long cardinal vowel 2, etc.).

[3] The SA speakers were selected by Julia Brandstätter and Sylvia Moosmüller of the Acoustics Research Institute, Austrian Academy of Sciences, Vienna.

[4] In this more modern version of articulometry, data is obtained not only from the horizontal and vertical movement of the articulators, but also from their lateral movements whereas in the EMMA system that was used for collecting data from the SG speakers, data collection is restricted to the horizontal and vertical movement in the midline of the sagittal plane. The restriction in the older EMMA system required the subject to wear a helmet to ensure data collection from the midline, whereas in the 5D-EMA system, the subject has more freedom of movement inside an EMA 'cube'. A disadvantage of the more modern technique is that the position of the sensor cannot always be uniquely determined, requiring considerable amounts of manual, post-processing time to identify errors (see Hoole et al. 2003 for further details).

[5] These were carried out with the glht() function in the multcomp package in R environment.

Bibliographical References

BANNERT Robert 1976. *Mittelbairische Phonologie auf akustischer und perzeptorischer Grundlage*. Lund: LiberLaromedel/Gleerup.

CHO Taehong 2004. Prosodically conditioned strengthening and vowel-to-vowel coarticulation in English. *Journal of Phonetics* 32. 141-176.

COX Felicity 2006. The acoustic characteristics of /hVd/ vowels in the speech of some Australian teenagers. *Australian Journal of Linguistics* 26. 147-179.

DI PAOLO Marianna & Alice FABER 1990. Phonation differences and the phonetic content of the tense-lax contrast in Utah English. *Language Variation and Change* 2. 155-204.

DOCHERTY Gerard J. & Norma MENDOZA-DENTON 2012. Speaker-related variation – sociophonetic factors. In COHN Abigail C., Cécile FOUGERON & Marie HUFFMAN (eds.). *The Oxford Handbook of Laboratory Phonology*. Oxford: Oxford University Press. 44-60.

FABER Alice & Marianna DI PAOLO 1995. The discriminability of nearly merged sounds. *Language Variation and Change* 7. 35-78.

FOULKES Paul 2010. Exploring social-indexical variation: a long past but a short history. *Laboratory Phonology* 1. 5-39.

GENG Christian & Christine MOOSHAMMER 2000. Modeling German stress distinction. In *Proceedings of the Vth Seminar on Speech Production. Models and Data & Crest Workshop on Models of Speech Production: Motor Planning and Articulatory Modelling* (May 1-4, 2000). Kloster Seeon. Germany. 161-164.

HARRINGTON Jonathan 2010. *Phonetic Analysis of Speech Corpora*. Chichester: Blackwell.

HARRINGTON Jonathan & Steve CASSIDY 1999. *Techniques in Speech Acoustics*. Dordrecht: Kluwer.

HARRINGTON Jonathan, Janet FLETCHER & Corinne ROBERTS 1995. An analysis of truncation and linear rescaling in the production of accented and unaccented vowels. *Journal of Phonetics* 23. 305-322.

HARRINGTON Jonathan, Phil HOOLE, Felicitas KLEBER & Ulrich REUBOLD 2011a. The physiological, acoustic, and perceptual basis of high back vowel fronting: evidence from German tense and lax vowels. *Journal of Phonetics* 39. 121-131.

HARRINGTON Jonathan, Felicitas KLEBER & Ulrich REUBOLD 2011b. The contributions of the lips and the tongue to the diachronic fronting of high back vowels in Standard Southern British English. *Journal of the International Phonetic Association* 41. 137-156.

HAY Jennifer & Katie DRAGER 2007. Sociophonetics. *The Annual Review of Anthropology* 36. 89-103.

HOOLE Phil 1999. On the lingual organization of the German vowel system. *Journal of the Acoustical Society of America* 106. 1020-1032.

HOOLE Phil & Kiyoshi HONDA 2011. Automaticity vs. feature-enhancement in the control of segmental F0. In CLEMENTS Nick & Rachid RIDOUANE (eds.). *Where do Phonological Features Come from? Cognitive, Physical and Developmental Bases of Distinctive Speech Categories*. Amsterdam: John Benjamins. 131-171.

HOOLE Phil & Christine MOOSHAMMER 2002. Articulatory analysis of the German vowel system. In AUER Peter, Peter GILLES & Helmut SPIEKERMANN (eds.) 2002. *Silbenschnitt und Tonakzente*. Tübingen: Niemeyer. 129-152.

HOOLE Phil, Andreas ZIERDT & Christian GENG 2003. Beyond 2D in articulatory data acquisition and analysis. In SOLÉ Maria J., Daniel RECASENS & Joaquim ROMERO (eds.). *Proceedings of the XVth International Conference of Phonetic Sciences,* (August 3-9, 2003). Barcelona. Spain. Vol. 1. 265-268.

Hoole Phil & Andreas Zierdt 2010. Five-dimensional articulography. In Maassen Ben, Pascal H.H.M. van Lieshout (eds.). *Speech Motor Control: New developments in basic and applied research*. Oxford: Oxfrod University Press. 331-349.

Huang Caroline 1986. The effect of formant trajectory and spectral shape on the tense/lax distinction in American vowels. In *Proceedings of ICASSP '86. IEEE-IECJ-ASJ International Conference on Acoustics, Speech, and Signal Processing* (April 7-11, 1986). Tokyo. Japan. Vol. 2. 893-896.

Jacewicz Ewa, Robert A. Fox & Joseph Salmons 2011. Vowel change across three age groups of speakers in three regional varieties of American English. *Journal of Phonetics* 39. 683-693.

Jespersen Otto 1913. *Lehrbuch der Phonetik* (2nd edition 1919). Leipzig: Teubner.

Klatt Dennis 1973. Interaction between two factors that influence vowel duration. *Journal of the Acoustical Society of America* 54. 1102-1104.

Kleber Felicitas 2011. *Neutralization and maintenance of phonological contrasts in varieties of Standard German*. Munich: Institute of Phonetics and Speech Processing, Ludwig Maximilian University of Munich. PhD Dissertation.

Labov William 1994. *Principles of Linguistic Change. Vol. 1: Internal Factors*. Oxford: Blackwell.

Labov William, Sharon Ash & Charles Boberg 2006. *The Atlas of North American English: Phonetics, Phonology and Sound Change*. Berlin: Mouton de Gruyter.

Ladefoged Peter 1964. *A Phonetic Study of West African Languages*. Cambridge: University Press.

Lehiste Ilse & Gordon E. Peterson 1961. Transitions, glides, and diphthongs. *Journal of the Acoustical Society of America* 33. 419-425.

Lindblom Björn, Harvey M. Sussman & Augustine Agwuele 2009. A duration-dependent account of coarticulation for hyper- and hypoarticulation. *Phonetica* 66. 188-195.

Maclagan Margaret & Jennifer Hay 2007. Getting *fed* up with our *feet*: contrast maintenance and the New Zealand English "short" front vowel shift. *Language Variation and Change* 19. 1-25.

Moon Seung-Jae & Björn Lindblom 1994. Interaction between duration, context, and speaking style in English stressed vowels. *Journal of the Acoustical Society of America* 96. 40-55.

Mooshammer Christine & Susanne Fuchs 2002. Stress distinction in German: Simulating kinematic parameters of tongue-tip gestures. *Journal of Phonetics* 30. 337-355.

Mooshammer Christine, Susanne Fuchs & Dirk Fischer 1999. Effects of stress and tenseness on the production of CVC syllables in German. In Ohala John J., Yoko Hasegawa, Manjari Ohala, Daniel Granville & Ashlee C. Bailey (eds.). *Proceedings of the XIVth International Congress of Phonetic Sciences* (August 1-7, 1999). San Francisco, California. 409–412.

Mooshammer Christine & Christian Geng 2008. Acoustic and articulatory manifestations of vowel reduction in German. *Journal of the International Phonetic Association* 38. 117-136.

MOOSMÜLLER Sylvia 2007. *Vowels in Standard Austrian German*. Vienna: University of Vienna. Habilitation Thesis.

MOOSMÜLLER Sylvia 2008. Interaction of phonetics, phonology, and socio-phonology – illustrated by the vowels of Standard Austrian German. In BOTINIS Antonis (ed.). *Proceedings of ISCA Tutorial and Research Workshop on Experimental Linguistics* (August 25-27, 2010). Athens, Greece. 173-176.

MOOSMÜLLER Sylvia 2011. Aussprachevarianten im Österreichischen Standarddeutsch. In BOSE Ines & Baldus NEUBER (eds.). *Interpersonelle Kommunikation – Analyse und Optimierung*. Frankfurt am Main: Peter Lang. 193-199.

MUNSON Benjamin 2010. Levels of phonological abstraction and knowl-edge of socially motivated speech-sound variation: a review, a pro-posal, and a commentary on the papers by Clopper, Pierrehumbert and Tamati; Drager; Foulkes; Mack; and Smith, Hall and Munson. *Journal of Laboratory Phonology* 1. 157-177.

OHALA John J. 1993. Sound change as nature's speech perception experiment. *Speech Communication* 13. 155-161.

OHALA John J. 2005. Phonetic explanations for sound patterns. Implications for grammars of competence. In HARDCASTLE William J. & Janet M. BECK (eds.). *A Figure of Speech. A Festschrift for John Laver*. London: Erlbaum. 23-38.

RAKERD Brad & Robert R. VERBRUGGE 1985. Linguistic and acoustic correlates of the perceptual structure found in an individual difference scaling study of vowels. *Journal of the Acoustical Society of America* 77. 296-301.

SCHIEL Florian 2004. MAuS goes iterative. In LINO Maria Teresa, Maria Francisca XAVIER, Fátima FERREIRA, Rute COSTA & Raquel SILVA (eds.). *Proceedings of the IVth International Conference on Languag Resources and Evaluation* (May 26-18, 2004). Lisbon, Portugal. 1015-1018.

SIEVERS Eduard 1901. *Grundzüge der Phonetik zur Einführung in das Studium der Lautlehre der indogermanischen Sprachen*. Leipzig: Breitkopf und Härtel.

STEWART John M. 1967. Tongue root position in Akan vowel harmony. *Phonetica* 16. 185-204.

TIEDE Mark 1996. An MRI-based study of pharyngeal volume contrasts in Akan and English. *Journal of Phonetics* 24. 399-421.

TRUBETZKOY Nikolai 1939. *Grundzüge der Phonologie* (7th edition 1989). Göttingen: Vandenhoeck & Ruprecht.

VAN BERGEM Dick R. 1993. Acoustic vowel reduction as a function of sentence accent, word stress, and word class. *Speech Communication* 12. 1-23.

VAN BERGEM Dick R. 1994. A model of coarticulatory effects on the schwa. *Speech Communication* 14. 143-162.

VENNEMANN Theo 1991. Syllable structure and syllable cut prosodies in Modern Standard German. In BERTINETTO Pier Marco, Michael KENSTOWICZ & Michele LOPORCARO (eds.). *Certamen Phonologicum II: Papers from the 1990 Cortona Phonology Meeting*. Torino: Rosenberg & Sellier. 211-243.

WATSON Catherine I., Margaret MACLAGAN & Jonathan HARRINGTON 2000. Acoustic evidence for vowel change in New Zealand English. *Language Variation and Change*. 12. 51-68.

WIESINGER Peter 1990. The central and southern Bavarian dialects in Bavaria and Austria. In RUSS Charles V.J. (ed.). *The Dialects of Modern German.* London: Routledge. 438-519.

WIESINGER Peter 2009. Die Standardaussprache in Österreich. In KRECH Eva-Maria, Eberhard STOCK, Ursula HIRSCHFELD & Lutz C. ANDERS (eds.). *Deutsches Aussprachewörterbuch*. Berlin: Mouton de Gruyter. 229-257.