THE CONTRIBUTION OF VOWEL COARTICULATION AND PROSODIC WEAKENING IN INITIAL AND FINAL FRICATIVES TO SOUND CHANGE

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ABSTRACT

This paper is concerned with the influence of vocalic context (/ɪ, ʊ/) and prosodic weakening on the production of the German fricatives /s, ʃ/ in two syllable positions and its relation to the frequent sound change from alveolar to post-alveolar fricatives. Previous studies reported coarticulatory influences of vowel context on fricatives and more coarticulation in prosodically weak positions. However, the influence of syllable position is unclear, even though sound change affects more often segments in coda than in onset position.

In order to test these factors, acoustic and articulatory data from six German speakers were analysed. They produced lexical words with fricatives in onsets and codas of stressed syllables in accented and deaccented words.

The results show a small influence of syllable position on the analysed acoustic and articulatory measurements, with higher spectral centers of gravity and more retracted mean tongue trajectories in coda position.

Keywords: coarticulation, syllable, prosody, EMA, sound change.

1. INTRODUCTION

The main aim of this study was to determine the extent to which vowel coarticulation and prosodic weakening affect the production of /s/ and /ʃ/ in German. More specifically, the study investigates the articulatory implementation of coarticulation for /ɪ, ʊ/ on /s, ʃ/ in accented and deaccented positions and in two different syllable positions. The current experiment was designed to extend previous studies on the coarticulatory influence of vowel context on the preceding fricative ([11, 16, 19, 20, 24]) by adding the coda condition in order to relate its findings to the common sound changes of alveolar to post-alveolar place of articulation in fricatives.

This sound change has been reported for example in European Portuguese and in the Swabian variety of German ([ˈbaʃtɐ] vs. [ˈbasta] *basta*, 'be enough' in European and Brazilian Portuguese, respectively, and [ˈhaʃt] vs. [ˈhast] *hast*, 'to have, 2.P.Sg' in Swabian and Standard German, respectively [13, 18]). Its occurrence is restricted to pre-consonantal coda position in Swabian [13], but more categorical in EP, applying to all alveolar fricatives in coda position. If not in word final position, the resulting post-alveolar fricative assimilates in voicing to the following consonant [18] (e.g.; EP [ˈdeʒdɨ] vs. BP [ˈdesde], *desde*, 'since'). How far this change can be explained due to strong coarticulation with the following consonant forming a cluster, as suggested by [5], has not been experimentally investigated yet. The resulting prediction would be that fricatives in coda position would coarticulate more with the following consonant and less with the preceding vowel (since they would be part of the following onset).

Previous experiments on coordination of segments in the framework of articulatory phonology showed on the one side for syllable-initial consonants and clusters the so-called c-center effect, i.e. a synchronization of the gestures with the following vowel's gesture; further findings were coarticulation of the initial consonants with the following vowel. In coda positions, however, a sequential ordering of syllable final consonants and clusters is to be assumed, and no signs regarding stronger or weaker coarticulation with the vowel in coda position (as opposed to onset position) were found ([3, 4, 10, 17]).

In metrical syllable phonology, the coda is assumed to be in a stronger relationship with the preceding nucleus forming the rhyme ([6] for German and [18] for Portuguese syllable account); syllable-final consonants are more often affected by sound change processes [22]. The perceptual equivalence of nasal vowels and vowel-nasal-sequences [2] can be seen as a piece of empirical evidence for the existence of the syllable rhyme. Assuming coarticulatory reasons for this perceptual equivalence in the sense of [2], we predict a stronger coarticulatory influence of the vocalic context on the fricatives in coda than in onset position.

Regarding vocalic context, the raised position of the tongue in high vowels facilitates the assimilation of the front-back location of the fricative's constriction, resulting in a more fronted constriction for fricatives in front /i/ than in back /u/ contexts (27). This anticipatory lingual coarticulation is acoustically detectable by a shift of F2 loci. Lip rounding for /u/ has also been associated with global shifts in the spectrum during the fricative ([20, 26, 27]). The realization of lip rounding in post-alveolar fricatives – considered to be an enhancement strategy ([28]) – is subject to great inter-speaker variability ([23], Fig. 6). Assuming lip rounding in the production of the post-alveolar fricative (at least in some speakers) and no lip rounding in the alveolar counterpart, we predict the greatest amount of spectral lowering due to lip rounding and/or backmost tongue constriction for /ʃ/ in the /ʊ/ context, since both segments are produced with rounding of the lips.

A further aim of this study was to assess the influence of prosodic weakening on the degree of coarticulation of fricative vowel sequences. More coarticulation has been attested in unaccented than in accented positions ([1, 14]). In an analysis of VCV-coarticulation in German, [9] suggested a similar magnitude of coarticulation in both prosodic positions, but an increase of variability resulting from target undershoot in deaccented position.

In the following sections, we make use of acoustic and articulatory data to address the influence of German /ɪ, ʊ/ on /s, ʃ/ in syllable and word initial and final positions in two prosodic environments.

2. METHODS

3D Physiological EMA data (CARSTENS AG501) were recorded with synchronised audio. The sensors relevant for analysis were five: Two sensors placed on the tongue: one on the midline 1 cm behind the tongue tip (TT) and the other on a level with the molar teeth at the tongue back (TB), two sensors were placed on the upper and lower lip (the latter henceforth LL) and one sensor at the jaw. Four additional sensors were fixed to the maxilla, the nose bridge, as well as to the left and right mastoid bones: these served as reference sensors to correct for head movement.

Additional subjects have been recorded acoustically in a sound-proof booth.

2.1. Speech materials and participants

The speech material consisted of voiceless fricatives in initial and final position. The initial fricative-vowel sequences include /ɪ, ʊ/ in the four German lexical words *Suppen* ‘soups’, *Schuppen* ‘dandruff, hovel’, *Sippen* ‘clans’, *Schippen* ‘scoops’. The final vowel-fricative sequences include the same vowels in the words *Bus* ‘bus’, *Busch* ‘bush’, *Biss* ‘bite’, and *Bisch* [family name]. The target syllables were in both cases closed syllables, since plosives after short vowel are ambisyllabic in German ([29]). These stimuli were supplemented with 14 distractor words.

The target words were embedded in phrase-final position in the carrier sentence *Maria mag [target word]* (‘Maria likes [target word]’). Two of the target words contain voiced fricatives which usually become devoiced in Southern German from around Munich (i.e., no Swabians) when following a voiceless/devoiced context (as in [maʁi:ama:ksʊpn̩]).

In order to elicit either accented or deaccented position by shifting the focus between the initial and the target word in the carrier phrase, the participants were presented with questions designed to elicit a narrow focus on the target word for the accented context and a broad focus for the deaccented context: either *WAS mag Maria?* (‘WHAT does Maria like?’) or *WER mag [target word]?* (‘WHO likes [target word]?’). Thereafter, the stimulus was presented with the word carrying the nuclear accent in capital letters (e.g. *Maria mag SCHUPPEN* vs. *MARIA mag Schuppen*).

The participants were six speakers of southern German (three male, three female) for the EMA experiment, and additional 10 speakers (5 male, 5 female) of the same variety were recorded only acoustically. If subjects misread a word, they were instructed to repeat the sentence. In total each speaker produced 240 utterances containing one of the target words (2 accentuation conditions x 8 target words (=2 fricatives x 2 vowels x 2 syllable positions) x 10 repetitions of the tokens in coda and 20 repetitions of the tokens in onset position).

2.2. Data analysis

The acoustic data were digitized at 25.6 kHz and automatically segmented and labelled using the Munich Automatic Segmentation tool (MAuS, [12], [24]). The segment boundaries of the target words’ fricatives and the vowels were manually corrected.

Post-processing of the physiological raw data was done semi-automatically in MATLAB, whereas labelling and subsequent analyses of the physiological data were conducted using EMU and EMU/R ([7]). The physiological annotation of the three sibilants was based on the horizontal movement of the TT (in mm) and the TT tangential velocity (in mm/s).

Our articulatory analyses were all based on the same time frame which was derived from the gesture trajectories of the horizontal movement of TT measured between the gestural onset of the fricative closing gesture (gon) and the acoustical vowel onset.

We used discrete cosine transform (DCT) to reduce the articulatory trajectories of the horizontal TT movement to a set of coefficients. The m^{th} DCT-coefficient C_m (m = 0, 1, 2) was calculated with the formula in (1):

$$(1) \quad C_m = \frac{2k_m}{N}\sum_{n=0}^{N-1} x(n)\cos\left(\frac{(2n+1)m\pi}{2N}\right)$$

These three coefficients C_m (m = 0, 1, 2) encode the mean, the slope, and curvature respectively of the signal to which the DCT transformation was applied ([7]). Considering the TT trajectory, the first coefficient DCT-k0 (corresponds to the mean of the TT trajectory) turned out to be the best separator between /s/ and /ʃ/.

Additionally, we analysed for the acoustics Spectral Moments from power spectra (in the range of 500 - 12000 Hz), averaged per fricative, speaker, and contexts (vowel, accentuation, position within the syllable) over measurements made in the half of the fricative that was adjacent to the vowel, i.e. from the fricative's midpoint to its end in onset position, and from the fricative's onset to its temporal midpoint in coda position. /s/ and /ʃ/ can be differentiated by spectral moments, especially by the first spectral moment (M1, ≈ spectral Center of Gravity, cf. eg. [15]). Repeated measures ANOVAs with the factors consonant (/s/ vs. /ʃ/), vowel (/ɪ/ vs. /ʊ/), position (*initial* vs. *final*) and accentuation (*accented* vs. *deaccented*) were applied. The dependent variables were the first spectral moment (≈ spectral Center of Gravity) for the acoustical data as well as the first DCT coefficient (≈ mean position) of the horizontal tongue tip position.

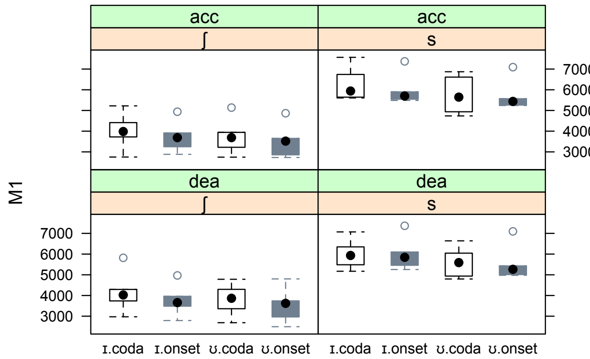
3. RESULTS

The effect of accentuation on the fundamental frequency of the target vowels was verified by conducting repeated measures ANOVA with F0 as dependent variable and accentuation (accented vs. deacccented) and vowel (/ɪ/, /ʊ/) as within-speaker factors for the onset stimuli. The results showed a significant effect only for accentuation ($F(1,7)= 6.8$, $p< 0.05$).

3.1. Acoustical analysis

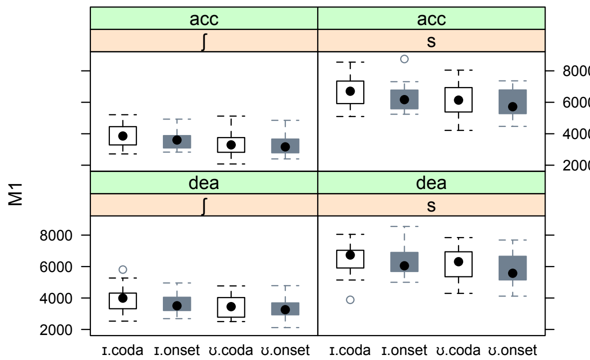
For comparison reasons, the first spectral moment (M1) from the participants of the articulatory study was displayed in Figure 1. Figure 2 presents the same acoustical measurement (M1) for all sixteen participants of both experiments. Both figures show a higher spectral centre of gravity for the two fricatives in coda compared to onset position. This is true in both accentuation conditions.

Figure 1: First spectral moment of /s-ʃ/ in 6 speakers for whom articulatory data was available.



For the participants of the articulatory study, an RM-ANOVA with the first spectral moment as dependent variable confirmed a significant effect of VOWEL ($F(1,5)= 30.5$, $p < 0.001$), CONSONANT ($F1,5)=256.1$, $p < 0.001$, and a significant interaction of CONSONANT X ACCENTUATION ($F[1,5])=44.0$, $p < 0.001$. Bonferroni-corrected post-hoc t-tests revealed a significant effect of ACCENTUATION in alveolar ($p < 0.05$), but not in post-alveolar fricatives.

Figure 2: First spectral moment of /s-ʃ/ for all 16 participants.

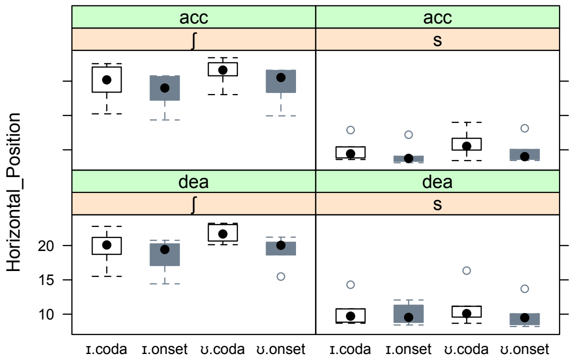


An RM-ANOVA with all the participants of the experiments show a significant main effect of VOWEL ($F(1,15)= 22.7$, $p< 0.001$), CONSONANT ($F[1,15]=211.6$, $p< 0.001$) and POSITION ($F[1,15]=5.4$, $p< 0.05$), as well as a significant interaction of CONSONANT X ACCENTUATION ($F[1,15])=4.9$, $p < 0.05$. However, no significant effects were found in post-hoc tests.

3.2. Articulatory tongue data

As evident in Fig. 3, the horizontal tongue positions were strongly influenced by consonant ($F(1,5)= 95.9$, $p< 0.001$). Vowel ($F(1,5)= 9.4$, $p< 0.05$) showed a main effect with generally more fronted positions at the fricative midpoint in front vocalic context and more backed positions in the /ʊ/ context. However, this effect was restricted by a significant interaction with consonant (F(1,5)= 17.7, $p < 0.01$) and post-hoc tests show a significant vowel effect only for /ʃ/ ($p < 0.05$), not for /s/.

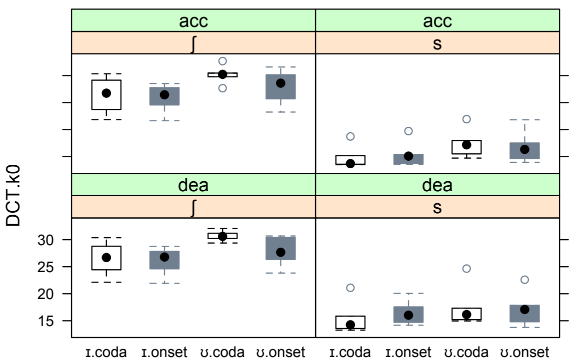
Figure 3: averaged positions of the horizontal TT movement, measured at the fricative midpoint in syllable-initial (left) and -final (right) position. Lower values mean fronting and high values backing of the tongue position.



The positions of both fricatives (F(1,5)= 25.0, $p < 0.01$) were significantly more fronted in coda than in onset position, which results in a higher centre of gravity as shown in the previous section. Accentuation had no influence on this variable.

The RM-ANOVA on the DCT-k0 showed similar results with a main effect for VOWEL (F(1,5)= 99.5, $p < 0.001$) and CONSONANT (F(1,5)= 17.7, $p < 0.01$). Contrary to the position data at the temporal midpoint, the influence of POSITION on the mean value of the TT trajectory calculated by DCT-k0 was under the significance level of 0.05, but ACCENTUATION (F[1,5]=7.5, $p < 0.05$) had a small effect, with deaccented tokens being less retracted than the accented ones. There were two interactions: VOWEL X CONSONANT (F[1,5]=11.8, $p < 0.01$) and VOWEL X POSITION (F[1,5]=9.3, $p < 0.05$).

Figure 4: mean of the horizontal TT trajectories (DCT-k0) syllable initially and finally in accented and deaccented position.



Post-hoc tests revealed an effect of vowel only on postalveolar fricatives ($p < 0.05$), and the mean difference between the fricatives was smaller in coda ($p < 0.01$) than in onset ($p < 0.001$) position.

4. DISCUSSION AND CONCLUSION

This study made use of acoustic and physiological data to analyse the coarticulatory influence of /ʊ, ɪ/ on /ʃ, s/ fricatives in two prosodic conditions and two syllable positions. This study could confirm the coarticulatory vowel effect on fricatives [16, 19, 20, 26].

The prominent hypothesis tested here was the influence of the syllable position on the place of articulation of the fricatives, but its effect remained more restricted than hypothesised: The first spectral moment of coda fricatives were significantly higher for the 16 participants, but not significant for the small data set. This factor showed also a main effect on the position on the mean value of the TT trajectory calculated by DCT-k0, but not on the average positions for the same speakers. A possible reason for the small size of the effect could be the increased variability in the coda data compared with the onsets.

Accentuation did not show the expected effect, since it had only a small effect on the tongue tip trajectories. However, variability was greater in deaccented than in accented position, as has been the case in [8], giving some evidence that the degree of variability resulting from target undershoot is much greater in deaccented position.

5. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Cho, T. 2004. Prosodically conditioned strengthening and vowel-to-vowel coarticulation in English. *Journal of Phonetics* 32, 141–176.

[2] Beddor, P. 2009. A coarticulatory path to sound change. *Language* 85, 785-821.

[3] Browman, C. P, Goldstein, L. 1986. Towards an articulatory phonology. *Phonology Yearbook 3*, 9–252.

[4] Browman, C. P, Goldstein, L. 1988. Some notes on syllable structure in articulatory phonology. *Phonetica* 45, 140–155.

[5] Freitas, M. J. 1997. Aquisição da Estrutura Silábico do Português Europeu. PhD. Lisboa FLUL.

[6] Hall, T. A. 1992. *Syllable Structure and Syllable Related Processes in German*. Tübingen: Niemeyer.

[7] Harrington, J. 2010 The Phonetic Analysis of Speech Corpora. Wiley-Blackwell.

[8] Harrington, J., Hoole, P., Kleber, F., Reubold, U. 2011. The physiological, acoustic, and perceptual basis of high back vowel fronting: evidence from

German tense and lax vowels. Journal of Phonetics, 39, 121-131.
[9] Harrington, J., Kleber, F., Reubold, U. 2013. "The effect of prosodic weakening on the production and perception of trans-consonantal vowel coarticulation in German". *Journal of the Acoustical Society of America* 134, 551–561.
[10] Katz, J., 2012. Compression effects in English. *Journal of Phonetics* 40, 390–402.
[11] Katz, W.F, Kripke, C. Tallal, P. 1991. "Anticipatory Coarticulation in the Speech of Adults and Young Children: Acoustic, Perceptual, and Video Data". *Journal of Speech and Hearing Research* 34, 1222-1232.
[12] Kisler, T., Schiel, F., Sloetjes, H. 2012. Signal processing via web services: the use case WebMAUS, *Proceedings Digital Humanities*, Hamburg, 30-34.
[13] Kümmel, M. J. 2007. Konsonantenwandel: Bausteine zu einer Typologie des Lautwandels und ihre Konsequenzen. Wiesbaden: Reichert
[14] Lindblom, B., Sussman, H., Agwuele, A. 2009. A duration dependent account of coarticulation for hyper-and hypoarticulation. *Phonetica* 66, 188–195.
[15] Mann, V. A., Repp, B. H. 1980. Influence of vocalic context on perception of the [ʃ]–[s] distinction. *Perception & Psychophysics* 28, 213-228.
[15] Jongman, A., Wayland, R., Wong, S., 2000. Acoustic characteristics of English fricatives. The Journal of the Acoustical Society of America 108, 1252–1263
[16] Mann, V. A., Repp, B. H. 1980. Influence of vocalic context on perception of the [ʃ]–[s] distinction. *Perception & Psychophysics* 28, 213-228.
[17] Marin, S., Pouplier, M. 2010. Temporal Organization of Complex Onsets and codas in American English: Testing the predictions of a gestural coupling model. *Motor Control* 14, 380–407.
[18] Mateus, M. H., d'Andrade, E. 2000. *The Phonology of Portuguese*. Oxford University Press.
[19] Nittrouer, S. Studdert-Kennedy, M. 1987. The role of coarticulatory effects in the perception of fricatives by children and adults. *Journal of Speech, Language and Hearing Research* 30, 73–93.
[20] Nittrouer, S., Whalen, D. H. 1989. The perceptual effects of child-adult differences in fricative-vowel coarticulation. *Journal of the Acoustical Society of America* 86, 1266–1276.
[21] Ohala, J.J. 1993. Sound change as nature's speech perception experiment. *Speech Communication* 13, 155–161.
[22] Ohala, J.J., Kawasaki, H., 1984. Prosodic phonology and phonetics. Phonology 1, 113–127.
[23] Proctor, M., Shadle, C. H. Iskarous, K. 2006. An MRI study of vocalic context effects and lip rounding in the production of English sibilants. *Proccedings AICSST*, 417–420.
[24] Recasens, D., Espinosa, A. 2009. An articulatory investigation of lingual coarticulatory resistance and aggressiveness for consonants and vowels in Catalan, *Journal of the Acoustical Society of America* 125, 2288-2298.
[25] Reichel, U.D. 2012. PermA and Balloon: Tools for string alignment and text processing, *Proc. Interspeech*. Portland, 346-349.
[26] Repp, B. H. 1986. Some observations on the development of anticipatory coarticulation. *Journal of the Acoustical Society of America* 79, 1616–1619.
[27] Soli, S. 1981. Second formants in fricatives: Acoustic consequences of fricative-vowel coarticulation. In: Journal of the Acoustical Society of America, 70, pp. 976–984.
[28] Stevens K. N., Keyser S. J. 2010 Quantal theory, enhancement and overlap, *Journal of Phonetics* 38, 10–19.
[29] Vennemann, T. 1972 On the Theory of Syllabic Phonology. *Linguistische Berichte* 18, 1-18.