TWO MECHANISMS FOR VOWEL REDUCTION IN POLISH

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It is a robust cross-linguistic observation that acoustic distances between vowels are greater in stressed syllables, compared to unstressed ones. This phenomenon has been modelled in the framework of vowel undershoot [4], localised hyperarticulation [3], sonority expansion [1, 2], and stress-conditioned coarticulatory resistance [6, 7]. Although these models invoke articulatory mechanisms, they have subsequently largely been tested based on their acoustic predictions, e.g. [8, 9]. In this paper, we present combined articulatory and acoustic data on vowel reduction in Polish that inform models of reduction in ways that acoustic data alone cannot.

The data are time-synchronised audio and midsagittal ultrasound recordings from 8 native speakers of Polish (7 females, mean age = 32). We elicited vowel reduction in two ways: by manipulating stress (e.g. *m<u>i</u>mo*, /ˈmi.mo/ 'despite' vs. *m<u>i</u>moza*, /mi.ˈmo.za/ 'mimosa'), and by manipulating speech rate through instruction to participants (slow, normal and fast). The segmental environment was controlled for. All six oral vowel phonemes were included (*i* /i/, *e* /e/, *a* /a/, *o* /o/, *u* /u/, *y* /ɨ/), appearing in stressed, and pre-stressed positions. 144 tokens were collected from each participant. Formants were extracted automatically in Praat at acoustic midpoint and normalised using $z-$score. Midsagittal tongue contours were extracted at the same time point in Cartesian coordinates. They were then submitted to a Principal Component Analysis, applied by-speaker [10], and reduced to two PCs, which typically accounted for more than 90% of the variance. In order to standardise the rotation of the PCs, the PCs were entered as predictors in linear models of normalised f1 and f2 (for each speaker; see [5] for a similar approach). We used the model predictors, labeled comp1 and comp2, as abstract normalised articulatory exponents of f1 and f2. We modelled the measurements, along with V1 duration using linear mixed models in `lme4`.

Figures 1-3 are based on model estimates. Both speech rate and stress exert a systematic effect on vowel duration, although the two also interact (Fig 1). Accordingly, the acoustic vowel space is systematically contracted from slow, through normal, to fast speech rate, and from stressed syllables to unstressed ones (Fig 2). The difference is mostly apparent in non-high vowels, it primarily affects f1, and the magnitude of difference is similar for rate and stress manipulations. In contrast, only speech rate systematically affects the articulatory components 1 and 2. The interaction between stress and vowel, shown in the right panel of Fig 3, is not significant, and neither is the main effect of stress.

We interpret the articulatory components as related to tongue displacement in the ultrasound image. For speech rate manipulations, displacement differences are consistent with vowel undershoot, which is also reflected in the acoustic output. For stress manipulations, however, there is a systematic acoustic difference between stressed and unstressed vowel that cannot be attributed to the same articulatory mechanism. The stress effects we find could potentially be explained if the speakers raised their larynx to mark stressed syllables, which results in raising of both f0 and f1. This hypothesis is generally confirmed by the f0 patterns we find in the data, although there is some individual variation. We also note that the absence of lingual undershoot in unstressed vowels coexists with regular temporal reduction. This would suggest that stress-conditioned temporal reduction is phonologised in Polish, along with compensatory mechanisms that mitigate against spatial reduction.

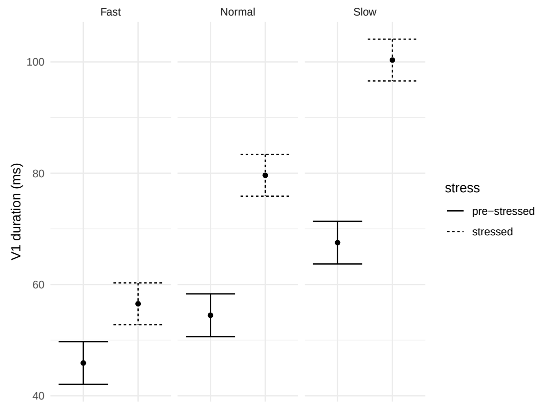

Figure 1. Vowel duration

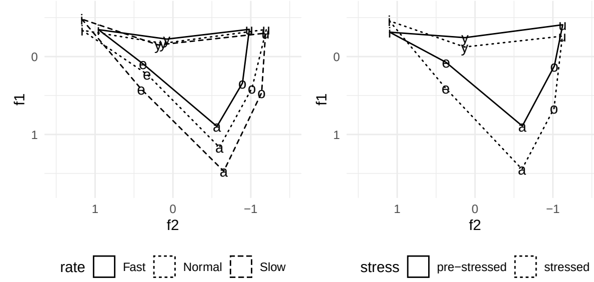

Figure 2. Normalised acoustic vowel spaces

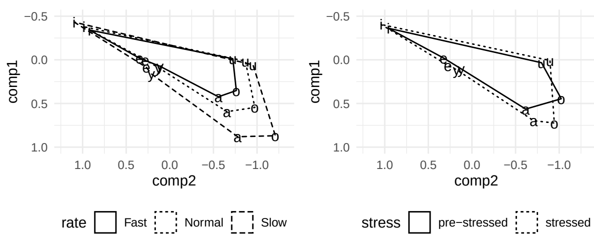

Figure 3. Normalised articulatory vowel spaces

References [1] M. E. Beckman, J. Edwards, and J. Fletcher. “Prosodic structure and tempo in a sonority model of articulatory dynamics”. In: *Papers in Laboratory Phonology II: Gesture, Segment, Prosody*. Ed. by G. Docherty and D. R. Ladd. Cambridge: Cambridge University Press, 1992. [2] K. De Jong, M. E. Beckman, and J. Edwards. “The interplay between prosodic structure and coarticulation”. In: *Language and speech* 36 (1993). [3] K. J. De Jong. “The supraglottal articulation of prominence in English: Linguistic stress as localized hyperarticulation”. In: *The Journal of the Acoustical Society of America* 97 (1995). [4] B. Lindblom. “Spectrographic study of vowel reduction”. In: *The Journal of the Acoustical Society of America* 35 (1963). [5] J. Mielke, C. Carignan, and E. R. Thomas. “The articulatory dynamics of pre-velar and pre-nasal /æ/-raising in English: An ultrasound study”. In: *The Journal of the Acoustical Society of America* 142 (2017). [6] C. Mooshammer and S. Fuchs. “Stress distinction in German: simulating kinematic parameters of tongue-tip gestures”. In: *Journal of Phonetics* 30 (2002). [7] C. Mooshammer and C. Geng. “Acoustic and articulatory manifestations of vowel reduction in German”. In: *Journal of the International Phonetic Association* 38 (2008). [8] M. Nadeu. “Stress-and speech rate-induced vowel quality variation in Catalan and Spanish”. In: *Journal of Phonetics* 46 (2014). [9] P. Nowak. “Vowel reduction in Polish”. PhD thesis. UC Berkeley, 2006. [10] D. Turton. “Determining categoricity in English /l/-darkening: A principal component analysis of ultrasound spline data”. In: *Proceedings of the XVII International Congress of Phonetic Sciences International Conference of Phonetic Science*. 2015.