

# Compensation for coarticulation in lexically unstressed syllables

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Unstressed syllables are more likely to be hypoarticulated than stressed syllables (Lindblom, 1990) and tend to be produced with more coarticulation (Fowler, 2005). Listeners compensate perceptually for the effects of coarticulation (Mann & Repp, 1980), but they may fail to correctly parse coarticulation in ways that match production in certain contexts (Beddor, Brasher, & Narayan, 2007). According to Ohala (1993), it is the misperception of coarticulatory patterns that is the driving force for sound change. The aim of this study was to test whether there is *less* compensation for coarticulatory effects in the perception of unstressed vowels although we predict *more* coarticulation in production in this context. Our overall aim is to relate such a mismatch in parsing coarticulation in production and perception of unstressed vowels to the prevalence of sound change in this context (Beckman, de Jong, Jun, & Lee, 1992).

In order to do so, we investigated the influence of lexical stress on transconsonantal vowel coarticulation ( $V_2$ -on- $V_1$ ) in perception and production. We chose this context because synchronic  $V_1CV_2$  coarticulation has been shown to be related to several diachronic changes in many different languages such as the development of vowel harmony in Turkish and of *Umlaut* in German. The following hypotheses were tested in a production and a perception study: (1) the extent of anticipatory vowel-on-vowel ( $V_2$ -on- $V_1$ ) coarticulation is greater in unstressed than in stressed syllables; (2) listeners compensate perceptually for the effect of  $V_2$ -on- $V_1$  coarticulation; and (3) listeners compensate less for  $V_2$ -on- $V_1$  coarticulation when the vowel occurs in an unstressed syllable.

We tested our hypotheses by means of German non-words with a  $/pV_1pV_2l/$  structure where  $V_1$  was either lax  $/y/$  or  $/ʊ/$ ,  $V_2$  was either tense  $/o:/$  or  $/e:/$ , and the lexical stress was either on the first or second syllable (e.g.,  $/pʊp'e:l/$ ,  $/'pypo:l/$ , etc).  $/p/$  was chosen because it interferes minimally with tongue articulation, although acoustically it can induce a perceptual retracting effect on vowels due its low labial F2-locus. Ten repetitions of each non-word embedded in a carrier phrase were produced with a pitch accent either on the first or second syllable by 18 speakers (6 male, 12 female) of standard German. We measured the fundamental frequency ( $f_0$ ), the second formant frequency (F2) and segment duration in the initial stressed and initial unstressed syllables. The segment durations were normalized for word duration (since there were no significant differences between word durations of words with primary stress on the first vs. second syllable). Mixed models with either F2 at the temporal midpoint of  $V_1$  or segment durations of  $C_1$  (i.e. of the word-initial  $/p/$ ) and  $V_1$  as the dependent variables,  $V_2$ -context and Stress as fixed factors and Speaker as well as  $V_1$  as random factors were conducted to analyze the production data. In addition, post-hoc Tukey tests were carried out.

Proportional durations of  $C_1$  and  $V_1$  were significantly greater in the stressed vs. unstressed condition ( $C_1$ :  $\chi^2 = 625.2$ ,  $p < 0.001$ ,  $V_1$ :  $\chi^2 = 360.8$ ,  $p < 0.001$ ) and  $f_0$  values were significantly higher in stressed than in unstressed vowels ( $\chi^2 = 703.1$ ,  $p < 0.001$ ). These results indicate that speakers used duration and  $f_0$  to mark stress. F2 of  $V_1 = /y/$  was significantly higher in the context  $V_2 = /e:/$  compared with  $V_2 = /o:/$  ( $z = 7.8$ ,  $p < 0.001$ ) but there was no  $V_2$  influence on  $V_1 = /ʊ/$ . Stress had a significant effect on the F2 target of  $V_1$  ( $\chi^2 = 4.4$ ,  $p < 0.05$ ). This finding, however, was not due to stress-dependent coarticulation differences as there was no significant interaction between  $V_2$ -context and Stress, i.e., contrary to our first hypothesis, the degree of  $V_2$ -on- $V_1$  coarticulation was the same in the stressed and unstressed condition (cf. Figure 1a).

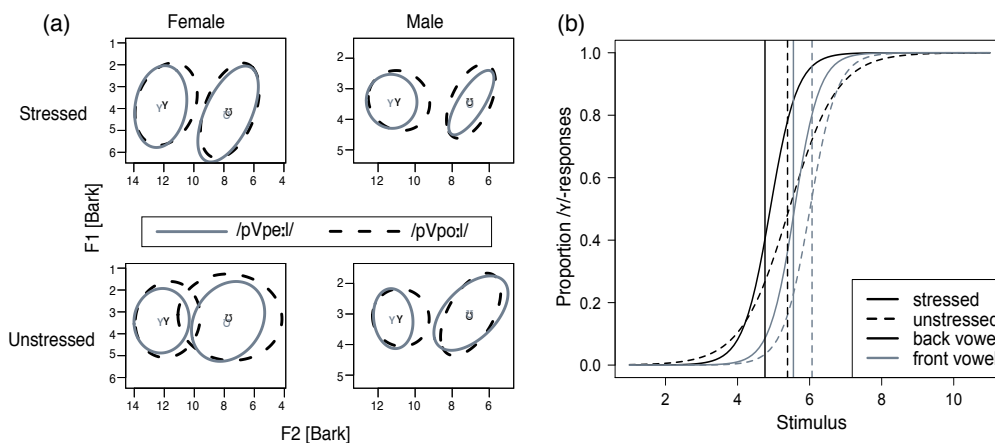
For the perception test, we morphed an 11-step F2 continuum between natural, stressed realizations of  $/pʊp/$  and  $/pyp/$  produced by a phonetically trained speaker. This continuum was then spliced into two contexts ( $/e:l/$  and  $/o:l/$ ) to create two different continua: “Ich habe  $/'pVpe:l/$  gesagt” (“I said  $/'pVpe:l/$ ”) and “Ich habe  $/'pVpo:l/$  gesagt” (“I said  $/'pVpo:l/$ ”). In a second condition,  $f_0$ , duration, and intensity were manipulated to shift the stress from the first to the second syllable; that is, as in the production data, words with an unstressed-stressed pattern had full vowels in both syllables and a pitch accent on the second syllable. Ten

repetitions of the 44 stimuli were presented to the same subjects in a two-alternative forced choice identification test. The subjects' task was to classify  $V_1$  as /y/ or /ʊ/. The stressed/unstressed conditions in the results below refer to the prominences of the first syllable. The perception data was analyzed by means of an RM-ANOVA with category boundary as the dependent variable and  $V_2$ -context and Stress as within-subject factors.

The significant main effect for  $V_2$ -context on the /y-/ category boundary ( $F[1,17] = 68.4, p < 0.001$ ) was commensurate with our second hypothesis: listeners perceived significantly more stimuli as /y/ in the context of a back vowel, i.e. they compensated perceptually for the backing effects of  $V_2 = /o:/$  relative to  $V_2 = /e:/$  (cf. Figure 1b). Contrary to our third hypothesis, there was no interaction between  $V_2$ -context and Stress: that is, the effect of  $V_2 = /e:, o:/$  on the category boundary of  $V_1$  was the same regardless of whether or not  $V_1$  was stressed. However, we also found that the  $V_1$  category boundaries were significantly shifted to the right for the unstressed compared with the stressed conditions in both vowel contexts ( $F[1,17] = 21.8, p < 0.001$ ). We interpret this to mean that listeners compensated less for F2-lowering effects that were induced by /p/ or possibly a combination of /p/ and the back vowel /o:/ when  $V_1$  was unstressed. Therefore, listeners were found to compensate less for the coarticulatory effects induced on an unstressed syllable.

In conclusion, listeners perceptually compensated less for coarticulation in unstressed syllables despite the fact that unstressed syllables were coarticulated to the same extent as stressed syllables. Thus, listeners do not compensate as extensively for coarticulation in unstressed syllables as they do in stressed syllables, and it is this mismatch between the perception and production that could be the source of the greater prevalence for weak vowels to be subject to diachronic change.

**Figure 1a:** 95% confidence ellipses in the F2 x F1 plane for /y/ and /ʊ/ before /e:/ and /o:/ shown separately for words with stressed (top) and unstressed (bottom) syllables and female (left) and male (right) speakers. **Figure 1b:** Proportional distribution of /y/-responses in /o:/ (black) and /e:/ (grey) contexts in stressed (solid) and unstressed (dashed) syllables.



## References

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