COARTICULATORY RESISTANCE AND AGGRESSION IN PITCH-ACCENTED VOWELS UNDER THE EFFECT OF VOWEL-TO-VOWEL COARTICULATION

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ABSTRACT

In the present study we tested if pitch accent increased coarticulatory resistance and aggression in vowels under the influence of vowel-to-vowel coarticulation, using both acoustic and articulatory measures. We studied F_2 and horizontal tongue positions (EMA) in /i/ and /u/ produced by 9 Hungarian females in non-words. Target vowels occurred either in neutral (e.g., first syllable /i/ in /pipipipi/) or in coarticulating (e.g., first syllable /i/ in /pipupupu/) contexts. We analysed differences of coarticulated and non-coarticulated tokens (quality shift), as well as dispersion of tokens across contexts (production range).

Results showed that pitch accent did not increase coarticulatory resistance and aggression in the tested vowels, which contradicts previous findings showing increased resistance in English and Hungarian. We assume that these results may be explained by language specific effects.

Keywords: vowel-to-vowel coarticulation, EMA, coarticulatory aggression, coarticulatory resistance

1. INTRODUCTION

Vowels interact in running speech even through an intervening consonant; this is termed vowel-to-vowel coarticulation [1, 2]. This interaction may be influenced by several factors. For instance, prosodic prominence is claimed to bring about segmental strengthening that leads to increased coarticulatory resistance and aggression [3, 4, 5]. As a result, vowels in accented syllables are assumed to resist coarticulatory effects more efficiently, and to exert a stronger influence on their (close or even transconsonantal) neighbours. Previous results on the effect of prominence on vowel-to-vowel coarticulation are, in part, inconclusive. (These were obtained for non-words in English, and either for acoustics or for articulation, but not for both at the same time.) These results showed increased resistance in accented syllables in acoustics [3], and in articulation [6], but regarding aggression, they did not confirm the hypothesis that increased coarticulatory resistance also leads to increase coarticulatory aggression in vowels, at least not in articulation [6].

In Hungarian, previous studies tested the effect of pitch accent on coarticulatory resistance against vowel-to-vowel effects in real words, both in acoustic and articulatory data which were gathered and analysed in parallel [7, 8]. These found that pitch accent increased coarticulatory aggression against vowel-to-vowel coarticulation in target vowels. However, the effect of pitch accent on coarticulatory aggression was not studied so far, as due to fixed first syllable stress/accent in Hungarian [9], it was not feasible to test in real words.

Following up on previous research, in the present study, we addressed the question if pitch-accent increased coarticulatory resistance and aggression in vowels against the effect of a transconsonantal vowel in nonsense words in Hungarian, and if resistance and aggression could be detected either in articulation, or in acoustics, or in both domains at the same time.

2. METHODS

We analysed simultaneously recorded acoustic and articulatory data of 9 adult female speakers (aged 25,2±5,9 years) producing /i/ and /u/ in /ˈpVpVpVpV/ shaped nonsense words (similar to e.g., Cho 2004, where data from CVCVC shaped non-words were used). Target vowels were embedded either in neutral (e.g., /ˈp**i**p<u>i</u>pipi/) or in coarticulating (e.g., /ˈp**i**p<u>u</u>pupu/) contexts (where bold denotes target vowels, underlining denotes trigger vowels, target vowels occur in pitch-accented syllables, and are under the effect of anticipatory coarticulation). Speakers were asked to produce the tested nonsense words as individual utterances (i.e., like "sentences"). Therefore, we could analyse vowels in pitch-accented (first) and unaccented (second and third) syllables. Note that prominence production was confirmed on the basis of auditory perception of the authors: all tested occurrences were perceived as bearing prominence on the first syllable of the test sequences.

Since /i/ and /u/ differ mainly on the dimensions of F_2 and horizontal tongue position, F_2 frequency and horizontal tongue positions were obtained from audio and Electromagnetic Articulography (EMA) recordings. Horizontal tongue positions were represented by *x*-axis displacement of the mean of two tongue body sensors on the sagittal plane. These sensors were placed on the backmost point on the speakers' tongue, and approx. 1 cm before that.

From these articulatory and acoustic data, we calculated and tested two distinct measures. First, we calculated differences of coarticulated and non-coarticulated/neutrally positioned tokens in the acoustic and articulatory spaces (Fig. 1, left), i.e., *distances* or *quality shift*, similarly to [3, 6, 7, 8]. For this purpose, we calculated distances of these tokens in F_2 in acoustics, and in horizontal tongue displacement measured on the *x*-axis in articulation. Second, we analysed *dispersion* (or *variation*) of vowel tokens *across contexts*, i.e., *production range* as in [7, 8] (Fig. 1, right). This means that we calculated relative standard deviation of F_2, and tongue position data pooled across vowel contexts (i.e., across neutral and coarticulating contexts), in the two production domains, respectively.

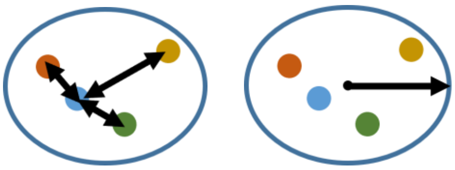

Figure 1: Derived and tested measures: distances or quality shift (left), and across context dispersion or production range (right).

Due to fixed first syllable stress/accent in Hungarian, it was not possible to test coarticulatory resistance and aggression in identical conditions. Coarticulatory resistance, i.e., the effect of pitch accent on target vowels, was tested using target vowels occurring in the first versus the second syllable, and in anticipatory coarticulation using unaccented trigger vowels exclusively (Table 1). Coarticulatory aggression was tested using target vowels under the effect of carryover coarticulation and occurring in unaccented second versus third syllables (Table 2). Note, however, that in this latter case, target vowel data are used for the purposes of drawing conclusions regarding trigger vowels indirectly, and these trigger vowels were also positioned in the first and second syllables. Therefore, all of the presented data reflect tendencies in vowels produced in the first (accented) versus the second (unaccented) syllable, in the same non-words, and this lets us to test if resistance and aggression occur at the same time.

Data were analysed using mixed models in R [10] and the lme4 [11], lmerTest [12], and lsmeans [13] packages. All models included *vowel quality* as a fixed factor, and they also included *target vowel accent* when we tested resistance, and *trigger vowel accent* when we tested aggression. Random intercepts and slopes for speakers and factors were also included in each case if they improved model fit. We report *p* values obtained using the Satterthwaite approximation of the degrees of freedom.

		Trigger /i/ (unacc.)	**Trigger /u/ (unacc.)**
Target /i/	*unacc.*	*pip**i**pipi* (N)	*pip**i**pupu* (C)
	acc.	*p**i**pipipi* (N)	*p**i**pupupu* (C)
Target /u/	*unacc.*	*pup**u**pipi* (C)	*pup**u**pupu* (N)
	acc.	*p**u**pipipi* (C)	*p**u**pupupu* (N)

Table 1: Material used to test coarticulatory resistance in anticipatory coarticulation (bold: target vowel; underline: trigger vowel; C = coarticulating context; N = neutral context)

	Trigger /i/		**Trigger /u/**	
	acc.	*unacc.*	*acc.*	*unacc.*
Target /i/ (unacc.)	*pip**i**pipi* (N)	*pipip**i**pi* (N)	*pup**i**pipi* (C)	*pupup**i**pi* (C)
Target /u/ (unacc.)	*pip**u**pupu* (C)	*pipip**u**pu* (C)	*pup**u**pupu* (N)	*pupup**u**pu* (N)

Table 2: Material used to test coarticulatory aggression in carryover coarticulation (bold: target vowel; underline: trigger vowel; C = coarticulating context; N = neutral context)

3. RESULTS

Since the main question of the study is if vowels exhibited increased coarticulatory resistance and aggression at the same time (i.e., if vowels in accented position show both), we present data on the two tested measures in pairs: figures on the left show resistance, while figures of the right show aggression of the same vowels (i.e., same vowel qualities in the same syllables, in the same words), both as a function of pitch-accent. First, we report production range, and then quality shift data, and we always start with acoustics, and then carry on with data on articulation.

3.1. Production range

As for coarticulatory resistance (Fig. 2, left), data of *production range* in acoustics showed only the effect of target vowel quality ($F(1, 36) = 6.88$; $p < .05$), as /u/ was clearly more variable than /i/, but no effect of pitch accent was found. As for coarticulatory aggression, we found an interaction effect of vowel quality and trigger vowel accent ($F(1, 27) = 6.05$; $p < .05$) (Fig. 2, right), resulting from a main effect of vowel quality being dependent on accent: /u/ was more variable (i.e., /i/ was more aggressive) only in those cases, where trigger vowels occurred in pitch-accented syllables (the main effect of trigger vowel accent was not significant).

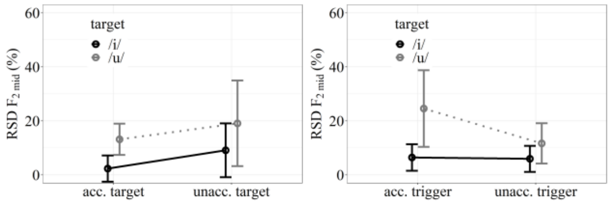

Figure 2: Production range in acoustics: coarticulatory resistance (left), coarticulatory aggression (right).

In articulatory data, we found a significant main effect of vowel quality for resistance exclusively ($F(1, 24) = 83.29$; $p < .001$) (Fig. 3, left), similar to what we observed in acoustics. As for aggression (Fig. 3, right), we found no effect of pitch accent either, only the significant main effect of vowel quality ($F(1, 32) = 60.34$; $p < .001$). To sum up, the measure of production range did not show that pitch-accent increased coarticulatory resistance and aggression in vowels under vowel-to-vowel coarticulation.

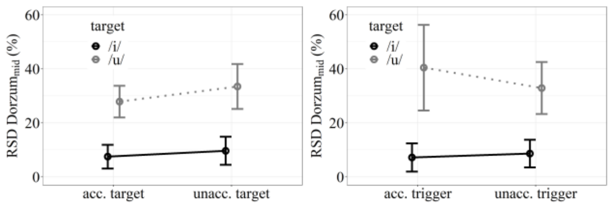

Figure 3: Production range in articulation: coarticulatory resistance (left), coarticulatory aggression (right).

3.2. Quality shift

Data on quality shift for /i/ and /u/ are basically capturing centralisation: if distances of coarticulated and neutrally positioned vowels are close to 0, there is no difference between the (articulatory or acoustic) quality of these tokens. However, if values are positive in the case of /u/, and negative in the case of /i/, it reflects tokens in coarticulating contexts being pulled towards the middle of the acoustic or articulatory space; in other words, to be more centralised. Absolute values of data reflect the magnitude of shift in quality, i.e., the magnitude of coarticulatory effects.

As for acoustics, we found the main effect of pitch-accent to be significant ($F(1, 28) = 4.22$; $p < .05$) (Fig. 4, left). Unexpectedly, however, in part, this was the result of /i/ being more centralised under the effect of vowel-to-vowel coarticulation in accented syllables than in unaccented syllables, while in unaccented syllables we found no centralisation (i.e., quality of /i/ was identical in coarticulating and neutral positions). Data on /u/ showed tendencies that may be considered increased resistance under the effect of pitch-accent: /u/ tokens in unaccented syllables showed basically no centralisation, while /u/ tokens in accented syllables (which were assumed to be less prone to coarticulatory effects) showed more peripheral realisations in coarticulating contexts than in neutral contexts, i.e., dissimilation (which is reflected by negative values in accented syllables).

As for coarticulatory aggression (Fig. 4, right), statistical analysis revealed that only the effect of vowel quality is significant ($F(1, 29) = 46.35$; $p < .001$), because /i/ exerted greater effects on /u/ than vice versa.

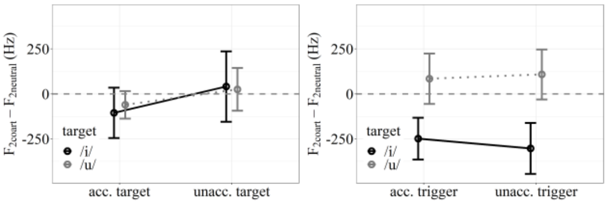

Figure 4: Quality shift in acoustics: coarticulatory resistance (left), coarticulatory aggression (right).

Lastly, we turn to quality shift data in the articulatory domain. With respect to resistance, again, only vowel quality showed a significant effect ($F(1, 33) = 4.65$; $p < .05$) (Fig. 5, left), as under the effect of vowel-to-vowel coarticulation, /u/ showed some degree of centralisation in unaccented syllables, and somewhat more peripheral realisation in accented syllables, but /i/ tokens were basically identical in coarticulating and in neutral contexts irrespective of prosodic prominence. With respect to coarticulatory aggression, we found no significant effect of pitch accent, but the effect of vowel quality ($F(1, 8) = 14{,}03$; $p < .05$) (Fig. 5, right). These data also showed that /i/ exerted a stronger effect of centralisation in /u/ than vice versa.

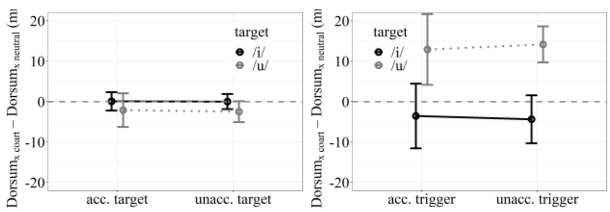

Figure 5: Quality shift in articulation: coarticulatory resistance (left), coarticulatory aggression (right).

4. DISCUSSION

We can conclude that transconsonantal vowels interacting exclusively on the backness dimension, and produced by Hungarian speakers, did not show clear effects of sentence level prominence, i.e., pitch-accent, either in articulation or in acoustics with respect to their resistance against coarticulatory effects, and to their coarticulatory aggression. We found some support for accent effects, as /u/ showed increased resistance in articulation in pitch-accented syllables, but trends in /i/ went against expectations, and they showed greater resistance in unaccented syllables than in pitch-accented syllables. Based on these results, we can conclude that prosodic prominence did not facilitate segmental strengthening in the tested non-word-shaped tokens.

Present results contradict earlier findings that showed greater coarticulatory resistance in accented vowels in real words in Hungarian [7, 8], and in non-words in English [3, 6]. This could lead us to conclude that production of non-words in the present study blocked possible coarticulatory effects to a greater extent. This can be supported by previous results revealing that non-words may be hyperarticulated [14, 15], and are thus, intrinsically, less prone to coarticulatory effects [15, 16]. We should also note, however, that previous results demonstrating increased coarticulatory resistance in English were obtained using non-words, suggesting that resistance caused by hyperarticulation (if any), may be overruled by prosodic strengthening.

We assume that limited effects of pitch-accent found in Hungarian data in non-words may partly be due to the fact that, as opposed to English, prosody is claimed to play a limited role in prominence marking in Hungarian [17]. Conclusively, segmental strengthening exerted by prosodic means may also be limited in this language. Lack of strengthening effect is also supported by recent empirical findings: a previous study, in which pitch-accented vowels were compared to other, unstressed vowels of the same non-sense word in Hungarian showed no (clear) evidence of the effect of prosodic strengthening in accented vowels either in articulation (horizontal tongue position), or in acoustics (F_2) [18].

Further, it is also important to note that in the present study, for the purposes of controlling tested effects, and have a clear alignment of articulatory and acoustic measures, we tested coarticulation between /i/ and /u/, which is limited to only one dimension, backness. By contrast, [6] tested more widely spaced vowels, /i/ and /a/, differing both in openness and backness, where one expects the most extreme coarticulatory interaction.

Lastly, fixed first syllable stress/accent placement in Hungarian also limited the creation of the linguistic material used in the present study, thus we should also enumerate possible ways these features of the linguistic material could reduce observable coarticulatory effects.

On the one hand, coarticulatory resistance was tested in anticipatory coarticulation involving unaccented trigger vowels exclusively. Although studies for several languages demonstrated that carryover effects may exceed those of anticipatory [19], which would mean that we find limited effects in the present case, previous results for Hungarian demonstrated no clear dominance of directionality in vowel-to-vowel coarticulation [20]. According to these, only /i/ in acoustics, and /u/ in articulation showed that effects of carryover coarticulation may exceed those of anticipatory in Hungarian, but probable consequences of this cannot be seen in the present data. As we found no effect of pitch-accent on coarticulatory aggression in the present analysis, we can also safely assume that the lack of accent in trigger vowels did not diminish particularly the observable coarticulatory interactions.

On the other hand, coarticulatory aggression was tested in carryover effects, using unaccented target vowels. As mentioned, possible effects of direction of coarticulation for Hungarian are not straightforward; nevertheless, previous results suggest they would have facilitated coarticulatory effects in /i/ in acoustics, and in /u/ in articulation. In other words, direction effects would have facilitated higher aggression in /u/ triggers in acoustics, and in /i/ triggers in articulation. But this is also not seen in present results. Lastly, based on previous findings, one might expect that the lack of accent on target vowels facilitates coarticulatory interactions, hence it is an ideal testbed to reveal if accent enhances coarticulatory aggression. Lack of effect of pitch-accent on increasing coarticulatory aggression is then found despite favourable conditions.

To conclude, data on non-words in Hungarian did not show that coarticulatory resistance and aggression are increased in syllables that are the most prominent in the utterance, which supports the assumption that positions that are intended to be produced as prominent, do not universally result in segmental strengthening.

Acknowledgements

The work was supported by the Bolyai János Research Scholarship of the Hungarian Academy of Sciences (A.D., T.G.Cs.), ÚNKP-22-3 (K.J.), ÚNKP-21-5 (A.D.), ÚNKP-22-5 (T.G.Cs.). We are grateful to Ákos Buza, Valéria Krepsz, István Mrázik, Zsófia Puzder, Zsófia Weidl, Anne Hermes, Doris Mücke, and Theo Klinker for their help in gathering data.

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