Prosodic Strengthening in American English Domain-initial Vowels

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Abstract

Previous studies investigating domain-initial prosodic strengthening have shown that consonants undergo cumulative strengthening at the beginning of prosodic domains. However, evidence for articulatory strengthening of domain-initial vowels is sparse [1], [2]. At least two possible hypotheses exist why vowels fail to show domain-initial strengthening: a) Domain-initial strengthening only targets syllable onsets, but not nuclei (structural explanation), and b) Domain-initial strengthening targets the initial segment in the domain, regardless of whether this segment is a consonant or a vowel (local explanation). The current study tries to distinguish between these two hypotheses by investigating the magnitude of the articulatory gestures for the English vowels [ɛ] and [ɔ] produced in consonant (CVC) and vowel-initial (VC) syllables in three different prosodic environments (IP, AP, and Wd) using ultrasound. Our results show that domain-initial strengthening is highly local and does affect vowels as well as consonants.

Index Terms: domain-initial strengthening, speech production, American English

1. Introduction

Prosodic strengthening – the realization of some phonetic property with greater magnitude in the acoustic and/or articulatory space due to prosodic prominence – has been shown to affect vowels differently depending on whether they are within a syllable that has a prominence-marking function (i.e. word stress, phrasal accent) or a grouping function (i.e. domain initial or domain final)[2]. Studies investigating the phonetic realization of segments in prominence-marking contexts found that consonants and vowels in prominent syllables are articulated stronger if they are higher on the prosodic hierarchy [3], [4]. However, studies investigating articulatory strengthening in boundary-marking contexts find that although vowels undergo strengthening in domain final syllables, domain initially, vowels do not appear to undergo such strengthening [1], [2]. Two explanations for the failure of vowels to show domain-initial strengthening exist: a) Domain-initial strengthening only targets syllable onsets (which are by definition consonants) but not nuclei (which are typically vowels), and b) Domain-initial strengthening targets the initial segment in the domain, regardless of whether this segment is a consonant or a vowel. Since stimuli in previous studies consisted exclusively of consonant-initial syllables, the two possibilities cannot be differentiated by existing data.

The current study addresses this problem by investigating the articulation of the English vowels [ɛ] and [ɔ] in consonant and vowel initial syllables in three different prosodic environments using ultrasound. More precisely, this study compares the magnitude of the articulatory gesture with which each vowel is produced when initial to a prosodic word (PWd), an accentual phrase (AP), and an intonational phrase (IP). If domain-initial articulatory strengthening is governed by structural criteria; i.e. if it targets only syllable onsets, we expect to see the same patterns of vowel gesture magnitude in syllables with onset-consonants (CVC context) and in onsetless syllables (VC context). If, on the other hand, domain-initial strengthening is local in the sense that it targets the initial segment of the prosodic domain, we expect to see different patterns of gesture magnitude in CVC and VC context. In particular, we expect that the magnitude of the articulatory gesture for syllable-inital (VC), domain-initial vowels will increase the higher the prosodic domain is on the prosodic hierarchy. Vowels in domain-initial CVC syllables, on the other hand, are not expected to show the same patterns of magnitude increase.

2. Methodology

Previous studies have used electro-palatography (EPG) [1] or electromagnetic articulography (EMA)[2], [4] to study domain-initial strengthening. The current study uses ultrasound, an imaging technology that is increasingly used for the study of speech production [5]. The use of ultrasound is advantageous in several respects, especially, since the current study focuses on vowel gestures. Unlike EPG data, which provides only an indirect measure of vowel gestures, since the magnitude of vowel gestures is estimated from the degree of absence of tongue contact with the palate, ultrasound provides information about the tongue directly. In comparison to EMA, which tracks flesh points on the tongue surface, ultrasound provides information about the entire scannable tongue surface, hence providing more information about the tongue surface as a whole.

2.1. Subjects and stimuli

Eight native speakers of American English – five female and three male – participated in the current study. Participants were seated and their heads were stabilized during data collection with the procedure described by Davidson and Decker [6] to ensure that the ultrasound probe was in a fixed position with respect to the participant's head. The tongue of the participants was scanned with an Antares Sonoline ultrasound machine at a frame rate of 29.97 fps as they produced six repetitions of the 12 target sentences in random order.

The stimuli for this study consisted of 12 target sentences. The sentences contained the vowels [ɛ] and [ɔ] in either a domain-initial CVC or VC syllable in the three prosodic environments (IP, AP, and Wd). The target sentences for the vowel [ɔ] in the two syllable types and the three prosodic environments are given in Table 1.

Table 1: *Target sentences for the vowel [ɔ] in VC and CVC domain-initial syllables in three prosodic environments*

	V-initial	C-initial
IP	That's interesting. **Au**k is a seabird.	That will interest him. C**au**lk is a sealant.
AP	Silk, **au**k, and bolus are rare words.	Sill, c**au**lk, and bolus are rare words.
Wd	The silk **au**k won't survive the winter.	The sill c**au**lk won't survive the winter.

2.1.1. Analysis

The sections of the ultrasound data that corresponded to the two vowels [ɛ] and [ɔ] in the different prosodic environments were extracted as sequences of JPEG images. The frame with the most advanced position of the tongue body for the target vowel was determined (cf. [7]), and the curvature of the tongue surface in the sagittal plane was traced in that frame using EdgeTrak [8]. This yielded six tracings – one for each repetition – for each condition (vowel ([ɛ] and [ɔ]) X syllable type (VC and CVC) X prosodic conditions (IP, AP, and Wd)). The six tracings obtained for each of these conditions were averaged and compared using the spline smoothing ANOVA procedure described in [9]. Figure 1 and 2 illustrate this procedure; all tracings are shown in an arbitrary but fixed coordinate system. Figure 1 shows 12 tracings of the tongue obtained from the repetitions of the vowel [ɔ]. Six of these tongue traces reflect productions in a VC syllable (red) and six were produced in a CVC syllable (green); both syllables were initial to an intonational phrase.

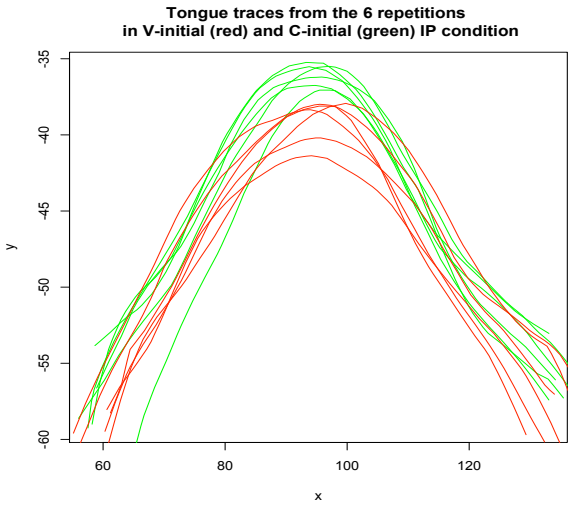

Figure 1: *Six tongue tracings of the vowel [ɔ] in 'auk' (red) and 'caulk' (green) in IP initial syllable.*

Figure 2 shows the averaged traces for each syllable type; the red trace constitutes the average of the six traces from the vowel [ɔ] in the VC syllable, and the green trace constitutes the average of the six traces from the same vowel in the CVC syllable. The dotted red and green lines above and below each solid line show the Bayesian confidence interval (BCI), demarcating the area within which traces should not be considered statistically different.

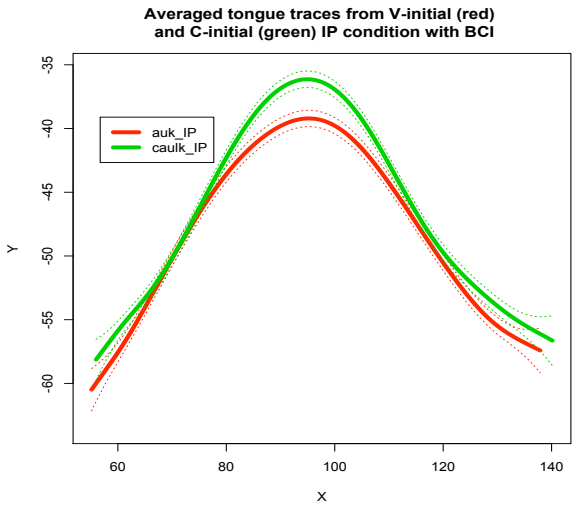

Figure 2: *Averaged tongue tracings of the vowel [ɔ] in 'auk' (red) and 'caulk' (green) in IP initial syllable.*

The data were analyzed for each of the eight participants in two different ways. First the vowel gestures were compared across syllable types and prosodic domains, and then within syllable type and across prosodic domains.

2.2. Analysis across syllable type

This comparison procedure attempts to answer the question of whether the vocalic gestures in VC domain-initial syllables are different from CVC domain-initial syllables in the three investigated prosodic domains. For this comparison, the vowel gestures of the target vowels [ɛ] and [ɔ] were compared across the two syllable types; i.e. 'auk' in IP-initial position was compared to 'caulk' in IP-initial position, then the vowels in 'auk' and 'caulk' were compared in AP-initial position and Wd-initial position. For each of the pair-wise comparison, it was then determined whether the tongue traces were significantly different or not. Two traces were judged as different if **no** overlap of the traces and the BCIs occurred over an extended portion of the tongue body in the two traces (cf. [9]). An example of the comparison procedure is shown in Figure 3, which shows the pairwise comparison of the averaged tongue tracings for the vowel [ɔ] in 'auk' and 'caulk' across the three different prosodic conditions.

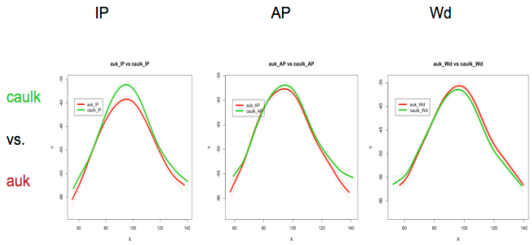

Figure 3: *Comparison of the vowel [ɔ] in 'auk' to that in 'caulk' across different prosodic environments.*

Note that in Figure 3, the vowel gesture for the vowel [ɔ] in 'auk' in the IP-initial position is produced with greater magnitude by that participant since it is lower than the corresponding vowel in the IP-initial 'caulk'. For this particular subject, the vowel gestures in VC syllables differed only from those in CVC syllables if they were initial to an intonational phrase.

2.3. Analysis within syllable type

This comparison procedure tries to answer the question of whether the magnitude of the vocalic gesture increases from a lower prosodic domain to a higher prosodic domain. The vowel gestures of the target vowels [ɛ] and [ɔ] were compared within each syllable type across the three prosodic domains; i.e. 'auk' in IP-initial position was compared to 'auk' in AP-initial and Wd-initial position. For each of the pair-wise comparison, it was then again determined whether the tongue traces were significantly different or not. An example of the comparison procedure is shown in Figure 4, which shows the pair-wise comparison of the averaged tongue tracings for the vowel [ɔ] in the VC (top row) and the CVC conditions (bottom row) across the different prosodic environments for one subject.

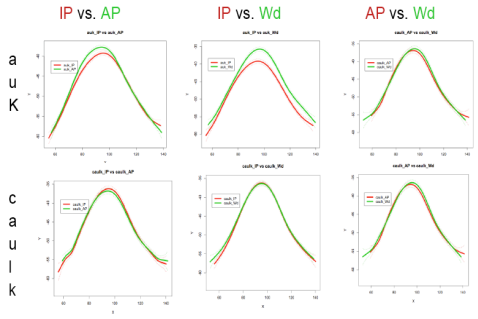

Figure 4: *Comparison of the vowel [ɔ] in 'auk' (top row) and 'caulk' (bottom row) across different prosodic environments.*

3. Results

3.1. Comparison across syllable type

Comparing the magnitude of the vowel gestures between vowel (VC) and consonant (CVC) initial syllables, we find a clear tendency for the vowels in VC syllables to be produced with greater magnitude. In other words, the vowel [ɛ] in 'egg' and [ɔ] in 'auk' were articulated with greater articulatory magnitude compared to the the same vowels in 'kegg' and 'caulk'. This trend increases with the height of the prosodic domain on the prosodic hierarchy: In word-initial position, the magnitude of the vowel gesture was more pronounced in VC syllables compared to CVC syllables in 56% of cases. In AP-initial position, the vowels in VC syllables were in 62% articulated with greater magnitude compared to those vowels in CVC syllables, and in IP-initial position in 94% of all investigated cases. These results are shown in Figure 5 below.

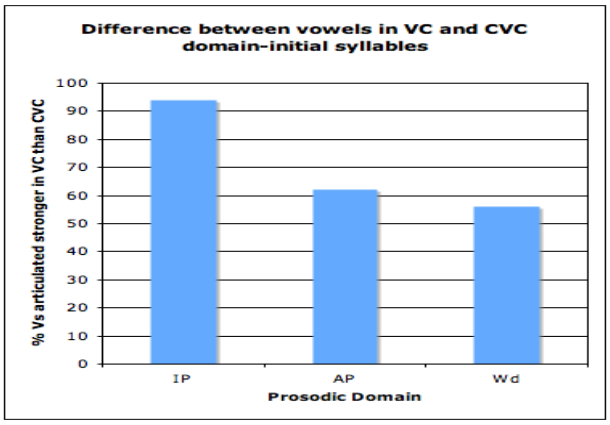

Figure 5: *Difference in magnitude of vowel gestures between vowels in VC and CVC domain-initial syllables across different prosodic environments.*

3.2. Comparison within syllable type

The comparison within syllable type shows cumulative strengthening of articulatory magnitude for domain-initial vowels if these vowels are the first segment in the prosodic domain (i.e. in a VC syllable). For these absolute domain-initial vowels we find that the articulatory difference between vowels that are initial to smaller prosodic domains, such as the prosodic word, and vowels initial to a larger prosodic domain increases with height on the prosodic hierarchy. For example, in 88% of all comparisons between IP-initial and Wd-initial vowels in VC syllables, the IP-initial vowel was articulated with greater gestural magnitude, while the same was true for only 63% when comparing IP- and AP-initial VC vowels. In other words, in 88% of the investigated VC syllables the intonational phrase and prosodic word were distinguished in the production of the domain-initial vowels, in 63% intonational phrase and accentual phrase were distinguished, and in 68% accentual phrase and word were distinguished. These results are indicative of the same cumulative strengthening effect found for domain-initial consonants (cf. [1]). Figure 6 shows the results for the vowels in domain-initial VC syllables.

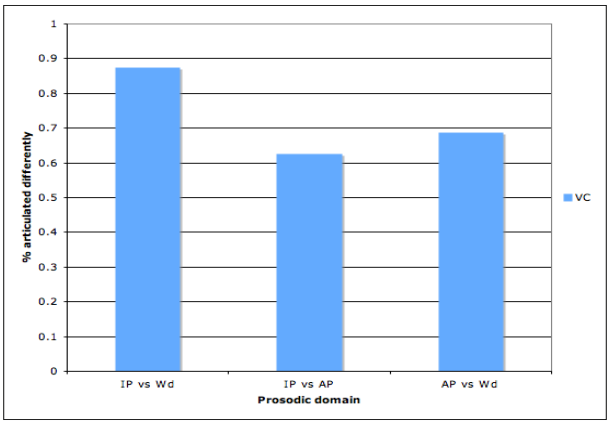

Figure 6: *Difference in magnitude of vowel gestures between vowels in VC domain-initial syllables across different prosodic environments.*

The vowels in domain-initial CVC syllables exhibit a very different pattern. While the prosodic domains intonational phrase versus accentual phrase as well as the domains accentual phrase versus prosodic word were distinguished in the production of vowels in domain-initial CVC syllables, only 20% of the investigated cases distinguished the IP-domain from the Wd-domain. This pattern does not show the cumulative effect seen in the vowels in domain-initial VC syllables. Figure 7 shows the results for the vowels in domain-initial CVC syllables.

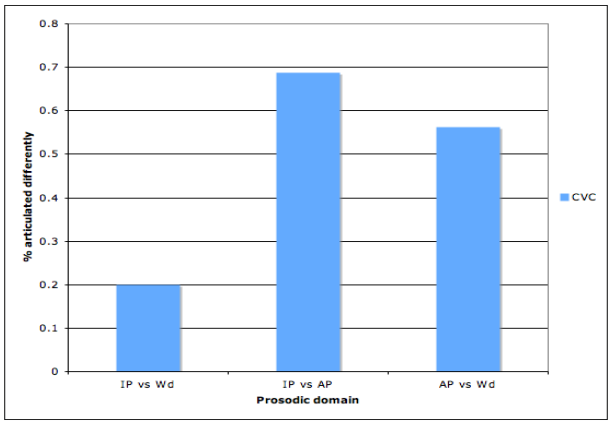

Figure 7: *Difference in magnitude of vowel gestures between vowels in CVC domain-initial syllables across different prosodic environments.*

4. Discussion and conclusion

Taken together, the results reported above and illustrated in Figures 6 and 7 strongly support the local hypothesis outlined in the introduction. We saw that the magnitude of the articulatory gesture for the vowels in domain-initial VC syllables was greater for the vowels that were initial to prosodic domains that are higher on the prosodic hierarchy. These patterns are the same as found in domain-initial consoanants [1], [4], and they suggest that it is the first segment in a prosodic domain that is affected by domain initial strengthening rather than a subset of syllabic constituents. The highly local character of domain-initial strengthening has also been reported by Fougeron [10] for French.

For vowels in domain-initial syllables that were not the first segment in the domain, i.e. the vowels in CVC syllables, we did not see a cumulative pattern of articulatory strengthening. Instead we saw that very few productions distinguished between the smallest prosodic domain (Wd) and the largest prosodic domain (IP) that were investigated in the current study. This strongly suggests that the vowels in CVC syllables initial to APs were produced differently from those in the IP and Wd environment. A possible explanation for this different behavior of the vowels in AP-initial CVC syllables is that these vowels were not only initial but also final to the AP due to the use of monosyllabic words in the current study. Therefore, the effect on the magnitude with which these vowels were produced could also be due to mechanisms governing the articulatory parameters of phrase finality. For the absolute domain-initial vowels, on the other hand, the same might be true but could have been overshadowed by the domain-initial strengthening effect.

5. Acknowledgements

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6. References

[1] Fougeron, C. and Keating, A. P., “Articulatory strengthening at the edges of prosodic domains”, JASA, 101(6):3728–3740, 1997.

[2] Cho, T.,“Prosodic strengthening and featural enhancement: Evidence from acoustic and articulatory realizations of /ɑ, i/ in English”, JASA, 117 (6):3867-3878, 2005.

[3] Beckman, M. E., Edwards, J.,“Articulatory evidence for differentiating stress categories.”, in P. A. Keating [Ed], Papers in Laboratory Phonology III: Phonological structure and phonetic form, 7-33, Cambridge University Press, 1992.

[4] Cho, T., “The effects of prosody on articulation in English”, Routledge, NY.

[5] Stone, M., “A guide to analyzing tongue motion from ultrasound images”, Clinical Linguistics and Phonetics, 19 (6-7):455-502, 2005.

[6] Davidson, L. and Decker, P., “Stabalization techniques for ultrasound imaging of speech articulators”, JASA, 117 (4): 2544, 2005.

[7] Benus, S. and Gafos, A., “Articulatory characteristics of Hungarian ’transparent’ vowels.” Journal of Phonetics, 35:271-300, 2007.

[8] Li, X., Stone, M. and Prince, J. L., “Tongue motion averaging from contour sequences”, Clinical Linguistics and Phonetics, 19(6-7):515-528, 2006.

[9] Davidson, L., “Comparing tongue shapes from ultrasound imaging using smoothing spline analysis of variance”, JASA, 120(1):407-415, 2006.

[10] Fougeron, C., “Articulatory properties of initial segments in several prosodic constituent in French”, Journal of Phonetics, 29:109-135, 2001.