EFFECT OF PROSODY ON VOWEL-TO-VOWEL COARTICULATION IN ENGLISH

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ABSTRACT

It has been claimed that segments are 'strongly' articulated in two prosodic positions: pitch-accented syllables [4, 5] and domain-initial positions [3, 6, 7, 9]. The current study examines the effect of these two prosodic conditions on resistance to vowel-to-vowel coarticulation, based on acoustic data. This study first shows that vowels are strongly articulated at the edges of prosodic domains. The degree of V-to-V coarticulation is in general greater when vowels are separated by a lower prosodic boundary (e.g., a word boundary), and it smaller when they are separated by a higher prosodic boundary (e.g., an Intonational Phrase boundary). A greater V-to-V coarticulation was found when the vowels have no pitch accent. Overall, vowels in prosodically stronger positions resist coarticulation.

1. INTRODUCTION

In recent years, there has been a growing interest in determining how prosody affects the physical realization of segments. There is an increasing consensus that there are no fixed phonetic properties associated with a segment; rather the phonetic realization of a segment varies depending on the prosodic structure. For example, many researchers have found that the articulatory magnitude varies depending on the prosodic position. Quite a few studies [2, 3, 4, 5, 6, 7] among many others point to two prosodic positions where segments may be 'strongly' articulated. One is in pitch-accented syllables and the other is at the edges of prosodic domains, especially the initial position.

The first type of prominence occurs in a certain point of the utterance which encodes the interplay of lexical stress and sentential stress. de Jong [4, 5] proposed that stressed (Nuclear- or Prenuclear pitch-accented) segments, both consonants and vowels, are hyperarticulated locally, making each segment maximally contrastive in these positions.

The evidence for the second type of prominence can be found in a series of EPG studies [3, 6, 7, 9] which show that consonants in a prosodic domain-initial position (e.g., Intonational Phrase (=IP)) are produced with greater linguopalatal contact relative to corresponding consonants in a domain-medial position (e.g., Intermediate Phrase (=ip) initial but IP-medial). This effect, known as *domain-initial strengthening*, is also cumulative — the higher the prosodic position, the more linguopalatal contact. In contrast, consonants in domain-final positions are not produced as strongly as they would be in domain-initial positions (cf. [2])

These findings lead us to wonder about the acoustic/articulatory behavior of vowels at 'strong' positions, both within (Nuclear) pitch-accented syllables and at the edges of prosodic domains. The first question is about the vowel in domain-initial CV's. Are vowels in this position also strengthened, just like consonants? If a syllable as a whole is strengthened domain initially, we might as well expect that any segment occurring in that syllable, consonant or vowel, would be strongly articulated. Some relevant data is provided by Vayra & Fowler [13] who showed that peripheral vowels (e.g., [a] & [i]) in 3 CV syllables in 3 syllable Italian words, become progressively more centralized from left to right as the word progresses. Put differently, the vowel in the initial (or left edge) CV syllable of a word has a more extreme F1 value (higher F1 for [a] and lower F1 for [i]), showing some kind of strengthening word-initially. The influence of prosodic positions on the articulation of the whole CV syllable is also found in [6, 13]: the entire CV in domain-initial positions tend to get strengthened. Our first goal, therefore, is to systematically examine how extreme the peripheral vowels (e.g., [a] and [i]) in domain-initial CV syllables are, relative to domain-medial position.

The second question concerns the domain-final vowel in a open syllable. Beckman, et al. [2] propose that the observed final lengthening in *pop* preceding an Intonational Phrase boundary is not attributable to 'bigger' displacement of the jaw but rather to a change in stiffness (less stiff, therefore slower). However, they did not examine any temporal or spatial changes for a domain-final vowel in an open syllable. Fougeron and Keating [6], on the other hand, show that vowel [o] generally becomes more open in a domain-final position (but not so cumulatively), resulting in a greater V-to-C displacement. The second goal of this paper, then, is to extend their study by examining the extremity of F1 and F2 values for domain-final [i] and [a].

The last question is how resistant vowels are to coarticulation when they occur in prosodically strong positions. As in de Jong [4, 6], it is hypothesized that strongly articulated (in de Jong's term, 'hyperarticulated') vowels resist coarticulation while vowels in weaker positions (such as unaccented syllable or domain-medial position) are more vulnerable to coarticulation. The current study tests this hypothesis by examining the extent to which vowel-to-vowel coarticulation varies depending on prosodic position and accentedness.

The model of phrasal organization of speech [1], which is adopted in this paper, is shown in Figure 1. This model illustrates a prosodic hierarchy where lower domains (e.g., *syllables*) are grouped into an immediately higher level (e.g., *word*). We predict that vowels before and/or after higher prosodic boundaries (e.g., IP) will be stronger and will resist coarticulation as a function of strength of boundary.

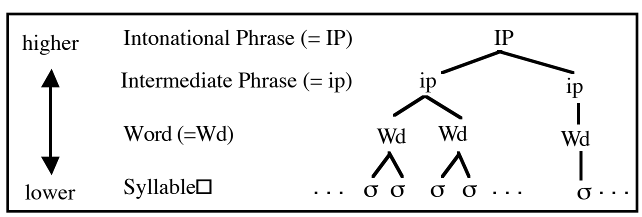


Figure 1. Prosodic Structure of English (adopted from Beckman & Pierrehumbert [1]).

2. METHOD

2.1. Speech Materials

To test the above-raised questions, sentences containing V1#*b*V2 were designed, varying with five factors:

- Types of prosodic boundary (Intonational Phrase (=IP)), Intermediate Phrase (= ip), and Word (=Wd)),
- V1 accentedness (accented/unaccented)
- V2 accentedness (accented/unaccented)
- Two vowels ([i]/[a]) for V1
- Two vowels ([i]/[a]) for V2

This yielded 48 different sentences with four different V1-V2 pairs ([a]#[ba], [a]#[bi], [i]#[ba], [i]#[bi]), each with 12 different prosodic patterns (e.g., Acc#Unacc with IP, Acc#Unacc with ip, Acc#Unacc with Wd, etc). A set of examples is given in Table 1.

Table 1. A subset of the corpus containing different prosodic boundaries (IP, ip, Wd) and accentual patterns.

(a) Word Boundary : V1 Accented-V2 Unaccented

A: Did you just say "Little Boo bobbed her hair last night"
B: No, I said, "Little **Bah** bobbed her hair last night."
rendition : H* [Wd L- L%

(b) Word Boundary: V1 Unaccented-V2 Accented

A: Did you just say "Little Bah popped her hair last night"
B: No, I said, "Little Bah **bobbed** her hair last night."
rendition : [Wd H* L- L%

(c) IP or ip Boundaries: V1 Accented-V2 Unaccented

A: Did you just say "Little Boo bopped Anna's hair last night"
B: No, I said, "Little **Bah** bobbed **Ann's** hair last night."
rendition 1: H* L- [ip H* L- L%
rendition 2: H* L-L% [IP H* L- L%

(d) IP or ip Boundaries:V1 Unaccented-V2 Accented

A: Did you just say "Big Bah popped her hair last night"
B: No, I said, "**Little** Bah **bobbed** her hair last night."
rendition 1: H* L- [ip H* L- L%
rendition 2: H* L-L% [IP H* L- L%

2.2. Procedures

The data reported here are from two male speakers of Californian English. One of them (spkr 2) was a trained speaker in the ToBI framework, and the other (spkr 1) was trained a few hours before recording. They read the test sentences producing the intended renditions as in the samples in Table 1. The prompts (i.e., speaker A's lines in the dialogs) were read silently to cue the intended prosodic patterns. Each sentence was repeated 10 times. Any mistakes in producing the intended renditions were corrected on the spot, either by the speakers themselves or by the experimenter, who is a trained ToBI transcriber. In addition, *posthoc* examination of the recorded utterances was made in order to double-check the rendition. In this procedure, some ambiguous tokens were discarded from the pool of the data, yielding 948 sentences for the analysis. The recorded sentences then were digitized with a sampling rate of 12600 Hz and analyzed by MultiSpeech (Kay Elemetrics Inc.)

For each vowel, eight values were measured: both F1 and F2 for the midpoint and offset for V1, and for the onset and midpoint for V2 for both F1 and F2. Formant values were obtained by comparing the LPC formant history in the spectrogram with LPC/FFT spectral readings. The FFT spectra were calculated with 256 data points. A 20 ms. LPC frame length was used for measuring midpoint values and a 15 ms. frame length for edge values. The best value for LPC coefficients was chosen between 12 to 18, determined by how well the spectrogram readings corresponded to the LPC formant history. In order to avoid the burst energy for [b], formant values for V2 were taken by calculating LPC spectra at a fixed point, 12 and 15 milliseconds after the release for [a] and [i] respectively.

3. RESULTS & DISCUSSION

3.1. Domain-final vowel

One-way ANOVAs using prosodic position as a factor show that the effect of prosodic position on the domain-final vowel is significant at least at $p < .05$ level for both F1 and F2 dimensions for both speakers. As summarized in Table 1, the vowel [a] was produced with higher F1 and lower F2 values at a higher domain-final position (e.g., IP-final) compared to a lower domain-final position (e.g., Wd-final). That is, the vowel [a] is more open and backer in a higher prosodic domain-final position.

For domain-final [i], a significant effect of prosodic position was found only in F1. As shown in Table 1, F1 was in general lower IP-finally and higher word-finally. However, no effect was found for F2. Our data suggest that the tongue position for [i] seems to be higher, but not necessarily fronter, in a higher domain-final position.

Table 1. Fisher's PLSD Pairwise *Posthoc* Comparisons of ANOVA. '>' or '<' refers to statistical significance at $p < .05$.

	Domain-Final [a]		Domain-Final [i]	
	F1	F2	F1	F2
Spkr 1	IP>(ip=Wd)	IP<ip<Wd	IP< ip < Wd	IP=ip=Wd
Spkr 2	(IP=ip) >Wd	IP<Wd	(IP=ip)<Wd	IP=ip=Wd

To sum up, vowels [i] and [a] tend to be more extremely articulated in a higher domain-final position — the high vowel [i] becomes higher and the low back vowel [a] becomes lower and backer. This suggests that vowels are strongly articulated domain-finally. This is different from domain-final consonants, which do not show greater articulatory magnitude (e.g., [2]).

3.2. Vowels in domain-initial CV syllables

For [a], there was a significant position effect on F1, with F1 being greater in higher domain-initial positions. This suggests that the open vowel [a] becomes more open in a higher prosodic position. For F2, only Speaker 1 shows a significant effect of position, but not in the direction expected. F2 was greater IP-initially, intermediate, ip-initially, and smaller word-initially — that is, the tongue body is fronter, not backer, in a higher position for the open back vowel [a]. For this speaker, there was no difference in F2 between nuclear pitch-accented and unaccented [a]s. For vowel [i], no systematic direction was found, though the effect of prosodic position on F1 and F2 was found to be significant in some cases.

So far, we have seen that F1 and F2 are varied with prosodic positions in a way that vowels are in general more extremely produced before and after higher prosodic boundaries. In what follows, we examine effect of prosodic position on resistance to V-to-V coarticulation.

3.3. Effect of prosodic position on degree of Vowel-to-Vowel coarticulation

F1 and F2 values for the test vowel V1 (V1≠V2) were compared with F1 and F2 values for the control vowel V1 (V1=V2), as the prosodic boundary varied between IP, ip and word. Then, the Euclidean distance between the test and control conditions was used as the index of degree of coarticulation: the longer the distance, the greater the coarticulatory effect in the test condition.

Anticipatory coarticulation. The positional effect on anticipatory coarticulation is illustrated in Figure 2. The first obvious and unsurprising fact is that F1 and F2 for test vowels are separated from their control counterparts, getting closer to the formant values of the following opposite vowel — anticipatory coarticulation. A more interesting point is that in general, the (Euclidean) distance between the control vowel and the test vowel was smaller at IP, intermediate at ip, and greater at a word boundary. The coarticulatory effect is in general seen in both F1 and F2, though for [a], Speaker 1 shows the effect only in F2. Overall, vowels in higher domain-final position have greater resistance to anticipatory coarticulation than do vowels in lower domain-final positions.

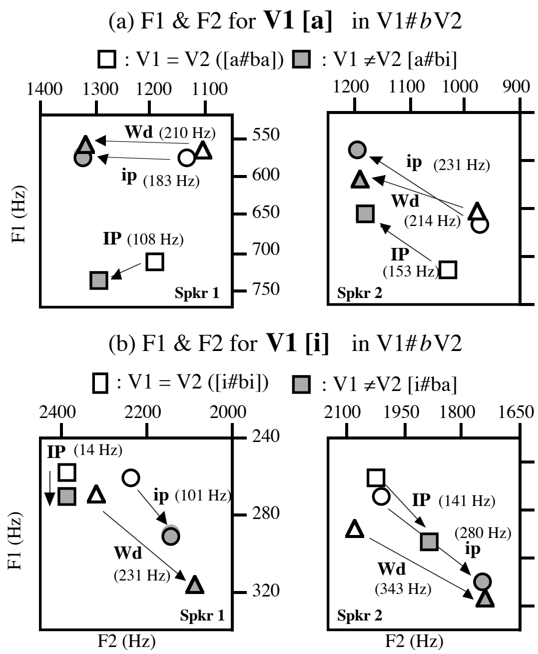


Figure 2. Effect of prosodic position on anticipatory coarticulation: (a) shows V1[a], (b) shows V1 [i]. White symbols indicate V1 followed by identical V2 (control), dark symbols indicate V1 followed by different V2 (test condition); arrows are labeled with the Euclidean distance (in Hz, not in scale of figures) between the test and control conditions.

Carryover Coarticulation. The effect of prosodic position on carryover coarticulation is illustrated in Figure 3. Again, the first obvious point is that F1 and F2 of the test vowels (V2) are closer to those of the preceding vowels, being separated from F1 and F2 of the control vowels (carryover coarticulation). As in the case of anticipatory coarticulation, the distance between the control and test vowels is smaller at IP, intermediate at ip, and greater at a word boundary, showing that higher domain-initial vowels resist carryover coarticulation to a greater degree than do lower domain-initial vowels.

Overall, the results show that the V-to-V coarticulatory resistance, as measured by Euclidean distance in vowel space, becomes progressively greater as its associated position moves up in the prosodic hierarchy. This confirms the hypothesis that vowels at edges of higher prosodic domains are strongly articulated and are more resistant to coarticulation with their neighboring vowels.

3.4. Effect of Pitch-Accent on V-to-V coarticulation.

As in the previous section, the Euclidean distance between the test vowel (V1≠V2) and the control vowel (V1=V2) was calculated from F1 & F2 values, for accented and unaccented vowels. For examining the effect of pitch-accent on V-to-V coarticulation, F1 & F2 values were compared between control and test vowels along with the Euclidean distances.

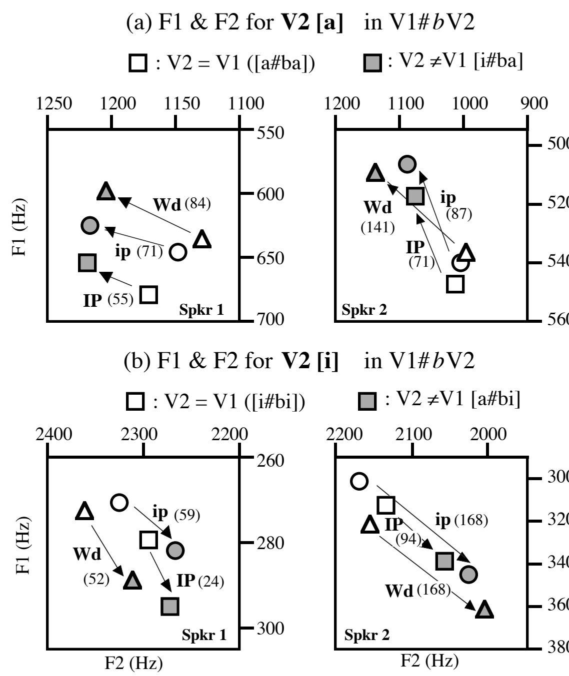
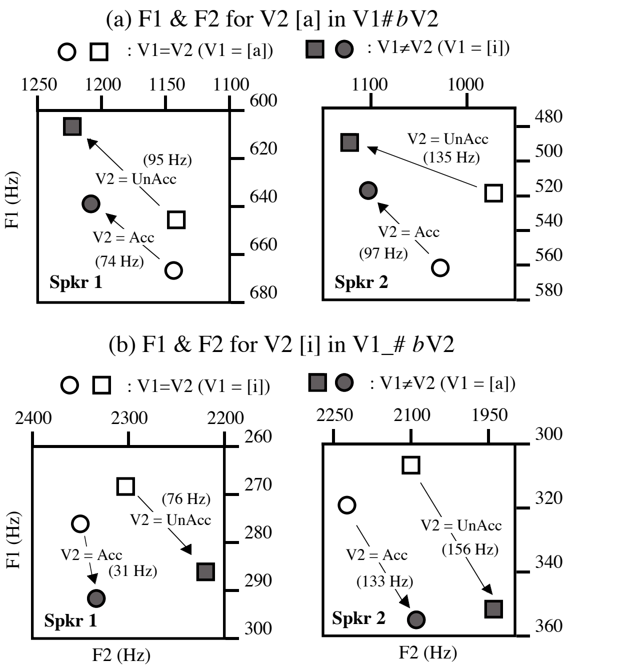


Figure 3. Effect of prosodic position on carryover coarticulation: (a) shows V2[a], (b) shows V2 [i]. (See the caption in Figure 2).

Anticipatory Coarticulation. For V1 [a], both speakers produced accented [a] with a greater deviation from the control vowel [a] in F1, but smaller deviation in F2 (figures not provided). Vowel [i], however, had a greater deviation from the control vowel in both F1 and F2 when the vowel [i] was accented than when it was unaccented. The common result for both [a] and [i] is that accented vowels resist coarticulation with the following opposite vowels at least in F1.

Carryover Coarticulation. The effect of pitch accent on carryover coarticulation is illustrated in Figure 4. As can be seen from the figure, a greater Euclidean distance was found for both [a] and [i] when a vowel is accented than when it is unaccented. A closer look at the figure, however, reveals that the greater coarticulatory resistance was not always found in both F1 and F2. For example, Speaker 2 produced the test accented vowel [a] with greater deviation from the control vowel in F1, but with smaller deviation in F2.

To sum up, both anticipatory and carryover coarticulation patterns have shown that vowels occurring in accented syllables in general resist coarticulation with neighboring vowels. This finding is consistently true in F1 across speakers, while there is speaker variation in F2.



ure 4. Effect of pitch-accent on carryover coarticulation: (a) shows V2[a], (b) shows V2[i]. Arrows are labeled with the Euclidean distance between the test and control conditions along with accentedness of V2.

4. GENERAL DISCUSSION

This paper examined (i) how vowels at edges of prosodic domain are realized as the prosodic domain varies from word up to Intonational Phrase and (ii) the extent to which vowels resist coarticulation in so-called strong positions. Results showed that vowels are in general strongly articulated domain-finally as well as in domain-initial CV syllables. We assume that such phonetic events at the edges of prosodic domains are linguistically motivated presumably for enhancing contrast of segments occurring at the edges of domains higher in the prosodic hierarchy (paradigmatic contrast). Such strengthening can also be viewed as enhancing the contrast between segments at the edges with the neighboring segments. Fougeron and Keating [6] suggested that the domain-initial strengthening results in a greater V-to-C and C-to-V displacement at the edges (syntagmatic contrast).

This type of prosodically conditioned strengthening can be better understood by examining coarticulation. de Jong [4, 5] suggested that the prominence associated with pitch-accent is linguistically motivated for enhancing lexical contrast and makes segments resist coarticulation with neighboring segments. In the current study, we have seen that vowels in pitch-accented syllables resist coarticulation with neighboring vowels, confirming de Jong's observation. In addition, a greater V-to-V coarticulatory resistance is also found at both edges of prosodic domains.

All in all, this study suggests that segments are strongly articulated in two prosodic positions: in pitch-accented syllables and at the edges of prosodic domains. Vowels occurring in the stronger positions are not only more extremely articulated but also more resistant in coarticulation with the neighbors. This study implies that the prosodic structure is closely related to, or influential on, phonetic realization of individual segment in a way that is crucial in understanding the low level phonetic events.

In this paper, we have not examined the relationship between the spatial and temporal aspects of the vowel production. Articulatory strengthening may be due to longer durations in stronger positions. Thus, examining the relationship between the duration and the articulatory magnitude would allow us to test the articulatory undershoot hypothesis that longer durations would result in articulator reaching its target (articulatory undershoot) (cf. [10, 11]). Examining the temporal aspects of the segments at the edges would also help understanding coarticulation. Our data contain a consonant [b] flanked by test vowels. It can be hypothesized that the shorter the intervening consonant, the less the coarticulatory resistance. We hope to present relevant data testing this hypothesis at the conference.

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REFERENCES

[1] Beckman, M.& Pierrehumbert, J. 1986. Intonational Structure in Japanese and English, Phonology Yearbook, **3**, 225-309.

[2] Beckman, M., Edwards, J., & Fletcher, J. 1992. Prosodic structure and tempo in a sonority model of articulatory dynamics. In *Paper in Laboratory Phonology II* (G.J. Docherty & D.R Ladd, editors), pp.68-86. CUP: Cambridge

[3] Cho, T. & Keating, P. 1999. Articulatory and acoustic studies on domain-initial strengthening in Korean. UCLA ms.

[4] de Jong, K. 1991. The oral articulation of English stress-accent. Ph.D. disseration, Ohio State University.

[5] de Jong, K. 1995. The supraglottal articulation of prominence in English: Linguistic stress as localized hyperarticulation. *JASA,* **97**(1), 491-504.

[6] Fougeron, C. & Keating, P. 1997. Articulatory strengthening at edges of prosodic domains. JASA **101**(6), 3728-3740.

[7] Hsu, C.-S. & Jun, S.-A. 1998. Prosodic strengthening in Taiwanese: Syntagmatic or paradigmatic?. *UCLA Working Papers in Phonetics*, **96**, 69-89.

[8] Keating, P. 1990. The Window Model of Coarticulation: Articulatory Evidence. In *Papers in Laboratory Phonology I: Between the grammar and physics of speech* (J. Kingston & M. Beckman, editors), pp. 451-470. CUP.

[9] Keating, P., T. Cho, C. Fougeron, & C. Hsu. 1998. Domain-initial strengthening in four langauges. To appear in *Papers in Laboratory Phonology 6.*

[10] Lindblom, B. 1963. Spectrographic study of vowel reduction. *JASA*, **35**, 1773-1781.

[11] Moon, S. J. & Lindblom, B. 1994. Interaction between duration, context, and speaking style in English stressed vowels. *Journal of the Acoustical Society of America,* **96**, 40-55.

[12] Pierrehumbert, J. & Talkin, D. (1992) Lenition of /h/ and glottal stop. In *Papers in Laboratory Phonology II: Gesture, Segment, Prosody* (G. Docherty & D. R. Ladd, editors), pp. 90-117. CUP.

[13] Vyra, M. & Folwer, C. 1992. Declination of supralaryngeal gestures in spoken Italian. *Phonetica* **45***,* 122-129