Additive Effects of Phrase Boundary on English Accented Vowels

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Abstract

This paper investigates cumulative effects of strengthening and lengthening on English vowels across two prominence-bearing prosodic factors, phrasal accent and prosodic phrase boundary. F1, F2 and duration measures are compared across vowels in three prosodic contexts: ip-medial unaccented, ip-medial accented, and ip-final accented. The results show that for most vowels there is only one degree of vowel strengthening, conditioned by phrasal accent, without any additive strengthening effect of prosodic phrase boundary. Lengthening is observed in both accent and added phrase boundary conditions, and the effect is consistently cumulative for at least some vowels, suggesting a gradient increase of duration as a function of the strength of prosodic structure. This finding also provides compelling evidence that strengthening and lengthening effects are two independent mechanisms that serve to mark prosodically strong positions.

1. Introduction

Prosody is realized not only in the form of suprasegmental features of pitch, loudness and duration, but also in the segment-level phonetic properties of speech sounds. A growing body of research demonstrates phonetic variation as a function of two main components of the prosodic structure, prosodic prominence (stress/accent) and prosodic phrasing (edges of prosodic domains). Prior studies show that both vowels and consonants exhibit prosody-induced strengthening and lengthening effects when they occur in prosodically strong positions: accented, phrase-initial and phrase-final. Articulatory studies show that in prosodically strong positions speech gestures are produced with greater magnitude and velocity, and with less coarticulation. Consonantal constrictions are produced with greater contact and longer duration, while vowels are produced with greater vocal tract opening [1-6]. The acoustic properties of speech sounds are also affected by prosodic structure, with longer overall acoustic durations for segments, and greater VOT and closure intervals for stops [2][7].

Prosody-induced strengthening and lengthening effects that are conditioned by position in the prosodic phrase are in some studies reported to be cumulative across levels of prosodic phrase structure; the effects increase incrementally at successively higher levels of prosodic phrase structure. The finding of cumulative prosodic effects is an important confirmation of prosodic theory. Prosodic structure is defined in terms of hierarchical layers of constituent structure, with a head element and edges encoded at each layer. The finding of similar effects of prosody at successive layers of prosodic structure supports the claim that the structures at each level are of the same type. The finding of cumulative effects across the levels supports the claim that the levels are hierarchically layered, with lower levels of structure contained within higher levels. Thus, a syllable that is final in a higher prosodic phrase will necessarily also be final in the lower level prosodic phrase. Evidence for cumulative prosodic effects on phrase-initial consonants is seen in measures of articulatory contact and acoustic duration [2][6], and in VOT for Korean voiceless stops [4]. In phrase-final positions, cumulative effects are observed in vowel duration [7]. However, contrary findings are reported in other studies that provide at best weak evidence of cumulative effects in phrase-initial positions [8], in phrase-final positions [9], and under prosodic prominence [10].

The studies cited above, among others, focus on evidence of cumulative effects exclusively across the prosodic prominence factors (e.g. unstressed vs. stressed vs. accented) or exclusively across the prosodic phrase levels (e.g. comparing medial vs. edge positions in the prosodic word, intermediate phrase, or intonational phrase). No study has drawn an explicit comparison of prosodic effects of prominence and phrase structure, or considered the interaction of these effects in combination. The present study undertakes this comparison, and looks for evidence of cumulative effects of prosodic strengthening and/or lengthening in positions that are both prosodically prominent and in a prosodic phrase boundary position. A direct comparison of the effects of prosodic prominence vs. prosodic phrase boundary will indicate whether these two features of prosodic structure (head-marking and edge-marking) have common effects on segment-level phonetic variation. Evidence for cumulative effects in positions of combined prosodic strength (prominence and phrase-boundary) would suggest a common mechanism of prosodic strengthening induced by these two different prosodic factors.

Our study investigates prosodic effects of phrasal accent and prosodic phrase boundary through an acoustic study of vowels in American English. We examine evidence of strengthening and lengthening of vowels in three prosodic contexts defined in terms of prominence and position in the intermediate phrase (ip), listed here in increasing order of prosodic strength: ip-medial unaccented, ip-medial accented, and ip-final accented. The ip-final accented vowels are predicted to exhibit combined effects of phrasal accent and prosodic phrase boundary, while ip-medial accented vowels should show only the effects of phrasal accent, and vowels in both of these prosodically strong positions are expected to be lengthened and/or strengthened in comparison to the vowels in the prosodically weak ip-medial, unaccented positions. We hypothesize three possible effects of prosodic strengthening. Relative to vowels in weak positions, vowels in prosodically strong positions will have (i) longer acoustic duration, (ii) enhanced sonority, measurable in higher F1 values, and (iii) expanded distinctions in F1 and F2 features that enhance phonological height and backness contrasts. Notice that hypotheses (ii) and (iii) are in conflict for high vowels, which under sonority enhancement should exhibit lowering (raised F1), but under height enhancement should exhibit raising

(lowered F1). One goal of this study is to determine which of these effects, if either, is evident for high vowels, and to compare effects on high and non-high vowels. These hypotheses are tested on the basis of acoustic duration, F1 and F2 measures in vowels in the three target prosodic contexts. A further hypothesis is that the strengthening and/or lengthening effects will increase with the strength of the prosodic context. These hypotheses are tested against the vowels of four speakers from a corpus of radio broadcast news speech.

2. Methods

2.1. Corpus

Prosodic effects on vowels are studied based on speech from the lab news portion of the Boston University Radio News corpus [11]. This portion of the corpus includes 4 news stories that were read by professional news announcers in their radio news style. We analyzed all the lab news data for 2 female speakers (F2B, F3A) and 2 male speakers (M1B, M2B) out of 6 speakers. The database we analyzed includes approximately 42 minutes of speech in total, and is accompanied by a word transcription using the TIMIT set of phone labels and a prosodic transcription according to the ToBI labeling convention [12].

2.2. Materials

The current study examines 7 vowels /i, ɪ, ɛ, æ, ɑ, ʌ, u/ in 3 prosodic contexts: ip-medial unaccented, ip-medial accented, and ip-final accented. Accent effects are analyzed for all 7 vowels, but due to data sparseness, examinations of boundary effects are made only for /i, ɪ, ɛ, æ, ɑ, ʌ/ for 3 speakers (F3A, M1B, M2B), and for /i, ɪ, æ, ʌ/ for one speaker (F2B). All ip-final tokens were extracted from the final rhyme of the word at ip and IP boundaries. Tokens preceded by a glide or followed by a liquid were excluded in the analysis of vowel quality due to the possible effects of coarticulation with those segments on the F2 value of the target vowel. Acoustic landmarks were manually labeled for the measurement of formant values and duration. Formant measurements were taken from the steady state mid-point of each target vowel, or from the temporal mid-point for vowels with no steady-state. The boundaries of vowel segments were manually located at the appearance of the second formant as the beginning to the disappearance of the second and higher formants as the end. Formant values were extracted in Bark value by computing the LPC coefficients applying the Burg algorithm using the Praat software for speech analysis and synthesis [13]. After measurements were extracted, tokens whose formant or duration measures were above or below two standard deviations from the mean values were also excluded. Tables 1 and 2 provide counts for each vowel and each prosodic context.

Table 1: *Number of vowels by vowel type (F1,F2/duration)*

	i	ɪ	ɛ	æ	ɑ	ʌ	u
F3A	157/ 180	159/ 166	142/ 147	65/ 65	55/ 54	88/ 89	54/ 76
F2B	172/ 198	202/ 206	138 /136	71/ 77	48/ 47	99/ 112	27/ 77
M1B	172/ 198	202/ 206	138 /136	71/ 77	48/ 47	99/ 112	27/ 77
M2B	167/ 199	192/ 198	169/ 166	81/ 85	63/ 62	102/ 109	45/ 52

Table 2: *Number of vowels by prosodic context (F1,F2/duration)*

	ip-med, unacc.	ip-med, acc.	ip-fin, acc.
F3A	260 / 320	397 / 392	63 / 65
F2B	333 / 386	367 / 392	57 / 75
M1B	276 / 329	446 / 446	97 / 96
M2B	236 / 386	390 / 449	90 / 85

3. Results

The results of F1, F2 and duration measures are compared for significant differences based on *t*-test analysis. ip-medial unaccented vowels are compared to ip-medial accented vowels for the effect of accent alone, and ip-medial accented vowels are compared to ip-final accented vowels to examine the effect of prosodic phrase boundary for accented vowels. The effect of phrase boundary is defined as cumulative when there are significant effects in the same direction for both the Accent and Phrase Boundary conditions. The effect of phrase boundary is defined as not cumulative if (i) there is a significant effect of Accent (on ip-medial vowels), but no significant effect of Phrase Boundary (on accented vowels), or (ii) there is a significant effect of Phrase Boundary but no significant effect of Accent.

3.1. Strengthening

Tables 3 and 4 display the results of the two *t*-test comparisons for measurements of F1 and F2, and Table 5 presents *t*-test results for duration measures. Results are given separately for each vowel and each speaker. In these tables the first column identifies the speaker, and the second column identifies the comparison: the 'A' row shows results for the effect of Accent (comparing ip-medial unaccented vowels and ip-medial accented vowels), while the 'B' label shows results for the Phrase Boundary effect (comparing ip-medial accented vowels and ip-final accented vowels). Two asterisks indicate a highly significant effect at $p < .01$, one asterisk a significant effect at $p < .05$, and 'n.s' a non-significant effect when alpha is set to .05. The 'R', 'L', 'F', and 'B' labels stand for raising, lowering, fronting, and backing effects, respectively. The label 'N/A' marks the cells of vowels that are excluded in the analysis due to scarcity of data. Gray cells mark vowels that exhibit cumulative effects, i.e., significant effects of both phrase boundary and accent for the given measure.

Table 3: *Results of t-test : F1*

		i	ɪ	ɛ	æ	ɑ	ʌ	u
F3A	**A**	** R	** L	** L	n.s.	n.s.	* L	n.s.
	B	n.s.	n.s.	n.s.	n.s.	n.s.	* L	N/A
F2B	**A**	* L	** L	* L	n.s.	n.s.	* L	* L
	B	n.s.	n.s.	N/A	n.s.	N/A	n.s.	N/A
M1B	**A**	n.s.	** L	** L	n.s.	n.s.	n.s	n.s.
	B	n.s.	n.s.	n.s.	** L	n.s.	n.s.	N/A
M2B	**A**	n.s.	** L	** L	* L	n.s.	** L	n.s
	B	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	N/A

As shown in Table 3, there is a significant lowering effect (F1 raising) on the sonority dimension that occurs primarily under phrasal accent. The most dominant effect is an across-the-board lowering effect on lax vowels (/ɪ/, /ɛ/: all speakers; /ʌ/: F3A, F2B, M2B) under phrasal accent in the ip-medial position. High vowels, whose sonority enhancement conflicts with the enhancement of their phonologically contrastive height feature, show inconsistent effects under phrasal accent (/i/: F3A-raising, F2B-lowering, M1B, M2B-no effect; /u/: F2B-lowering, the other speakers-no effect), and there is no effect for /i/ in the ip-final position. We find almost no effects of any kind for low vowels, with only 2 speakers exhibiting lowering of /æ/ in the accented (M2B) and ip-final positions (M1B), respectively. Effects of phrase boundary are insignificant for most of the accented vowels but lowering of /æ/ and /ʌ/ for one speaker (M1B, F3A, each) in the ip-final position. Cumulative effects in the sonority dimension (i.e. lowering or raising effects) are found only for /ʌ/ for speaker F3A.

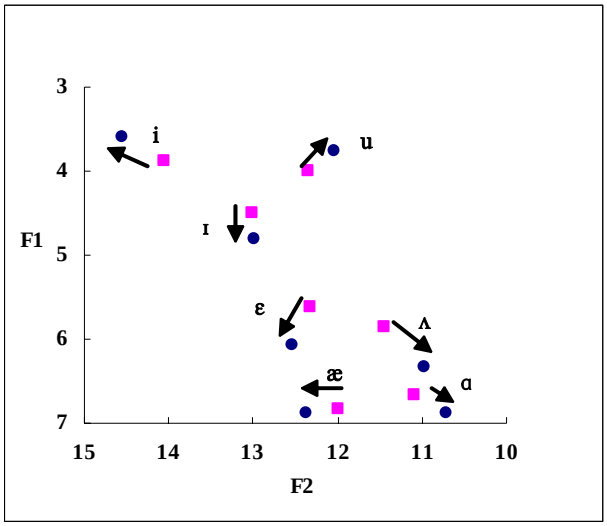
Table 4: *Results of t-test: F2*

		i	ɪ	ɛ	æ	ɑ	ʌ	u
F3A	A	** F	n.s.	n.s.	** F	n.s.	* B	** B
	B	* F	n.s.	n.s.	n.s.	* B	n.s.	N/A
F2B	A	** F	n.s.	n.s.	* F	n.s.	n.s.	** B
	B	n.s.	n.s.	N/A	n.s.	N/A	** F	N/A
M1B	A	** F	* B	n.s.	n.s.	** B	n.s.	** B
	B	n.s.	n.s.	** F	n.s.	n.s.	n.s.	N/A
M2B	A	** F	* B	n.s.	n.s.	n.s.	n.s.	n.s
	B	n.s.	n.s.	n.s.	n.s.	n.s.	* F	N/A

Table 4 demonstrates significant fronting effects of front vowels and significant backing effects of back vowels under phrasal accent. These effects are consistently observed for at least some speakers (fronting of /i/ (all speakers) and /æ/ (F3A, F2B), backing of /ɑ/ (M1B) and /u/ (F3A, F2B, M1B)). In the ip-final position, there are significant fronting and backing effects only sporadically across vowels and speakers (fronting of /i/ (F3A) and /ɛ/ (M1B), backing of /ɑ/ (F3A)). Backing of /ɪ/ is significant for 2 speakers (M1B, M2B) under phrasal accent in the ip-medial position, but we find no further significant backing effect for accented vowels in the ip-final position. Additive effects of prosodic phrase boundary are significant only for /i/ for speaker F3A. The central vowel /ʌ/ shows a significant backing effect for one speaker (F3A) under phrasal accent while significant fronting effects for two speakers (F2B, M2B) in the ip-final accented position.

Figure 1 displays a plot of ip-medial unaccented vowels and ip-medial accented vowels for speaker F3A. The figure shows the expansion of the acoustic vowel space, and consistent lowering of lax vowels in the ip-medial accented position relative to the ip-medial unaccented position. The expansion of the space is mostly attributable to the movement of front and back vowels in the opposite direction in backness dimension. The contrast between tense and lax vowels is also enhanced for 2 speakers (M1B, M2B) who show significant backing effects for /ɪ/ in the ip-medial accented position, though that effect is shown only by lowering of /ɪ/ for speaker F3A. The accent-induced effects for the other 3 speakers show overall similar patterns to what is displayed in the figure 1 below.

Figure 1: *Plot of ip-medial unaccented vowels (square) and ip-medial accented vowels (circle), speaker F3A*



3.2. Lengthening

Table 5 exhibits results of the *t*-test analysis on duration. Significant lengthening effects are observed in the ip-medial accented position for all vowels for at least one speaker except for /ɑ/. /i/ is uniformly lengthened across all speakers when accented in the ip-medial position. /ɪ/, /æ/, and /u/ show significant lengthening effects for 3 speakers, /ʌ/ for 2 speakers, and /ɛ/ for one speaker. /ɑ/ shows no lengthening effect for all speakers. Effects of prosodic phrase boundary are more consistent across vowels and speakers compared to accent-induced lengthening effects. Four vowels, /i/, /ɛ/, /æ/, and /ɑ/, exhibit uniform lengthening effects for all speakers we analyzed. The other two vowels, /ɪ/ and /ʌ/ are also significantly lengthened in the ip-final accented position for 2 speakers. Cumulative effects of lengthening are found for /i/ for all speakers and /æ/ for 3 speakers (F2B, M1B, M2B). Also, speaker M2B shows cumulative lengthening effects for all front vowels, exhibiting significant effects in both of the 2-way comparisons.

Table 5: *Results of t-test: duration*

		i	ɪ	ɛ	æ	ɑ	ʌ	u
F3A	A	**	**	n.s.	n.s.	n.s.	**	*
	B	**	n.s.	*	**	**	n.s.	N/A
F2B	A	*	n.s.	n.s.	**	n.s.	n.s.	n.s.
	B	**	*	N/A	**	N/A	**	N/A
M1B	A	**	**	n.s.	**	n.s.	n.s.	**

	B	*	n.s.	**	**	*	*	N/A
M2B	**A**	**	**	**	**	n.s.	**	**
	B	**	**	**	**	**	n.s.	N/A

4. Discussion

From the findings of this study, strengthening effects on vowels that enhance sonority or place features are evident mainly under the condition of phrasal accent. The patterns of enhancement on accented vowels are asymmetric, with a greater effect on the backness dimension than on sonority. Phonological contrasts are also consistently enhanced between front and back vowels, and between tense and lax vowels, under phrasal accent. Additive strengthening effects of the prosodic phrase boundary condition also induce enhancement of phonological features mostly in the same direction, if any, but the effects are minor and sporadic across vowels and speakers, providing at best weak evidence of cumulativity. In contrast, lengthening effects are cumulative across the three prosodic contexts for some vowels, most notably /i/, where vowel duration increases with the prosodic strength of the syllable. For those vowels with cumulative lengthening effects, vowel duration measures show ip-medial unaccented < ip-medial accented < ip-final accented. For vowels that do not exhibit cumulative lengthening, some exhibit lengthening only under accent, while others exhibit lengthening only under the prosodic phrase boundary condition. The non-cumulative lengthening effects vary both by vowel and by speaker, but there are more lengthening effects under the phrase boundary condition.

Comparison of the results for strengthening in the spatial (F1/F2) and temporal dimensions suggests implications for models of speech production. With respect to the prosodic strengthening of vowels, there seem to be just two distinct variants for most vowels: a hyperarticulated variant that occurs in positions of phrasal prominence (accent, or accent in combination with phrase boundary), and a non-hyperarticulated variant that occurs in non-prominent positions. There is no strong evidence that prosodic strengthening is gradient; strengthening effects that enhance sonority or backness features do not in general increase with the prosodic strength of the syllable. In contrast to the limited variation in the spatial displacement of vowels (in F1/F2 space), prosodic effects on vowel duration give rise to gradient lengthening, which increases with the prosodic strength of the syllable.

These findings provide indirect evidence that prosody-induced strengthening and lengthening are separate mechanisms in speech production. Previous studies taken together present an inconsistent picture of the relationship between prosody-induced strengthening and lengthening. Some studies report articulatory strengthening effects combined with lengthening effects in prosodically strong positions [2], while others report only lengthening effects without increased strengthening [14]. Our findings show differences between lengthening and strengthening, with cumulative effects primarily in lengthening. This finding suggests that prosodic structure affects the temporal and spatial dimensions of vowel production differently. The hierarchical feature of the prosodic context (the prosodic level) is reflected more closely in vowel duration, while vowel quality reflects a coarser distinction between prosodically strong and weak positions.

In conclusion, we find additive lengthening effects of prosodic phrase boundary for some accented vowels in the ip-final position, and very little evidence of additive strengthening effects. Overall, lengthening is found to show a gradient pattern of variation as a function of the strength of prosodic structure in contrast to strengthening, which is expressed by only one degree of enhancement.

5. References

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