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Acoustic Effects of Prosodic Boundary on Vowels in American English

EUN-KYUNG LEE & JENNIFER COLE
University of Illinois at Urbana-Champaign

0. Introduction

Prosody in speech is expressed through the modulation of pitch, duration, loudness and spectral balance. These features encode (i) phonological phrase structures that serve to group words into sense units, and (ii) prominence structures that mark the location of perceptually prominent syllables and words within larger domains. The prosodic phonological structures that encode phrasing and prominence are hierarchically organized: smaller/lower phrases are contained within larger/higher ones, and prominent units defined within a larger domain are projections of prominent units defined in successively lower domains. The hierarchical model of prosodic structure posits that the distinction between smaller and larger prosodic domains is a distinction in level. The effects of prosodic domains on phonological and phonetic structures are similar in type across levels, but levels may differ in the number or strength of those effects. This paper investigates the presence of acoustic correlates of the level distinction between prosodic domains. The focus is on the distinction between the smaller 'intermediate' phrase and the larger 'intonational' phrase through a comparison of the effects of the phrasal boundary on the final vowel in the phrase. The study reported here addresses the question of whether the effects of the higher phrase boundary on acoustic measures are of the same type as the effects of the lower boundary, and if so, whether the higher phrase level exhibits acoustic effects with consistently stronger magnitude compared to the lower phrase level. The goal is to discover if there is evidence that prosodic phrase boundaries produce acoustic effects that are cumulative over successive layers of prosodic structure.

Earlier research has found that articulatory speech gestures undergo spatiotemporal enhancement when they occur at the left or right edge of a prosodic domain (Edwards et al. 1991, Beckman et al. 1992, Fougeron and Keating 1997, Byrd and Saltzman 1998, Keating et al. 1999, Cho and Keating 2001). In domain-edge positions, the speech gestures that form constrictions in the vocal tract are produced with temporally longer duration, greater linguopalatal contact and larger displacement. These effects are modeled by Byrd (2000) and Byrd and Saltzman (2003) in terms of a prosodic "π-gesture", which warps the temporal dimension of speech in the region of a juncture between prosodic domains, providing a mechanism for the widely observed phenomenon of boundary lengthening. Acoustic evidence of prosodically-induced strengthening is also found for segments at prosodic phrase boundaries, with greater VOT in voiceless stops and less nasal energy in nasal stops (Cooper 1991, Pierrehumbert and Talkin 1992, Jun 1993, Fougeron and Keating 1997, Cho and Keating 2001). Of interest, similar patterns of acoustic and articulatory strengthening are observed for segments in boundary positions at higher and lower prosodic phrases (Wightman et al. 1992, Keating et al. 1999, Cho and Keating 2001, Fougeron 2001, Tabain 2003a, b, Cho 2005). There is also some evidence to suggest that boundary-induced strengthening effects are cumulative across successively higher levels of prosodic phrase structure, for both temporal and spatial strengthening, and for domain-initial and domain-final segments; however, the effects are not uniform (cumulative strengthening is not observed across all levels of phrasal domains in the prosodic hierarchy) and cumulative effects in domain-final position are less consistent across studies than in domain-initial position.

Segments in boundary positions of prosodic domains are shown to exhibit both temporal lengthening and spatial strengthening effects, but there are conflicting findings across studies with respect to whether these two effects are correlated with each other or not. Fougeron and Keating (1997) report that articulatory measures of peak contact for a domain-initial /n/ increase as a function of the strength of the prosodic juncture, and this pattern is combined with an increase in temporal duration. Byrd and Saltzman (1998) find a correlation between increased magnitude of lip movement and temporal duration for consonants across the edges of multiple levels prosodic domains. Keating et al. (1999) and Cho and Keating (2001) also show that greater VOT and greater linguopalatal contact for consonants are correlated with increased duration in Korean. However, a few studies suggest the independence of articulatory strengthening and temporal lengthening. Byrd et al. (2000) find segments in larger phrases are distinguished from those in smaller phrases and words in their temporal duration but not in their articulatory magnitude, indicating that they are two independent effects. Keating et al. (1999) also find less evidence for the correlation between articulatory strengthening and lengthening in languages they examined, other than Korean.

Prosodic boundary consonants are observed for consonants in the form of more complete gestures that form consonantal constrictions. Boundary effects for vowels are less clear, and studies report inconsistent findings on whether prosodic strengthening for vowels results in more open vowels (sonority expansion) or vowels with more peripheral articulation (place enhancement). Farnetani and Vayra (1996) find a main effect of sonority expansion. Tabain (2003a, b) and Cho (2005) find that the low vowel /a/ is lowered and further back at high level prosodic boundaries in French and in English, respectively. For this vowel, lowering results in the enhancement of both sonority and height features simultaneously. However, for high vowels, sonority expansion and enhancement of the height feature are antagonistic effects, pulling the vowel gesture in opposite directions. The front high vowel /i/ has been found to be raised and fronted in boundary positions at higher levels of prosodic phrase structure compared to lower levels (Cho 2005), and the back high vowel /u/ is more raised and further back. Thus, both vowels occupy more peripheral positions in the acoustic vowel space (Tabain et al. 2004). These findings show that for domain-edge high vowels, enhancement of the phonologically contrastive place features is primary over sonority expansion.

Relatively few of the prior studies have investigated the acoustic consequences of prosodic boundary strengthening. Most of the earlier studies are based on articulatory data, and the focus is more on consonants than on vowels. In addition, nearly all prior work is based on data obtained from controlled laboratory speech, in which speakers are asked to read scripted materials adopting a prosodic phrasing predetermined by the experimenter. Also, existing data is limited to three point vowels, /i, a, u/, with few findings regarding other vowels. One important source of acoustic data for prosodic boundary effects is the study by Wightman et al. (1992) based on data from the Boston University Radio News corpus (Ostendorf et al. 1995). Wightman et al. reports cumulative lengthening of the vowels in the final rhyme at successively higher levels of prosodic domains. However, the question of whether the lengthening effect is prevalent across all vowels or variant depending on the individual vowel is yet to be answered.

The present study investigates acoustic variation of vowels in domain-final position as a function of the level of the prosodic boundary, through acoustic measures of F1, F2 and duration. The investigation is based on the speech of four professional news announcers from the Boston Radio News corpus. While these data do not represent spontaneous speech, the speech is produced with a communicative function and includes a variety of naturally occurring sentence types. Unlike experimenter-controlled speech, in Radio News speech the speaker chooses the prosody that is most natural given the form and meaning of the utterance, with no influence from the experimenter on the design or delivery of the sentences. The goal of our study is to investigate acoustic evidence of pre-boundary strengthening and lengthening on vowels, comparable to the articulatory evidence reported in earlier work. A further objective of the current study is to examine evidence for differences between prosodic phrase levels in their lengthening and/or strengthening effects on domain-final vowels. Further, the relationship between these two effects is also examined. The investigation is based on two vowel subsets: the high, front vowel monophthongs (/i/, /ɪ/) and two mid-rising diphthongs (/eɪ/, /oʊ/).

0.1. Hypotheses

In this study, strengthening is defined as the enhancement of phonological place contrasts in the backness or height dimensions, and/or expansion of sonority, as measured in variation in acoustic F1 and F2 features. Lengthening is measured in an increase in acoustic duration. We test four hypotheses related to prosodic effects for domain-final vowels. Hypotheses 1-3 state the predicted effects of prosodic strengthening and lengthening for the acoustic measures of vowels and the correlation between the spectral and temporal effects. Hypothesis 4 follows from a strong version of prosodic layering; if level distinctions are recognized for prosodic phrases, then there should be clear evidence of those distinctions in the phonetic features that encode phrasal boundaries.

(1) **Prosodic strengthening:** Vowels in the final rhyme of a higher prosodic domain will be strengthened compared to final vowels in a lower domain, with measurable acoustic effects on the F1 and F2 features that reflect either sonority or place feature enhancement. For /i/ and /ɪ/, this strengthening will result in their greater separation in acoustic space. For the diphthongs /eɪ/ and /oʊ/, strengthening will increase the diphthongal gliding gesture, with greater distance between the onset (nucleus) and offset (glide) targets of the glide, enhancing the difference between diphthong and monophthong. Further, evidence of sonority expansion will be observed in uniformly higher F1 values for all vowels.
(2) **Prosodic lengthening:** Vowels in the final rhyme of higher prosodic domains are expected to have longer duration than those in the final rhyme of lower prosodic domains.
(3) **Correlated lengthening and strengthening:** Strengthening effects in higher prosodic domains are expected to be observed only in the presence of lengthening effects, and vice-versa.
(4) **Prosodic level encoding:** The distinction between prosodic phrases at different levels is evident in differences in the acoustic features that encode prosodic phrase boundaries. Specifically, the strengthening and/or lengthening of domain-final vowels will produce distinct vowel variants depending on the phrase level.

1. Methods

1.1. Corpus

The present study examines vowels taken from the lab news portion of the Boston Radio News corpus. This portion of the corpus includes four news stories read by six professional news announcers in their radio style. The recordings were made in a laboratory at Boston University. All the lab news data were analyzed for two female speakers (F2B, F3A) and two male speakers (M1B, M2B) out of six speakers. The database for these four speakers includes approximately 42 minute speech in total, and is accompanied by time-aligned phone and word transcriptions using the TIMIT set of phone labels and the prosodic transcription marking pitch accents and phrasal boundaries according to the ToBI labeling convention (Beckman and Elam 1997).

1.2. Materials

Vowel tokens were extracted from the final rhyme of words in three prosodic phrase contexts: phrase-medial (Wd), final in the intermediate phrase (ip), and final in the intonational phrases (IP). These contexts represent distinct prosodic domains at successively higher levels in the hierarchical prosodic structure, namely, Prosodic Word, Intermediate Phrase, and Intonational Phrase. Each ip can have one or more phonological words, and is marked with an H- or L- phrase accent. The ip contains at least one pitch accent, associated with a pragmatically marked (e.g., focused, new information) word at the sentence level. The intonational phrase is a larger phrasal constituent that is composed of one or more ips, and delimited by an H% or L% boundary tone at the end.

To look at the effect of the prosodic boundary alone, only unaccented vowels were considered in this study. Vowels marked as prominent at the phrase level, i.e., accented vowels, were excluded in order to avoid confusing possible strengthening or lengthening effects due to phrasal accent with boundary effects. Four vowels are examined in the final syllables of Wds, ips, and IPs: two front vowels (/i/, /ɪ/) and two diphthongs (/eɪ/, /oʊ/). All tokens preceded by /j/ or /w/ or followed by /r/ or /l/ were excluded from the analysis because those preceding or following segments tend to affect the F2 value of the adjacent vowel. The number of tokens varied across prosodic conditions, across individual vowels and across speakers. All speakers had sufficient tokens for high front vowels in the final rhyme of all three prosodic domains (Wd, ip, IP), but only three speakers (F2B, F3A, M2B) had enough tokens of the diphthong /eɪ/ in the final rhyme of all three prosodic domains. For the diphthong /oʊ/, the data from all four speakers were compared for two prosodic domains (Wd, IP). Table 1 presents a summary of the subset of vowels examined in this study and prosodic conditions compared for each vowel.

Table 1. Summary of the data for analysis

Vowels		**Categories of comparison**	**N of speakers**
Monophthong	Tense (/i/)	Wd, ip, IP	4 speakers
	Lax (/ɪ/)		
Diphthong	Front (/eɪ/)		3 speakers
	Back (/oʊ/)	Wd, IP	4 speakers

1.3. Measurements

1.3.1. Acoustic Measurements

Acoustic landmarks for the measurement of formant values and segment boundaries were manually labeled. The formant values were automatically taken using Praat, computer software for speech analysis and synthesis (Boersma and Weenik 2005). For monophthongs (/i/, /ɪ/), the label was marked at the steady-state or middle point of each target vowel. In cases where a steady-state point was not observed, measurements were taken from the middle. For diphthongs (/eɪ/, /oʊ/), onset and offset points were separately marked. The onset target was taken from the temporal point around the 2^{nd} -4^{th} glottalic cycle from the beginning of the vowel while the offset target was taken from the temporal point around the 2^{nd}-4^{th} glottalic cycle before the end. The boundaries of vowel segments were hand-corrected to mark from the appearance of the second formant to the disappearance of the second and higher formants. Formant values were extracted from the marked temporal points by computing the LPC coefficients applying the Burg algorithm. The time step of Gaussian analysis windows was set to 0.025s with Pre-emphasis of frequencies above 50 Hz. The Maximum formant was set to 5,000 Hz for male speakers and 5,500 Hz for female speakers for the extraction of five formants. In this study, only the first two formant values were extracted with values both in Hertz and Bark, and used for analysis. Duration was measured based on the difference between the starting time and the end time of the vowel interval.

1.3.2. Statistical Analysis

The statistical analysis was conducted for data pooled across all four speakers. To reduce unnecessary variation while not losing phonological variation (Adank et al. 2004), the data were normalized within-speaker for F1, F2 and duration measures of each vowel separately using the z-score transformation. The z-score computation was based on the following equation.

(5) $z = (f - \mu) / \sigma$

In the above equation, z is the normalized transformed value of F1, F2 and duration for each vowel token, indicating the observed data point relative to the overall mean. f is the raw frequency values in Hz for F1 and F2 measures, and the raw value in ms. for duration measure. μ is the overall mean frequency and duration calculated for the vowel category within speaker, and σ is the standard deviation of the overall mean of F1, F2 and duration of the vowel category for each speaker. After transforming, all data with absolute z-score value above 3 were excluded from the analysis. Table 2 summarizes the number of vowel tokens used for statistical analysis for each measure by vowel type and by prosodic context.

Table 2. Number of vowels by vowel type (left) and by prosodic context (right)

	/i/	**/ɪ/**	**/eɪ/**		**/oʊ/**	
			onset	offset	onset	offset
F1	462	391	82	89	99	77
F2	465	395	81	87	98	76
Dur	462	391	82	89	98	77

	Wd	**ip**	**IP**
F1	739	168	293
F2	739	169	294
Dur	747	166	286

A two-way ANOVA was conducted using prosodic context (Wd, ip, and IP) and speaker (F2B, F3A, M1B, M2B) as independent variables for the pooled data for each vowel (/i/, /ɪ/, onset and offset targets of /eɪ/, and onset and offset targets of /oʊ/) for each of three z-transformed acoustic measures: F1 z-score, F2 z-score, and duration z-score. In the ANOVA analysis, the effect of each of the two independent factors and the interaction between those two factors were investigated. A significant interaction between prosodic context and speaker imply that there is speaker variability in the effects of prosodic boundaries. Tukey post-hoc analyses were performed for /i/, /ɪ/, and /oʊ/ for all comparisons that included three levels (Wd, ip, IP). To compensate for multiple comparison levels, the alpha value for significance was set to .01. The relationship between strengthening and lengthening was tested based on regression analysis.

2. Results

2.1. Strengthening

Table 3 presents the summary of results.

Table 3. Results from 2-way ANOVAs for each vowel separately, with dependent variables of F1 and F2 z-scores, and independent variable of Prosodic context (Wd, ip, IP).[Null effects of speaker not shown.] **: $p<.01$, n.s.: $p>.05$. Tukey post hoc comparisons of *F1 z-score and F2 z-score* among 3 levels of prosodic boundaries (Wd, ip, IP) for data pooled across speakers are presented in italics for /i/, /ɪ/, and /eɪ/ (with alpha set at .01). For /oʊ/, means are compared between vowels at the IP and Wd boundaries. For diphthongs, _b labels the onset (beginning) target, and _e labels the offset (end) target.

	/ι/	**/I/**	**/εI_b/**	**/εI_e/**	**/oY_b/**	**/oY_e/**
F1 (Height)	n.s.	Lowering ** *Wd=ip<IP*	Lowering ** *Wd=ip<IP*	n.s.	Lowering ** *Wd<IP*	n.s.
F2 (Backness)	n.s.	Backing ** *Wd>IP=ip*		n.s.	Backing ** *Wd>IP*	Backing ** *Wd>IP*

Summarizing the ANOVA and post-hoc analyses, for /i/, there was no main effect of prosodic boundary on vowel formants in either the height (F1) or backness (F2) dimensions. For /ɪ/, significant lowering and backing effects were observed for vowels in the final rhyme of high level prosodic domains compared to lower levels (F1: $F(2, 379)=16.168$, $p<.01$; F2: $F(2, 383)=9.969$, $<.01$). The onset target of /eɪ/ showed a significant lowering as a function of the level of prosodic boundary (F1: $F(2, 73)=14.875$, $p<.01$) while no main effect of prosodic boundary was observed for the offset target. For the onset target of /oʊ/, main effects of prosodic boundary were found both in height and backness dimensions for vowels at high level prosodic boundaries. The onset target of /oʊ/ was more lowered and further back in the acoustic vowel space (F1: $F(2, 91)=12.722$, $p<.01$; F2: $F(2, 90)=14.376$, $p<.01$). The offset target of /oʊ/ showed significant backing effect (F2: $F(1, 68) = 8.396$, $p<.01$) without a main effect of prosodic context in the vertical dimension. There was no main effect of speaker, and the interaction between prosodic context and speaker was not significant for F1 and F2 for all vowels. Post hoc results reveal that vowels in the IP boundary condition are distinctively distinguished from vowels in the Wd boundary condition for all acoustic measures that show a main effect of prosodic boundary in the two-way ANOVA. Vowels in the ip boundary condition exhibit no consistent patterns either relative to vowels in the IP boundary condition or relative to vowels in the Wd boundary condition. Though the IP boundary is separated from both the ip and Wd boundaries for the F1 measure, and the Wd boundary is grouped separately from both the ip and IP boundaries for the F2 measure, data from additional vowels are needed for further generalization.

Figure 1 displays an ellipse plot showing the relative positions of /i/ and /ɪ/ in the acoustic vowel space of F1 and F2, comparing vowels in the Wd and IP boundary conditions. Vowel data are pooled across all speakers. The figure shows that the space between high front tense and lax vowels is expanded in the IP boundary condition relative to the Wd boundary condition based on the pooled data. Similar expansion of the acoustic distinction is seen in ellipse plots of individual speakers.

Figure 1. Ellipse plot of F1 and F2 in bark values for /i/ and /ɪ/, from all speakers pooled (left), and from speaker F3A alone (right). Dashed lines: vowels in the Wd boundary condition, plain lines: vowels in the IP boundary condition.

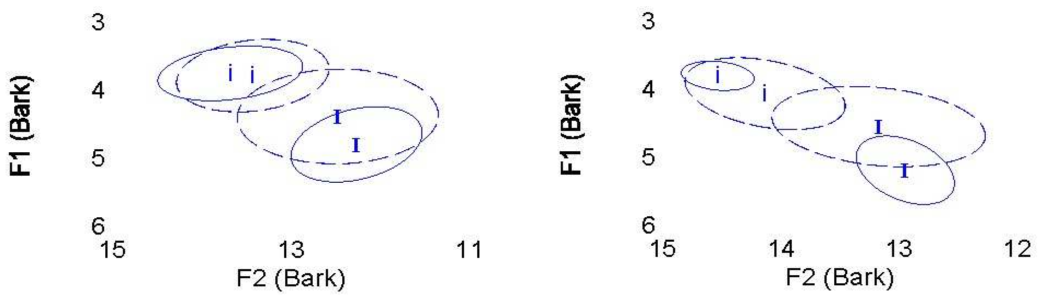

Figure 2. Mean plot of F1 and F2 in bark values for onset and offset targets of diphthongs. Empty Squares: vowels in the Wd boundary condition, filled squares: vowels in the IP boundary condition.

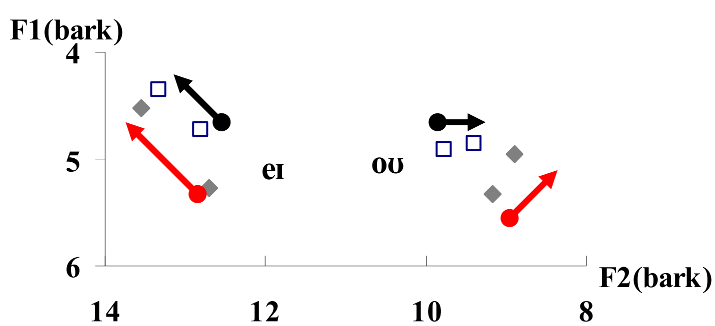

Figure 2 presents the plot comparing means of F1 z-score and F2 z-score for diphthongs in the final rhymes of Wd and IP, over all the speakers' data pooled. The arrow indicates the trajectory from the onset target to the offset target. The figure shows that trajectories are longer in the IP boundary condition compared to the Wd boundary condition. The greater distance between onset and offset targets indicates that vowel quality varies more between those two targets when diphthongs occur in the final rhyme of IP than in the final rhyme of Wd.

2.2. Lengthening

As shown in Table 4 below, all vowels except for /eɪ/ were lengthened in the final rhyme of higher level prosodic domains relative to those in lower level prosodic domains.

Table 4. Results from ANOVA analyses and Tukey post hoc comparisons of *duration z-score.* **: $p<.01$, n.s.: $p>.05$

	/i/	**/ɪ/**	**/eɪ/**	**/oʊ/**
ANOVA	**	**	n.s.	**
Post hoc	Wd < ip < IP	Wd = ip < IP		Wd < IP

Post hoc results show that /i/ is categorically distinguished across three different levels of prosodic boundaries in its duration. For /ɪ/, lengthening effects are localized to the IP boundary, and vowels at the IP boundary are distinguished both from those at the Wd and the ip boundaries. The back diphthong /oʊ/ also shows lengthening as a function of the level of prosodic boundary. There was no main effect of speaker, but a significant interaction of prosodic context and speaker was observed for /i/ and /ɪ/ ($F(6, 450) = 2.364$, $p < .05$ for /i/, and $F(6, 379) = 2.359$, $p < .05$ for /ɪ/). For /i/, all speakers showed significant lengthening for vowels before the IP boundary compared to vowels preceding the Wd boundary. However, the grouping of ip varied according to the speaker (ip=Wd<IP for F2B, Wd=ip<IP for F3A, Wd=ip<ip<IP for M1B, and Wd<ip=IP for M2B). For /ɪ/, lengthening effects were not consistent across speakers. Two speakers (F2B, F3A) showed significant lengthening with a localized effect at the IP boundary while for the other two speakers (M1B, M2B), lengthening was not significant as a function of the level of prosodic boundary.

2.3. Strengthening vs. Lengthening

Table 5 summarizes strengthening and lengthening effects observed in this study for vowels in the final rhyme of high level prosodic domains relative to vowels in the final rhyme of low level prosodic domains.

Table 5. Summary of strengthening and lengthening effects for each vowel. Significant effects are indicated by check marks.

	/i/	/ɪ/	/eɪ/	/oʊ/
Strengthening		√	√	√
Lengthening	√	√		√

Strengthening in F1 and/or F2 is observed along with increased duration for /ɪ/ and /oʊ/. /eɪ/ at high level prosodic boundaries is marked only by strengthening while /i/ shows only lengthening without combined strengthening effects in the final rhyme of high level prosodic domains. The following results from linear regression analyses are computed with duration as an independent variable, and F1 and F2 as dependent variables.

Table 6. Results of regression analyses in R-squared values.

	/i/	/ɪ/	/eɪ/		/oʊ/	
			onset	offset	onset	Offset
Duration on F1	.020	.042	.005	.151	.107	.000
Duration on F2	.074	.002	.017	.050	.024	.124

The results show that only less than 20% of the variation in F1 or F2 may be explained by variation in duration, indicating that there is little correlation between temporal duration and acoustic measures of F1 and F2. This suggests that strengthening effects on vowels in the final rhyme of high level prosodic domains are not always correlated with an increase in duration.

3. Discussion

The effect of a high level prosodic boundary is significant for all vowels /i, ɪ, eɪ, oʊ/ under study in terms of at least one of the acoustic measurements of F1, F2 and duration. The major trends are: (1) Effects on /i/ are weaker, when compared with earlier findings; (2) Strengthening occurs through sonority enhancement non-high vowels and enhancement of phonological backness contrasts; (3) Vowel lengthening varies for some individual vowels and some speakers;. (4) Vowels in the IP boundary condition are mostly distinguished from vowels in the Wd boundary condition in their strengthening and/or lengthening and there is not consistent pattern of distinction between ip and either IP or Wd boundaries; (5) Strengthening and lengthening are not strongly correlated, and must therefore constitute independent effects.

3.1. Laboratory Speech vs. Radio News Speech

When compared to prior acoustic results based on laboratory speech, a weaker boundary-induced effect is observed in the current study regarding acoustic measures of the vowel /i/. The finding from controlled laboratory speech shows that the vowel /i/ is more fronted and raised at higher level prosodic boundaries and as a consequence located in a more peripheral position in the acoustic vowel space, compared to /i/ at lower level prosodic boundaries (Cho 2005). However, in the present study, no significant effect was observed for the vowel /i/ in the spatial dimension for data pooled across all speakers. There was also no significant interaction between prosodic context and speaker. The question is how we can explain these discrepancies between our results and those of earlier studies. There are at least two possible interpretations. One is that this discrepancy is attributable to the difference in speech styles (i.e. laboratory speech and public-addressed nonlaboratory speech), given that previous work is based on laboratory speech which tends to be more carefully and clearly produced with more exaggeration in terms of both segmental and suprasegmental properties. The more exaggerated the speech is, the greater prosodic effects may be expected with respect to variation in the phonetic dimension. Another possibility is that differences between studies in the location of the target vowel relative to prosodic boundary is responsible for differences in the results. Earlier work (Cho 2005) examines the very last vowel in each prosodic domain while the current study examines vowels in the last rhyme of prosodic domains which may be followed by one or more coda consonants in the same syllable. Thus, in previous studies, vowels may be more vulnerable to boundary-induced effects since they are located more closely to the prosodic boundary compared to the current study.

3.2. Asymmetric Enhancement of Phonological Features

Vowels at high level prosodic boundaries exhibit asymmetric enhancement of phonological features with a more consistent effect on sonority than on place features. Lowering effects are observed for vowels in the final rhyme of a high level prosodic domain when there is a significant effect in the spatial dimension (/ɪ/, onsets of /eɪ/ and /oʊ/). This suggests that for lax vowels, lowering is a main effect of prosodic boundary. In the backness dimension, significant effects are observed only for /ɪ/ and the onset and offset of /oʊ/. For high vowels (/i/, offsets of the diphthongs) the enhancement of whose height features conflicts with sonority expansion, neither of the features shows significant enhancement. This finding is contrary to the findings from Cho (2005), which finds that for high vowels, the height feature is primarily enhanced over the sonority feature in strengthening at high level prosodic boundaries.

3.3. Enhancement of the Tense/Lax Vowel Contrast

Enhancement of the phonological contrast between tense and lax vowels is another noticeable finding observed for vowels followed by a high level prosodic boundary. The front lax vowel /ɪ/ shows raised F1 and lowered F2, indicating lowering combined with backing in the articulatory dimension, when it occurs in the final rhyme of higher level prosodic domains relative to in the final rhyme of lower level prosodic domains. Lowering and backing of /ɪ/ result in a greater separation of that vowel from the front tense vowel /i/, and consequently, the two vowels become more spread apart from each other in the acoustic vowel space. This provides evidence for strengthening via enhancement of phonological contrast between tense and lax vowels as one correlate of the level of prosodic boundary.

3.4. Enhancement of the Diphthong/Monophthong Contrast

For diphthongs, enhancement of phonological features in the final rhyme of high level prosodic domains leads to a greater change in quality between the onset and offset targets. The diphthong /eɪ/ shows lowering at the onset target, while the diphthong /oʊ/ shows lowering at the onset target, and backing both at the onset and offset targets. The lowering effects at the onset target and a backing effect at the offset target of the back diphthong increase the difference in quality between the onset and offset targets. Given that diphthongs are defined as vowels that show changes in quality across onset and offset targets, the increased difference in quality between the beginning and end portions renders the diphthongs more diphthong-like when they appear at high level prosodic boundaries.

3.5. Variable Effect on Lengthening

Lengthening effects are found to vary depending on individual vowels and speakers. Significant lengthening for the vowels /i/, /ɪ/, and /oʊ/ in higher prosodic domains relative to those in lower prosodic domains suggests that distinctively layered prosodic domains may be identified in the durational property of the domain-final vowel. The finding that /eɪ/ does not lengthen at high level prosodic boundaries indicates that the prosodic boundary is not cued by duration for this vowel. Significant prosodic context and speaker interactions for /i/ and /ɪ/ reveal that /i/ shows consistent lengthening effects for all speakers despite the difference in grouping of the ip boundary, while the lax vowel /ɪ/ is lengthened for only two speakers (F2B, F3A). This asymmetric lengthening pattern enhances the phonetic difference as well as the phonological contrast between these two vowels in the final rhyme of high level prosodic domains. For two speakers (M1B, M2B) who exhibit asymmetric lengthening between /i/ and /ɪ/ combined with spatial strengthening (via lowering and backing in the acoustic vowel space) for /ɪ/, tense and lax vowels end up being more distinctive in higher prosodic domains, compared to the other two speakers (F2B, F3A) who show only strengthening effects for /ɪ/. The absence of lengthening for the front diphthong /eɪ/ may be attributable to a ceiling effect. The mean durations for /eɪ/ are relatively long in the final rhyme of the word when compared with other vowels (F2B: /i/ 69.3 ms, /ɪ/ 51.2 ms, /eɪ/ <u>100.2 ms</u>, /oʊ/ 72.1 ms; for F3A: /i/ 71.2 ms, /ɪ/ 46.4 ms, /eɪ/ <u>107.7 ms</u>, /oʊ/ 66.4 ms; for M2B: /i/ 59.2 ms, /ɪ/ 40.0 ms, /eɪ/ <u>103.2 ms</u>, /oʊ/ 66.4 ms). The duration of the diphthong /eɪ/ may have already reached an upper limit in the Wd boundary condition, so an increase in duration may not be obtainable even in the higher prosodic boundary conditions, which might explain the inter-vowel variability in the lengthening effect. Whatever the explanation, the absence of lengthening effects for /eɪ/ means that duration is not a necessary cue for identifying the prosodic phrase level.

3.6. Strengthening vs. Lengthening

The overall results indicate that vowels in the final rhyme of higher prosodic domains are differentiated from vowels in the final rhyme of lower prosodic domains through strengthening, lengthening or both. The question to be raised is whether strengthening is an independent mechanism to mark prosodically strong positions, or simply a side effect of lengthening. The findings in the current study show that strengthening and lengthening are two separate effects that distinguish vowels in the final rhyme of high level prosodic domains. The specific phonetic exponents of prosodic structure also seem to vary according to individual vowels. The vowels /ɪ/ and /oʊ/ are strengthened at high level prosodic boundaries via lowering and backing without any significant lengthening. However, the front diphthong /eɪ/ shows lowering without any significant increase in duration and the vowel /i/ at high level prosodic boundaries exhibits only the durational effect. These findings provide compelling evidence that prosodically-induced strengthening of vowels can be implemented independently of their temporal duration in speech production, which is contrary to the finding in Gay (1968), where vowel quality at the offset of the diphthongs is reported to be influenced by changes in temporal duration.

4. Conclusion

The current study provides evidence for strengthening and lengthening effects for vowels in the final rhyme of higher prosodic domains based on the acoustic measures of F1, F2 and duration. The data comes from the speech of four professional news announcers from the Radio News corpus, which is a different style of speech from controlled laboratory speech used in previous studies. The results show that the final position in high level prosodic domains are prosodically strong positions in which vocalic duration is increased and phonological contrasts between vowels are enhanced. Enhancement of the sonority feature is more consistently observed in high level prosodic domains than enhancement in backness. As a consequence of sonority expansion, vowels become more vowel-like in the final rhyme of high level prosodic domains compared to lower domains, especially when combined with temporal lengthening. The phonological contrast between vowels is enhanced in a way that the lax vowel is more differentiated from the tense vowel, and the diphthong is more distinctive from the monophthong in the acoustic vowel space. In most cases, vowels in the IP boundary condition are distinguished from vowels in the Wd boundary condition in their strengthening and lengthening effects, but only sporadically from vowels in the ip boundary condition. Further, the finding suggests the independence of strengthening and lengthening effects, showing the presence of only either of the effects may be sufficient to encode distinctive levels of prosodic domains for certain vowels.

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Department of Linguistics
4080 FLB, 707 S. Mathews Avenue
Urbana, IL 61801 U.S.A.

eklee1@uiuc.edu

Department of Linguistics
4080 FLB, 707 S. Mathews Avenue
Urbana, IL 61801 U.S.A.

jscole@uiuc.edu