Acoustic Effects of Prosodic Phrasing on Domain-initial Vowels in Korean

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ABSTRACT

This paper investigates acoustic evidence of strengthening and lengthening on post-boundary vowels (#V..) in Korean, by comparing the acoustic F1, F2, and duration measures across vowels /a, e, i, o, u/ at the beginning of three different prosodic domains; the Intonational Phrase (IP), the Accentual Phrase (AP), and the Phonological Word (Wd). In contrary to previous findings on domain-initial vowels in the CV syllable where no prosodic strengthening effects were observed, acoustic features of onsetless domain-initial vowels are found to serve as cues to distinctively layered prosodic domains: place features are enhanced and duration is reduced in higher level prosodic domains relative to lower domains. This indicates that layered prosodic domains may be manifested in the property of vowels as well as in that of consonants if vowels are immediately adjacent to prosodic boundaries. The findings also suggest that strengthening and lengthening are independent effects on domain-initial vowels in Korean, providing compelling evidence against the undershoot hypothesis.

Keywords: prosody, vowel production, domain-initial strengthening, Korean

1. INTRODUCTION

The phonetic realization of segments is affected by factors such as speaker's age, gender, and speech rate, etc. As a structural factor, prosodic structure is also one of the important sources of variation in segment-level phonetic features. According to the hierarchical model of prosodic phonological structure, utterances are hierarchically organized with multiple levels of prosodic phrasing: lower level prosodic phrases are contained within higher level ones. An extensive body of research has found that articulatory/acoustic properties of segments have remarkable sensitivity to higher-level prosodic structure. Particularly, prosody-induced variation in domain-initial segments, known as domain-initial strengthening, has received attention from researchers because it provides not only a linguistic function of enhancing phonological contrasts but also communicative functions of assisting the chunking of the signal and facilitating lexical access [1]. Numerous studies have found that domain-initial consonants in higher level prosodic domains are articulated with greater magnitude, greater displacement in the spatial dimension, and longer seal duration in the temporal dimension, compared to those in lower domains. [1-5]. Comparable effects are also observed in the acoustic signal. Domain-initial consonants are produced with greater VOT and closure interval, and longer acoustic duration as the level of prosodic domain increases [1][5]. Of interest, similar patterns of effects have been reported in diverse languages. Among those languages, Korean is the language that reveals the most robust and consistent patterns [3]. In Korean, the level of prosodic domains are identified in the articulatory/acoustic features of domain-initial consonants, and strengthening in higher level prosodic domains is strongly correlated with lengthening [3][5], which firmly supports the undershoot hypothesis in speech production [6]. The effects are also cumulative across distinctively layered prosodic domains in that strengthening takes place incrementally as the level of prosodic phrasing increases.

While prior work shows evidence of domain-initial strengthening of consonants, relatively few studies examine prosody-induced variation in domain initial vowels, and those that do find no consistent articulatory and acoustic correlates of prosodic phrase structure [1][7-8]. Cho [8] investigates the effects of prosodic phrasing on English vowels /a, i/ in the domain-initial CV syllable by comparing articulatory measures of tongue position, and lip and jaw opening, and acoustic measures of F1 and F2 at several prosodic levels, and finds little evidence of strengthening in those articulatory or acoustic measures. Cho and Keating [5] measure acoustic duration of vowels in the initial syllables of 4 different prosodic domains (Utterance, Intonational Phrase, Accentual Phrase, and phonological Word) in Korean, and find no

significant effects of the level of prosodic constituents with respect to vowel duration. Strengthening in acoustic features other than duration is yet to be examined for Korean domain-initial vowels. However, noticeably, in the previous studies mentioned above, the vowels under examination are not the first segments after the prosodic boundary, but are located after domain-initial consonants (#CV..). In other words, while prosodic strengthening effects are found for consonants directly adjacent to the prosodic boundary, no effects are found for the vowel that follows the initial consonant. Thus, it is not clear from prior findings whether the absence of strengthening effects on the vowels in #CV marks an asymmetry between consonants and vowels in prosodic effects, or reflects the increased distance of the vowel from the prosodic boundary, as shown in [4].

The current study tackles this issue, and investigates acoustic evidence of strengthening and lengthening on the vowels /a, e, i, o, u/ at the very edge of different prosodic domains in Korean, by comparing acoustic measures of F1, F2 and duration. One of the goals of this study is to examine the presence of the effects of prosodic phrase structure on vowels comparable to those on Korean domain-initial consonants. In the analysis, strengthening is defined as the enhancement of phonological contrasts and/or sonority expansion (indicated by the variation in F1 and F2) and lengthening is indexed by an increase in duration. The relationship between these two effects and the presence of cumulative effects are also examined.

1.1. Hypotheses

If effects of prosodic phrase structure on domain-initial vowels are comparable to those on domain-initial consonants, strengthening and lengthening are expected as the level of prosodic phrasing increases: i) enhancement of phonological contrasts in the height or backness dimension, and/or sonority expansion ii) longer duration. If these two effects are strongly correlated, correlation coefficients (r-square) are expected to be high in regression analyses. If effects are cumulative across successive layers of prosodic domains, post hoc results will reveal a distinction between prosodic domains.

2. METHODS

2.1. Corpora and Procedure

Test sentences were constructed to elicit five different vowels /a, e, i, o, u/ in the initial position of three different prosodic domains (Intonational Phrase, Accentual Phrase, and phonological Word).

(1) igosɨn tʃibap, [IP ***utʃegugi*** innɨn kosida.
"This is the place in front of the house, where the post office is located".
idiɾiɨn tʃibap [AP ***utʃeguge*** gaɾjəgo handa.
"These people are going to visit the post office in front of the house".
idiɾɨn [AP tʃibap [Wd ***utʃegugi***l tʃoahanda.
"These people like the post office in front of the house".

In the above corpus for /u/, the target vowel is in bold and the word containing it is italicized. The italicized word was replaced by *ibalso* ('barber shop'), *ep^{h}ɨlbi* (name of restaurant), *ap^{h}at^{h}ɨ* ('apartment'), and *okkage* ('clothing store') in the corpora for different vowels. In order to eliminate confounding effects of coarticulation with neighboring segments, immediate segmental environments were controlled. Six Seoul Korean female speakers were asked to read sentences five times at a moderately slow rate. This helped elicit the intended intonation contour in the AP condition. No explicit instruction of prosodic phrasing was given. For the word condition, a context that requires a correction of information regarding the preceding underlined word was provided to elicit contrastive focus on it. This helped the production of the Word boundary (and not a stronger prosodic boundary) before the word containing the target vowel. All six speakers produced sentences in the IP condition with an appropriate boundary tone at the end of the preceding phrase (L% for five speakers, H% for one speaker), and f0 reset at the beginning of the target phrase. Sentences in the AP condition were produced with a final rising phrasal tone (LHa) prior to the target phrase.

2.2. Measurements

Formant values were extracted at the temporal mid point of vowels by computing the LPC coefficients applying the Burg algorithm, in Hertz value. Duration was measured from the point where the second formant appears to the point where the second and high formants disappear. Statistical analysis was conducted for the data pooled across

all speakers. The data was normalized within-speaker for F1, F2, and duration across all vowels using the following z-transformation equation. (z: normalized transformed value, f: raw formant value in Hertz for F1 and F2, and raw duration value in ms, μ: overall mean value, and σ: standard deviation of the overall mean)

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

A one-way ANOVA (with alpha set at .05) was performed for each vowel, comparing z-transformed F1, F2, and duration values across different prosodic domains. Tukey post hoc analysis (with alpha set at .05) and regression analysis were also conducted.

3. RESULTS

Despite inter-vowel variability, major findings from the z-transformed data pooled across all speakers are: i) domain-initial vowels are strengthened and/or reduced in duration after higher level prosodic boundaries, ii) strengthening is implemented via enhancement of vowel quality contrasts mainly in the height dimension, iii) strengthening and lengthening are not correlated, and iv) vowels in different levels of prosodic domains are distinguished in their spectral and temporal acoustic features at least with a two-way distinction between the IP and Wd domains.

Figure 1 presents the effects of the level of prosodic phrasing on domain-initial vowels for acoustic measure of F1. The results of one-way ANOVA with prosodic context as an independent variable show that F1 of high vowels significantly decreases (a raising effect) as the level of prosodic domains increases (/i/: $F(2, 87)=4.481$, $p<.05$; /u/: $F(2, 87)=16.589$, $p<.01$), indicating that the enhancement of place features is a primary effect over sonority expansion on domain-initial vowels. As shown in Figure 1, the raising effect of /i/ is localized at the AP boundary (Wd>AP=IP), while the same effect distinguishes all three levels for /u/ (Wd>AP>IP). For the low vowel /a/, F1 significantly increases as a function of the level of prosodic phrasing (a lowering effect) with a 3-way distinction of Wd<AP<IP ($F(2, 87)=34.376$, $p<.01$). The effect of prosodic phrase structure is not significant for mid vowels /e/ and /o/.

Figure 1: Dot graphs comparing vowels (high vowels: left, nonhigh vowels: right) in three different prosodic domains for F1.

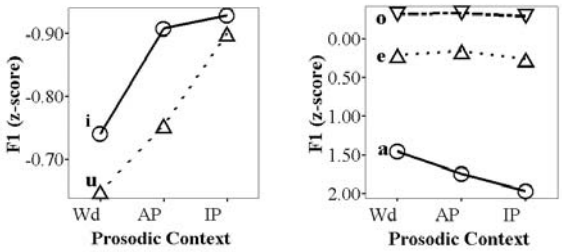

Figure 2 shows the results for F2. In the backness dimension, /e/ and /a/ show significant F2 raising (a fronting effect) in higher level prosodic domains compared to the Word domain (/e/: $F(2, 87)=11.537$, $p<.01$; /o/:$F(2, 87)=17.256$, $p<.01$) with a 2-way distinction of Wd<IP=AP. For /o/, the difference in mean is large between IP and the lower domains, but the result of one-way ANOVA indicates that the effect is not statistically significant ($F(2, 87)=1.886$, $p>.05$). For high vowels, no main effect of prosodic context is observed in the acoustic measure of F2.

Figure 2: Dot graphs comparing vowels (nonback vowels: left, back vowels: right) in three different prosodic domains for F2.

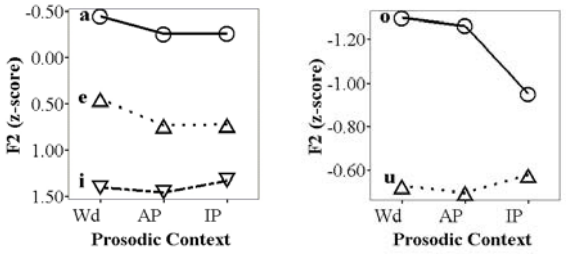

Figure 3: Mean plot of F1 and F2 in normalized values for vowels /a, e, i, o, u/. Circles: vowels in the Wd condition, squares: vowels in the IP condition.

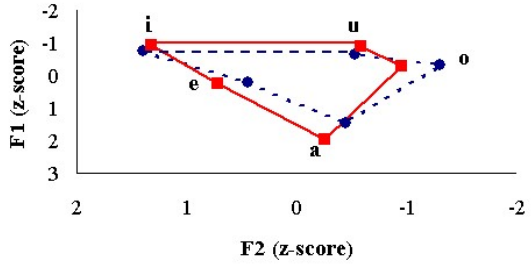

Figure 3 displays the plot comparing means of F1 and F2 in normalized values for five vowels in the Wd and IP conditions. Vowels are compared for these two prosodic conditions because post hoc

results show that there is a consistent distinction between the two conditions across vowels. The figure shows that the acoustic vowel space is expanded in the IP condition, relative to the Wd condition, mostly through the enhancement of phonological contrast in the height dimension: high vowels /i, u/ are raised while the low vowel /a/ is lowered. Fronting of /e/ and /a/ in the backness dimension also contributes to the expansion of acoustic vowel space.

Figure 4: Dot Graphs comparing vowel duration in three different levels of prosodic domains.

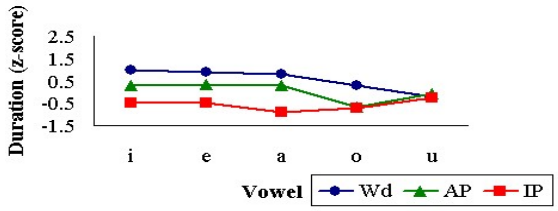

Figure 4 compares acoustic duration of vowels for 3 different prosodic contexts. All vowels but /u/ reveal highly significant shortening effects as a function of the level of prosodic domains (/i/: $F(2, 87)=23.346$, $p<.01$; /e/: $F(2, 87)=16.505$, $p<.01$; /a/: $F(2, 87)=37.315$), $p<.01$;/o/: $F(2, 87)=16.463$, $p<.01$). Among these vowels, all vowels but /o/ show a three-way distinction of Wd>AP>IP with incrementally cumulative effect across all levels of prosodic domains. For /o/, the effects are localized at AP (Wd>AP=IP). The lack of significant effect on duration of /u/ may result from a floor effect: its duration is sufficiently short in the Wd condition.

The results demonstrate that acoustic correlates of prosodic phrasing are present on Korean domain-initial vowels at least either in their F1 and/or F2 measures or in their duration measure. However, linear regression analyses show that r^2 values are negligible under 0.2 for all vowels, confirming that there is little correlation between these two measures in domain-initial vowels.

4. DISCUSSION

The findings show that vowels vary with the level of prosodic phrasing in their acoustic features when they are the first segments after the prosodic boundary. As evidence for cumulative effects, three levels of prosodic domains (IP, AP, and Wd) are distinguished in their strengthening effects for some vowels, while distinguished in their shortening effects for most vowels. This result is consistent with the previous finding on domain-initial consonants with respect to the presence of cumulative effects, but conflicting with respect to the presence of correlation between strengthening and duration. Little correlation between the F1 and F2 acoustic measures and duration in domain-initial vowels disconfirms the undershoot hypothesis because it indicates that vowel quality contrasts can be enhanced without an increase in duration. Implications for the model of Korean vowel production are that strengthening and lengthening are independently controlled and shorter duration does not necessarily result in undershoot of the target segment. Further, fronting of /a/ in the acoustic vowel space as a function of the level of prosodic phrasing may reflect an ongoing diachronic change that could follow the merge of /e/ and /æ/, provided that prosody-induced variation in vowels may lead to sound change over time [9]. However, the current results should be interpreted cautiously as they may be affected by the degree of coarticulation with the vowel /a/ in the preceding syllable. A direction for future work will be to investigate how prosody-induced variation interacts with segment level coarticulation.

5. REFERENCES

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