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Articulatory modification of /m/ in the coda and the onset as a function of prosodic boundary strength and focus in Korean

Sahyang Kim[1)] · Taehong Cho[2)]

ABSTRACT

An articulatory study (using an Electromagnetic Articulography, EMA) was conducted to explore effects of prosodic boundary strength (Intonational Phrase/IP versus Word/Wd), and focus (Focused/accented, Neutral, Unfocused/unaccented) on the kinematic realization of /m/ in the coda (...a**m#**i...) and the onset (...a**#m**i...) conditions in Korean. (Here # refers to a prosodic boundary such as an IP or a Wd boundary). Several important points have emerged. First, the boundary effect on /m/s was most robustly observed in the temporal dimension in both the coda (IP-final) and the onset (IP-initial) conditions, generally in line with cross-linguistically observable boundary-related lengthening patterns. Crucially, however, in contrast with boundary-related slowing-down effects that have been observed in English, both the IP-final and IP-initial temporal expansions of Korean /m/s were not accompanied by an articulatory slowing down. They were, if anything, associated with a faster movement in the lip opening (release) phase (into the vowel). This suggests that the mechanisms underlying boundary-related temporal expansions may differ between languages. Second, observed boundary-induced strengthening effects (both spatial and temporal expansions, especially on the IP-initial /m/s) were remarkably similar to prominence (focus)-induced strengthening effects, which is again counter to phrase-initial strengthening patterns observed in English in which boundary effects are dissociated from prominent effects. This suggests that initial syllables in Korean may be a common focus for both boundary and prominence marking. These results, taken together, imply that the boundary-induced strengthening in Korean is different in nature from that in English, each being modulated by the individual language's prosodic system. Third, the coda and the onset /m/s were found to be produced in a subtly but significantly different way even in a Wd boundary condition, a potentially neutralizing (resyllabification) context. This suggests that although the coda may be phonologically 'resyllabified' into the following syllable in a phrase-medial position, its underlying syllable affiliation is kinematically distinguished from the onset.

Keywords: prosodic boundary, focus, kinematics, /m/, Korean, phrase-final, phrase-initial, lip opening, lip closing, Electromagnetic Articulography

1. Introduction

Prosodic positional effects on the phonetic realization of individual segments have long been a locus of phonetic research as they provide insights into the phonetics-prosody interface (Fletcher 2010; Cho, 2011). Two of the traditionally well-known positional effects are that word-initial consonants are produced with more constriction compared to word-medial counterparts (Browman & Goldstein, 1995; Byrd, 1996), and that vowels in the word-final syllable undergo substantial lengthening (Oller, 1973; Klatt, 1975, among others). Word-initial consonants often show a temporal expansion as well, being longer than both word-medial and final consonants (Lehiste 1960, 1961; Quené, 1992), although the temporal effect (i.e., longer for initial than for final consonants) may be reversed, depending on the

1) Hongik University, sahyang@hongik.ac.kr
2) Hanyang University, tcho@hanyang.ac.kr, corresponding author

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consonant type (Keating & Zhang, 1999). Along with the development of theories on prosodic hierarchy, however, it has been revealed that many of the previously known word-level positional effects are in fact attributable to their interactions with the higher-order prosodic structure—i.e,. whether or not the word-initial/final position is aligned with a phrase-initial/final position. For example, in Oller's seminal work (1973) on positional effects, a target word was contained in a carrier sentence, "*Say a X*", and hence the word final segment in the target word (X) was effectively a phrase final segment. Subsequent research has therefore focused on investigating positional effects in various levels of prosodic boundary. Crucially, the word-level positional effects have been found to be further modified by higher-level prosodic structure in a cumulative way: the effect becomes progressively stronger as the level of prosodic constituent moves up in the hierarchy. For example, an onset of a syllable that occupies a word-initial position is produced more strongly (in both spatial and temporal dimensions) relative to when it occurs in a word-medial position, and yet the positional effect becomes progressively more robust as the word-initial syllable occupies a higher-level phrase-initial position (Fougeron & Keating, 1997; Keating, Cho, Fougeron & Hsu, 2003; Cho & Keating, 2009, among others). Likewise, word-final lengthening may be progressively augmented as the word-final syllable is aligned with a higher-level phrase-final position (e.g., Beckman, Edwards, & Fletcher, 1992; Wightman, et al., 1992).

A large body of studies (including those mentioned above) has therefore advanced our knowledge of positional effects on the phonetic realization, illuminating the nature of the phonetics-prosody interface. Many of these studies, however, have explored initial or final segments separately (as compared with medial segments), and rarely both. Furthermore, initial versus final segments have been examined in an unbalanced way in terms of segmental types—i.e. initial effects have been focused on consonants but final effects on vowels. Among studies on prosodic positional effects, Keating, Wright & Zhang's EPG study (1991) and Byrd, Lee, Riggs & Adams' EMA study (2005) are probably only existing articulatory-phonetic studies that have investigated word initial versus final consonants in a balanced way. They showed that word final consonants are longer and have more consonantal contact utterance-finally than utterance-medially (Keating et al., 1991), although the spatial displacement due to finality is rather inconsistently observed (Byrd et al., 2005). In addition, Keating et al. (1991) found that the word-level asymmetry (i.e., word-initial consonant stronger and longer than word-final consonant) disappears at the phrase edges due to phrase-final lengthening, and Byrd et al. (2005) also confirmed that phrase-initial and phrase-final lengthening patterns are comparable.

These studies have therefore made one step further to understanding how the word-level positional effects on initial versus final consonants are intricately intertwined with higher-level position effects. These studies, however, have their own limitations. They are confined to one language (English), leaving uncertain its cross-linguistic generalizability, and they did not consider the influence of prominence (e.g., phrase-level accentuation), although positional effects have been well known to interact with prominence effects (e.g., Cho & Keating, 2009; Fletcher, 2010; Cho, 2011).

1.1 The present study

As discussed above, there is a substantial gap in our understanding of positional effects in various aspects including their language-specificity versus cross-linguistic generalizability, and their interaction effects with prominence (phase-level accents). The primary purpose of the present study is therefore to narrow this gap by examining the word-level positional effect on initial versus final consonants in Korean, and to explore how the effect is further modulated by a higher level prosodic-structure, and interacts with prominence. The investigation of the prosodic modulation on both the final and the initial consonants will further allow us to balance our knowledge on the prosody-phonetics interface in Korean which have been skewed to the studies on initial phenomena (e.g., Cho & Keating, 2001).

To explore these effects, we have designed an articulatory kinematic study (using EMA, Electromagnetic Articulography) with the target consonant /m/ in Korean, in order to directly observe prosodically-conditioned variation in the consonantal lip movements associated with /m/. (/m/ was chosen because its bilabiality would make it relatively easy to observe kinematics of the consonantal gesture, independently of vocalic gestures. /m/ was also preferred over a voiceless stop (e.g., /p/) as the release component of the latter (along with VOT) is likely related with a laryngeal gesture, complicating the kinematic realization of the consonantal gesture.) /m/ was positioned in two critical positions —i.e., in a word-initial onset position (a#**m**i; # indicates a prosodic word or a phrase boundary), and in a word-final coda position (a**m**#i). The intervening boundary was either an

Intonational Phrase (IP) boundary or an IP-medial word (Wd) boundary. The prominence on the target word was also controlled by varying the location of contrastive focus within a sentence, such that a post-boundary target word was accented, unaccented, or neutral (See Section 2 for details). With this experimental architecture, this study addresses several questions that are crucial to understanding underpinnings of the prosody-phonetics interface in Korean.

1.1.1 Prosodic effects on the coda

The first goal of the present study is to investigate how word-final coda consonants are manifested in spatial as well as temporal dimensions, and how they are influenced by phrase-finality and by prominence conditions of the following words. Given the cross-linguistically common phrase-final lengthening effect (Vaissière, 1983), the word-final consonant is expected to be longer phrase-finally than phrase-medially. What is particularly interesting to test, however, is which part of the consonantal articulation undergoes lengthening. The production of /m/ involves three components: the lip closing gesture (for the formation of the consonantal constriction), the lip constriction (closure) phase; and the lip opening gesture (for the release into the following vowel). Previous studies on English have revealed somewhat contradictory effects. Beckman et al. (1992) observed that the slowing down effect is primarily associated with the consonantal *closing* gesture. But in a later study, Byrd et al (2005) demonstrated that it is the lip *opening* gesture for the codas that primarily undergoes final lengthening. They explained that the degree of final lengthening is determined by a gesture's proximity to the boundary, and that the consonantal *opening* gesture in VC#V is influenced most by the boundary-induced lengthening effect, as it is precisely at the boundary. This effect has been discussed under the rubric of the theory of pi-gesture (e.g., Byrd & Saltzman, 2003). A pi-gesture is an abstract (non-tract variable) gesture which is assumed to control the clock-rate that governs temporal realization of articulatory gestures in the vicinity of prosodic boundary. Thus, the more robust lengthening effect on the C#V lip opening gesture in English is assumed to come from a stronger effect of a pi-gesture due to its closer proximity to the boundary (as compared with the gesture in VC#). This effect is to be reflected kinematically in more lowering of peak velocity of the lip *opening* gesture in C#V (than of the lip *closing* gesture in VC#). In the present study, we test these possibilities by exploring which part during the coda /m/ articulation is influenced primarily by the final lengthening in Korean in order to understand the kinematic nature of the final lengthening of the coda consonant.

The exploration of the kinematic nature of final lengthening will be further elaborated by considering the influence of the prominence from the following word—i.e., whether the boundary effects on the production of the (preboundary) coda consonant is further constrained by the presence or absence of accentuation of the following word. This will have further implications for the domain of accentuation in Korean—i.e., the extent to which the accentual effect spreads leftwards across a lexical boundary (see Turk & White, 1999; White & Turk, 2010 and Cho, Kim, & Kim, 2013 for a related discussion on English).

1.1.2 Prosodic effects on the onset

The second goal of the present study is to examine the spatio-temporal variation of word-initial onset consonants in phrase-initial versus phrase-medial positions along with its interaction with the effect of prominence (accent). Since previous studies on phrase-initial boundary-induced strengthening on Korean has revealed robust effects of boundary (Cho & Keating, 2001; Keating et al., 2003; Cho, Lee & Kim, 2011), it is expected that the current study will exhibit similar results as far as the initial strengthening is concerned. A more interesting issue that this study attempts to delve into has to do with the interaction between prominence and boundary at the phrase-initial position. Along with the robust boundary effect, a recent study showed that Korean boundary-induced strengthening is characterized by larger, longer, and *faster* movement of vocalic gesture (a transboundary tongue movement from /a/ to /i/) (Cho, Yoon & Kim, 2010). This kinematic pattern is in fact quite comparable to the pattern associated with phrase-level prominence marking in English (Byrd, 2000; Cho, 2008). (Note that in English, boundary marking is expressed kinematically by longer and *slower* movement.) Such a cross-linguistic difference is accountable by the propensity that the phonetics-prosody interplay is modulated by the prosodic system of a given language (cf. Cho et al., 2010, 2011). An important question is then why such a spatio-temporal expansion along with a heightened movement velocity, which is generally known as the characteristics of prominence (but not of boundary) in other languages, occurs in association with prosodic boundaries in Korean.

Following Cho et al. (2010, 2011), we hypothesize that this is due to the fact that Korean lacks lexical level prominence in their prosodic system, and hence prosodic boundary marking serves a dual function to delineate both grouping and prominence units in the language. This idea is not too far-fetched when considering how prosodic phrasing in Korean may function similarly to accentuation in English. For example, in English, segmental materials are compressed post-focally by being 'deaccented,' but the post-focal compression is realized by 'dephrasing' in Korean (Ladd 2008; Jun, 1993). It is also well-known that English marks information structure by the type and location of pitch accent, while Korean does it by modifying prosodic phrasing (Schafer & Jun, 2002). That said, the current study tests how comparable the boundary effect is to the prominence effect in Korean, by comparing the boundary effect in three accent-related conditions: accented (focused), neutral, unaccented. The neutral condition means that a post-boundary target word was not accented or unaccented, and hence the speakers would produce a sentence naturally, not emphasizing any specific part of the sentence. So if the boundary effect in the neutral condition is similar to the prominence effect that arises in the accented (focused) condition, the boundary effect may be taken to convey similar phonetic information as the prominence effect. To test this kinematically, examining the movement velocity of consonantal articulation in the neutral condition will be particularly relevant, as it has been generally known that the boundary-induced versus prominence-induced articulation can be kinematically differentiated by slower versus faster articulatory movement in English (e.g,. Cho, 2006, 2008). More specifically, if the movement velocity is similar to that in the accented condition, and different from that in the unaccented condition, the boundary marking in Korean may be seen as working similarly as the prominence marking in languages in which the prominence system is modulated by lexical stress.

1.1.3 Articulatory reflexes of the onset-coda syllable affiliation

The present study will also allow us to compare the onset consonants with coda consonants when the intervening boundary is a word boundary (i.e., phrase-internally), in order to examine word-level (a)symmetry in consonantal articulation. On the one hand, given the likelihood that the coda consonant may be resyllabified into the onset of the following syllable in VC#V contexts, it is possible that neutralization occurs between /am#i/ and /a#mi/ in articulatory kinematic dimensions. On the other hand, there may still be some differences in producing the same consonant even in the potentially neutralizing (resyllabifying) environment, so that underlyingly different syllable affiliations are expressed kinematically (and available to the listener). The current study will explore these possibilities—i.e., whether there are differences in the lip movement depending on the position in a word, and if so, how the potentially ambiguous /am#i/ and /a#mi/ are manifested in kinematic terms. This will be tested in connection with how the prominence effect further modulates the onset-coda (a)symmetry.

1.1.4 Language-specificity versus cross-linguistic universality

What has emerged from the cross-linguistic literature on prosodic strengthening is that articulatory realization of a speech segment is systematically modulated by prosodic boundary and prominence components of the prosodic structure of a given utterance. No language appears to be an exception to this aspect of the phonetics-prosodic interface. For example, both English and Korean, though typologically unrelated, show phrase-final lengthening, phrase-initial strengthening, and prominence-induced strengthening. However, as has been discussed above in connection with specific research questions of the present study, Korean is expected to differ from English in details of phonetic implementation of the phonetics-prosodic interface, due to their differential prosodic systems (e.g., unlike English, Korean does not employ lexical stress and phrase pitch accent, and its prominence marking is closely related with phrasing.) The results of the present study, when compared with existing data in English, are therefore expected to provide further linguistic insights into the phonetics-prosody interface from the perspectives of both cross-linguistic universality and language specificity. The results will also inform the theory of the pi-gesture regarding the extent to which its effect is cross-linguistically applicable.

2. Methods

2.1 Participants

Four female and two male native speakers of Seoul Korean, who were in their 20s, participated in the study. They were naïve as to the purpose of the experiment and were compensated for their participation.

2.2 Speech material

The VCV sequence of /ami/ were created, varying in the position of /m/: the consonant /m/ was in the word-initial, syllable onset position (/a#**m**i/, the onset condition), and the word-final, syllable coda position (/a**m**#i/, the coda condition).

The prosodic boundary (#) that the target sequences straddled across was either an Intonational Phrase boundary (IP) or an IP-internal word boundary (Wd). There were three accent conditions. The post-boundary words were accented with a contrastive focus (Accented), or deaccented by locating a contrastive focus somewhere else (Unaccentd) or without a prominence on a specific word in an utterance (Neutral). The accented words are underlined in bold in Table 1. The words italicized in bold are the contrasted words which always occurred before the target sequence. (The neutral condition is not shown in Table 1.)

Table 1. Test speech materials

A. With an IP boundary

Target		Target-bearing sentences
/a#mi/ (onset)	A	[ja],[***insa***hweikaanira], [jʌŋmaniilnjʌntʃʰa]$_{IP}$,#[**minsa**hweiɛatʃikankas*ni] ‘Hey, I’m not talking about the personnel meeting; First-year Youngman, didn’t you go to the civil affairs meeting yet?’
	U	[ja],[minsa***dʒɛpʰan***ianira], [jʌŋmaniilnjʌntʃʰa]$_{IP}$,#[minsa**hwei**ɛatʃikankas*ni] ‘Hey, I’m not talking about the civil trial; First-year Youngman, didn’t you go to the civil affairs meeting yet?’
/am#i/ (coda)	A	[ja],[***minsa***hweikaanira], [jʌŋmaniwaŋkotʃʰam]$_{IP}$,#[**insa**hweiɛatʃikankas*ni] ‘Hey, I’m not talking about the civial affairs meeting; Senior Youngman, didn’t you go to the personnel meeting yet?’
	U	[ja],[insa***dʒɛpʰan***ianira], [jʌŋmaniwaŋkotʃʰam]$_{IP}$,#[insa**hwei**ɛatʃikankas*ni] ‘Hey, I’m not talking about the personnel affairs trial; Senior Youngman, didn’t you go to the personnal affairs meeting yet?’

B. With a Wd boundary

Target		Target-bearing sentences
/a#mi/ (onset)	A	[ilnjʌntʃʰa***insa***hweikaanira], [jʌŋmana], [ilnjʌntʃʰa#**minsa**hweiɛatʃikankas*ni] 'I'm not talking about the first-year personnel meeting, Youngman; Didn't you go to the first-year civil affairs meeting yet?’
	U	[ilnjʌntʃʰaminsa***dʒɛpʰan***ianira], [jʌŋmana], [ilnjʌntʃʰa#minsa**hwei**ɛatʃikankas*ni] 'I'm not talking about the first-year civil trial, Youngman; Didn't you go to the first-year civil affairs meeting yet?’
/am#i/ (coda)	A	[waŋkotʃʰam***minsa***hweikaanira], [jʌŋmana], [waŋkotʃʰam#**insa**hweiɛatʃikankas*ni] 'I'm not talking about the senior civil affairs meeting, Youngman; Didn't you go to the senior personnel affairs meeting yet?’
	U	[waŋkotʃʰaminsa***dʒɛpʰan***ianira], [jʌŋmana], [waŋkotʃʰam#insa**hwei**ɛatʃikankas*ni] 'I'm not talking about the senior personnel affairs trial, Youngman; Didn't you go to the senior personnel affairs meeting yet?’

2.3 Procedures

The 2D Electromagnetic Articulograph (Carstens AG200) was used to track the movements from the sensor coils attached on articulators as shown in Figure 1. In addition, two extra sensors were attached to a bite plate in order to obtain the occlusal plane (x-axis) to which the data were rotated. The y-axis was perpendicular to the occlusal plane. The sensors most relevant to the present study were those attached on the upper and lower lips (Fig.1f, 1g). When the lips were naturally closed, the two sensor coils were set apart roughly by 1 cm. Note that when the lips are constricted with certain amount of articulatory force, the distance between the two sensors becomes shorter. The entire articulatory movement data were sampled at 200Hz and low-pass filtered at a cut-off frequency of 20Hz. All the filtering and rotation processes were performed by the TAILOR program (Carsten’s data processing program).

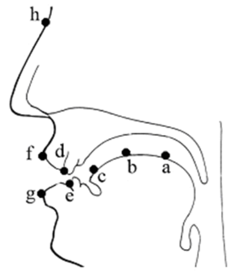


Figure 1. Locations of sensor coils: (a) the tongue dorsum; (b) the tongue body (c) the tongue tip; (d)-(e) the maxillary (upper) and mandibular (lower) central incisors; (f)-(g) the upper and lower lips; and (h) the nose bridge. (This figure is adopted from Figure 1 in Son & Cho (2010).)

Speakers practiced the target bearing sentences (including the ones in Table 1) several times before the experiment, such that they could become familiar with the speech materials. In order to avoid any unclear noise in the articulatory data which can be created by a pause between two Intonational Phrases, speakers were asked to produce IP boundary sentences ‘smoothly’ without any substantial pause. Sentences were repeated four times in a random order. Sentences which were not produced with a deviation from the intended prosodic renderings and those with noises in velocity profiles were excluded for further analyses. The total of 245 tokens out of 288 tokens (2 boundaries x 3 accent types x 2 syllable affiliations x 4 repetitions x 6 speakers) were included for the data analyses.

2.4 Measurements

In order to examine the lip movement characteristics, the Euclidean distance between the two lip sensors (i.e., the upper and lower lip sensors) was used as an index of Lip Aperture (Byrd, 2000; Byrd & Saltzman, 1998, among others) in which horizontal and vertical position signals are combined into one dimension.

The following kinematic measures were taken to observe the lip closing/opening movement, based on crucial time points for each movement (Figure 2). The gesture onset (Fig.2c, 2e) and movement target (Fig.2b, 2f) were defined as a point in time at which the velocity reached 20% of the peak velocity (rather than the zero-crossing point) which effectively removed the inherent noise in the velocity profile.

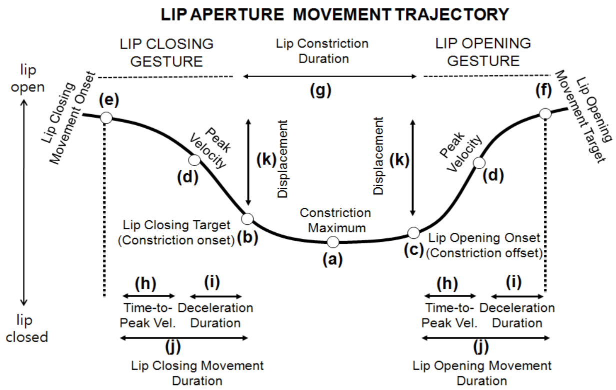


Figure 2. Lip aperture trajectory

(1) Lip constriction maximum (Fig.2a) (*mm*): The lip constriction maximum during the constriction duration

(2) Lip constriction duration (Fig.2g) (*ms*): The interval between the lip closing target point (Fig.2b) and the lip opening onset point (Fig.2c)

(3) Displacement (Fig.2k) (*mm*): The spatial difference between the movement onset and the movement target. (i.e., the spatial distance between Fig.2b and Fig. 2e for the lip closing movement and that between Fig.2c and Fig.2f for the lip opening movement)

(4) Peak velocity (Fig.2d) (*cm/s*): The actual peak velocity value during the lip closing and opening movements

(5) Acceleration duration (=Time-to-peak-velocity; Fig.2h) (*ms*): The time interval from the onset of the movement to the timepoint of peak velocity (i.e., the distance between Fig.2e to Fig.2d during the lip closing gesture and that between Fig.2c to 2d during the lip opening gesture)

(6) Deceleration duration (Fig.2i) (*ms*): The time intervval from the timepoint of peak velocity to the movement target (i.e., the distance between Fig.2d to 2b during the lip closing gesture and that between Fig.2d to Fig.2f during the lip opening gesture)

(7) Total movement duration (Fig.2j) (*ms*): The interval from the movement onset to movement target (i.e., the sum of time-to-peak velocity and deceleration duration)

Of the seven measures listed above, the spatial measures were the lip constriction maximum and the lip closing and opening displacement ((1) and (3)). The peak velocity was measured to observe the movement speed of the articulators (4). The rest were temporal measures ((2), (5), (6) and (7)). Note that time-to-peak velocity (=acceleration duration) and deceleration duration were separately measured in order to see in detail how the various factors (Boundary, Accent) take effects during the temporal realization of consonants.

2.5 Statistical Analyses

A series of univariate Analyses of Variance was performed to statistically evaluate the effects of Boundary and Accent on the lip aperture kinematics for onset and coda consonants, respectively. This was done to examine the phrase-final effect on coda consonants and the phrase-initial effect on onset consonants, and how they are further modified by the Focus factor. Boundary and Accent factors were employed as fixed factors and Speaker as a random factor. (Note that the results of the univariate ANOVAs with Speaker as a random factor were comparable to those of repeated measures ANOVAs, as both statistical methods use the same denominator degrees of freedom. See Marin, 2013, for a related discussion.) Since there was a factor with three levels (i.e., Accent), F- and p-values were reported based on Huynh-Feldt corrected degrees of freedom. For posthoc comparisons between levels within a factor, Bonferroni corrections for multiple comparisons were made. A p-value less than 0.05 were considered significant, and that between 0.05 and 0.08 was treated as a trend effect.

In order to compare the onset-coda difference in the Word boundary condition, where the positional effect can be potentially neutralized, univariate ANOVAs were also performed with Word Position (Onset vs Coda) and Accent as fixed factors and Speaker as a random factor. When the interactions between the two factors were found, the difference between the onset and coda consonants was compared separately in three accent conditions.

3. Results

3.1 Lip kinematics for coda consonants

As shown in Table 2, robust effects of Boundary were found in most of the kinematic measures taken for the study. The results showed clear boundary-induced lengthening during the course of lip closing – lip constriction – lip opening articulation for the coda /m/ in /am#i/. The segment was produced with significantly longer lip closing duration (acceleration, deceleration, and total movement), longer constriction duration, and longer lip opening acceleration duration in the IP-final than in the Wd-final position. This phrase-final temporal lengthening was not observed for the deceleration duration of the lip opening movement (i.e., after the point where the lip opening movement reached the time point of peak velocity). In addition, peak velocity was higher (faster) IP-finally than IP-medially for the lip opening movement, but no effect was found for the lip closing movement.

Table 2. Coda results summary

Measures	Boundary	Accent	B x A
Constriction max	F[1,5.1]=6.6 p<.05; IP<Wd	*n.s.*	*n.s.*
Constriction duration	F[1,5]=24.2, p<.01; IP>Wd	*n.s.*	*n.s.*
Closing displacement	F[1,5]=7.5, p<.05; IP>Wd	*n.s.*	*n.s.*
Closing peak velocity	*n.s.*	*n.s.*	*n.s.*
Closing acc. duration	F[1,5]=52.8, p<.01; IP>Wd	F[2,10.8]=3.3, *p=.07;* A=U<N	*n.s.*
Closing dec. duration	F[1,5]=23.3, p<.01; IP>Wd	*n.s.*	*n.s.*
Closing total movt.duration	F[1,5]=42.4, p<.01; IP>Wd	*n.s.*	*n.s.*
Opening displacement	F[1,5.1]=19.1, p<.01; IP>Wd	*n.s.*	*n.s.*
Opening peak velocity	F[1,5.1]=7.8, p<.05; IP>Wd	*n.s.*	*n.s.*
Opening acc. duration	F[1,5.2]=80, p<.001; IP>Wd	*n.s.*	*n.s.*
Opening dec. duration	*n.s.*	*n.s.*	*n.s.*
Opening total movt. duration	F[1,5]=5.8, *p=.06;* IP>Wd	*n.s.*	F[2,11]=4.5, p<.05

While the temporal expansion is robust, spatial expansion seems to be rather inconsistent at first glance. The lip constriction maximum was smaller for IP than for Wd, suggesting a weaker consonantal constriction in the IP-final position. In contrast, the lip closing and opening displacement, on the other hand, was larger for IP than for Wd. The larger displacement, however, does not seem to directly reflect the spatial expansion of phrase-final consonants. Additional analyses on the lip closing movement onset and the lip opening movement target during the preceding and the following vowel showed that the amount of the lip opening were larger in the IP than in Wd conditions in both cases (p<.001, p<.01 respectively). This indicates that the larger displacement associated with IP is attributable to the fact that surrounding vowels are produced with more lip opening at an IP than at a Wd boundary. It therefore can be concluded that the spatial expansion is not characteristic of the IP-final consonants in Korean.

Note that since the Accent factor was systematically controlled for the post-boundary target words (i.e., #CV, see Table 1), an effect of Accent on the coda consonants, if any, comes from the following syllable across a boundary (i.e,. pre-accentual effect). As shown in Table 2, the Accent factor on the following word did not influence the target coda significantly. (There was one trend effect which showed a tendency towards longer lip closing acceleration duration when the following word was in a neutral condition (not accented or deaccented), for which we do not have any explanation at the moment.) There was a significant interaction between Boundary and Accent on the lip opening movement duration. A further analysis, however, did not show any significant difference due to Accent in either IP or Wd boundary conditions.

3.2 Lip kinematics for onset consonants

Onset consonants also showed significant Boundary effects on kinematic parameters for both the lip closing and the lip opening movements. Unlike coda consonants, IP-initial onsets were produced with stronger articulation than Wd-initial onsets in many aspects: Constriction maximum was larger; constriction duration was longer; spatial displacement were larger in both lip closing and opening; and the lip closing duration was longer for IP than for Wd. These differences were all statistically significant as summarized in Table 3.

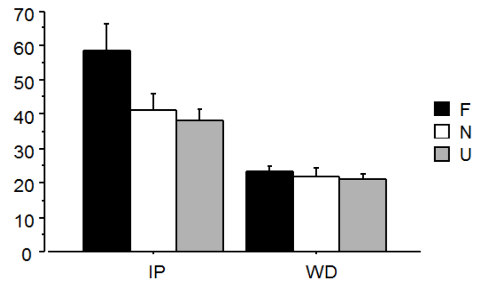
Similar to the findings for the coda consonants, the boundary induced lengthening was robust across the lip opening/closing measures—i.e., on the lip opening movement (on both the acceleration and the deceleration durations) and the lip opening acceleration duration. There was a significant interaction between Boundary and Accent on constriction duration which was due to the fact that the effect of Accent (i.e., A>N=U) was significant in the IP condition, while no Accent effect was found in the Wd condition (Figure 3a).

Peak velocity showed a tendency to be slower for IP than for Wd in the lip closing movement. Peak velocity for the lip opening movement showed a significant interaction between Boundary and Accent. This interaction is worth further noting. As shown in Figure 3b, the interaction was due to the fact that the effect of Accent patterned differently in the IP versus Wd conditions. On the one hand, in the IP-initial position, the accented and the neutral conditions were not significantly different from each other, but both showed a significant difference from the unaccented condition (A>U, p<.001; N>U, p<.01). On the other hand, in the Wd-initial position, the accented condition was significantly different from the other two conditions (A>N, p<.001; A>U, p<.01), but the neutral condition was not different from the unaccented condition. It is also worth noting that IP-initial lip opening was significantly faster than (IP-medial) Wd-initial lip opening only in the neutral condition (p<.05), and no such effect was found in the accented and unaccented condition. The results on lip opening peak velocity therefore revealed that the consonantal opening movement was faster for IP than for Wd, not only when the word was accented (due to prominence) but also when the target word was produced IP-initially without specific prominence (in the neutral condition). This indicates that the boundary effect is comparable to the accent effect in Korean at least in terms of the lip opening peak velocity.

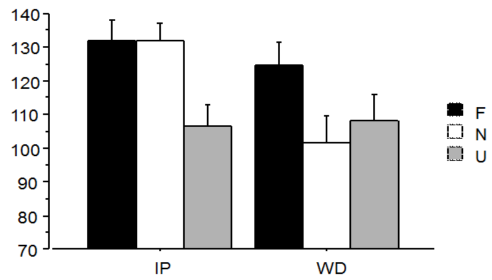
Regarding the main effects of Accent, two measures showed significant effects: constriction duration was longer when accented (than unaccented/neutral), and lip opening peak velocity was faster in an order of accented > neutral> unaccented.

Table 3. Onset results summary

Measures	Boundary	Accent	B x A
Constriction max	F[1,5]=8.4, p<.05; IP>Wd	*n.s.*	*n.s.*
Constriction duration	F[1,5]=24, p<.01; IP>Wd	F[2,10.1]= 4.2, p<.05; A>N=U	F[2,10.2]= 4.1, p<.05
Closing displacement	F[1,5]=11.4, p<.05; IP>Wd	*n.s.*	*n.s.*
Closing peak velocity	F[1,5]=5.8, *p=.06*; IP<Wd	*n.s.*	*n.s.*
Closing acc. duration	F[1,5]=45.8, p<.01; IP>Wd	*n.s.*	*n.s.*
Closing dec. duration	F[1,5]=9.2, p<.05; IP>Wd	*n.s.*	*n.s.*
Closing total movt. duration	F[1,5]=32.1, p<.01; IP>Wd	*n.s.*	*n.s.*
Opening displacement	F[1,5]=5.4, *p=.07;* IP>Wd	*n.s.*	*n.s.*
Opening peak velocity	*n.s.*	F[2,10]=4.5, p<.05; A>N>U	F[2,10.2]= 7, p<.05
Opening acc. duration	F[1,5]=6.9, p<.05; IP>Wd	*n.s.*	*n.s.*
Opening dec. duration	*n.s.*	*n.s.*	*n.s.*
Opening total movt. duration	*n.s.*	*n.s.*	*n.s.*



(a) Lip constriction duration (mm)



(b) lip opening peak velocity (cm/s)

Figure 3. Boundary x Accent interaction on the onset consonants

3.3 Word-level (a)symmetry between Onset and Coda

Results of statistical analyses carried out only in the Wd (IP-medial) condition showed some articulatory evidence for no clear neutralization between /am#i/ and /a#mi/ conditions. (Recall that these analyses were to test whether the coda /m/ in /am#i/ that may be phonologically 'resyllabified' into the following vowel in a potentially neutralizing phrase-internal condition is indeed completely neutralized with /m/ in the onset condition.) Regarding the onset/coda asymmetry, as summarized in Table 4, the coda consonants were more constricted than the onset consonants. Constriction duration, however, showed the opposite tendency towards longer duration for the onset than for the coda. A similar trend was found for the lip opening movement duration which was longer in the onset than in the coda condition. These three measures (constriction max, constriction duration, lip opening duration) clearly showed that /m/ in the coda conditoin (/am#i/) is not fully resyllabified into the following vowel in the potentially neutralizing environment—i.e., in the phrase-internal (IP-medial) conditions. Other than these three kinematic measures onset-coda asymmetry was not observed. (It should be noted, however, that although the current results show no complete neutralization, it is subject to further corroboration whether the assumed 'resyllabification' never entails phonetically complete neutralization across the board (e.g., in a fast speech rate condition or in a casual speech context)).

Interestingly, the effect of Accent was not significant in any measure, but significant interactions were found between Syllable Affiliation and Accent in constriction duration, lip closing movement (duration, peak velocity and displacement), and lip opening displacement. Planned comparisons were performed on the measures that exhibited significant interactions in order to examine how the onset-coda difference was further modified by the Accent factor. Results showed just one clear pattern that onset consonants were longer in constriction duration and larger in the lip opening displacement than the coda consonants only when the post-boundary words were accented. In other words, the onset consonants are distinguished more from the coda consonants when the onset consonants are initial in an accented word. No other significant effects were observed.

Table 4. Onset vs Coda in the Wd condition: Results summary

Measures	Syll. Affiliation	Accent	SA x A
Constriction max	F[1,5]=16.1, p<.05; O<C	*n.s.*	*n.s.*
Constriction duration	F[1,5]=5.5, *p=.07; O>C*	*n.s.*	F[2,10]=4.5, p<.05
Closing displacement	*n.s.*	*n.s.*	F[2,10]=7.5, p<.05
Closing peak velocity	*n.s.*	*n.s.*	F[2,10]=4.1, p<.05
Closing acc. duration	*n.s.*	*n.s.*	*n.s.*
Closing dec. duration	*n.s.*	*n.s.*	F[2,10]=3.8, *p=.06*
Clo. total movement duration	*n.s.*	*n.s.*	F[2,10]=5.2, p<.05
Opening displacement	*n.s.*	*n.s.*	F[2,10.2]=3.8, *p=.058*
Opening peak velocity	*n.s.*	*n.s.*	*n.s.*
Opening acc. duration	*n.s.*	*n.s.*	*n.s.*
Opening dec. duration	*n.s.*	*n.s.*	*n.s.*
Opening total movt. duration	F[1,5]=5.2, *p=.072; O>C*	*n.s.*	*n.s.*

4. Summary and Discussion

4.1 Phrase final effects

The most robust phrase-final effect on the articulatory realization of the coda /m/ that we found in the present study was modification of its temporal structure as a function of boundary strength: IP-final lengthening of /m/ was observed in lip closing duration (both in acceleration and deceleration duration), lip constriction duration, and lip opening acceleration duration. That is, in the sequence of /...a**m**#i.../, the effect of phrase-final lengthening permeates quite widely, ranging from the lip opening gesture to the first component (acceleration duration) of the lip opening gesture.

Along with the phrase-final lengthening, the coda /m/ was produced with a faster lip *opening* movement (out of the consonant) for IP than for Wd, but not in the lip *closing* movement (into the consonant). Given that the lip *opening* movement may, in theory, be activated by the following vocalic gesture, the asymmetric effect (the faster movement only for the lip *opening* gesture) may not be seen entirely as a consonantal strengthening effect, but it is likely conflated with the IP-initial strengthening of the following vocalic gesture.

Regarding the phrase-final effects on the spatial dimension, we observed inconsistent patterns. Although lips were *less* constricted for IP than for Wd (showing some degree of weakening of the coda /m/ IP-finally than Wd-finally), the opposite was true with displacement which was larger for IP than for Wd in both lip closing and opening movement. Again this contradicting result may be interpreted as having stemmed from strengthening of vocalic articulation of the flanking vowels. The further analyses of our data indeed showed that the degree of lip opening during the vowel (both before and after /m/) was larger for IP than for Wd. (Recall that the displacement measure was calculated as a spatial difference between the amount of consonantal constriction and the amount of lip opening during the neighboring vowels). The increase in displacement associated with the IP-final /m/ therefore appears to be attributable in large part to the vocalic strengthening of flanking vowels at a higher boundary.

The overall consonantal lengthening effect on the coda is by and large in line with the temporal change in phrase final consonants in English as reported in Beckman et al. (1992) and Byrd et al. (2005), especially in that the coda consonant undergoes phrase-final lengthening. The two studies on English, however, diverge in terms of where during the course of consonantal movement the phrase-final lengthening effect comes from. Beckman et al. (1992), in their investigation of the jaw movement for /p/, noted that lengthening is not evenly distributed over the syllable, but it affects primarily the *closing* movement (into the consonant). Byrd et al. (2005), on the other hand, showed that it was the *opening* movement of phrase-final /p, f, t/ (out of the consonant) that lengthened more. The results of the present study in Korean are in line with Beckman et al., given that the lip *closing* movement showed robust lengthening for IP as reflected in three temporal measures (i.e., total movement duration, acceleration duration and deceleration duration), whereas the opening movement showed a lengthening effect only for acceleration duration. On a related point, the lip closing movement for IP was not accompanied by a slower movement, despite the fact that the movement was longer for IP than for Wd. This is in sharp contrast with the final lengthening pattern previously observed in English which shows a clear slowing down of articulatory movement at a prosodic juncture (e.g., Beckman et al., 1992; Byrd and Saltzman, 1998, 2003). The longer closing movement duration for IP in Korean may then be due to a larger displacement for IP—i.e,. the larger the displacement, the longer it takes to reach the target. (See section 4.3 for further discussion on a related point.)

Finally, the phrase-final effects on the coda /m/ was not found to be further constrained by the presence or absence of prominence (accentuation) on the following (post-boundary) word. There was no effect of accent (of the following word) on the (preceding) coda /m/, even in the phrase-medial condition in which /m/ may be potentially resyllabified into the following vowel. This suggests that the accentual effect is blocked by the lexical boundary, regardless of whether the lexical boundary is aligned with a large (IP) or a small (Wd) prosodic boundary. This is largely consistent with patterns found in English in that accentual effects are robust within a syllable but attenuated across a syllable boundary (and across a lexical word boundary) (e.g., Turk & White, 1999; see also White & Turk, 2010 and Cho, Kim, & Kim, 2013, for related discussion). Furthermore, unlike the blocking effect across a lexical boundary observed in the present study, the accentual effect on /s/-stop clusters in English may be extended to /s/ even when it belongs underlyingly to the coda of the preceding syllable across a word boundary as in *rice#cone* (Cho, Lee & Kim, 2014). Thus, the present study has a potentially important theoretical implication for the domain of accentuation in Korean: The domain of accentuation appears to be strictly within a lexical word, so that the accentual effect operates just on the segments that belong underlyingly to the accented syllable. It is hoped that further studies continue to explore this issue to refine the domain of accentuation in Korean.

4.2 Phrase initial effects

As for the boundary effect, the onset /m/ showed robust spatio-temporal strengthening in the IP-initial position. The IP-initial /m/ (compared to the IP-medial one) was produced with more constriction, larger displacement, and longer duration in lip closing (both acceleration and deceleration) movement duration, constriction duration, and lip opening acceleration duration. As for the prominence (accent) effect, less robust patterns were observed: only constriction duration and peak velocity (of the lip opening movement) showed reliable effects with an interaction between the two. Constriction duration was longer in the accented condition than in the neutral and unaccented conditions only when they occurred in the IP-initial position, and the opening peak velocity was significantly faster in the accented/neutral conditions than in the unaccented conditions again only when in the IP-initial position.

The generally robust boundary effects found in this study are in line with previous studies which showed more robust boundary-initial strengthening effects for Korean compared to languages like English (Keating et al., 2003; Cho et al., 2011). Previous studies attributed the robust initial effect to the lack of lexical level prominence in its prosodic system. That is, unlike English which has to mark both prosodic prominence and boundary in a prosodic structure, Korean only marks prosodic boundary, and hence leaves more freedom for the prosodic grouping to be phonetically realized. Related to this interpretation, Cho et al. (2010) observed a longer, larger, and faster (transboundary) vocalic movement across a larger prosodic boundary, which was indeed comparable to a pattern arising with prominence marking found in English (Byrd, 2000; Cho, 2008). Based on this finding, they claimed that prosodic boundary marking in Korean likely serves another function to signal prominence. This is also consistent with the view that prosodic phrasing may play a role in marking information structure in Korean (Jun, 1993; Ladd, 2008; Schafer & Jun, 2001). In the present study, we have tested this claim by comparing the boundary effects in different accentual conditions. Most crucially, as far as the lip *opening* movement speed (as reflected in peak velocity) was concerned, the boundary-induced effect in the neutral condition (i.e., when no particular focus was assigned in the utterance) was similar to the accent-induced effect, both showing a faster lip opening movement than in the unaccented condition. The current finding therefore is favorably inclined towards the claim the prosodic phrasing can indeed function as marking prominence in Korean.

4.3 Implications for the theory of pi-gesture

The results of the present study have some theoretical implications for the theory of pi-gesture. We found that the distribution of consonantal lengthening associated with /m/ was very similar in the coda and the onset. This is quite different from differential lengthening effects for the coda versus the onset in English as reported in Byrd et al. (2005)--i.e., the boundary effect on the coda affects primarily the lip opening movement (out of the consonant) while the boundary effect on the onset was observed during the lip closing movement (into the consonant). This coda-onset asymmetry in English was interpreted as coming from the proximity of the gesture to the boundary. That is, the lip opening gesture (out of the consonant) for the coda in /V**C#**V/ is immediately adjacent to the boundary (because the **C**-to-V opening movement straddles the boundary), being subject to more boundary-induced lengthening, whereas for the onset in /V**#C**V/, it is the lip closing gesture (into the consonant) that is closer to the boundary (because the V-to-**C** closing movement straddles the boundary in /V**#C**V/). This case in English is in line with the theory of pi-gesture advanced by Byrd and colleagues (e.g., Byrd & Saltzman 2003; Byrd, Krivokapić, & Lee, 2006) which stipulates that the temporal structure of articulatory gestures at the boundary is governed by the pi-gesture which modulates the rate of clock, such that the closer the gestural component, the larger the clock-slowing effect.

While the pi-gesture effect on the temporal realization of boundary-adjacent gestures is in theory expected to be applicable across languages, the results of the present study clearly runs counter to the prediction made by the theory at least in two aspects. First, as just summarized above, there was no difference of boundary effects on the temporal realization of the onset versus the coda /m/s in Korean (as opposed to the English case where the onset/coda asymmetry was observed in line with the predictions made by the pi-gesture theory). Second, no obvious slowing down effects were found on the lip closing and the opening movements. In other words, while the lip closing (into the consonant) movement was not slower for IP than for Wd (as reflected in peak velocity), the lip opening (out of the consonant) movement was in fact faster for IP than for Wd, again precisely the opposite of what is expected by the pi-gesture theory. The present study therefore implies that different languages might use different lengthening mechanisms, perhaps fine-tuned by other constraints imposed by the prosodic system of the language (e.g., the presence or absence of the role of lexical stress). We are currently expanding our study to explore this issue further.

4.4 Effects of Syllable Affiliation: Onset versus Coda

Another important question of the present study concerns potential neutralization of /a**m**#i/ with /a#**m**i/ in a phrase-medial (IP-medial/Wd-boundary) condition in which the coda /m/ may be resyllabified into the following vowel. We found that the kinematic realization of /m/s in the coda (/a**m**#i/) versus the onset (/a#**m**i/) was not neutralized. They were differentiated most clearly in constriction maximum, such that the coda /m/ was strongly articulated than the onset /m/ within a word (although the coda /m/ was produced with less constriction IP-finally than IP-medially). It appears that speakers reinforce the underlying syllable affiliation of the coda /m/ by making its lip constriction more extreme compared to its production in the onset. This observation is, however, inconsistent with some of the results reported in Byrd et al (2005)'s study on English consonants. In their study, 3 out of 5 subjects made more constriction for the onset than the coda consonants in English, counter to what we have found in Korean. This suggests that different languages may employ different articulatory strategies to encode underlying syllable affiliation, although we cannot entirely rule out that the underlying syllable affiliation of the consonant may also differ depending on the segmental makeups.

In addition to the constriction degree that varied as a function of the consonant's syllable affiliation, the onset /m/ tended to be longer compared to the coda /m/ in the temporal dimension—i.e., in constriction duration and lip opening movement duration. The observed temporal expansion for the onset /m/ is similar to what was previously observed in English and Dutch (Lehiste 1960, 1961; Quené, 1992). Interestingly, the temporal expansion (especially constriction duration) associated with the onset /m/ (relative to the coda /m/) was found to become more reliable in the accented condition in which the onset /m/ belongs to an accented word (while the coda /m/ belongs to the syllable before the accented word). It appears that the temporal distinction between /m/s in the coda and the onset is augmented in the accented condition in which more attention is paid to the target consonant, especially in the onset. This implies that the onset/coda information interacts with higher-order informational structure, so that the articulatory manifestation of their distinction (at least in the temporal dimension) becomes clearer under prominence (when accented), presumably being available to the listener.

5. Conclusion

In the present study, we have examined how the articulatory-kinematic realization associated with /m/s in Korean differs in the onset versus the coda positions, and how it is further modulated when they are aligned with a higher level prosodic boundary (IP versus Wd) in different prominence conditions (Accented versus Neutral versus Unaccented). Results of the present study clearly demonstrated that articulatory properties of the consonants can be understood in full only when they are systematically examined in connection with various higher-level prosodic factors such as syllable affiliation, prosodic boundaries, and prominence. Furthermore, many of the findings of the present study on Korean were not comparable to those found in English in various aspects, including the way that the boundary-related articulatory modification may be modeled in dynamical terms (e.g., the applicability of the pi-gesture). This implies that the influence of higher-level prosodic structure on phonetic realization is tuned by the language's prosodic system in a language-specific way. It appears promising to continue to compile the kinematic data in Korean from which, when compared to existing data in other languages, we can obtain the linguistic insights into the phonetics-prosody interface from the perspectives of both language specificity and cross-linguistic universality.

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• **김사향 (Kim, Sahyang)**
홍익대학교 영어교육과
서울시 마포구 상수동
Tel: 02-320-1848 Email: sahyang@hongik.ac.kr

• **조태홍 (Cho, Taehong)**
한양대학교 영어영문학과
서울시 성동구 행당동
Tel: 02-2220-0746 Email: tcho@hanyang.ac.kr