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Preboundary lengthening of alveolar consonants: Acoustic and articulatory evidence from Seoul Korean*

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Kwon, Soohyun and Mira Oh. 2024. Preboundary lengthening of alveolar consonants: Acoustic and articulatory evidence from Seoul Korean. *Linguistic Research* 41(2): 231-251. This study investigates the effects of prosodic boundaries on the acoustic and articulatory realization of alveolar consonants [n] and [t] in Seoul Korean. The ultrasound analysis shows that a higher prosodic boundary results in a greater magnitude of temporal and spatial expansion for the consonant gestures of Korean alveolars: when located in an IP-final compared to an AP-final position, [n, t] exhibit a significant lengthening, an advancement of the tongue root and lowering of the tongue body. We suggest that these acoustic and articulatory strategies variously employed among Korean speakers have a shared goal of expanding a pharyngeal cavity that often serves as the articulatory goal across world's languages when the target segment is temporally and/or spatially expanded. This study lends support to the cross-linguistic patterns of boundary-induced strengthening and contributes novel articulatory evidence demonstrating that consonantal gestures located at the right-edge are structurally conditioned by prosodic hierarchy in Korean. The findings of this study also illuminate how the preboundary lengthening of consonant gesture in Korean is articulatorily implemented. **(Seoul National University · Chonnam National University)**

Keywords preboundary lengthening, ultrasound, Korean alveolar consonants

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1. Introduction

Our speech utterances are organized by a hierarchical structure of phonologically defined constituents and heads (Beckman 1996). The prosodic structure of Korean, for example, is multi-layered (Jun 1998; Cho and Keating 2001): lower (or smaller) prosodic domains (e.g., prosodic words) are grouped into higher (or larger) levels (e.g., Accentual Phrase (AP)), which constitute an even higher domain, the Intonational Phrase (IP, generally punctuated by a comma) into which APs are grouped, or Utterance (U, generally punctuated by a period) into which IPs are grouped.

While the hypothesis of a prosodic hierarchy has been widely established, prosodic phonologists have not agreed upon what constitutes the highest prosodic unit. While the IP is often posited to be the highest prosodic unit (Beckman and Pierrehumbert 1986; Beckman et al. 2005), Selkirk (1984, 1995) and Nespor and Vogel (1986) argue that the Utterance is the highest prosodic unit above the IP. The highest prosodic level in Korean has also been treated differently across studies. Jun (1998) argues that there are no prosodic or acoustic cues (e.g., intonation, phrase-final duration, degree of phrase-initial strengthening, pause) that separate IP-final from U-final position. In contrast, Cho and Keating (2001) and Keating et al. (2004) found that Utterance-initial [n] and [t] exhibit larger linguopalatal contact and longer seal duration than those in IP-initial position.

The prosodic hierarchy plays a crucial role in shaping the phonetic realization of segments (Cho 2005, 2016, *inter alia*). Sounds located at the edges of different levels of the prosodic structure display systematic phonetic variations. For instance, domain-final vowels at a higher prosodic level were observed to be articulated with greater magnitude in comparison to those at a lower level (Fougeron and Keating 1997; Tabain 2003; Georgeton and Fougeron 2014). In a similar vein, Byrd (2000) observed that vocalic articulations increased in duration before stronger prosodic boundaries in all subjects. Cho and Keating (2009) show that word-initial CVs in English words are produced with "stronger" articulation at a higher prosodic boundary. The effect that sounds located at the edges of a higher prosodic domain is found to be associated with a greater degree of acoustic and articulatory expansion is known as prosodic strengthening (Cho 2016).

Previous studies have identified two types of prosodic strengthening effect. One is the effect of domain-initial strengthening whereby a given segment is produced with a longer duration (temporal expansion) and more constriction (spatial expansion) when the segment is located after a higher than a lower prosodic boundary (e.g., Fougeron and

Keating 1997; Cho and Keating 2001, 2009; Keating et al. 2004; Cho and McQueen 2005; Kuzla et al. 2007; Cho et al. 2011, 2014, *inter alia*). The other type is preboundary lengthening, whereby domain-final phonological units before a prosodic boundary are temporally modulated (e.g., Edwards et al. 1991; Gussenhoven and Rietveld 1992; Wightman et al. 1992; Berkovits 1993, 1994; Byrd and Saltzman 1998; Byrd 2000; Byrd et al. 2006; Cho 2006; Turk and Shattuck-Hufnagel 2007; Nakaia et al. 2009; Katsika 2016; Kim et al. 2017; Baek 2017; Seo et al. 2019). This second type of prosodic strengthening phenomenon, preboundary lengthening, is the focus of this study.

It has been suggested that preboundary lengthening is a cross-linguistic phenomenon that is physiologically driven. Articulatory gestures tend to slow down as they approach the end of each prosodic domain, with movements gradually coming to a stop (Lindblom 1968; Cho 2016). Fletcher (2010) argues that preboundary lengthening can be seen as a supralaryngeal declination that occurs during the course of an utterance (Fowler 1988; Vayra and Fowler 1992; Berkovits 1994; Krakow, Bell-Berti and Wang 1995; Tabain 2003). In line with these interpretations, research has uncovered that the degree of lengthening increases progressively from the start to the end of a phrase-final disyllabic word in Hebrew (Berkovits 1993, 1994), indicating a gradual temporal decline.

Of note, however, is that preboundary lengthening that may have initially arisen from physiological constraints eventually evolves to have language-specific patterns. Stress-timed languages such as English (Turk and Shattuck-Hufnagel 2007; Kim et al. 2017), Greek (Katsika 2016) and German (Kohler 1983), for example, show the patterns for domain-final lengthening that interact with prominence (lexical stress). Preboundary lengthening in mora-timed languages such as Japanese was shown to be attracted toward a non-final moraic nasal, showing some influence from the mora (Seo et al. 2019).

The spatio-temporal patterning of preboundary lengthening in Korean has received relatively less attention compared to domain-initial strengthening in Korean (but see Baek 2017). While Baek (2017) provides the acoustic evidence for the preboundary lengthening in Korean, no articulatory evidence has been provided. In this light, the current study aims to investigate how preboundary lengthening is acoustically and articulatorily manifested in alveolar consonants [n, t] in Korean. More specifically, the patterns of temporal and spatial expansion of alveolar consonants in an AP-final position will be compared with that in an IP-final and Utterance-final level, respectively. The prediction is that alveolar consonants at higher prosodic junctures (IP-final and U-final) will be produced with longer closure duration and more spatial expansion compared to those at lower prosodic juncture (the final edge of AP). As aforementioned, whether the Utterance-final is differentiated from IP-final position in Korean is not established. Therefore, the degree of temporal and spatial expansion in IP-final and U-final positions will be compared to test the hypothesis that Utterance constitutes a separate prosodic unit in Korean.

As for the spatial expansion of Korean alveolar consonants, we made an observation that young Korean speakers often produce alveolar consonants interdentally, with the tongue protruding from the mouth when the sounds are located at the final position of prosodic domains and that this tendency is more salient at a higher prosodic boundary. We posit that the tongue protrusion or tongue fronting, at the least, can be interpreted as boundary-related expansion effect that usually involves longer movements with larger displacements (Kelso et al. 1985; Ostry and Munhall 1985). This makes more sense considering Cho and Keating's (2001) findings that Korean /n/ and /t/ in a higher domain-initial position have the front denti-alveolar contact, whereas /n/ and /t/ in a lower domain-initial position were found to have the palatoalveolar contact, although the effect was less dramatic for /t/. That is, it can be speculated that when enough time is given to Korean alveolar consonants, tongue tip may travel beyond the target location all the way to the point where an interdental articulation is achieved. This prediction is tested to probe the articulatory manifestation of the preboundary lengthening of alveolar consonants [n, t] in Seoul Korean, using ultrasound and video capturing the movements of the entire tongue and tip, respectively. As will be detailed in Section 3, the results reveal that tongue protrusion and interdental constriction indeed take place for Korean alveolar consonants [n, t] in the final position of prosodic domains and that the degree of this prosodic strengthening is greater at a higher prosodic boundary. The rest of the paper is organized as follows. We first explain the materials and procedures of the ultrasound experiment and its analysis employed in this study in Section 2 and presents the results of the experiment in Section 3. We then discuss the universals and language-specific patterns of boundary-induced strengthening and further suggest that a combination of multiple articulatory strategies is employed to achieve the lengthening or strengthening of segments across languages in Section 4.

2. Methods

2.1 Test sentences

Each test sentence included either [n] or [t] at different prosodic positions as seen in sample sentences provided in Table 1. A total of 18 sentences were constructed.

Table 1. An example set of test sentences containing [n] or [t] at the final edges of various prosodic levels. (# denotes a prosodic boundary, and angled brackets [ ] indicate an intended prosodic grouping of speech materials.)

Target sound	Test sentences	Expected results
[n]	(i) AP-final *[mutɨŋsan] [kaponik'a koŋkika tʃott^{h}ʌra]* */mutɨŋsan/ 'Mudeung Mountain#' (#=AP)* 'I went to the Mudeung Mountain, and the air there was fresh' Korean: 무등산 가보니까 공기가 좋더라. (ii) IP-final *[mutɨŋsan] [kaponik'a koŋkika tʃott^{h}ʌra]* */mutɨŋsan/ 'Mudeung Mountain#' (#=IP)* 'Mudeung Mountain, I went there and the air there was fresh' Korean: 무등산, 가보니까 공기가 좋더라. (iii) Utterance-final *[ʌti koŋkika tʃott^{h}aku?][mutɨŋsan]* */mutɨŋsan/ 'Mudeung Mountain#' (#=Utterance)* 'Where is the air fresh? Mudeung Mountain' Korean: 어디 공기가 좋다구? 무등산.	***Less*** *amount of temporal and spatial expansion* ↕ ***Greater*** *amount of temporal and spatial expansion*
[t]	(i) AP-final [ʌtʃe poripat]AP [katnɨnte] [atʃik porika an poitejo] /poripat/ 'barley field#' (#=AP) 'I went to the barley field yesterday, but no barley was seen'. Korean: 어제 보리밭 갔는데 아직 보리가 안 보이데요. (ii) IP-final [ʌtʃe poripat]IP, [katnɨnte] [atʃik porika an poitejo] /poripat/ 'barley field#' (#=IP) 'I went to the barley field yesterday, but no barley was seen'.	***Less*** *amount of temporal and spatial expansion* ↕ ***Greater***

	Korean: 어제 보리밭, 갔는데 아직 보리가 안 보이데요. (iii) U-final [ʌtʃe ʌtil kattaku? poripat] /poripat/ 'barley field#' (#=Utterance) 'I went to the barley field yesterday, but no barley was seen'. Korean: 어제 어딜 갔다구? 보리밭.	*amount of temporal and spatial expansion*

2.2 Participants and procedures

The articulatory and acoustic data were collected from six native speakers of Seoul Korean (three female and three male speakers) in their 20s who were born and raised in Seoul. Midsagittal images of the speakers' tongues were obtained with a Micro ultrasound machine. A 5-8 MHz convex-curved transducer that produces up to 120 scans per second across 120 degrees field of view was used. The focal depth was set to 70mm. The speakers' heads were stabilized using a probe stabilization headset designed by Articulate Instruments. This lightweight and portable headset is used to fix the transducer midsagitally beneath the speaker's chin. This ensures minimal lateral movement of the probe and prevents any rotation. Nevertheless, speakers are able to move freely during recording because the headset features adjustable components that securely conform to the speaker's head.

Once the participants were seated in the chair, a microphone was affixed to each participant, enabling simultaneous audio recording. Additionally, a front-view video recording of the participants' faces was taken to capture any potential tongue protrusions. The audio signal from a microphone was synchronized with the incoming video signals from the ultrasound machine. At the start of each recording session, participants were instructed to hold a mouthful of water briefly and then swallow, enabling us to capture images of the palate. The participants read aloud each test sentence at a comfortable pace. Articulate Assistant Advanced (AAA) software was used to present these sentences and record ultrasound images, videos, and acoustic data from the participants. Ten additional filler sentences were added to the list and the order of sentences was randomized. The target sentences were repeated five times.

2.3 Data analysis

Quantitative analyses of this study were made on the basis of three types of data: 1) durational measures that can demonstrate the effect of temporal expansion, 2) the degree of tongue protrusion measured from the front-view face video and ultrasound video and 3) tongue shapes measured from the traced tongue splines from the ultrasound data that can demonstrate the effect of spatial expansion. All quantitative comparisons were performed on the most extreme point of consonant gestures indicating the greatest extent of tongue protrusion for each token.

2.3.1 Durational measures

For all quantitative analyses, sound files exported from Articulate Assistant Advanced (AAA) were segmented acoustically using primarily the Korean Forced Aligner (Yoon and Kang 2012). All TextGrid files were manually inspected and, when needed, corrected in Praat. The duration of [n] and [t] was extracted using a Praat script.

2.3.2 Tongue protrusion: Protrusion Distance (PD)

It would be simpler if we can rely on the ultrasound data only for the measurement of tongue protrusion. In many ultrasound images, however, the tongue tip can often be obscured by sublingual air or the mandible, or it can be simply out of view of the ultrasound transducer because the tongue is extended forward. Therefore, we will rely on the face video data as well to quantify tongue protrusion. Following Mielke et al. (2011), the distance between the tongue tip and a reference point (e.g. the lowest point of upper teeth) was measured to determine tongue protrusion , using a built-in ruler of AAA as shown in Figure 1. PD was normalized across speakers.

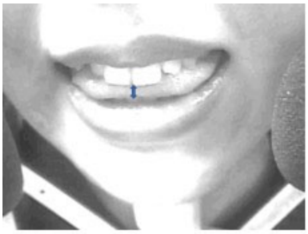

Figure 1. The measurement of tongue protrusion.

We employed mixed-effects linear regression models to investigate the effects of prosodic boundaries on the protrusion distance for [n] and [t], respectively, at the final edges of various prosodic levels. We utilized the lmer function from the lme4.0 package in R (R Development Core Team 2013) to fit models to the protrusion distance (PD), with the SPEAKER and ITEM as potential random effects that account for variations among individual speakers and different test items. Model selection was guided by log-likelihood tests as well as Akaike Information Criterion (Akaike 1974) and Bayesian Information Criterion (Schwarz 1978) values. The significance levels or p-values were computed using Satterthwaite's (1946) approximations for degrees of freedom, implemented through the lmerTest package (Kuznetsova, Brockhoff, and Christensen 2017). Posthoc comparisons between levels were conducted using Tukey's Honest Significant Difference (HSD) test, with alpha set at 0.05.

2.3.3 Tongue spline: SS-ANOVA

To trace tongue and palate contours in the ultrasound images, AAA was used. The tongue contours were extracted as a series of x-y coordinates. To compare tongue contours for [n] and [t] in the final position across various prosodic levels, we employed smoothing spline-ANOVA (SS-ANOVA; Davidson 2006; Gu 2013), a statistical method used for comparing curve data, to assess the significance of differences between the two sets of curves. In the SS-ANOVA test, smooth lines are generated for each set of curves, representing the average contours of the subset of tokens under investigation. Then Bayesian confidence intervals of 95% are calculated and plotted around the curves. Areas where the confidence intervals of the two sets do not overlap are interpreted as indicating differences between the sets of curves.

3. Results

The results reveal that Korean alveolar consonants [n, t] exhibit a greater magnitude of temporal and spatial expansion in IP-final position compared to AP-final position. In contrast, the comparison of [n, t] in U-final and AP-final positions provides mixed evidence.

3.1 Temporal expansion: Duration

Figure 2 displays the segmental duration of [n] and [t] at different prosodic boundaries. It is clearly shown that the segmental duration is far longer for those in IP-final position compared to those in AP-final position for both [n] and [t]. However, the duration for those in U-final position was not necessarily longer than those in IP-final position. The results from the linear mixed effects model fitted on the segmental duration (see Table 2) confirm that Korean alveolar consonants [n, t] exhibit a greater magnitude of preboundary lengthening in IP-final position compared to in AP-final position: for both [n] and [t], the segmental duration is far longer for those in IP-final position compared to those in AP-final position ($p<0.001$***). Since we found similar degrees of temporal expansion for [n, t] in IP-final and U-final positions, these findings can be seen to lend support to Jun's (1998) claim that Utterance is not differentiated from IP.

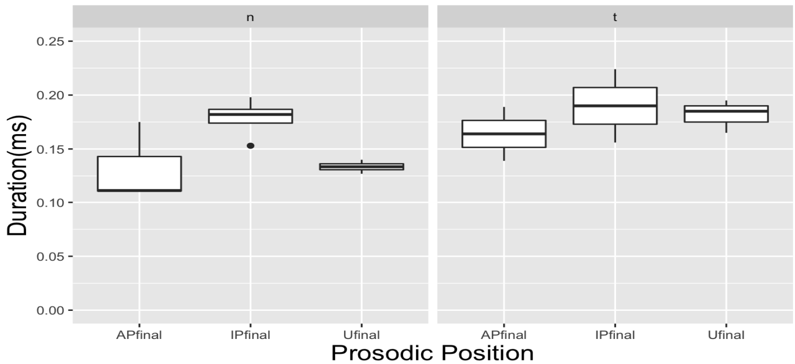

Figure 2. Durational measures for [n, t] by prosodic boundaries

Table 2. Coefficient tables from the linear mixed-effects models

Factors	Estimate	Standard Error	t-value	p-value
(Intercept)	0.132	0.008	16.171	< 2e-16***
Segment: t (vs. n)	-0.032	0.008	3.94	0.000414***
PP:IP-final (vs. AP-final)	0.039	0.01	3.923	0.000434***
PP:U-final (vs. AP-final)	0.008	0.009	0.859	0.396

Interestingly, however, the durational difference between AP- and U-final position failed to reach significance (p=0.396). Moreover, the durational difference between IP and U-final position is minimal for [t] and the duration of [n] in U-final position is even smaller than that of IP-final position although it is marginally significant (p=0.063). These results appear surprising in the context of the prosodic model predicting AP inevitably differentiated from Utterance, but we attempt to account for this discrepancy more in depth in Section 4.1.

The interaction between segment (n vs. t) and prosodic position was not significant (p=0.906), which indicates that [n] and [t] do not behave differently under the influence of prosodic hierarchy.

3.2 Spatial expansion (1): Tongue protrusion

The front-view video data reveals that Korean alveolar consonants [n, t] occasionally involve a tongue protrusion in IP-final position as compared to AP-final position, showing a greater magnitude of boundary-induced spatial expansion. Although the difference appears subtle as shown in Figure 3, the tongue protrudes more for IP-final [t] compared to AP-final [t].

Figure 3. Tongue protrusion for [t] by prosodic boundaries.

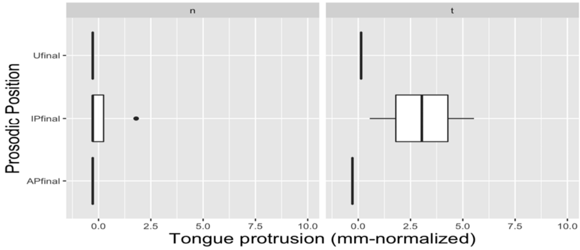

Figure 4. Degree of tongue protrusion for [n] and [t] by prosodic boundaries

Figure 4 shows the tongue protrusion measures (in millimeters) for [n, t] produced at various prosodic positions. It is clear that IP-final [n, t] exhibit more tongue protrusion than AP-final counterparts that rarely exhibit any tongue protrusion at all. Note, however, for IP-final [t], tongue protrudes from the mouth only when the duration of phrase-final alveolar consonant is quite long. Thus, some tokens of IP-final [t] involve no tongue protrusion at all. Also, only three (two female and one male) out of six speakers exhibited tongue protrusion. The quantitative analyses confirm this, showing that the degree of tongue protrusion is greater for IP-final [n, t] compared to AP-final alveolars. No token of AP-final alveolars exhibited tongue protrusion. Interestingly, no token of Utterance-final consonants exhibited tongue protrusion either. Again, this unexpected finding will be further discussed in Section 4.1.

3.3 Spatial expansion (2): Tongue contours

Lastly, we are going to probe what tongue contours are associated with tongue protrusion. Figure 5 and 6 provide Smoothing Spline ANOVA plots of six Korean speakers that display their tongue configurations for [n] and [t] at three different prosodic levels: AP-final, IP-final and Utterance-final positions (Tongue tip is to the left and the tongue root is to the right). We found that speakers exhibit a different combination of three articulatory patterns in achieving the strengthening of alveolar consonant [n] or [t] at a higher prosodic boundary.[1]

One pattern consistently observed across speakers for [n] is to advance the tongue root: as can be seen in Figure 5, the tongue root is more advanced for [n] in IP-final and U-final than in AP-final position, although the difference is subtle for S3 and S5. Interestingly, the tongue root was not necessarily more advanced for U-final [n] compared to IP-final [n]. Rather, what differentiates U-final [n] from IP-final [n] was the highest point of the tongue being lower for U-final [n] compared to its IP-final counterpart. However, a large difference is found for S1 and S4 but the other speakers show subtle differences only. Lastly, the tongue body was observed to be lower for IP-final and U-final [n] than AP-final [n] for some speakers. This was the case for S1, S3, S4, S5, but the opposite pattern was observed in S2 and S6 who exhibited a far lowered tongue tip and body for AP-final [n] compared to IP and U-final [n].

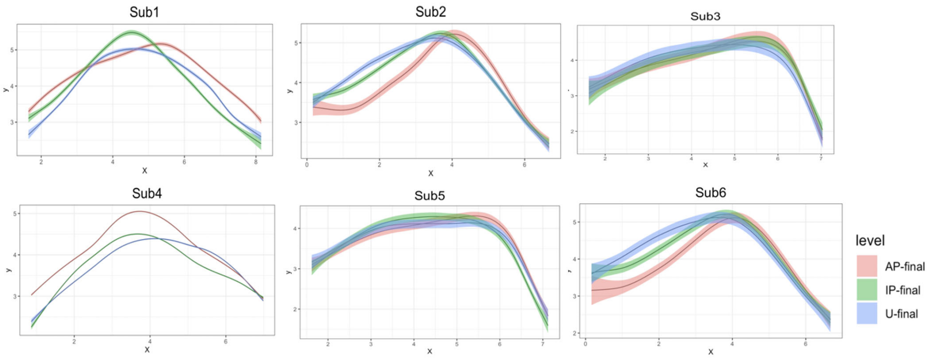

Figure 5. Smoothing Spline ANOVA plots of six Korean speakers for their production of [n]. Bayesian intervals of 95% are plotted as shaded areas surrounding the curves. (Tongue tip is to the left and the tongue root is to the right.)

1 We will illustrate all observed articulatory strategies as if they are independent, but it is highly probable that these strategies are kinematically related.

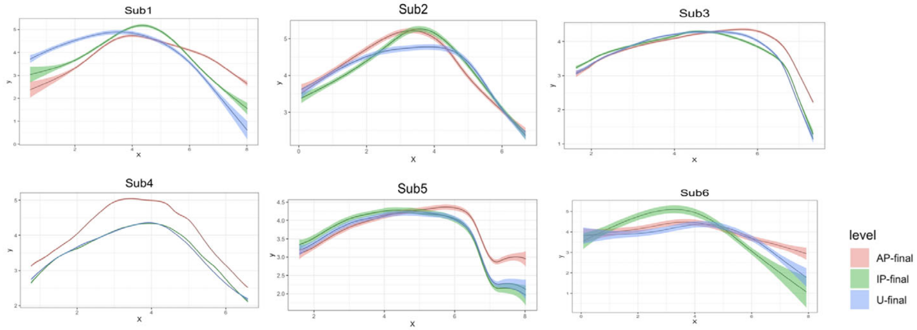

Figure 6. Smoothing Spline ANOVA plots of six Korean speakers for their production of [t]. Shaded areas surrounding the curves represent 95% Bayesian intervals. (Tongue tip is to the left and the tongue root is to the right.)

Similar patterns were found for [t] at different prosodic levels as seen in Figure 6. First, tongue root tends to be more advanced for [t] in IP-final and U-final than in AP-final position for all speakers except for S2. As in [n], tongue root was not necessarily more advanced for U-final [t] compared to IP-final [t]. Tongue root positions for IP-final and U-final [t] almost overlap for S2, S3, S4 and S5 and even opposite pattern was observed for S6. Second, the highest point of the tongue was lower for U-final [t] for some speakers (S1, S2 and S6) but it turned out to have a similar highest point for S3, S4 and S5. Lastly, the anterior part of the tongue or tongue body was observed to be lower for IP-final and U-final [t] compared to AP-final [t] for some speakers. This was the case for S2, S4 and S6, but the opposite pattern was observed in S1 who exhibited a lowered tongue tip for AP-final [t] (S1) or in S3 and S5 whose AP-final [t] almost overlap with IP and U-final [t] (S3 and S5).

3.4 Summary

To summarize, there are three main findings in this study. First, a higher prosodic boundary results in a greater magnitude of temporal and spatial expansion for the consonant gestures of Korean alveolar consonants. That is, IP-final [n, t] exhibit a significantly more lengthening, advancement of the tongue root and lowering of the tongue body compared to AP-final [n, t]. Second, U-final [n, t] were not always differentiated from IP-final [n, t]. Lastly, Korean speakers appear to employ a combination of the two articulatory strategies in lengthening [n, t] in domain-final positions: the advancement of the tongue root and the tongue body lowering. Some speakers rely on the robust tongue root distinction in differentiating IP-final [n, t] from AP-final counterparts, while other speakers use both tongue root advancement and tongue body lowering.

4. Discussion

4.1 Preboundary lengthening and the highest prosodic unit in Korean

This study presents the acoustic and articulatory evidence showing that a larger prosodic boundary results in a greater magnitude of temporal and spatial expansion for consonant gestures. That is, the alveolar consonants [n, t] in Korean exhibit a significantly more lengthening and tongue fronting (or protrusion) when located in IP-final compared to an AP-final position. This confirms the universal patterns of domain-induced strengthening of the consonant gestures (Byrd 2000; Cho and Keating 2001, *inter alia*). IP-initial consonants in English were shown to be articulated with longer durations than word-initial consonants (Cho and Keating 2001; Cho et al. 2007). Similar effect of domain-initial strengthening of consonant gestures has been reported in different languages. Kuzla et al. (2007) found that German fricatives /f, v, z/ following /ə/ were longer and produced with less glottal vibration after higher prosodic boundaries. Similarly, consonants at the beginnings of larger phrases were found to be more constricted than consonants at the beginnings of smaller phrases in French, Korean and Taiwanese (Fougeron and Keating 1997; Hsu and Jun 1998; Cho et al. 2004; Keating et al. 2004). The findings of this study add to the growing body of literature demonstrating that consonantal gestures are structurally conditioned by prosodic hierarchy.

Another interesting aspect of boundary-induced strengthening in Korean that is newly revealed in this study is that the right-edge as well as the left-edge of prosodic domain is strengthened in Korean. Although preboundary strengthening is usually physiologically motivated (Lindblom 1968), it is language-specifically tuned: languages vary as regard to what exact patterns of prosodic strengthening are involved. French, a language without lexical stress and pitch accent, the right-edge is more robustly strengthened (Keating et al. 2004). In contrast, Korean that also lacks lexical stress and pitch accent, has been known to exhibit strong strengthening effects primarily at the left-edge (Cho et al. 2011). The results of this study, therefore, contribute novel articulatory evidence of the strengthening of consonantal gestures located at the right-edge in Korean.

One point in need of further discussion at this point regards whether Utterance forms a separate level from IP as the highest prosodic unit in Korean. The findings of this study provide somewhat mixed evidence. Overall, the articulatory findings of this study demonstrate that Utterance is barely differentiated from IP in that the tongue root is not more advanced for [n, t] in U-final position compared to those in IP-final position for all subjects. These findings support Jun's (1998) position that Utterance is not differentiated from IP. However, a few speakers distinguished tongue configurations for U-final alveolar consonants from IP-final counterparts in that the highest point of the tongue was lower for U-final than IP-final alveolars. Also, it is puzzling to find that, in the temporal dimension, the duration of [n, t] in U-final position is even shorter than those in IP-final position. We are unable to offer a principled explanation based on a small amount of data presented in this study but we attempt to provide a potential answer for such unexpected results.

We speculate that such a discrepancy stems from the nature of utterance finality. It is possible that an IP-final position within an Utterance is given a larger amount of time for a consonant for lengthening not only to mark a relevant boundary but also to signal listener(s) that the speech is not terminated but will be continued. In U-final position, the effect of domain-final lengthening might be as strong as that for IP-final position, but speakers need to indicate that they have finished speaking and even pass the turn to the listener. The U-final position, therefore, can be considered being under two competing forces acting against each other: the lengthening effect for boundary marking and the opposing effect for signaling the termination of speech. We speculate that the latter may have diminished or overshadowed the former effect of final lengthening. The highest point of tongue being lower for U-final than IP-final position receives a similar explanation. A few speakers exhibiting a lower tongue position for [n, t] in U-final position may have returned to the resting tongue position more quickly to signal the termination of speech. In order to rule out this utterance finality effect, the experimental design needs to include one more U-final condition which examines the final lengthening effect in the Utterance that consist of multiple APs and IPs and followed by another

Utterance. We aim to investigate the effects by comparing these two Utterance conditions and tease apart the final lengthening effect only. Taken together, we argue that, overall, the current findings are consistent with the view that does not differentiate IP from U (Jun 1998) and some discrepancy in the findings arises from a different factor. Further research into the effect of final lengthening that rules out the effect of utterance finality is clearly called for.

4.2 Articulatory implementation of preboundary lengthening in Korean

The findings of this study illuminate how the preboundary lengthening of consonant gesture is articulatorily implemented in Korean. While how segments are temporally and spatially expanded in the domain-initial position has been investigated in the acoustic and articulatory dimensions (Cho et al. 2011), the mechanism of preboundary lengthening in Korean still remains poorly understood due to a lack of instrumental studies (but see Baek 2017). Cho and Keating (2001) demonstrated that Korean alveolar consonants located at the left-edge in higher prosodic domains have greater linguopalatal contact than those in lower domains. This increased contact was shown to be correlated with longer duration, from which they suggest that "strengthening" and "lengthening" are manifestations of a single underlying process in Korean. The results of the current study indicate that alveolar consonants located at the right-edge of higher prosodic domains also involves both fronting (or strengthening) and lengthening that may be strongly correlate with each other, which suggests that the two can be considered a single effect as well.

The mechanism of spatial expansion employed by the speakers of this study to achieve the preboundary lengthening in Korean merits a further discussion. It was observed that both the tongue root advancement and tongue body lowering were used towards the goal of lengthening the alveolar consonants in Korean. These are reminiscent of the articulatory patterns variously employed to achieve the advanced tongue root vowel contrast and the tense/lax vowel contrast in different languages. Kirkham and Nance (2017) reported that both tongue root distinctions and tongue height distinctions were employed to differentiate [TENSE] vowels from [LAX] vowels in British English, whereas only tongue root distinction was used for the [TENSE] contrast in Ghanaian English. Meanwhile, Twi speakers produced [+ATR] vowels with a significantly more advanced tongue root, but only small height distinctions were observed for [+ATR] vowels in Twi. Based on these findings, they further suggested that these articulatory strategies have a shared goal of expanding a pharyngeal cavity for [+ATR] and [TENSE] vowels compared to [-ATR] or [LAX] vowels, respectively. The articulatory strategies similar to those employed in the current study can also be found in Ahn's (2018) investigation into the articulatory patterns employed to distinguish voiced stops from voiceless counterparts in English and Portuguese. She found that tongue root advancement or tongue body lowering was used by English and Portuguese speakers for the production of voiced stops as opposed to their voiceless counterparts. What is interesting is that there was a substantial variation across speakers in employing tongue root advancement or tongue body lowering depending on language and the stops' place of articulation. For example, all eight English speakers showed more tongue root advancement for voiced alveolar stops whereas only a half of the speakers used tongue root advancement and the other half of the speakers used tongue body lowering to achieve the distinction between voiced and voiceless velar stops. For labial stops, in contrast, all speakers exhibited a lowered tongue body and blade for voiced stops in comparison to voiceless stops, while tongue root advancement is used by some speakers. Based on these findings, Ahn suggests that whether speakers employ tongue body lowering or advancing the tongue root, their goal is to enlarge the pharyngeal cavity volume to produce voiced stops.

The findings of the current study therefore suggest that Korean speakers aim to achieve the pharyngeal expansion as the language-specific articulatory goal of prosodic strengthening. Also, the pharyngeal expansion appears to serve as the speech production goal across the world's languages when the target segment is under lengthening or strengthening.

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