Prosodically driven phonetic properties in the production of Korean fricatives

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Jang, Mi. 2011. Prosodically driven phonetic properties in the production of Korean fricatives. *Studies in Phonetics, Phonology and Morphology* 17.1. 65-86. Consonants at the beginning of prosodic domains, such as syllables, words or phrases, are known to be more clearly articulated and distinguishable than later-occurring consonants. However, relative to plosives, the prosodic domain effect on Korean fricatives was not found to be consistent across speakers and fricative categories. The present study investigated how prosodic position and word type affect the phonetic structure of Korean fricatives. The acoustic properties of fricatives were compared across IP, PP and Wd-initial positions both in real and nonsense words. It was found that segments in the higher prosodic domain-initial positions showed enhanced durational properties compared to the lower prosodic domain-initial positions. But the prosodic domain-initial effect was not found in the properties of the vowel following target fricatives. The enhancing strategies were different across phonation types. Relative to plain fricative, fortis fricative showed less consistent variation as a function of prosodic position and word type. The present study provided evidence that speakers tend to enhance speech clarity when there is less contextual information as in prosodic domain-initial position and in nonsense words. **(Seoul National University)**

Keywords: prosodic domain-initial, fricatives, enhanced duration

1. Introduction

The focus of this research is to explore how prosodic position and word type affect the phonetic structure of Korean fricatives. Speakers try to achieve sufficient distinctiveness in articulating segments to increase intelligibility for listeners (Lindblom (1990)). When there is less contextual information (with higher information content), talkers tend to produce clear speech (Hay et al. (2006)). For example, consonants at the beginning of prosodic domains, such as syllables, words or phrases, are more clearly articulated and distinguishable than later-occurring consonants (Browman and Goldstein (1995), Redford and Diehl (1999), Keating et al. (2003), Cho and Keating (2001)). By enhancing phonetic properties and phonological contrast, talkers tend to provide perceptual cues for the prosodic position with higher information content (Hay et al. (2006).

Segmental properties are known to be affected by prosodic structure. Acoustic and articulatory studies have focused on both phrase-final intonational contrasts and final lengthening (Pierrehumbert and Beckman (1988), Shattuck-Hufnagel et al. (1996)) as well as initial prosodic domains across syllable, word and phrasal levels (Pirrehumbert and Talkin (1992), Browman and Goldstein (1995), Redford and Diehl (1999), Keating et al. (1999), Fougeron (2001)). It

has been recently found that the initial segment of prosodic domains is more strongly articulated and longer relative to prosodic domain-medial segments (Fougeron and Keating (1997), Cho and Keating (2001), Keating et al. (2003)), and there is reduced coarticulation between phonemes that span the phonological phrase boundary (Byrd et al. (2000), Cho (2004)).

Several studies examining word edges have shown that articulations of the tongue, lips, velum and glottis differ in magnitude in word-initial versus non-initial position (Browman and Goldstein (1992)). Initial consonants had a higher velum position for both nasal (Krakow (1989)) and oral segments (Vaissiére (1988)). In studies of vowel formant transitions at the syllable level, F2 trajectories were more distinctive for place value in CV than in VC syllables (Sussman et al. (1997)). The realization of both /h/ and /ʔ/ in English was influenced by prosodic position as both phrasal accent and phrasal boundary increased the magnitude and duration of the glottal gestures for the segments (Pierrehumbert and Talkin (1992)).

With regard to linguopalatal articulation at the word level, initial consonants were found to have a greater linguopalatal constriction than medial consonants (Byrd (1994), Keating et al. (1999)). At phrase and sentence levels, more linguopalatal contact for coronal stops was shown in initial position of higher domain than in lower ones, as measured by electropalatography (e.g. in English (Keating et al. (2003), in French (Fougeron and Keating (1997), Fougeron (2001)) and in Korean (Cho and Keating (2001)). Fougeron and Keating (1997) described the increase in linguopalatal contact in domain-initial position as articulatory strengthening, meaning that the articulation of a consonant was more extreme in initial position compared to medial, and more extreme at the beginning of higher level constituents than at the beginning of lower ones. The articulatory properties found in initial segments reflected the hierarchical organization of the constituents.

However, in comparison to oral and nasal stops, there are only a few studies focusing on the domain-initial properties of fricatives. In a study of French consonants, Fougeron (2001) showed that the domain-initial strengthening effect was less robust for the fricative /s/ than for the stop /t/ in terms of linguopalatal contact. For linguopalatal contact of /s/, it was found that /s/ was less systematically affected by prosodic position compared to the other consonants. In addition, it was noted that /s/ showed fewer positional differences in the comparison between onset and coda in English (Byrd (1994)).

In a study of prosodic domain effects on Korean fricatives (plain /s/ and fortis /s*/), Kim (2001) examined the acoustic and articulatory properties in two divided sets of domains - higher prosodic domains (Intonational phrase-initial (IPi), Accentual phrase-initial (APi), and Accentual phrase-medial (APm) positions) and lower prosodic domains (Word-initial (Wi) and Syllable-initial (Si) positions). In degree of linguopalatal contact, it was found that both fricatives in Korean showed difference between IP and AP but no difference between APi and APm. In the results of acoustic properties, fricative duration was shown to be longer in higher prosodic domains than in

lower prosodic domains. The centroid frequency for fricatives was found to be higher in higher prosodic domains than in lower prosodic domains. Amplitude difference between the first and second harmonics ([H1-H2])[1] for fortis fricative /s*/ was lower in higher domains than in lower domains but there was no significant difference across different prosodic levels for /s/.

The summary of Kim (2001) showing acoustic and articulatory variation of Korean fricatives in different prosodic domain-initial positions is shown in table 1.

Table 1. Summary of Kim (2001) showing acoustic and articulatory variation of Korean fricatives in different prosodic-initial positions

Acoustic or articulatory properties	Results
Linguopalatal contact	IPi >> APi, APm
Fricative duration	IPi>> APi>>APm
Centroid frequency	IPi, APi >>APm
H1-H2	APm >> IPi, APi for /s*/

However, the prosodic domain effect on Korean fricatives was not found to be consistent across speakers and fricative categories. For example, in the results for fricative duration, the two speakers participating in the study showed significant differences among three prosodic domains for /s/, but for /s*/, only one of the two speakers showed significant differences among the domains. In the results examining centroid frequency[2], /s*/ in IP and AP initial position showed a higher centroid frequency relative to AP medial position but only one of the two speakers showed a significant domain difference for /s*/. Since the study was conducted with only two speakers and the results were not consistent between speakers, it is hard to conclude how the articulatory and acoustic properties of Korean fricatives are affected by prosodic structure. Thus, it appears that the observed phenomenon needs to be examined with a larger amount of data.

The inconsistent results might be caused by the articulatory properties of fricatives. Fricatives are known to be less subject to articulatory variation in general because they tend to be more constrained in their articulatory and acoustic properties (Fougeron (2001)). Acoustically, their inherent longer duration with intense noise might cause less distinctive durational enhancement across prosodic domains compared to stops. The less articulatory variation would cause fewer prosodically dependent variations in the production. Kim (2001) also argued that the prosodic domain effect on Korean fricatives was not as strong as the one on Korean stops.

[1] Amplitude difference between the first (H1) and second (H2) harmonics was used to distinguish between breathiness and pressed voicing quality of the vowel after different phonation types.

[2] The centroid is the center of gravity of a defined part of the spectrum, each frequency being weighted according to its amplitude (Cho et al. (2002: 121). The detailed measurement methods will be seen in section 2.4.

Another possibility is that the Korean fricatives show different prosodically conditioned properties depending on phonation types. In a study of Korean stops (Cho and Keating (2001) and Jang (2009)), it was found that lenis and aspirated stops showed enhanced durations as a function of prosodic domains but fortis stops did not show variation in VOT across prosodic domain-initial positions. Cho and Keating (2001) found less variability for fortis /t*/ than lenis /t/ across prosodic domains in terms of linguo-palatal contact. In Kim (2001), the degree of contact in oral articulation was found to be the same for both Korean fricatives /s/ and /s*/ but fortis fricative /s*/ showed less variation in the fricative duration. In order to find out whether /s/ shows more variation across prosodic domain-initial positions than /s*/, more detailed quantitative studies are necessary.

In addition to the effect of prosodic domain-initial position, different word type is expected to influence speech clarity. It has been shown that speakers modulate the clarity of speech according to demands imposed by the information content of the message. For example, words produced in isolation were more accurately identified than the same words excised from running speech (Pollack and Pickett (1963)). The excised word tokens tend to have lower information content due to their greater predictability in the original contexts. According to Lindblom (1990), speakers have to be more careful in production when the listener has trouble understanding but they can be less careful and coarticulate more when the listeners have better conditions for understanding. Relative to real word condition, nonsense words are hard to be predictable in the context and tend to contain higher information content. So, phonetic segments in nonsense words are expected to be more clearly articulated than those in real words due to the hyperarticulation of target words produced as nonsense words.

There are few studies comparing the segmental properties between real and nonsense words but it is worth examining how phonetic properties of segments in the prosodic domain-initial positions vary as a function of different word type. If there is more enhancing of the phonetic properties in nonsense words, the results will also show more extended prosodic domain effects.

The goal of the present study is to examine whether initial fricatives in higher prosodic domains have more enhanced acoustic properties than those in lower prosodic domains and to find out whether prosodic domain-initial properties are more reinforced in nonsense words than in real words. Based on the results of the previous analysis, it is expected that the durational properties of initial fricatives are enhanced in the higher prosodic domains than in lower prosodic domains. [H1-H2], on the other hand, demonstrated the opposite trend: Kim (2001) showed that [H1-H2] following fortis fricative was lower in higher prosodic domain-initial positions than in lower prosodic domain-initial positions. Since lower [H1-H2] indicates more pressed voice, fortis fricative is expected to show more enhanced phonetic properties of the fortis consonant category in higher prosodic domain-initial positions than in lower prosodic domain-initial positions. F0 of the following vowel is expected to be higher in higher prosodic domains than in

lower prosodic domains due to the effect of declination of F0 in utterance.

In addition to the properties of prosodic domain-initial positions, phrase final lengthening is also examined in the present study. It has been suggested that consonants or vowels in phrase-final positions are longer in duration than those located phrase medially (Byrd et al. (2000), Keating et al. (2003)). Phrase final lengthening has been regarded as the realization of prosodic boundary marker in addition to boundary tone. In Korean, it was found that final vowel was lengthened cumulatively when the prosodic domain gets higher (Cho and Keating (2001)). The results of final vowel duration will show the properties of right edge of each prosodic domain.

The organization of this paper is as follows. I briefly introduce Korean fricatives and their acoustic properties, and phonological phrasing in Korean in section 1.1 and 1.2. In Section 2, the research methods are provided. The results of the experiment are seen in section 3. Section 4 concludes the paper.

1.1 Korean fricatives

There is a two-way contrast between fricatives, namely the plain fricative, /s/ and fortis fricative, /s*/ in Korean (i.e. sata 'to buy' vs. s*ata 'to wrap'). Relative to a variety of previous studies on the nature of the three-way contrast among the plosives, comparatively few studies have investigated the two-way contrast between the fricatives.

Relative to the identification of fortis fricative, categorization of /s/ has been controversial in previous researches. In Kagaya (1974) and Jun, Beckman, and Lee (1998), /s/ was reported to have a glottal opening configuration similar to aspirated stops in fiberscopic data. Park (1999) claimed that /s/ should be categorized in the aspirated category because the vowel onset after /s/ was breathier than after /s*/. On the contrary, Cho et al. (2002) suggested that /s/ was regarded as a lenis segment because /s/ had a similar breathy voice quality to vowels after the lenis stop and F0 after /s/ was lower than that after an aspirated stop. In addition, they reported that half the tokens of /s/ were fully voiced intervocalically, which was not shown in the aspirated stop category. In some phonological processes such as Post-Obstruent Tensing (Kim (2001)), /s/ becomes tense following an obstruent just as the lenis stop does. Since the present study is not concerned with the categorization of /s/, /s/ will be referred to as plain fricative.

In comparing fricative durations, there were discrepancies across previous studies. Park (1999) reported that there was no significant durational difference between /s/ and /s*/ in a VCV context. In Yoon (1999) and Chang (2007), /s*/ had longer duration than /s/ in non-high vowel contexts. On the contrary, Cho et al. (2002) showed that /s/ consisted of two components (frication and aspiration) and that the duration of /s/ was significantly longer than that of /s*/ in word-initial position. However, if the aspiration portion was excluded, /s*/ was reported to be longer than /s/ in Seoul Korean in Cho et al. (2002).

With regard to centroid frequency, Cho et al. (2002) claimed that /s*/ was produced with a relatively smaller front cavity because the centroid frequency was higher for /s*/ than /s/ in Seoul Korean. However, half of the Cheju speakers did not show this distinction. Park (1999) and Yoon (1999) did not find a significant difference in spectral peak between the two fricatives.

In the results of Seoul Korean in Cho et al. (2002) and Chang (2007), there was no difference in F0 between the two fricatives in Seoul Korean. But [H1-H2] was found to be significantly higher for /s/ (positive) than for /s*/(negative), indicating the breathiness of vowels after /s/ and creakiness of vowels after /s*/. The summary of phonetic correlates across fricative pairs is shown in Table 2.

Table 2. Summary of phonetic correlates of Korean fricative categories

Acoustic properties	Order in fricative category
Fricative duration	plain >> fortis
Centroid frequency	fortis >> plain
H1-H2	plain >> fortis
F0	no difference between them

1.2 Prosodic hierarchy

Speech utterances are hierarchically organized, with higher units being decomposed into lower constituents (Nespor and Vogel (1986), Selkirk (1986)). Prosodic constituents have been defined within several different theoretical frameworks, and in terms of the domains of: (1) phonological rules, (2) intonation, and (3) rhythmic prominence (Shattuck-Hufnagel and Turk (1996:209)). Since the focus of the present study is not concerned with a particular constituent in the prosodic hierarchy, I follow the general hierarchical structure of spoken utterances, without relying on the detailed assumptions of a particular theoretical proposal.

An Intonational Phrase (IP) is defined by a complete intonational contour, including a final boundary tone (Shattuck-Hufnagel and Turk (1996)). It consists of a whole clause or sentence and is often marked by a pause with final lengthening. The Phonological Phrase (PP) has been defined in syntactic terms, although precise syntactic definitions differ between theorists. In terms of the relation-based theory (Nespor and Vogel (1986)), the PP in Korean is formed by adjoining the head and its adjacent complement in the maximal projection. On the other hand, in terms of intonation-based studies, the intermediate phrase appears to be constrained by non-syntactic factors such as pitch accent and phrasal tone (Jun (1993, 1998)) which is termed as Accentual Phrase (AP). An AP usually consists of content words and function words with an associated phrasal tone pattern. The Korean AP is known to have the underlying phrasal tone sequences, LHLH or HHLH. The sample structure of the hierarchical organization of the prosodic domains is given in Fig. 1.

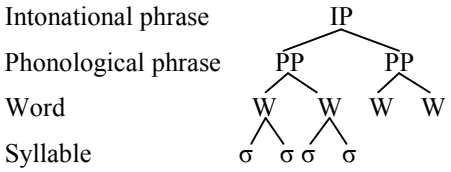


Figure 1. Prosodic structure of Korean

2. Methods

2.1 Participants

Three male and three female speakers, aged 30 to 43, participated in the study. They were speakers of Seoul Korean, with no known hearing problems. They were graduate and undergraduate students at the University of Texas at Austin.

2.2 Materials

In order to examine the acoustic properties at different prosodic positions, the stimuli consisted of real words and nonsense words in which each of two fricatives /s, s*/ appeared in IP, PP and Wd-initial positions. To place the target segments in IP-initial position, the target segments were placed after vocative words followed by a comma. It has been noted that parentheticals, non-restrictive relative clauses, preposed adverbials, tag questions, expletives, vocatives, and certain moved elements are produced with their own Intonational Phrases (Selkirk (1986), Nespor and Vogel (1986)). The IP was followed by a pause and also marked by lengthening on the final vowel and boundary tone (L%). To place the target segments in PP-initial position, the segments were placed in the initial position of the second PP as in table 3(b). The preceding phonological phrase was marked by either LHLH or HHLH[3] phrasal tone and the following PP was marked by boundary tone (L%), which was in an IP-final position. To place the target segments in Wd-initial position, I placed the segments in the initial position of a word in the middle of a PP.

In order to control vowel context, the low vowel /a/ was used as the preceding and following vowel of the initial consonant of each prosodic domain. All test sentences consisted of 13 syllables in order to control the speech length. To summarize, there were 2 segment types, 3 prosodic positions and 2 word types. 3 test sentences are used for each condition. Filler utterances, /ʧ, ʧʰ, ʧ*[4]/ were used in the same prosodic positions both in real and nonsense words. There were two repetitions of those sentences, yielding a total of 144 sentences per speaker. Representative stimuli are shown in table 3. The target segment is underlined in each prosodic position below.

[3] The PPs start with H when the target segments are fortis, aspirated stops, or fricatives as noted in Jun (1993, 2000).
[4] /ʧ*/ represents fortis voiceless affricate in Korean.

Table 3. Example stimuli

a. IP-initial position
[IP nae toŋseŋdɨ-ɾa], [IP [PP s̲adʒingi-lɨl kadʒjə-wa]] my brothers-VOC camera-ACC bring-IMP 'My brothers, bring your camera'
b. PP-initial position
[IP [PP sosimhan minsu-ka] [PP s̲asil-ɨl mal-he-s*ə-jo]] Timid Minsu-Nom truth-ACC tell-do-past-DEC 'Timid Minsu told the truth'
c. Wd-initial position
[IP[PP minjəŋi-ka] [PP[Wd mina] [Wd s̲adʒin-ɨl] pəɾjə-s*ə-jo]] Minyoung-Nom mina picture-ACC throw out–past-DEC 'Minyoung threw out Mina's picture'

In order to ensure that any enhanced phonetic properties of the target segments are due to the effect of prosodic domain-initial position, other prosodic factors need to be controlled. For example, Hay et al. (2006) noted that there were several distinctiveness-enhancing correlates of vowels in [+focus] context in English, French and German. In producing vowels in [+focus] context, all three language groups increased spectral differences among vowels and German speakers increased vowel duration differences. So, to avoid possible confounding effects from focus, wh-questions and focus-cueing sentences were given in parenthesis before the target sentence. Since subjects tended to put their contrastive focus on the subject phrase as an answer to a wh-word, the target words were controlled in non-focused position. To avoid focus on the target IP, a focus-cueing sentence was suggested before the target sentence. The focus-cueing sentence was exactly the same as the target sentence except for the words in the first IP. Because the target IP already had the same information, speakers tended to put a contrastive focus on the initial IP with new information and the target word in the second IP was thus controlled in non-focused position.

In the recording, subjects were not asked to read the wh-questions and focus-cueing sentences. The sample wh-question is given in (1).

(1) nuga sasilɨl malhes*əjo?
Who-Nom truth-ACC tell-do-past-INT
'Who told the truth?'

2.3 Procedures

Participants were asked to read materials written in Korean orthography, at a self selected speaking rate throughout the recording session. The test sentences were presented in random order on separate slides in a timed PowerPoint presentation on an IBM laptop. Speakers

were recorded in a sound-proof booth, using a solid state recorder, Maranz PMD 670, in the Phonetics Laboratory at the University of Texas at Austin. Recorded materials were digitized at a sampling rate of 22050 Hz.

2.4 Measurements

In order to compare the acoustic properties of fricatives across prosodic domain-initial positions, I measured fricative duration, centroid frequency and [H1-H2], which were also studied in Kim (2001). In addition, I measured vowel duration and F0 of following vowels for fricatives. All measurements were taken in Praat. The detailed measurement points are specified in (2).

(2) a. Fricative duration:
The fricative duration was taken from the beginning of high frequency noise to the onset of periodicity in the following vowel, using both the spectrogram and waveform.

b. Vowel duration:
The vowel duration was measured from the point in the expanded waveform at which waveform amplitude and complexity begin to rise to the point where the decline in waveform amplitude and complexity end.

c. Centroid of the fricative noise:
Centroid values were taken from FFT spectra using a 25 ms window centered around the midpoint of the fricative portion.

d. F0:
F0 was taken at the midpoint of the following vowel, using the pitch tracking function in PRAAT. When the pitch line abruptly moved or was discontinued, F0 was calculated by measuring the duration of the relevant period in seconds. As supplementary checks, the tenth harmonic values were divided by 10 from an FFT with a 25 ms window.

e. [H1-H2]:
The amplitude (dB) difference between the first (H1) and the second (H2) harmonic was measured just after the first full glottal pulse of the vowel onset in the waveform. The amplitude values were calculated using a narrowband fast Fourier transform spectrum using a Hamming window (window length of 25 ms).

3. Results

As evidence for demarcation across three different prosodic positions, phrase-final lengthening was considered in section 3.3. However, it was found that two male speakers participated in the experiment did not produce a significant distinction between IP and PP levels in the phrase-final lengthening. Since they did not show a three-way

distinction across the prosodic domains, it may distort the results of pooled data. Thus, the results from the two speakers were excluded in the analysis of the results[5]. In the results of fricative duration, I excluded several test utterances for /s/ in Wd-initial position due to the voicing of the segment. Cho et al. (2002) already noted that /s/ in Word-initial position showed voicing between vowels although voicing of /s/ occurred in a gradient fashion. In this experiment, only one speaker showed intervocalic voicing of /s/ in half of the tokens.

A repeated measures analysis of variance (ANOVA) was performed with three within-subjects factors (segment, prosodic position, and word type) using SPSS 19.

3.1 Fricative duration

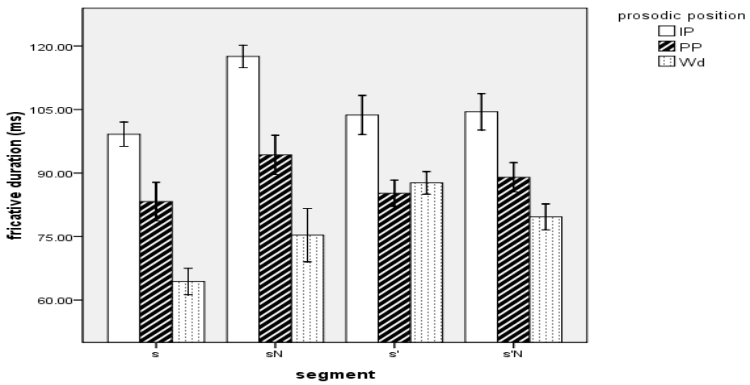


Figure 2. Pooled graph for fricative duration by segment type * prosodic position

Figure 2 illustrates fricative durations of fricative categories in real and nonsense words across IP, PP and Wd-initial positions. In the graph, s and s-NS represent plain fricative /s/ in real and nonsense words, respectively. s' and s'-NS show fortis fricative /s*/ in real and nonsense words. The fricative duration is longest in IP-initial position, intermediate in PP-initial position and shortest in Wd-initial position, except for /s*/ in real words. /s*/ in real words does not show a difference between PP and Wd-initial positions.

[5] I deeply appreciate the comments of one anonymous reviewer who provided critical comments about the distinction between IP and PP levels in the results of my original paper.

The main effects for prosodic position and word type were significant but the fricative category effect was not significant ($F(2, 6) = 9.327$, $p = .014$ for prosodic position; $F(1, 3) = 13.308$, $p = .036$ for word type; $F(1, 3) = .314$, $p = .614$ for fricative category). The interaction of prosodic position and fricative category was significant ($p=.044$) but the interaction of the other factors was not found to be significant.

The results of pairwise post hoc analyses are seen in Table 4. For /s/ in real and nonsense words, there was a three-way distinction among prosodic positions at the level of $p < 0.005$. On the contrary, for /s*/, there was a significant difference between IP and PP, and between IP and Wd-initial positions in both real and nonsense words. But /s*/ did not show significant difference between PP and Wd levels in the two different word conditions.

The comparison between real and nonsense words revealed that only plain fricatives exhibited significant difference between the two word types in IP ($p=.001$) and PP-initial positions ($p=.045$). In short, fortis fricative showed less variability across prosodic positions and between the two word types relative to plain fricative.

The results of plain fricative in Kim (2001) also presented increasing fricative duration when the prosodic domain gets higher but for fortis fricative, only one of the two speakers showed progressively increasing fricative duration in higher prosodic domain-initial positions. The between speaker variation seems to be caused by variation between phonation types. In the durational variation of stops, lenis and aspirated categories revealed enhanced duration as a function of prosodic position, while fortis stop did not show any durational variation (Cho and Keating (2001) and Jang (2009)). Likewise, for fortis fricative, the less consistent variation across prosodic position seems to be caused by the properties of fortis category. Alternatively, since Kim (2001) did not control focus on the target segments, the between subjects variance might be caused by random focus effect on the target segments.

Table 4. The results of post hoc test for fricative duration

	Real word		Nonsense word	
/s/	IP, PP IP, Wd PP, Wd	p=.004 p <.000 p=.001	IP, PP IP, Wd PP, Wd	p<.000 p<.000 p=.001
/s*/	IP, PP IP, Wd PP, Wd	p=.001 p=.004 p=.665	IP, PP IP, Wd PP, Wd	p=.005 p<.000 p=.092

3.2 Vowel duration

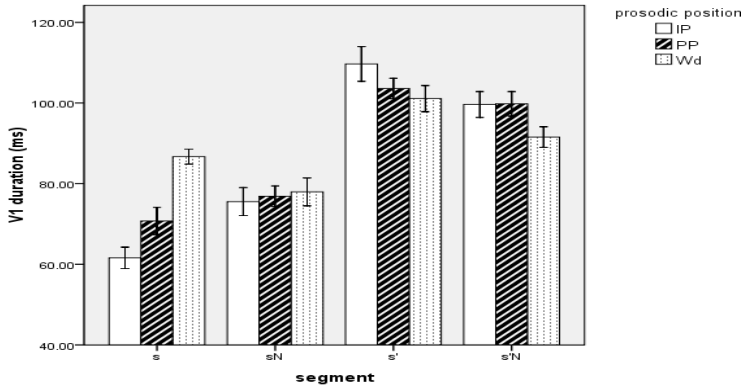


Figure 3. Pooled graph for vowel duration by segment type * prosodic position

In figure 3, vowel durations after /s/ and /s*/ were compared at three different prosodic positions between real and nonsense words. The pooled graph illustrated that there was no systematic distinction across IP, PP and Wd-initial positions and between the two word conditions. For /s/ in real word condition, the vowel was longest in Wd, intermediate in PP and shortest in IP. On the other hand, for /s*/ in real words, the vowel was longer in the higher prosodic domain-initial positions than in the lower prosodic domain-initial positions. In nonsense word condition, /s/ does not show a systematic distinction across prosodic domains, and /s*/ does not show a difference between IP and PP-initial positions. Relative to the inconsistent distinction across prosodic positions and word types, it was seen that vowel durations were longer after /s*/ than /s/ in all conditions.

The main effect for fricative category was significant but the other main effects were not significant ($F(1, 3) = 27.496$, $p = .014$ for fricative category; $F(2, 6) = 1.505$, $p = .295$ for prosodic position; $F(1, 3) = .506$, $p = .528$ for word type). The interaction of fricative category and prosodic position and word type was significant ($F(2, 6) = 8.599$, $p = .017$).

Cho and Keating (2001) noted that the prosodic position effect was not found in vowel duration following Korean stop categories. The prosodic domain-initial effects were limited to the durational properties of initial stop in Korean but did not extend to the phonetic properties of the vowels following Korean stops (e.g., F0 and H1-H2 in Jang (2009)).

With regard to the distinction between fricative categories, Chang (2007) reported that vowel length between the two fricatives was not significant for vowels /a/ and /u/. But, the results of current study showed that the vowels after /s*/ are significantly longer than /s/. Since the results of vowel duration between Korean fricative categories showed variation across different studies, a more quantitative experiment needs to follow.

3.3 Final vowel duration

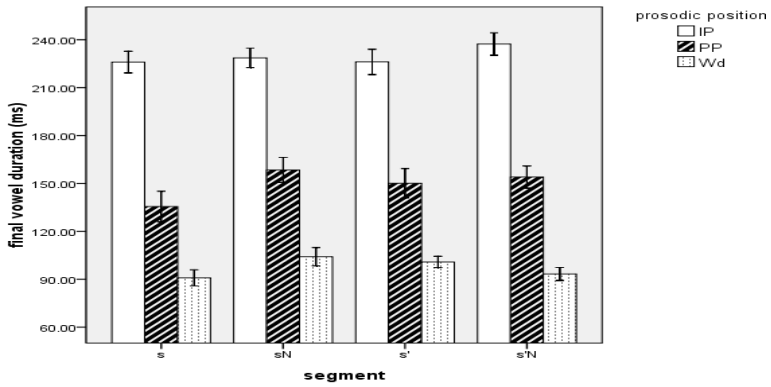


Figure 4. Pooled graph for final vowel duration by segment type * prosodic position

Figure 4 displays vowel durations before /s/ and /s*/ in real and nonsense words across IP, PP and Wd-final positions. The pooled graph illustrates that the final vowel is longest in IP, intermediate in PP and shortest in Wd.

The main effect for prosodic position was significant but the effects of fricative category and word type were not significant. ($F(1, 3) = 12.850$, $p = .037$ for fricative category; $F(2, 6) = 43.679$, $p < .000$ for prosodic position; $F(1, 3) = 1.526$, $p = .305$ for word type). None of the interactions were significant. Pairwise post hoc tests for final vowel duration confirmed that there is a three-way distinction among prosodic positions for both fricative categories in real and nonsense words (IP> PP> Wd) at the level of $p < .000$.

In short, final vowel was lengthened cumulatively when the position moves up in the hierarchy and the final vowel lengthening showed more robust distinction across prosodic domains. It did not vary with phonation types for fricatives following the target vowels, which was contrary to the durational properties of prosodic domain-initial fricatives.

3.4 Centroid frequency

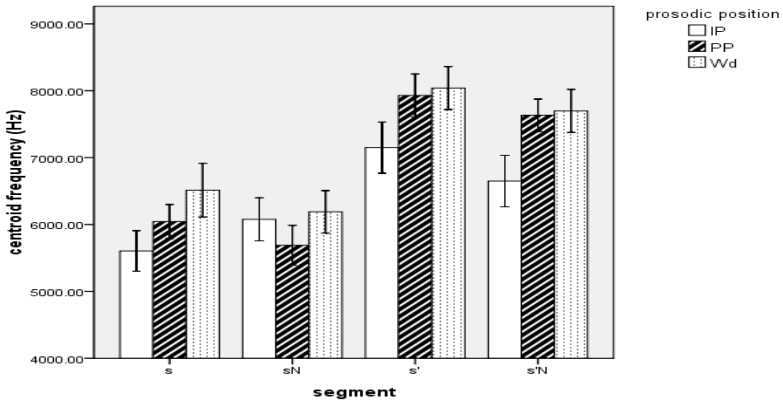


Figure 5. Pooled graph for centroid frequency by segment type * prosodic position

In Figure 5, centroid frequency of each fricative is compared at IP, PP and Wd-initial positions in real and nonsense words. The pooled graph shows that the centroid frequencies of /s/ and /s*/ in real words are progressively higher when the prosodic domain gets lower. But, in nonsense word condition, /s/ does not show a systematic pattern across prosodic domains, and /s*/ does not show a difference between PP and Wd-initial positions.

The main effect for prosodic position was significant but the other main effects were not significant ($F(2, 6) = 6.515$, $p = .031$ for prosodic position; $F(1, 3) = 5.609$, $p = .099$ for fricative category; $F(1, 3) = 1.169$, $p = .359$ for word type). None of the interactions were significant.

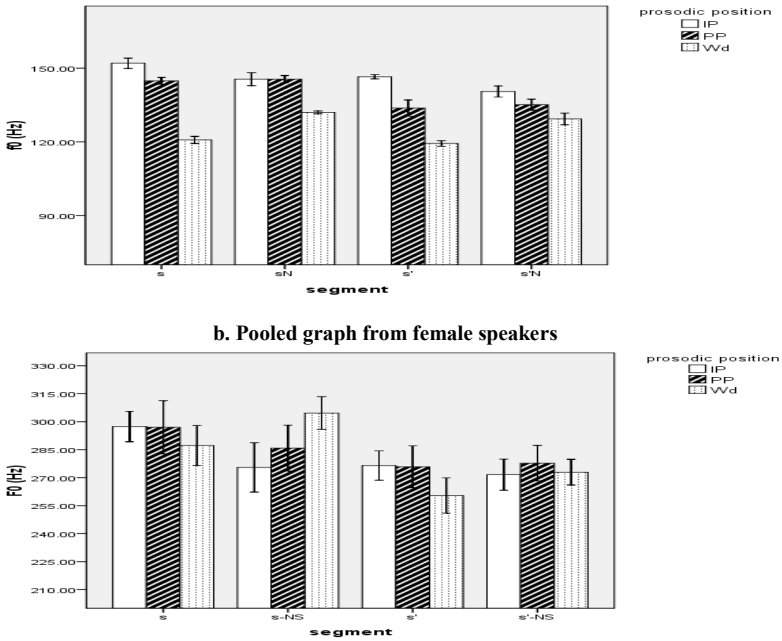
In the results of pairwise post hoc tests, centroid frequency for /s/ in real words was significantly lower in IP than in Wd-initial positions ($p=.048$) but the centroid frequency for /s*/ in nonsense words was significantly different between IP and PP ($p=.030$), and between IP and Wd-initial positions ($p=.024$). In the centroid frequency for /s*/ in real words, the difference between IP and Wd was close to the significance level ($p=.055$).

Relative to the results of fricative duration, the results of centroid frequency did not show consistent distinction across three different prosodic positions. But a progressively decreasing trend revealed that there was the effect of prosodic position on the centroid frequency of Korean fricatives.

Since the centroid frequency of /s*/ was shown to be greater than that of /s/ in all prosodic positions, this results support Cho et al. (2002)'s claim that, in Korean, /s*/ is produced with a relatively smaller front cavity.

3.5 Fundamental frequency

a. Pooled graph from male speakers



b. Pooled graph from female speakers

Figure 6. Pooled graph for F0 by segment type

Figure 6 presents F0 after each fricative across prosodic domain-initial positions both in real and nonsense words. The pooled graph from male speakers in Figure 6a shows that F0 is highest in IP-initial position among three different prosodic positions but there is no systematic difference between IP and PP-initial positions for /s/ in nonsense words. The pooled graph from female speakers in Figure 6b does not show any consistent difference across three prosodic positions.

In the pooled results from both male and female speakers, the main effect for fricative category was significant but the other main effects were not significant ($F(1, 3) = 15.475$, $p = .029$ for fricative category; $F(2, 6) = .191$, $p = .831$ for prosodic position; $F(1, 3) = .042$, $p = .851$ for word type). None of the interactions were significant.

The significant effect of fricative category was due to the higher F0 after plain fricative than after fortis fricative. In Cho et al. (2002), no significant difference of F0 was found between the two fricative categories in the Seoul speakers. But since the target fricatives were produced in isolation, it is hard to compare the results of F0 to the findings in the present study.

3.6 [H1-H2]

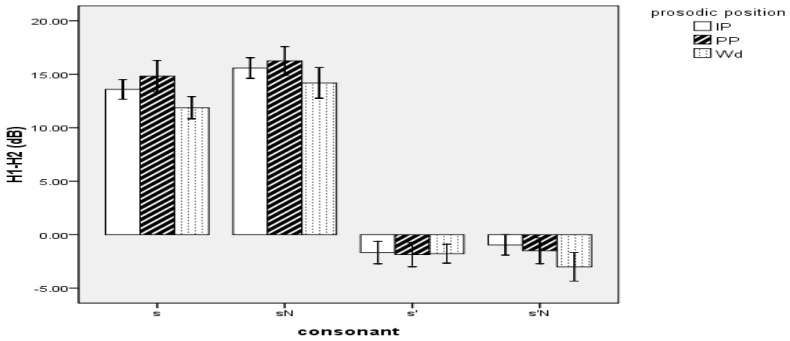


Figure 7. Pooled graph for [H1-H2] by segment type * prosodic position

In Figure 7, [H1-H2] difference after fricatives was compared at IP, PP and Wd initial positions in real and nonsense words. It is seen that there is no systematic distinction among the three prosodic domain-initial positions, but that [H1-H2] values are different between the two fricatives.

The main effect for fricative category was significant but the other main effects were not significant ($F(1, 5) = 94.667$, $p < .000$ for fricative category; $F(2, 10) = .726$, $p = .508$ for prosodic position; $F(1, 5) = 2.595$, $p = .168$ for word type). None of the interactions were significant. The significant effect of fricative category was caused by the different [H1-H2] between /s/ and /s*/. This result is compatible with the results of Cho et al. (2002).

Kim (2001) reported that one of the two speakers showed a significant difference in [H1-H2] between IPi and APm (AP medial position), and between APi and APm. Since all speakers in the present study showed different patterns across prosodic domains in the results of [H1-H2], it is hard to conclude that there is a significant prosodic effect on [H1-H2].

4. Discussion

The results of various analyses of prosodic domain-initial effects confirmed the fact that Korean fricatives have a limited set of acoustic parameters that show more enhanced acoustic properties in higher prosodic domains relative to lower prosodic domains. Both fricative categories showed enhanced fricative duration in higher prosodic domain-initial positions but there was less variation across prosodic domain-initial positions for fortis fricative relative to plain fricative. In the results of fricative duration, there was a three-way distinction among IP, PP and Wd –initial positions for plain fricative but fortis fricative did not show significant distinction between PP and Wd levels. Centroid frequency of fricatives was also affected to a lesser extent by prosodic position. There was a decreasing trend when the prosodic position gets higher but the significant distinction was not found to be consistent across prosodic positions for both fricative categories.

In the results of vowel duration, F0 and [H1-H2] of the following vowels for fricatives, there was no significant prosodic domain-initial effect. Since segment effects were found for these properties, the results only reflected the distinctions across fricative categories. In the study of Korean stops, the enhanced phonetic properties were not found in the results of vowels after prosodic domain-initial stops (Jang (2009)). In short, the phonetic properties correlated with prosodic structure are limited to the durational parameters of initial stops and fricatives in the prosodic domains in Korean.

The prosodically-driven properties in domain-initial positions were also affected by word types (real vs. nonsense words). The results of fricative duration support the hypothesis that the durations are longer in nonsense words than in real words. That is, the duration parameters in prosodic domain-initial positions were more enhanced in nonsense words than in real words. However, a significant durational difference between the two word types was only found in plain fricative, as fortis fricative did not show enhanced duration in nonsense words.

With regard to the variability depending on phonation types, it was also noted that Korean fortis stop did not show variation in VOT across prosodic domain-initial positions (Cho and Keating (2001), Jang (2009)). The less variability in fortis category is related to its articulatory properties. Cho and Keating (2001) claimed that fortis and aspirated stops can be considered to be a "strong" consonant type because they have greater linguopalatal contact compared to nasal and plain stops. Aspirated and fortis stops were known to have longer acoustic closure duration, more tongue blade contact, higher tongue movements and higher glottal raising than lenis stop. On the other hand, lenis category seems to have enough room for variation in linguopalatal contact and acoustic duration as a function of prosodic domain and word type (Jang (2009)).

In MRI, acoustic and aerodynamic study of fricatives (Kim et al. (2005)), it was found that contrary to /s/, /s*/ has longer and narrower oral constriction, greater pharyngeal width and the highest tongue blade and glottal height was sustained longer. Less variability in articulation could be a reason for less variability of duration in prosodic position and word type effects for fortis fricative.

In conclusion, the segmental properties are affected by information content, in terms of prosodic position and word type. When there is less contextual information as in prosodic domain-initial position and in nonsense words, the enhanced properties of initial segments could provide perceptual cues for the higher information content of the segment. However, it is not yet clear how the variability across the distinction of prosodic domains is perceived by listeners. In addition, it is necessary to examine whether listeners are sensitive to the prosodically conditioned realizations of a segment in the perception of continuous speech. A perception experiment that manipulates the different prosodically conditioned properties of stops and fricatives in Korean is in preparation for a subsequent paper.

Appendix: Stimuli

(1) /s/
IP-initial
(a) [IP Nae toŋseŋdɨra], [IP saʤingilɨl kaʤjəwa]
My brothers-VOC, camera-Acc bring-IMP
'My brothers, bring your camera'
(b) [IP Nae toŋseŋdɨra], [IP saʤinɨl porəgara]
My brothers-VOC, picture-Acc look at-go-IMP
'My brothers, go and look at the pictures'
(c) [IP Nae toŋseŋdɨra], [IP satʃʰilɨl haʤimaɾa]
My brothers-VOC, luxury-Acc do-NEG-IMP
'My brothers, don't indulge in luxury'
PP-initial
(a) [IP [PP Sosimhan minsuka] [PP satʃʰika simhes*əjo]]
Timid minsu-Nom luxury extreme-do-past-DEC
'A timid Minsu lived in extreme luxury'
(b) [IP [PP Sosimhan minsuka] [PP sasilɨl malhes*əjo]]
Timid minsu-Nom truth-Acc tell-do-past-DEC
'A timid Minsu told the truth'
(c) [IP [PP Sosimhan minsuka] [PP saʤinɨl pərjəs*əjo]]
Timid minsu-Nom picture-Acc throw out-past-DEC
'A timid Minsu threw out the picture'
Wd-initial
(a) [IP minjəŋika [PP pak*a [Wd saʤulɨl] powas*əjo]]
Minyoung-Nom Park fate-Acc see-past-DEC
'Minyoung had Park's fortune told by an astrologer'
(b) [IP minjəŋika [PP pak*a [Wd saʤinɨl] ʧ*igəs*əjo]]
Minyoung-Nom Park picture-Acc take-past-DEC
'Minyoung took Park's picture'
(c) [IP minjəŋika [PP mina [Wd saʤinɨl] pərjəs*əjo]]
Minyoung-Nom Mina picture-Acc throw-past-DEC
'Minyoung threw Mina's picture'

(2) /s*/
IP-initial
(a) [IP Nae toŋseŋdɨra], [IP s*age salsudo is*ə]
My brothers-VOC, cheaply buy-can be-DEC
'My brothers, you can buy that cheaply'
(b) [IP Nae toŋseŋdɨra], [IP s*agelɨl ʧunbi hera]
My brothers-VOC, blanket-Acc prepare for do-IMP
'My brothers, prepare for a blanket'
(c) [IP Nae toŋseŋdɨra], [IP s*agelɨl mandɨrəra]
My brothers-VOC, blanket-Acc make-IMP
'My brothers, make a blanket'
PP-initial
(a) [IP [PP Sesimhan minsuka] [PP s*agelɨl mandɨrəjo]]
Prudent Minsu-Nom blanket-Acc make-DEC

'A prudent Minsu makes a blanket'

(b) [IP [PP Sosimhan minsuka] [PP s*agelɨl pərjəs*əjo]]
Prudent Minsu-Nom blanket-Acc throw out-past-DEC
'A prudent Minsu threw out a blanket'

(c) [IP [PP Sesimhan minsuka] [PP s*agelɨl sawas*əjo]]
Prudent Minsu-Nom blanket-Acc buy-past-DEC
'A prudent Minsu bought a blanket'

Wd-initial

(a) [IP minjəŋi-ka [PP aga [Wd s*agelɨl] sawas*əjo]]
Minyoung-Nom baby blanket-Acc buy-past-DEC
'Minyoung bought the baby's blanket'

(b) [IP minjəŋi-ka [PP mina [Wd s*agelɨl] pərjəs*əjo]]
Minyoung-Nom Mina blanket-Acc throw out-past-DEC
'Minyoung threw out Mina's blanket'

(c) [IP minjəŋi-ka [PP mina [Wd s*agelɨl] mandɨrəjo]]
Minyoung-Nom Mina blanket -Acc make-DEC
'Minyoung makes Mina's blanket'

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