

Acoustic properties of Korean fricatives and post-fricative vowels*

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Miyeon Ahn. 2015. Acoustic properties of Korean fricatives and post-fricative vowels. *Studies in Phonetics, Phonology and Morphology*. 21.2. 245-256. This study aims at examining the acoustical properties of the Korean fricatives /s/ and /s^{*}/ and post-fricative vowels. We examined both temporal and spectral properties in terms of the duration of friction, center of gravity (CoG) of /s/ and /s^{*}/ and the duration of periodic pulses, vowel qualities (*F*1, *F*2 and mean of *F*2 and *F*3), and the fundamental frequency (*f*₀) of the immediate vowels. The results showed that /s^{*}/ was systematically longer and has a higher CoG than /s/ in all vowel contexts. Also, post-tense vowels were significantly longer than post-lax ones while *f*₀ and vowel qualities were contrastive in limited contexts. (Seoul National University)

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1. Introduction

Korean fricatives have two-way distinction; a tense [s^{*}] and a lax [s] as in [s^{*}ata] 'to wrap' and [sata] 'to buy'. The contrast between the tense and the lax has drawn a number of linguists' interests, and various phonological processes involving these two Korean fricatives have been widely discussed (Han 1996, S. Ahn 1998, Park 1999, S. Ahn and Iverson 2004). Most of research conducted comparative studies between English and Korean in a light of the asymmetry of fricatives of the two languages and its consequences in loanword adaptation (Kang 2008), second language acquisition (Cheon 2005, 2006) and non-native speech perception.

Studies on Korean fricatives were not limited to phonological aspects but have been extended to finding the articulatory properties and their acoustic correlates in speech production (Cho et al. 2002 among others). Although a complete consensus among detailed acoustic measurements has been absent, considerable previous research has agreed that the tense [s^{*}], in general, has a longer duration (Kim 1999, Cho et al. 2002) and a higher Center of Gravity (CoG) than [s] (Kang et al. 2009, Ahn 2011). Despite the fact that the comparison of the acoustic characteristics in the tense and lax has been largely well-profiled, the discussion regarding the vowel properties that appear after the fricatives have been limited. Fricatives were considered less than stops and the context were limited to one type of vowel [a] when their

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acoustic properties were examined (Cho et al. 2002).

The purpose of the present study is to examine the acoustic properties of both Korean fricatives and post-fricative vowels. We represent the acoustic measures of the consonants and their following vowels concurrently. This method of investigation is needed in that segments never stand alone; consonants and vowels often interact each other and, in terms of an articulatory approach, the local coarticulatory effects are often found between them. The integrated method of investigation may be advantageous in terms of an auditory approach by virtue of, for instance, the contribution of vocalic properties in identifying preceding consonants (Kim et al. 2002). Phonological analyses also have noted that vowels are often affected by preceding consonants as in post-obstruent tensification (Cho and Inkelas 1994) by preserving or losing the contrast (Lee 1999). Exploration of the current acoustic study, thus, may explain how consonantal properties correlate with vocalic ones.

We designed a production experiment to investigate the extent to which Korean speakers' production of word-initial fricatives was compatible with vocalic properties that appeared after the fricatives. In order to examine contextual effects of types of vowels to the production of fricatives, vowels were varied from [a], [ʌ], [o] to [u]. Also, in order to minimize other contextual effects, target tokens were limited to disyllabic words with equally distributing both CV and CVC syllable structures. By evenly comprising both male and female speakers and by recording one type of dialect speakers (*Seoul*), any non-contextual effects were minimally involved. Under this experimental design, any properties either consonantal or vocalic may be effectively dominant to the other. In such a case, only consonant-related or vowel-related acoustic measures vary from [s^{*}] to [s] or from post-tense to post-lax vowels. Alternatively, however, it may turn out to be that both consonantal and vocalic measures significantly differ in [s^{*}] and [s]. If speakers are to differentiate both of the acoustic measures, it may be interpreted as the effectiveness for the consonantal contrast being correlated with vocalic properties.

2. Methods

2.1 Speakers

Six native speakers of Korean (three male and three female respectively) participated in recording. The speakers were recruited around the University of Michigan. All of them were born and grew up in Korea and arrived in United States after their critical periods of language acquisition (Newport 2002). Although they were fluent in English and had stayed in US for 5-10 years, all speakers reported Korean as their native language.

2.2 Stimulus materials and recording

The reading materials consisted 32 disyllabic words in which they were either $C_1V_1.CV(C)$ or $C_1V_1C.CV(C)$ sequences. The half of the materials had the C_1V_1 syllable structure on their first syllable while the other half C_1V_1C . Among the sequences C_1 was either the tense $[s^*]$ or the lax $[s]$, and V_1 was one of the four vowel types /a, ʌ, o, u/. Table 1 illustrates the stimulus materials for the experiment. Speakers were recorded when reading the word lists of target tokens. Recordings were collected at a sound attenuated booth of the phonetics lab in the University of Michigan with a sampling rate of 44,100 Hz.

Table 1. Stimulus materials for Korean fricatives and the post-fricative vowels: $[s^*]$ and $[s]$ and their following vowels

		Post-fricative Vowels			
		__a	__ʌ	__o	__u
$[s^*]$	CV	/s [*] a.ta/	/s [*] ʌ.re/	/s [*] o.ta/	/s [*] u.ta/
		/s [*] a.um/	/s [*] ʌ.cim/	/s [*] o.im/	/s [*] u.sim/
	CVC	/s [*] ak.nun/	/s [*] ʌk.ta/	/s [*] on.sal/	/s [*] uk.kas/
		/s [*] a.mci/	/s [*] ʌl.ta/	/s [*] ol.rim/	/s [*] uk.t [*] im/
$[s]$	CV	/sa.ta/	/sʌ.ta/	/so.kæ/	/su.rak/
		/sa.cin/	/sʌ.ul/	/so.maŋ/	/su.jʌŋ/
	CVC	/sal.ta/	/sʌŋ.ii/	/sok.ta/	/suk.mjʌŋ/
		/sam.c ^h on/	/sʌŋ.kjʌk/	/sol.cik/	/sun.su/

2.3 Acoustic analysis

In order to examine most of consonantal and vocalic characteristics thoroughly, both temporal and spectral components that were possibly relevant to the fricatives and their following vowels were measured. All procedures regarding manual segmentation, acoustic measures and extracting results were processed using *Praat* speech analysis software (Boersma and Weenink 2015). For the consonantal characteristics, the duration of the tense and the lax fricatives $[s^*]$ and $[s]$ (i.e., the length of the noise of the frication) and the CoG (i.e., the spectral shape of the fricative noise) were measured. For the vocalic ones, the fundamental frequencies (i.e., f_0), the first three formants (i.e., $F1$, $F2$ and $F3$) and the duration of the vowel were examined. f_0 were measured on the onset, the midpoint and the offset of the vowels. The duration of the vowel was the measure of the temporal length from the onset to the offset of the vowel with periodic pulses. The first three formants were measured at the three locations: the onset, midpoint and offset of the vowels. Not only the mean but also the minimum and maximum values of each formant were examined. Time-normalized formants of individual speakers were also examined in order to explore any inter-speaker variations.

3. Results

3.1 Temporal properties

The durations of friction of /s/ and /s*/ and those of post-lax and post-tense vowels are provided in Figure 1. As illustrated, the fricative noise of /s/ and /s*/ in Korean fell in 73~89 ms and 98~129 ms, respectively. The duration varied according to the qualities of the following vowels in which both /s/ and /s*/ were longest in the pre-[a] context while they were the shortest in the pre-[u]. Across all vowels, the duration of /s/ were significantly shorter than that of /s*/ ($t(944)=7.89$, $p<0.001$). Examining the fricative noise individually, /s/ was significantly shorter than /s*/ in pre-[a] ($t(231)=4.71$, $p<0.001$), pre-[o] ($t(233)=4.64$, $p<0.001$) and pre-[ʌ] contexts ($t(235)=6.8$, $p<0.001$). However, the significant temporal duration of /s/ and /s*/ in pre-[u] context was not found ($t(233)=1.01$, $p=0.157$).

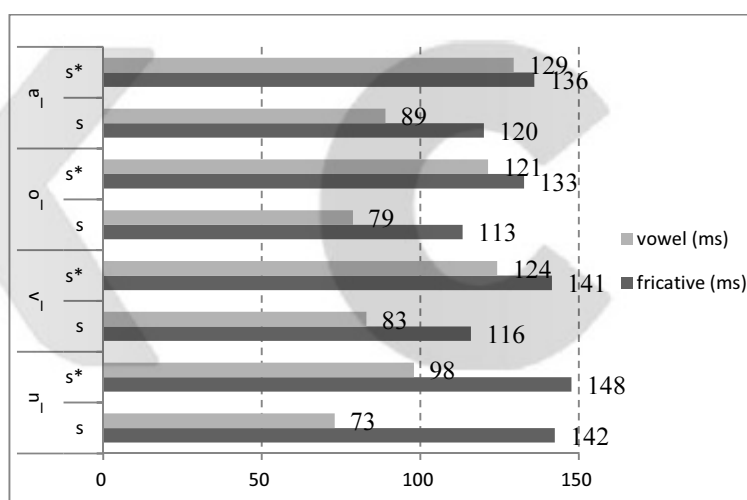


Figure 1. The fricative duration of /s/ and /s*/ and the duration of post-/s/ and post-/s*/ vowels in Korean

The durations of post-lax and post-tense vowels were in the same figure. The post-tense vowels ranged between 98~129 ms, while the post-lax ones between 73~89 ms. Unlike the duration of fricative noise, the post-fricative [u] vowel were the longest and post-fricative [a] were the shortest. Overall, the duration of post-tense vowels were significantly longer than post-lax ($t(944)=13.76$, $p<0.001$). The durations of each vowel were significant in all post-lax and post-tense conditions in which post-lax [a] was significantly shorter than post-tense [a] ($t(231)=6.47$, $p<0.001$), post-lax [o] than post-

tense [o] ($t(233)=8.49, p<0.001$), post-lax [u] than post-tense [u] ($t(233)=5.2, p<0.001$) and post-lax [ʌ] than post-tense [u] ($t(235)=8.06, p<0.001$).

3.2 Spectral properties

For the spectral properties of the fricative consonants /s/ and /s*/ in Korean, the Center of Gravity (CoG) was measured. The CoG values of the two fricatives according to the four following vowels are presented in Figure 2. The CoG of /s/ was significantly lower than that of /s*/ ($t(953)=16.34, p<0.001$). The value of /s/ was the lowest in the pre-[a] and the highest in the pre-[u] context while that of /s*/ was the lowest in the pre-[ʌ] and the highest in the pre-[a] context. The significant CoG difference was found in all vowel contexts as in the pre-[a] ($t(235)=10.72, p<0.001$), the pre-[o] ($t(234)=9.62, p<0.001$), the pre-[ʌ] ($t(236)=9.67, p<0.001$) and the pre-[u] contexts ($t(236)=3.51, p<0.001$).

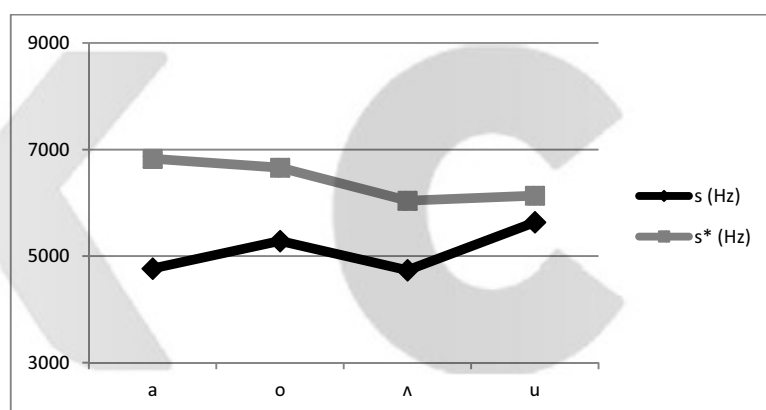


Figure 2. The CoG of /s/ and /s*/ in Korean

In examining vowel qualities of post-lax and post-tense vowels, the first three formants were measured. Each mean value of $F1$, $F2$ and the average of $F2$ and $F3$ along with the maximum and minimum values are described in Table 2. The average of $F2$ and $F3$ is ‘a joint indicator of tongue frontness’ (Xu 2007).

Table 2. Mean, Maximum and Minimum values of *F1*, *F2* and the average of *F2* and *F3*

		<i>F1</i>			<i>F2</i>			$(F2+F3)/2$		
		mean	MAX	MIN	mean	MAX	MIN	mean	MAX	MIN
s	a	744	857	587	1380	1569	1262	1759	1996	1632
	o	490	589	404	1092	1313	995	1774	1945	1681
	ʌ	676	767	578	1449	1655	1336	1794	1975	1665
	u	468	624	404	1165	1354	1066	1948	2124	1836
s*	a	739	811	577	1339	1486	1210	1723	1922	1622
	o	496	562	428	1186	1450	1066	1805	2031	1673
	ʌ	643	692	524	1426	1716	1249	1807	2034	1669
	u	448	582	345	1271	1483	1143	1970	2203	1849

The mean *F1* and the average of *F2* and *F3* of post-lax vowel were not significantly different ($t(944)=1.48$, $p=0.139$ and $t(944)=0.65$, $p=0.51$, respectively). Only the mean of *F2* of post-tense vowels were found to be significantly higher than that of post-lax vowels ($t(944)=2.6$, $p<0.01$). Being consistent with many studies regarding vowel qualities, *F1* values were found to be low in high vowels as in [u] compared to be high in low vowels as in [a].

In order to examine inter-speaker variations and gender differences, the continuous trajectories of *F1*, *F2* and mean *F2* and *F3* were plotted in Figure 3. The trajectories of the post-lax and post-tense vowels were illustrated from the onset to the offset of each vowel and they were time-normalized in 20 points. Compared to male speakers, *F2* vs. mean of *F2* and *F3* of females were found to be close. While the trajectories of male speakers were constant and relatively invariable across the time-normalization, more changes of the trajectories were noted among female speakers in that, in general, the values were high on the onset of the vowels and the offset but low in the midpoints.

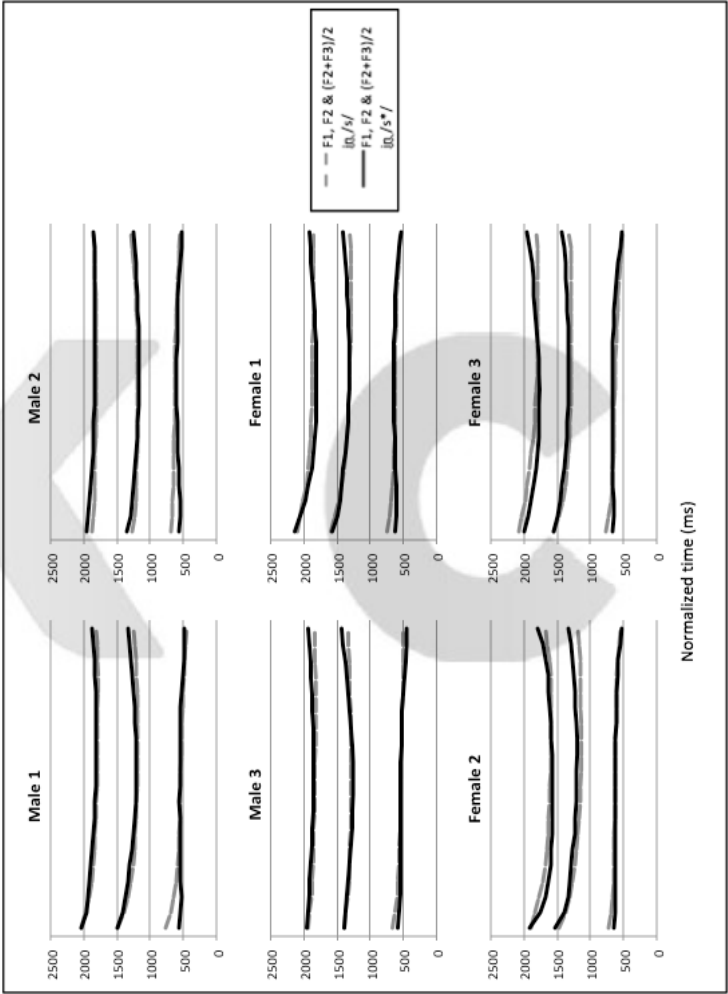


Figure 3. Time-normalized continuous trajectories of $F1$, $F2$ and mean of $F2$ and $F3$

Fundamental Frequency was also measured in 20-points and normalized for time across male and female speakers, respectively. Visual illustration by means of f_0 time-normalized trajectories of post-tense and post-lax vowels is provided in Figure 4.

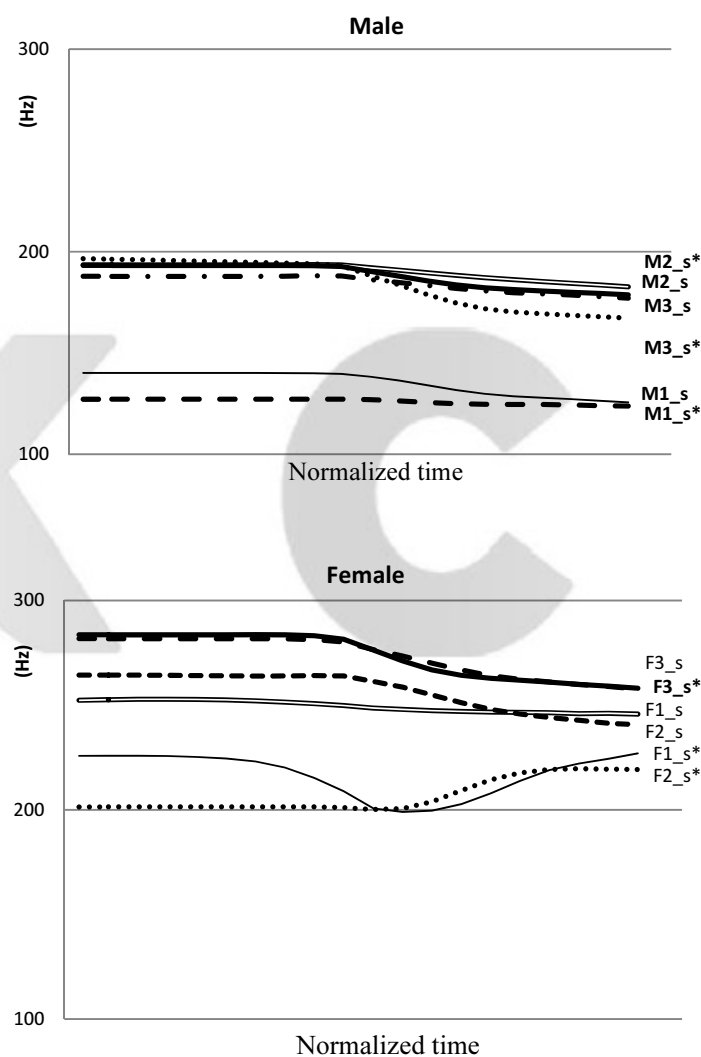


Figure 4. f_0 contour of male and female speakers

As shown in the figure, fundamental frequencies for male speakers ranged around between 100~200 Hz while those of females placed around between 200~300 Hz. The result of study was consistent with the previous findings in the literature wherein males have lower f_0 than females. f_0 values of males were significantly lower than those of females in all contexts; that is, male speakers had lower f_0 than females in both post-/s/ and post-/s*/ contexts. Statistical analysis was conducted on the onset ($t(476)=31.5$, $p<0.001$), midpoint ($t(476)=34.47$, $p<0.001$) and the offset ($t(476)=37.63$, $p<0.001$) of the post-/s/ vowels, and the onset ($t(476)=10.06$, $p<0.001$), midpoint ($t(476)=11.06$, $p<0.001$) and the offset ($t(476)=25.28$, $p<0.001$) of the post-/s*/ ones. Within male speakers, f_0 of the post /s*/ vowels was significantly lower than that of the post /s/ only on the offset ($t(476)=2.51$, $p=0.01$) but no differences was found on the onset ($t(476)=0.54$, $p=0.6$) and the midpoint ($t(476)=0.54$, $p=0.6$). On the other hand, within female speakers, f_0 of the post /s*/ was significantly lower than that of post /s/ on the onset ($t(476)=4.55$, $p<0.001$) and the midpoint ($t(476)=6.39$, $p<0.001$) as well as the offset ($t(476)=4.3$, $p<0.001$).

Despite general tendencies of lower f_0 in the post /s*/ than the post /s/ contexts, it should be noted, that inter-speaker variations are also found. For instance, f_0 in the post /s/ of male speaker 1 (i.e., M1) was entirely lower than that in the post /s/ of male speaker 2 and 3 (i.e., M2 and M3). In addition, f_0 in both the post /s/ and post /s*/ of female speaker 3 (i.e., F3) was absolutely higher than the other two speakers (i.e., F1 and F2).

4. Discussion

This study examined the acoustic properties of Korean fricatives and post-fricative vowels and found that the tense and lax distinction in Korean fricatives is strongly correlated with the properties of the following vowels. Previous acoustic measurements do not consider the dynamic properties of the following vowels. In this study, by exploring both consonantal and vocalic properties of fricatives and post-fricative vowels, a through acoustic comparison between the two Korean fricatives and their following vowels was examined.

Specifically, we measured and compared the duration, f_0 , $F1$, $F2$ and $F3$ of the post-lax and post-tense fricative vowels for vocalic properties. We also measured the duration of friction and CoG for the two fricatives for consonantal properties. In doing so, we have investigated (i) that the post-tense vowels are longer than post-lax ones, (ii) that f_0 of post-tense are higher than that of post-lax only limitedly, and (iii) that vowel qualities are not significantly different in post-lax and post-tense vowels. We have also examined (i) that Korean tense fricative is longer than its lax counterpart in general, but not always (e.g., the pre-[u] context) and (ii) that CoG values of the tense /s*/ is longer than those of the lax /s/.

Below, we review these results with regard to the following two respects. We first consider the results in terms of the robustness of the cues. We then consider the extent to which the results might be accounted for in terms of more general phonological realization.

First of all, the acoustic examination of this study suggests that the two fricatives /s/ and /s^{*}/ are contrastive in terms of both temporal (i.e., the duration of post-tense and post-lax vowels) and spectral (i.e., CoG of fricatives) properties from Korean speakers' production. The acoustic measurement of this study may be considered in terms of its implication to speech perception. The results of this study indicate that the consonant-internal property, CoG, along with the vocalic property, the duration of post-fricatives may be potential acoustic cues for Korean listeners to distinguish the two. The temporal cues of fricatives themselves, on the other hand, systematically vary across contexts, which suggests that the duration of the fricative noise may not be the robust invariant cues for Korean listeners (cf. Kim 1999, Kim and Curtis 2002).

Secondly, the results of this study may be extended to a broader aspect, Korean post-obstruent tensification. While Korean post-obstruent tensification is largely discussed in the context of stops as in /malk.ta/ → [mak.t^{*}a] 'to be clear' (Cho and Inkelas 1994), the phonological phenomenon is also found in fricatives. In Korean, the lax and tense fricatives often lose their contrast when the lax appears after obstruents by being subject to be tensified as in /pak.su/ → [pak.s^{*}u] 'clap' and /pak.sa/ → [pak.s^{*}a] 'PhD'. The loss of the fricative contrast, aka, neutralization of the tense and the lax fricatives in part support the idea that Korean listeners may not adopt the consonant-internal acoustic properties as their perceptual cues in distinguishing /s/ and /s^{*}/.

5. Conclusion

In this study, I examined the acoustic properties of Korean /s/ and /s^{*}/ and those of post-lax and post-tense vowels. The findings of this study were discussed in terms of the robustness of cues and a phonological aspect. The results of the acoustic measurement and the discussion of implication imply that it is the vocalic cues rather than consonantal ones to be robust for Korean listeners to distinguish /s/ and /s^{*}/ . Unlike the duration of fricatives, those of the post-tense and post-lax fricatives were consistently contrastive across all vowel contexts. While it seems certain that Korean listeners may be sensitive to vocalic cues over consonantal ones, a perceptual study will be straightforward to confirm the interpretation of the perceptual consequences of the results.

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