한국어 치찰음의 마찰구간의 스펙트럼 특성

황현경
서울대학교 언어학과

Spectral Characteristics of Frication Noise in Korean Sibilants

Hyunkyung Hwang
Dep. of Linguistics, Seoul National Univ.

eileenhhk@hotmail.com

Abstract

This study investigates spectral characteristics of frication noise in Korean sibilants in terms of center of gravity and skewness. Specifically, the present study seeks to observe the two parameters with emphasis on place of articulation in different vowel environments. This study also examines whether these parameters can discriminate phonation types. The results showed that the fricatives are palatalized in front of the front vowel /i/ and the affricates are articulated at the same place of articulation regardless of the following vowels. This study also suggests that the place of articulation of the fricatives followed by /i/ is the same as those of the Korean affricates. With regard to the phonation type, there was a significant difference in the center of gravity between lax and tense series for both fricatives and affricates.

I . Introduction

1.1. Objectives of this study

This study investigates spectral characteristics of the frication noise in word initial alveolar fricatives and affricates in Korean by examining center of gravity and skewness with emphasis on the place of articulation in different vowel environments and phonation types.

1.2. Previous studies

There are two alveolar fricatives /s/ and /s*/ in Korean. Unlike stops or affricates, only two-way contrast exists in alveolar fricatives, so there is a controversy over whether /s/ is lax or aspirated. However, /s/ was considered as a lax consonant in this study following Lee (1989)[1], and Lee (1996)[2]. For articulatory characteristics, in his X-ray study, Kim (1991)[3] observed that the constriction of /s/ was made at the alveolar region but, when followed by /i, j/, the place of constriction moved to the palatal region. For phonation type, Baik (2001)[4] observed from an EPG study that the point of articulation for the tense fricative moved forward, compared to the lax counterpart. For spectral characteristics, Cho *et al.* (2002)[5] calculated center of gravity. The results showed that there was a small but significant difference in center of gravity between /s/ and /s*/. The tense fricatives had a higher center of gravity than the lax ones.

Korean has a three-way contrast in affricates: lax, /c/; aspirated, /c^h/; and tense, /c*/. These symbols were used for Korean affricates neutrally because consensus on the place of articulation for the

Korean affricates does not exist in the relevant linguistics literature. Scholars classified /c/ as an alveolar, as a palato-alveolar, or as an alveolo-palatal sound.

In the EPG studies of the Korean sibilants, the same method often provided different results. The previous studies have also been limited to qualitative and impressionistic description. No quantitative data for spectral characteristics of the sibilants have been provided so that they can be applied to speech synthesis or recognition.

II. Method

1.1. Subject

Five male native speakers of Standard Korean participated in recording. All were born and raised in Seoul. Three of them are undergraduate students and the others are graduate students at Seoul National University. None of them has any history of speech or hearing impairment.

1.2. Materials

Bi-syllabic words were recorded. All of them were real Korean words except /s*ita/. Test words are listed in Table 1. Each word begins with one of the five consonants /s, s*, c, c^h, c*/, followed by one of the two vowels /a, ɪ/. The second syllable was /-ta/, the verbal ending of the Korean infinitival forms Each word was repeated fifteen times. The total number of tokens was 750 (5 consonants x 2 vowels x 5 speakers x 15 repetitions).

Table 1 Test Words

fricatives	/sata/	'to buy'
	/sɪta/	'to be sour'
	/s*ata/	'to be cheap'
	/s*ɪta/	'ɪt's a seed'
affricates	/cata/	'to sleep'
	/cɪta/	'to lose'
	/chata/	'to kick'
	/chɪta/	'to hɪt'
	/c*ata/	'to squeeze'
	/c*ɪta/	'to steam'

1.3. Recording

The words were presented in Korean alphabets. Subjects were asked to read a randomly ordered word list. The words were recorded directly to CSL 4400 with a Shure SM48 microphone approximately 15cm away from the speakers' lips. The speech signals were digitized at a sampling rate of 22,050 Hz and at a quantization rate of 16 bits. All recordings were made in a sound attenuated room in Phonetics Lab at SNU.

1.4. Measurements

Center of gravity and skewness were mseasured with Praat 4.1.9. I extracted speech samples using a 20ms Hamming window at the midpoint of the frication noise in the fricatives and affricates. Then, the samples were preemphasized from 50 Hz and Fast Fourier Transforms (FFTs) were calculated. The spectra were made with the power of 2.

Center of gravity and skewness were measured from the power spectra. The center of gravity was calculated by formula (1).

$$\frac{\int_0^\infty f|S(f)|^p df}{\int_0^\infty |S(f)|^p df} \quad (1)$$

where f is frequency, $S(f)$ is spectrum, and p is power. In formula (1), the denominator represents the energy of the power spectrum. Thus, "the center of gravity is the average of f over the entire frequency domain, weighted by $|S(f)|^p$. For p = 2, the weighting is done by the power spectrum".

Skewness is a parameter that describes the asymmetry of a frequency distribution. Skewness gives information about the spectral shape, specifically symmetry of distribution. Skewness was calculated by formula (2), divided by the 1.5 power of formula (3),

$$\frac{\int_0^\infty (f - f_c)^3 |S(f)|^p df}{\int_0^\infty |S(f)|^p df} \quad (2)$$

$$\frac{\int_0^\infty (f - f_c)^2 |S(f)|^p df}{\int_0^\infty |S(f)|^p df} \quad (3)$$

where f_c is the center of gravity of spectrum. The power was set to 2 in this study

These two parameters were selected because many studies about English reported that these were useful to classify obstruents[6][7][8]. Forrest *et al.* (1988) first applied this statistical technique to obstruents to quantify the spectral characteristics of obstruents. Spectral information provides the most critical cues to the place of articulation in English fricatives[7][8].

III. Results and Discussion

1.1. Spectral characteristics of fricatives

Mean and standard deviation of the parameters are presented in Table 2 and 3 below.

Table 2. Mean and standard deviation of the two parameters in /sa/ and /si/

sa/si	CG (Hz)		SK	
vowels	M	SD	M	SD
a	7432.82	639.19	-0.228	0.53
i	5688.29	409.68	0.839	0.37

CG: center of gravity, SK: skewness, M: mean, SD: standard deviation

Table 3. Mean and standard deviation of the two parameters in /s*a/ and /s*i/

s*a/s*i	CG (Hz)		SK	
vowels	M	SD	M	SD
a	7902.32	659.478	-0.404	0.793
i	5934.91	459	1.063	0.559

Note that the mean values of center of gravity in the fricatives in front of /a/ were higher than those in front of /i/ by about 2000 Hz across phonation types. The fricatives followed by /a/ had negative skewness, while they showed positive skewness when followed by /i/. For phonation type, the differences were much smaller but the tense fricatives had higher values in center of gravity. Skewness did not show any consistency. The tense fricatives followed by /a/ had lower values in skewness, but those followed by /i/ showed higher values.

A two-way ANOVA was performed to test the significance of the differences between /sa, s*a/ and /si, s*i/, andbetween /sa, si/ and /sa*, si*/ in center of gravity and skewness. The dependent variables were center of gravity and skewness while the independent variables were the following vowel and phonation type.

As for center of gravity, there was no interaction effect between the two independent variables ($F(1, 299) = 3.049$, $p > 0.05$). For the following vowel, the results showed that there was a significant difference between /sa, s*a/ and /si, s*i/ in center of gravity ($F(1, 299) = 845.648$, $p < 0.05$). The results suggest that the place of articulation of /s, s*/ may shift backwards before /i/ compared to that of /s, s*/ before /a/. For phonation type, the results also showed that there was a significant difference between /s/ and /s*/. Center of gravity was significantly higher in tense fricatives than in lax ones ($F(1, 299) = 31.475$, $p < 0.05$).

As for skewness, however, there was a significant interaction effect between the following vowel and phonation type ($F(1, 299) = 8.786$, $p < 0.05$). Therefore, the effects of independent variables were examined separately. Concerning phonation type, paired T-tests were conducted separately. The results showed a significant difference between the two groups. When the following vowel is /a/, /s/ showed significantly greater values in skewness than /s*/ ($t = 2.034$, $p < 0.05$), while when the following vowel is /i/, /s*/ showed greater values than /s/ ($t = -3.368$, $p < 0.05$). Considering that greater values in skewness, in general, mean that energy is concentrated in lower frequencies, the greater values in /s/ before/a/ compared to /s*/ are consistent with the results that /s*/ had greater values in center of gravity. However, the greater values in /s*/ before /i/ compared to /s/ are contrary to our expectation. These results suggest that skewness alone does not distinguish phonation types. Further research is needed to clarify the causes of this difference. Regarding following vowel, /si, s*i/ showed significantly greater values than /sa, s*a/ across phonation type ($F(1, 299) = 353.402$, $p < 0.05$). It could be interpreted that energy is concentrated in higher frequencies in the spectra of /sa, s*a/ than in those of /si, s*i/.

The results regarding phonation type confirmed the results reported in Cho *et al.* (2002)[5] in that center of gravity of the tense fricatives were greater than that of their lax counterparts ($F(1, 76) = 5.59$, $p < 0.05$). However, the mean center of gravity frequency was different in this study. As shown in Table 2 and Table 3, the mean value of center of gravity was 7432 Hz for /s/ and 7902 Hz for /s*/ in front of /a/ in the word-initial position. In Cho *et al.* (2002), the mean centroid frequency was around 6200 Hz for /s/ and 6600 Hz for /s*/ in the same environments. The lack of explanations about experimental procedures in that research makes it difficult to know the reasons behind such discrepancies.

The results suggest that Korean alveolar fricatives followed by /i/ are articulated at a position posterior to those followed by /a/ in agreement with previous articulatory studies.

1.2. Spectral characteristics of affricates

Mean and standard deviation of center of gravity and skewness are presented in Table 4, 5 and 6 below. As shown in Table 4, 5, and 6, there was no substantial difference in mean values of either center of gravity or skewness across the following vowels and phonation type.

Table 4. Mean and standard deviation of the two parameters in /ca/ and /ci/

ca/ci	CG (Hz)		SK	
vowels	M	SD	M	SD
a	5772.72	363.47	0.662	0.439
i	5860.43	478.19	0.723	0.463

Table 5.Mean and standard deviation of the two parameters in /c^ha/ and /c^hi/

c^ha/c^hi	CG (Hz)		SK	
vowels	M	SD	M	SD
a	5940	375.99	0.566	0.496
i	5911.85	469.77	0.634	0.398

Table 6.Mean and standard deviation of the two parameters in /c*a/ and /c*i/

c*a/c*i	CG (Hz)		SK	
vowels	M	SD	M	SD
a	5945.14	495.72	0.648	0.511
i	5957.04	607.61	0.78	0.609

Unlike the fricatives, there was no remarkable difference among the affricates in the different following vowel contexts across phonation types.

To test the significance of the differences across the following vowel (between /ca, cha, c*a/ and /ci, chi, c*i/), and across phonation type (between /ca, ci/, /c^ha, chi/ and /c*a, c*i/) in center of gravity and skewness, a two-way ANOVA test was conducted with the following vowel and phonation type as the independent variables and center of gravity and skewness as the dependent variables. There were no interaction effects for either center of gravity ($F(2, 449) = 0.582$, $p > 0.05$) or skewness ($F(2, 449) = 0.237$, $p > 0.05$). With regard to the following vowel, the result showed that there was no significant difference in either center of gravity ($F(1, 449) = 0.286$, $p > 0.05$) or skewness ($F(1, 449) = 3.535$, $p > 0.05$). Concerning phonation type, the result showed that there was a significant difference in center of gravity ($F(2, 449) = 3.441$, $p < 0.05$). However, the result of *post hoc* comparison for center of gravity in the affricates using Tukey's HSD showed that there was a significant difference only between the lax and tense affricates. The tense affricates showed higher values of center of gravity than those of lax ones. There was no significant difference in skewness ($F(2, 449) = 2.305$, $p > 0.05$).

These results suggest that the place of articulation of the affricates stays the same in the different following vowel contexts. For phonation type, there was a small but significant difference only between the lax and tense affricates. This finding is in agreement with that of the fricatives indicated above. These differences suggest that /s*/ and /c*/ are articulated with a relatively shorter front cavity than their non-tense counterparts. The difference between the lax and tense sibilants is consistent with previous results based on EPG data [4] in that the place of articulation shifts forward as tensity increases.

1.3. Comparison between fricatives and affricates

Boxplots for center of gravity and skewness across five consonants and two vowels are illustrated in Figure 2. The left-hand graph is for center of gravity and the right-hand one is for skewness. Circles in each graph represent fricatives followed by /a/. Geminates (ss and cc) were used for tense fricatives and affricates.

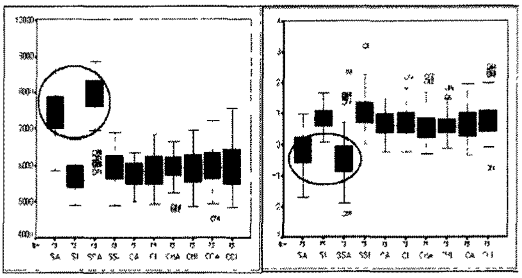

Figure 2. Boxplots for center of gravity and skewness across the sibilants and different vowel contexts

The graphs showed that the place of articulation for the fricatives and affricates was divided into two distinct groups: the fricatives followed by /a/ and the others. There was a substantial difference between the two groups as shown in Figure 2.

The data were subjected to a two-way ANOVA test in order to compare the place of articulation between /si, s*i/ and /ci, c*i/ with center of gravity and skewness as dependent variables, and phonation type as independent variables. For phonation type, there was a significant difference between the lax consonants and tense ones in center of gravity ($F(1, 299) = 9.049$, $p < 0.05$). However, there was no significant difference between /si, ci/ and /s*i, c*i/ in skewness ($F(1, 299) = 5.728$, $p > 0.05$).

These results of comparison between the fricatives followed by /i/ and affricates suggest that the frication portion of the affricates are articulated at the same place of articulation with the fricatives in front of /i/.

Ⅳ. Conclusion

The present study investigated the spectral characteristics of Korean sibilants across the following vowels and phonation types in terms of two parameters, i.e. center of gravity and skewness. For the following vowel, the results showed that the place of articulation of /s, s*/ shifts backwards before /i/ compared to those before /a/. Also, the affricates are articulated at the same place of articulation in the different vowel contexts. With regard to the phonation type, there was a significant difference in center of gravity between the lax and tense series for both fricatives and affricates The results showed that the place of articulation moves forward as tensity increases. The most important result was that there was no significant difference in center of gravity between the fricatives followed by /i/ and the affricates. Consequently, it is possible to conclude that the place of articulation of the alveolar fricatives followed by /i/ and that of the affricates are the same. Therefore, the frication part of the Korean affricates should be transcribed as the same symbols of the Korean fricatives before /i/.

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