Spectral Characteristics of Frication Noise in Korean Sibilants

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<Abstract>

Spectral Characteristics of Frication Noise in Korean Sibilants

Hyun Kyung Hwang

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.

* Keywords: center of gravity, skewness, sibilants, fricatives, affricates, phonation type

1. Introduction

1.1. Objectives of the present 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.

The present study is significant in that the place of articulation is investigated quantitatively and systematically. This study is also significant in that quantitative results are helpful in modeling the spectral energy distribution of the frication noise in the Korean sibilants and can serve as a basis of controlling the parameters for speech synthesis and perception tests.

1.2. Review of the previous studies

1.2.1. Korean fricatives

There are two alveolar fricatives /s/ and /s*/ in Korean. /s/ is lax[1] and /s*/[2] is tense. For articulatory characteristics, in his X-ray study, Kim (1991)[1] 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. Fricatives have allophones according to phonetic environments as described by Lee(1996)[2][3].

/s, s=/ [ʃ, ʃ=]: before vowel /y/ and semi-vowel /ɥ/
[ɕ, ɕ=]: before vowel /i/ and semi-vowel /j/
[sw, s=w]: before /u, o, / and semi-vowel /w/
[s , s=]: in other contexts.

Alveolar fricatives are realized as alveolar-palatals in front of /i/ and /j/[2]. This

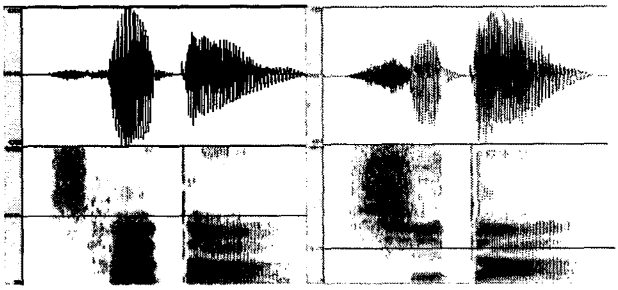
1) Unlike stops or affricates, only two-way contrast exists in alveolar fricatives, so there is a controversy over whether /s/ is lax or aspirated. However, /s/ was considered as a lax consonant in this study following Lee (1989), and Lee (1996)[2][13].

2) Diacritic '*' has been used to mark tenseness throughout this study

3) The diacritic '=' was used to mark tense consonants in Lee (1996).

allophonic variation results from anticipatory coarticulation. However, there was no evidence for using the symbol [ɕ] for the fricatives followed by /i/. For phonation type, Baik (2001)[3] observed from an EPG study that the point of articulation for the tense fricative moved forward, compared to the lax counterpart.

Spectrograms of the Korean fricatives followed by two different vowels are given in <Figure 1>.



<Figure 1> Spectrograms of /sata/ and /sita/

As shown in <Figure 1>, the first syllable of /sata/ has a sequence of frication, aspiration, and the vowel /a/, while that of /sita/ lacks aspiration, hence a sequence of frication and vowel /i/. The cutoff frequency of the fricative followed by /i/ is much lower than that of the fricative followed by /a/, such that the cutoff frequency is about 4000 Hz in /sata/ and around 2500 Hz in /sita/, which is indicated by horizontal lines. Lee *et al.* (1993)[4] also indicated this phenomenon with only qualitative descriptions. They did not show more quantitative evidence to explain the difference of energy distribution.

For spectral characteristics, Cho *et al.* (2002)[5] calculated center of gravity, namely, centroid. They measured centroid values from FFT spectra by using 25ms windows centered at the midpoint of the fricative portion to distinguish lax from tense fricatives. The results showed that there was a small but significant difference in centroid between /s/ and /s*/. The tense fricatives had a higher centroid than the lax ones. It should be noted that this study was also performed not to examine the place of articulation of the fricatives but to discriminate the two Korean alveolar fricatives, and that the vowel was fixed to /a/ in all cases.

1.2.2. Korean affricates

Korean has a three-way contrast in affricates: lax, /c/; aspirated, /c^h/; and tense /c* /[4]. Consensus on the place of articulation for the Korean affricates does not exist in the relevant linguistics literature. Korean affricates have been transcribed as [ʦ], [ʧ] or [ʨ]. Scholars classified /c/ as an alveolar[6], as a post-alveolar or palato-alveolar[7][8][9], or as an alveolo-palatal[2][10] sound. In his EPG study, Baik (2003)[11] showed that the lax affricate /c/ is articulated at the same place of articulation as that of /s/ for both its stop portion and its fricative portion. Lee (1980)[12] argued that /c^h/ is articulated a little posterior to /c/, and /c*/ is post-alveolar. The phoneticians who classified the place of articulation of the Korean affricates as post-alveolar or palato-alveolar used the phonetic symbols [ʧ, ʧ^h, ʧ*] [5][9][13] because the place of articulation of [ʃ] is post-alveolar even though the Korean affricates do not have the 'roundness' feature. Lee (1996)[2] transcribed the Korean affricates as [ʥ, ʨ^h, ʨ=], stating that the affricates were realized as the same allophones [ʥ, ʨ^h, ʨ=] except before rounded vowels.

By means of LPC spectra, Kim (1998)[6] concluded that the Korean lax affricate /c/, like /t, s/, is alveolar in intervocalic positions, since the spectral peaks at its stop part and frication part were either between F4 and F5 or above F5 of the following vowel. Assuming that /c^h, c*/ have the same place of articulation as their lax counterpart, she transcribed the Korean affricates as [ʦ, ʦ^h, ʦ*].

1.2.3. Problems

In the EPG studies of the Korean sibilants, the same method often provided different results[10][11][12]. In addition, utterances were seldom spoken naturally, since EPG studies require the insertion of an artificial palate to the speaker's mouth. The EPG studies recruited only one speaker, usually the author, making it hard to generalize the results. In the LPC study[6], there was no detailed explanation of experimental methods. She did not refer even to the LPC coefficient that she used.

There was no systematic study for auditory, articulatory, and acoustic characteristics of the Korean sibilants before other vowels than /a/. 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

4) These symbols were used for Korean affricates neutrally because there is a controversy over the place of articulation of Korean affricates.

to speech synthesis or recognition.

2. Methods

2.1. Subjects

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. Speaker information is provided in <Table 1>.

<Table 1> Speaker information

	Birth Place	Age
S1	Seoul	23
S2	Seoul	23
S3	Seoul	27
S4	Seoul	25
S5	Seoul	20

2.2. Materials

Bi-syllabic words were recorded. All of them were real Korean words except /s*ita/. Test words are listed in <Table 2>. Each word begins with one of the five consonants /s, s*, c, c^h, c*/, followed by one of the two vowels /a, i/. 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 × 2 vowels × 5 speakers × 15 repetitions).

<Table 2> Test words

fricatives	sata	'to buy'
	sita	'to be sour'
	s*ata	'to be cheap'
	s*ita	it's a seed'
affricates	cata	'to sleep'
	cita	'to lose'
	chata	'to kick'
	chita	'to hit'
	c*ata	'to squeeze'
	c*ita	'to steam'

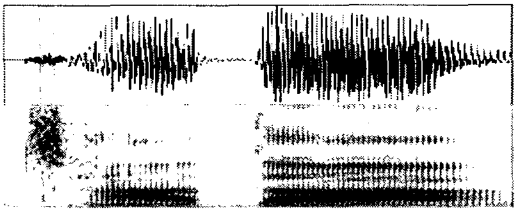
2.3. Recording

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.

2.4. Measurements

Center of gravity and skewness were measured 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. An analysis window was centered over the midpoint of the frication to avoid the effect of vowels or aspiration. Then, the samples were preemphasized from 50 Hz and Fast Fourier Transforms (FFTs) were calculated. The power spectra were made with the power of 2. Spectra were LPC smoothed for a better view. For LPC, 12 peaks were used.

I chose the size of 20ms, since the average duration of frication noise of /c*a/ was 27.69ms, and the duration of the shortest tokens was 21.442ms. The average duration of the other consonants was much longer. I excluded the release burst. The measured section is displayed in <Figure 2>.



<Figure 2> Waveform and spectrogram of /cata/

In <Figure 2>, the leftmost line represents the onset of frication and the rightmost line the onset of aspiration. There is 20ms selection portion at the midpoint of the frication.

Center of gravity and skewness were measured from the power spectra. The center of gravity was calculated by formula (1). Formulae and interpretation of each formula were quoted from Praat manual,

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

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". In this study, the value of p was set to 2.

Skewness is a parameter that describes the asymmetry of a frequency distribution. Skewness measures the extent to which data deviate positively or negatively from symmetry. Therefore, 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),

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

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

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[14][15][16]. The distribution of spectral energy can be obtained by measuring the center of gravity and skewness in the spectra of the frication. The spectral shape of frication noise is related to the characteristics of the cavities in front of and at the constriction. Thus, spectral information provides the most critical cues to the place of articulation in English fricatives[14][16]. Forrest *et al.* (1988)[14] first applied this statistical technique to obstruents to quantify the spectral characteristics of obstruents. Nittrouer (1995)[15] reported that use of spectral moments is advantageous because just a few numbers can describe spectral shapes completely. Jongman *et al.* (2000)[16] showed that spectral moments served to distinguish all four places of articulation in English fricatives.

Forrest *et al.* (1988)[14] found out that the combination of the first and third spectral moments correctly classified /s/ and /ʃ/ noises approximately 98%. Recently, Park (2003)[17] measured center of gravity and skewness of the release burst in Korean stops to examine the differences across phonation types. The results showed that there was no significant difference between Korean stops across phonation types in center of gravity and skewness.

Center of gravity and skewness can be the proper parameters to describe the energy distribution varying with the following vowels and to quantify the place of articulation of Korean sibilants.

3. Results and Discussion

3.1. Spectral characteristics of fricatives

The center of gravity and skewness in the fricatives were examined. Mean and standard deviation of the parameters are presented in <Table 3> and <Table 4> below.

<Table 3> Mean and standard deviation of the two parameters in /sa/ and/si/

sa/si		parameters			
		CG (Hz)		SK	
Speakers	vowels	M	SD	M	SD
DJE	a	7549.64	595.86	-0.6	0.57
	i	5467.57	208.87	0.857	0.29
SCH	a	7674.49	365.99	-0.333	0.34
	i	6044.42	345.82	0.478	0.24
YGD	a	7952.66	221.05	-0.225	0.51
	i	5487.48	139.84	1.116	0.38
MSW	a	7214.4	402.25	-0.253	0.401
	i	6099.29	237.18	0.695	0.212
PHS	a	6856.74	758.54	0.179	0.476
	i	5401.7	328.46	1.02	0.309
	a	**7432.82**	**639.19**	**-0.228**	**0.53**
	i	**5688.29**	**409.68**	**0.839**	**0.37**

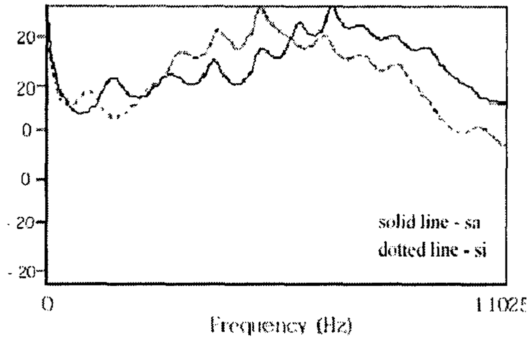
CG: center of gravity, SK: skewness, M: mean, SD: standard deviation.

<Table 4> Mean and standard deviation of the two parameters in /s*a/ and /s*i/

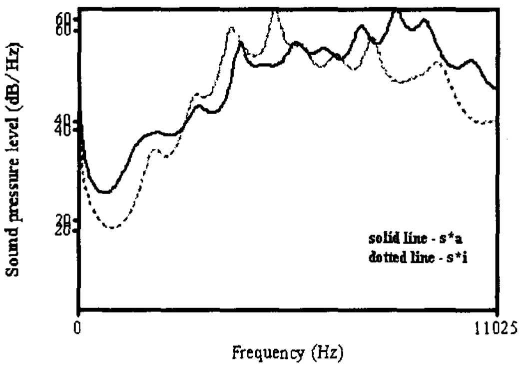
s*a/s*i		parameters			
		CG (Hz)		SK	
Speakers	vowels	M	SD	M	SD
DJE	a	8013.4	385.03	-0.758	0.396
	i	6044.84	391.77	1.195	0.722
SCH	a	8471.62	238.41	-0.958	0.389
	i	6510.85	298.26	0.531	0.357
YGD	a	8080.78	269.61	-0.254	0.318
	i	5886.88	237.85	0.967	0.341
MSW	a	7854.66	459.523	-0.536	0.811
	i	5766.16	335.1	1.34	0.384
PHS	a	7091.14	841.324	0.486	0.949
	i	5465.83	255.38	1.28	0.526
	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 and speakers. 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.

To compare the place of articulation varying with the following vowels and the differences among phonation types in center of gravity and skewness, the overlapped LPCs were examined before statistical analysis. The difference between /s*a/ and /s*i/ is given in <Figure 3> and <Figure 4>.



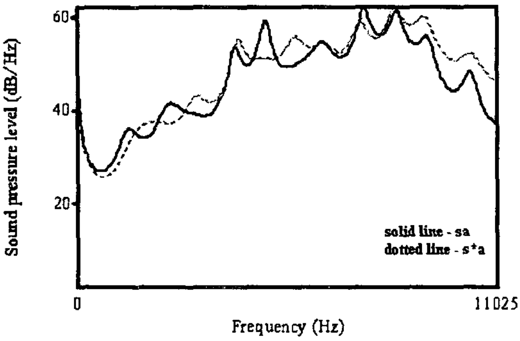
<Figure 3> Overlapped LPCs for /sa/ and /si/



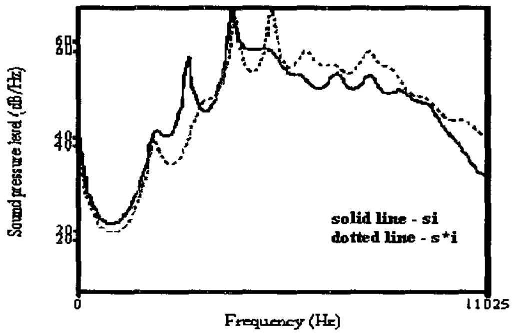
<Figure 4> Overlapped LPCs of /s*a/ and /s*i/

As shown in <Figure 3> and <Figure 4>, the peaks of the spectrum of /sa/ and /s*a/ occurred in higher frequencies.

Overlapped LPCs of the tense and lax fricatives followed by the same vowel are provided in <Figure 5> and <Figure 6>.



<Figure 5> Overlapped LPCs of /sa/ and /s*a/



<Figure 6> Overlapped LPCs of /si/ and /s*i/

As shown in <Figure 5> and <Figure 6>, the frequency range of /s/ and /s*/ were similar when followed by the same vowel. The peaks of the spectra of the tense fricatives occurred at slightly higher frequencies.

A two-way[5] ANOVA was performed to test the significance of the differences between /sa, s*a/ and /si, s*i/, and between /sa, si/ and /s*a, s*i/ 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. The significance level was set at 0.05.

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 support the hypothesis that the place of articulation of /s, s*/ may shift backwards before /i/ compared to that

5) SPSS 10.0 for windows program was used for statistical analysis.

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 centroid frequency was different in this study. As shown in <Table 3> and <Table 4>, 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)[5], 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 present finding of a negative skewness in /sa/ and positive skewness in /si/ is in accordance with previous findings about /s/ and /ʃ/ in English by Nittrouer (1995)[15]. She exhibited that /s/ had negative skewness while /ʃ/ had positive one, and the difference was statistically significant. 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.

3.2. Spectral characteristics of affricates

Mean and standard deviation of center of gravity and skewness are presented in <Table 5>, <Table 6> and <Table 7> below.

<Table 5> Mean and standard deviation of the two parameters in /ca/ and /ci/

ca/ci		parameters			
		CG (Hz)		SK	
Speakers	vowels	M	SD	M	SD
DJE	a	5412.35	320.34	0.786	0.484
	i	5710.41	283.72	0.511	0.331
SCH	a	6099388	211.97	0.47	0.306
	i	6216.71	388.92	0.712	0.328
YGD	a	5929.16	265.87	0.491	0.438
	i	5535.33	242.15	0.912	0.422
MSW	a	5904.1	225.5	0.452	0.308
	i	6335.17	294.43	0.461	0.214
PHS	a	5518.13	247.47	1.11	0.233
	i	5504.55	425.49	1.019	0.66
	a	**5772.72**	**363.47**	**0.662**	**0.439**
	i	**5860.43**	**478.19**	**0.723**	**0.463**

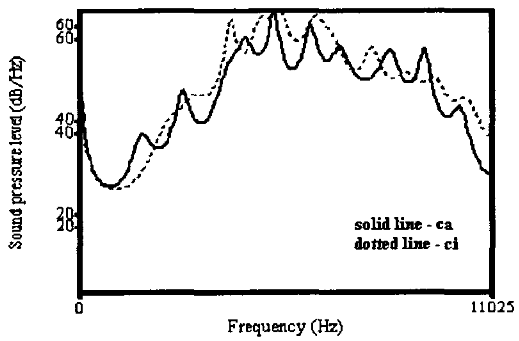
<Table 6> Mean and standard deviation of the two parameters in /c^ha/ and /c^hi/

cha/chi		parameters			
		CG (Hz)		SK	
Speakers	vowels	M	SD	M	SD
DJE	a	5638.88	299.28	0.514	0.596
	i	5504.34	408.12	0.78	0.461
SCH	a	6300.13	212.5	0.47	0.306
	i	6268.6	421.82	0.674	0.366
YGD	a	6087.56	281.24	0.44	0.42
	i	5894.77	345.6	0.404	0.398
MSW	a	5964.36	265.58	0.49	0.396
	i	6321.65	225.46	0.519	0.217
PHS	a	5709.07	381.68	0.92	0.594
	i	5569.9	178.56	0.791	0.407
	a	**5940**	**375.99**	**0.566**	**0.496**
	i	**5911.85**	**469.77**	**0.634**	**0.398**

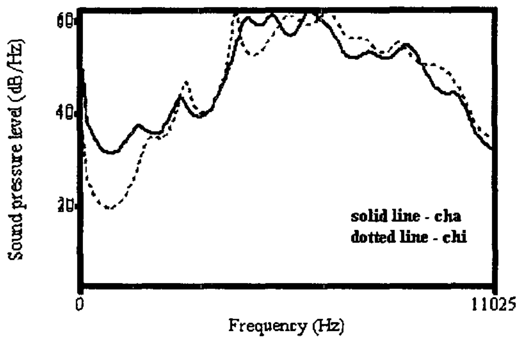
<Table 7> Mean and standard deviation of the two parameters in /c*a/ and /c*i/

c*a/c*I		parameters			
		CG (Hz)		SK	
Speakers	vowels	M	SD	M	SD
DJE	a	5862.75	393.66	0.43	0.417
	i	5755.54	379	0.764	0.368
SCH	a	6414.13	328.91	0.52	0.426
	i	6657.07	442.78	0.338	0.518
YGD	a	5798.34	335.72	0.88	0.444
	i	5319.17	249.97	1.437	0.7
MSW	a	6256.25	271.23	0.317	0.344
	i	6453.7	234.8	0.476	0.255
PHS	a	5394.26	393.16	1.094	0.502
	i	5599.73	297.63	0.885	0.47
	a	**5945.14**	**495.72**	**0.648**	**0.511**
	i	**5957.04**	**607.61**	**0.78**	**0.609**

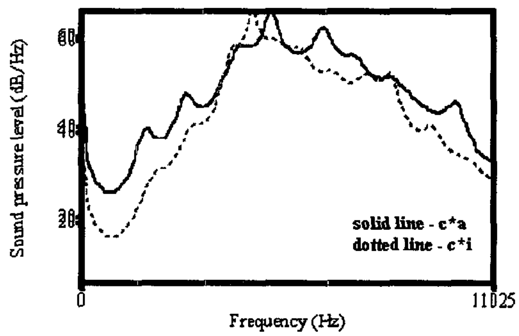
As shown in <Table 5>, <Table 6>, and <Table 7>, there was no substantial difference in mean values of either center of gravity or skewness across the following vowels and phonation type. Overlapped LPCs of the affricates varying with the following vowels are illustrated in <Figure 7>, <Figure 8>, and <Figure 9> below.



<Figure 7> Overlapped LPCs of /ca/ and /ci/

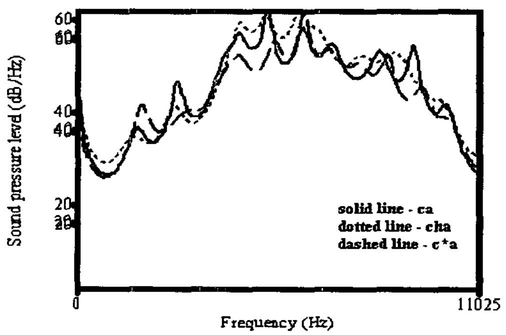


<Figure 8> Overlapped LPCs of /cha/ and /chi/

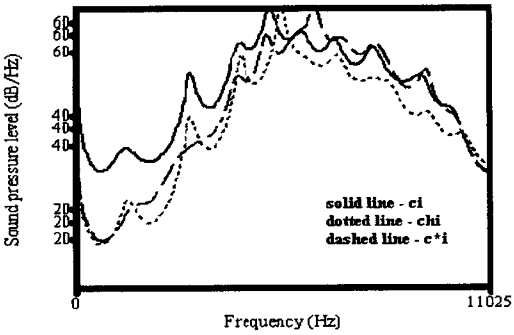


<Figure 9> Overlapped LPCs of /c*a/ and /c*i/

Unlike the fricatives, there was no remarkable difference among the affricates in the different following vowel contexts across phonation types. Overlapped LPCs of the affricates varying with phonation types are illustrated in <Figure 10> and <Figure 11>.



<Figure 10> Overlapped LPCs of affricates followed by /a/



<Figure 11> Overlapped LPCs of affricates followed by /i/

As shown in <Figure 10> and <Figure 11>, there was no remarkable difference between the affricates followed by /a/ and /i/.

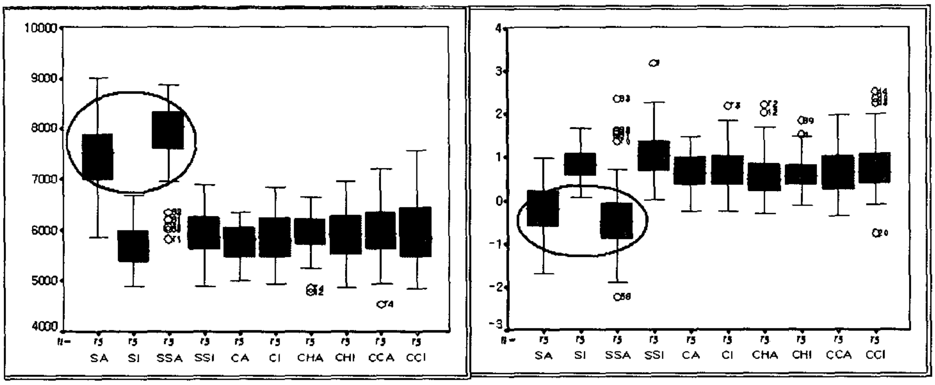
To test the significance of the differences across the following vowel (between /ca, cha, c*a/ and /ci, c^{h}i, c*i/), and across phonation type (between /ca, ci/, /c^{h}a, c^{h}i/ and /c*a, c*i/) in center of gravity and skewness, a two-way ANOVA test was conducted with the following vowel and phonation 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 support the hypothesis 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 (Baik, 2001)[3] in that the place of articulation shifts forward as tensity increases.

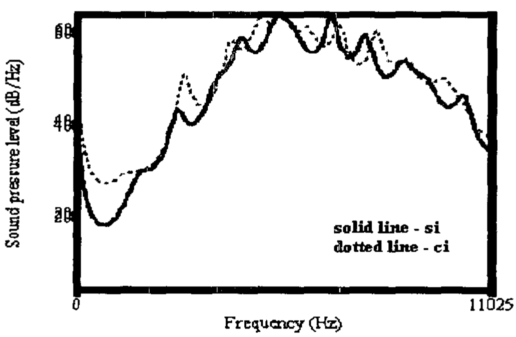
3.3. Comparison between fricatives and affricates

Boxplots for center of gravity and skewness across five consonants and two vowels are illustrated in <Figure 12>. For a technical reason, symbols in the boxplots are slightly different from those in the text. Geminate (ss and cc) were used for tense fricatives and affricates. 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/.

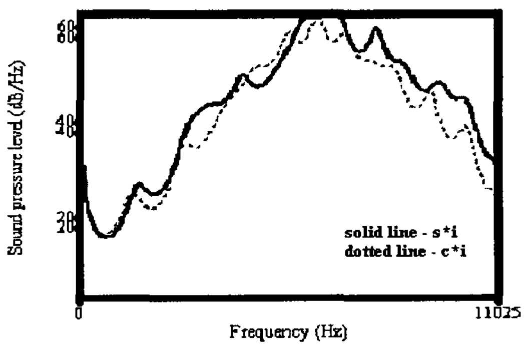


<Figure 12> Boxplots for center of gravity and skewness across the sibilants and different vowel contexts

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 12>. Overlapped LPCs for the fricatives and affricates followed by /i/ are illustrated in <Figure 13> and <Figure 14> below.



<Figure 13> Overlapped LPCs of /si/ and /ci/



<Figure 14> Overlapped LPCs of /s*i/ and /c*i/

As shown in <Figure 13> and <Figure 14>, there was overlapping between the fricatives followed by /i/ and the affricates across phonation types. These results suggest that the place of articulation of the fricatives followed by /i/ and affricates are the same.

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 support the hypothesis that the frication portion of the affricates are articulated at the same place of articulation with the fricatives in front of /i/.

4. 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. In this study, center of gravity and skewness of frication noise in Korean sibilants in word-initial positions have been examined. 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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