ISSN 2005-8063
2017. 12. 31.
Vol.9 No.4
pp. 51-57

말소리와 음성과학

Phonetics and Speech Sciences

한국음성학회지

http://dx.doi.org/10.13064/KSSS.2017.9.4.051

Phonation types of Korean fricatives and affricates

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Abstract

The current study compared the acoustic features of the two phonation types for Korean fricatives (plain: /s/, fortis : /s'/) and the three types for affricates (aspirated : /tsʰ/, lenis : /ts/, and fortis : /ts'/) in order to determine the phonetic status of the plain fricative /s/. Considering the different manners of articulation between fricatives and affricates, we examined four acoustic parameters (rise time, intensity, fundamental frequency, and Cepstral Peak Prominence (CPP) values) of the 20 Korean native speakers' productions. The results showed that unlike Korean affricates, F0 cannot distinguish two fricatives, and voice quality (CPP values) only distinguishes phonation types of Korean fricatives and affricates by grouping non-fortis sibilants together. Therefore, based on the similarity found in /tsʰ/ and /ts/ and the idiosyncratic pattern found in /s/, this research concludes that non-fortis fricative /s/ cannot be categorized as belonging to either phonation type.

Keywords: Korean fricatives, Korean affricates, phonation type, acoustic characteristics, breathy voice

1. Introduction

Korean has very well established three-way contrasts (e.g., aspirated, lenis, and fortis) both in stops and affricates in three places of articulation (bilabial, alveolar, velar). However, this distinction does not occur in fricatives, leaving only a two-way contrast between fortis fricative /s'/ and non-fortis (hereafter, plain) fricative /s/. While many scholars have attempted to investigate the phonation type of Korean fricatives /s/, there has not been a strong consensus how to categorize the plain fricative.

Phonologically, the plain fricative /s/ shows an ambivalent pattern, sometimes patterning with lenis consonants and sometimes patterning with aspirated ones. For example, in Post-Obstruent Tensification (Kim, 2003), the plain fricative /s/ shows lenis-like characteristics by becoming a fortis fricative after an obstruent sound (e.g., /paksa/ → /[paks'a] 'Ph.D.'). Since lenis stops undergo the same transformation (e.g., /pakta/ → /[pakt'a] 'to pin down'), this process provides strong evidence in favor of categorizing the plain fricative as lenis.

On the other hand, the plain fricative /s/ also shows an aspirated-like characteristic by remaining voiceless in intervocalic position. Whereas the lenis stops become voiced in intervocalic position (e.g., /pata/ → / [pada] 'sea'), the aspirated stops do not undergo intervocalic voicing (e.g., /patʰaŋ/ → [patʰaŋ] 'foundation'). Since the plain fricative /s/, like the aspirated stops, does not undergo intervocalic voicing, categorizing the plain fricative as aspirated is also possible. However, previous research does not completely support the pattern of the intervocalic voicing. Chang (2008) and Kang *et al.* (2009) reported no intervocalic voicing in word-medial position, but Cho *et al.* (2002) and Kim *et al.* (2010) reported intervocalic voicing rates of 46% and 19.8% in word-medial position, respectively.

Phonetically, four acoustic pieces of evidence have been suggested in support of lenis categorization: (1) shortened duration in intervocalic position (Kang, 2000; Cho *et al.*, 2002) (2) centroid frequencies (Hwang, 2004; Kang *et al.*, 2009), (3) F0 value at onset of the following vowel (Cho *et al.*, 2002), and (4) vowel quality (Cho *et al.*, 2012).

For example, Kang (2000) and Cho *et al.*, (2002) reported a shortened frication duration of plain /s/ in intervocalic position,

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Received 1 November 2017 ; Revised 19 December 2017; Accepted 21 December 2017

which can also be observed for intervocalic lenis stops. Furthermore, Cho *et al.* (2002) reported that plain fricative /s/ became voiced in word-medial position in 46% of instances. With respect to the center of gravity (COG) measurement, when several scholars (Kang *et al.*, 2009; Hwang, 2004) measured the COG values of the fricatives and affricates, and compared the values. The results showed that the fortis fricatives had significantlly higher COG values than the plain fricative, while aspirated affricate and fortis affricate had somewhat overapping COG values. Based on this result, these studies have categorized plain /s/ as the lenis fricative. However, these studies leaves some open question whether the aspirated frication interval was correctly measured, given the fact that the aspiration onset point was not clearly defined. Lee (2017) measured COG values at 10 ms window, and found that the COG decline of the non-fortis siblants (plain fricative, aspirated affricate, and lenis affricate) patterns similarly. Thus, the acoustic evidence regarding COG values to categorize the plain fricative as lenis might have been misleading. Lastly, F0 was measured to see the pattern of fricatives in comparison with the F0 pattern in stops (Lenis < Fortis ≤ Aspirated), and Cho *et al.* (2002) reported a marginally lower F0 in the plain fricative and took that as support for the categorization of the fricative as the lenis. However, previous studies have also reported an opposite result such that F0 of the non-fortis fricatives does not pattern like either lenis stop or lenis affricates, concluding F0 does not play an impotant role in categorization of phonation type in fricatives (Chang, 2008; Kang *et al.*, 2009; Park, 2002b).

In contrast, other researchers have proposed different acoustic parameters to categorize plain /s/ as aspirated. Four acoustic pieces of evidence have been suggested to support the categorization as aspirated fricative: (1) word-initial duration (Kang, 2000; Park, 2002b), (2) aspiration interval (Chang, 2008; Yoon, 1999), (3) voice quality (Kang, 2000; Park, 1999, 2002a, 2002b), and (4) no systematic difference in F0 (Chang, 2008; Kang *et al.*, 2009; Park, 2002b).

Firstly, Kang (2000) and Park (2002) examined the frication duration of the plain fricative /s/ and the VOT of aspirated stops in word-initial position and reported a similar duration between them. Secondly, Park (1999), Yoon (1999), Chang (2008) and Kim *et al.* (2010) all reported that the plain fricative /s/ has some degree of aspiration. In a perception experiment, Yoon (1999) showed that aspiration in the consonant acted as a strong perceptual cue to the distinction between fortis and plain fricative. Park (1999) further found that the energy difference between the first and second harmonic (H1-H2) also supports the categorization of aspirated fricative. He claimed that the greater value of H1-H2 for the plain fricative than for the fortis fricative can indicate the aspiration portions included in the frication of /s/ (H1-H2: /s/ > /s'/). However, Cho *et al.* (2002) used the same parameter, H1-H2, to reach a different conclusion – categorize plain /s/ as lenis. Since both aspirated and lenis H1-H2 values of stop sounds are higher than fortis values (lenis > aspirated > fortis), it does not tell which category range the plain /s/ should be included in.

However, it should be noted that it is extremely important to consider the vowel height of the stimuli when examining the phonation type since vowel height can strongly affects the voice quality (Keating & Esposito, 2007). Previous studies have tried to avoid this problem by adopting corrected amplitudes of H1-H2 or adopting a new parameter like *k*1 (Park, 2002a, 2002b), and showed that plain fricative /s/ patterns like aspirated affricate than lenis. However, it is still important to examine whether the same finding can be replicated by using further acoustic parameters such as rise time, intensity, F0, and Cepstral Peak Prominence (CPP) values in order to add more evidence to firm the status of the phonation type of plain fricative. Thus, we aim to examine how the phonation type of non-fortis siblants pattern. Lee (2017) analyzed COG values in 20 ms window of the fricatives and affricates to examine how the aspiration pattern of plain /s/ differs from those of aspirated and lenis affricate. Additionally, she also examined H1-H2* values in order to whether the phonemes contained aspiration in frication interval had breathy voice. The findings showed that lenis affricate also contained aspiration and thus all non-fortis siblants (plain fricative, lenis affricate, and aspirated affricate) had breathy voice. Based on this, the current study aims to further examine the phonation type of Korean fricatives and affricates with additional acoustic parameters.

2. Methods

2.1. Subjects

Twenty Korean native speakers (10 females, 10 males) were recorded for the experiment. All subjects were native speakers of Seoul dialect in mid 20s to early 30s at the time of the experiment. None of the subjects had any articulatory or auditory impairment.

2.2. Stimuli

For the recordings, two frictiaveis (/s/, /s'/) and three affricaties (tsʰ /, /ts/, /ts'/) in three vowel conditions ([ɛ], [ʌ], [a]) were embedded in carrier sentences ([neka __ rago malhamnida] ("I say _______.").
We used the target words in mid and low vowels since the aspiration in plain fricative can disappear in high-vowel context (Kim *et al.*, 2010). The word list used for the recordings are reported in <Table 1>.

Table 1. List of the words used for the recordings

Fricatives	Affricates
[sɛta] 'to count' [sʌta] 'to stop' [sata] 'to buy'	[tsʰɛhata] 'to upset the stomach' [tsʰʌnhata] 'humble' [tsʰata] 'cold'/'to kick'
	[tsɛhata] 'to exclude' [tsʌnhata] 'to deliver' [tsata] 'to sleep'
[s'ɛta] 'strong' [s'ʌta] 'to subside' [s'ata] 'cheap	[ts'ɛts'ɛhan] 'stingy' [ts'ʌnta] 'awesome' [ts'ata] 'salty'

These words were provided with a randomized order with filler sentences in order to avoid the list effect. The subjects read the sentences with two repetitions, but only the second repetition is analyzed and reported. Thus, a total of 300 tokens were examined for the acoustical analysis (5 phonemes x 3 vowel conditions x 20 subjects). The recordings were conducted in a semi-sound proof room in one of the universities located in Seoul with a Sony Vaio laptop and Shure SM58 microphone at 44.1k sampling rate. Three programs (Praat, Matlab, and VoiceSauce (version 1.11, 2011)) were used as the analysis tool.

2.3. Measurements

For the consonantal segments, five measurements were examined for fricatives: (1) rise time, (2) intensity, (3) F0 values at the onset and midpoint of the following vowel, (4) Ceptrasl Peak Prominence (CPP) values at the onset and midpoint of the following vowels

2.3.1. Rise time

Howell & Rosen (1983) suggested rise time as one of the acoustic parameters to distinguish two manners of articulation. Rise time is the temporal interval from the minimum to the maximum of the intensity contour of the consonant. Howell & Rosen (1983) observed the amplitude change in the frication and found that rise time in affricates is shorter than in fricatives. This paper examined whether rise time can distinguish not only the manner of articulation (fricative vs. affricate) but also the different phonation types (aspirated vs. lenis vs. fortis). In examining rise time, we found that, due to coarticulation, some fricatives showed a fluctuation in the turbulence noise at the onset and offset of the frication, and as a result these points had the maximum amplitude. For this reason, the partial-voicing effect was removed from the fricative. Following Howell & Rosen (1983), all stimuli were high-pass filtered at 3.6k Hz (48 dB per octave, implemented in Matlab), and the duration was then calculated from the minimum to the maximum point of the intensity.

2.3.2. Intensity

The interval from the onset of the aperiodicity of the waveform to the onset of the periodicity of the waveform is measured. Among the numerous phonetic features used to distinguish different laryngeal contrasts, intensity is one of the suggested cues which show the difference between tense and lax stops (higher in tense and lower in lax; Kim & San, 2004). To investigate whether intensity shows a different pattern in Korean fricatives, the mean intensity (dB) was calculated from the beginning of the frication to the offset of the frication.

2.3.3. Fundamental Frequency (F0) at onset and midpoint of the vowel

F0 has been suggested as one of the strongest cues used to distinguish the Korean three-way laryngeal contrast in stop consonants (Han & Weitzman, 1970; Kim, 1965; Kim *et al.*, 2002; Cho *et al.*, 2002; Kim *et al.*, 2010; Lee & Jongman, 2012). F0 values are the lowest for the lenis, followed by the fortis and the aspirated stop. Therefore, this study also measured F0 values using a 25 ms window at the onset and the midpoint of the vowel to examine potential differences among the three affricates and two fricatives. F0 values were obtained by VoiceSauce after measuring the onset and offset of the vowel.

2.3.4. Cepstral Peak Prominence (CPP) at onset and midpoint of the vowel

CPP is obtained from the normalized amplitude of Fourier spectra. CPP is obtained by measuring the peak prominence of the harmonic structure. In addition to H1*-H2* examined in Lee (2017), Cepstral Peak Prominent (CPP) values were analyzed in evaluating voice quality since assessing voice quality H1*-H2* values could be relative. For example, even though positive values of 3 and 13 are classified as breathy voice because of the positive values, 3 has a less breathy feature than 13 when comparing two values. Therefore, to cross-check the breathiness of voice quality with previous study (Lee, 2017), CPP is considered for this research. In the research of Hillebrand *et al.* (1994), the distance from the linear regression line relating quefrequncy to cepstral magnitude (Hillebrand *et al.*, 1994: 4-16) was measured and this paper followed their method. Since that the more periodic signal, the clearer harmonic is, the bigger prominent CPP value can be obtained from the clear and modal voice. In other words, if the voice is clear and modal, the periodic signal from the vocal fold vibration will show a prominent cepstral peak, and consequently a higher CPP value is observed. With a breathy voice, the prominent cepstral peak gets a magnitude and therefore a smaller CPP value is observed (Hillenbrand *et al.*, 1994). CPP is analyzed by automatically calculting by VoiceSauce from 25 ms window of the onset and midpoint of the following vowel.

2.4. Analysis

For the statistical analysis, repeated measures of ANOVAs were conducted with each acoustic measurement (rise time, intenstiy, F0 values, CPP values) as dependent variables, and Phoneme (aspirated affricate, lenis affricate, fortis affricate, plain fricative, fortis fricative) and Gender (male, female) as independent variables. For post-hoc analysis, Bonferron/Dunn post hocanalyses were conducted to evaluate the result within a factor (Phoneme).

3. Results

3.1. Rise time

Howell & Rosen (1983) reported a difference in rise time between English fricatives and affricates, and the present research replicated this result for Korean. A two-way ANOVA (Phoneme × Gender) shows a significant main effect of rise time ($F(4, 290) = 15.35$, $p < .001$). *Post hoc* Bonferroni/Dunn comparisons show that the rise time can successfully distinguish between fricatives and affricates. The two fricatives were found to be significantly different from the affricates ($p < .05$). Korean affricates yielded a shorter rise time than fricatives. A significant difference was found for Gender ($F(1, 290) = 4.16$, $p = .042$). Rise time was found to be longer for male speakers (mean 34 ms) than female speakers (mean 29 ms) across all phonemes. There was no interaction between Gender and Phoneme ($F(4, 290) = 0.49$, $p = .75$). <Table 2> shows the rise time of the Korean fricatives and affricates.

Table 2. Rise time (ms) of the three affricates and two fricatives in Korean. Standard deviations are in parenthesis.

	Male	Female	Total
/s/ (plain)	41 (30)	40 (25)	40 (27)
/s'/ (fortis)	49 (35)	38 (25)	44 (30)
/tsʰ/ (asp)	29 (11)	24 (12)	27 (12)
/ts/ (lenis)	30 (12)	27 (14)	29 (13)
/ts'/ (fortis)	21 (9)	17 (8)	19 (8)

<Table 3> shows the rise time, frication duration and rise time expressed as a proportion of the entire frication noise. Regardless of the appearance of aspiration, for both fricatives the maximum intensity (the offset of the rise time) occurred at 39% into the frication. For affricates, the amplitude peak occurred earlier than for fricatives, at 31% for both /tsʰ/ and /ts/. However, for the fortis affricate /ts'/, the peak point was at 59% of the frication. Even though the rise time of the fortis affricate was the shortest, due to its shortest frication duration, the relative peak point occurred the latest

among the five sounds examined here.

Table 3. Mean values of rise time (ms), frication duration (ms) and rise time proportion (%) (rise time/frication duration) for each phoneme

	Rise time	Frication duration	Rise time proportion
/s/ (plain)	40 ms	104 ms	39%
/s'/ (fortis)	44 ms	113 ms	39%
/tsʰ/ (asp)	27 ms	85 ms	31%
/ts/ (lenis)	28 ms	78 ms	36%
/ts'/ (fortis)	19 ms	32 ms	59%

3.2. Intensity

The result of a two-way ANOVA (Phoneme × Gender) shows that there is no significant difference in intensity as a function of phonemes (F(4, 290) = 1.76, $p = .14$). The ANOVA also did not find a significant effect of Gender (F(1, 290) = 0.20, $p = .66$). The detailed information can be seen in <Table 4> which shows the intensity values of the two fricatives and three affricates.

Table 4. Intensity values (dB) of the two fricatives in Korean. Standard deviations are in parenthesis.

	Male	Female	Total
/s/ (plain)	48.37 (3.28)	45.99 (3.62)	47.18 (3.63)
/s'/ (fortis)	48.25 (3.97)	46.61 (2.91)	47.43 (3.55)
/tsʰ/ (asp)	49.68 (2.52)	53.89 (37.79)	51.79 (26.63)
/ts/ (lenis)	48.63 (2.78)	46.91 (4.86)	47.77 (4.02)
/ts'/ (fortis)	51.57 (2.75)	49.90 (3.64)	50.74 (3.31)

3.3. Fundamental Frequency

A two-way ANOVA (Phoneme × Gender) shows a significant main effect of F0 at vowel onset (F(4, 290) = 72.91, $p < .001$) and at vowel midpoint (F(4, 290 = 104.87, $p < .001$). *Post hoc* results show that the plain fricative is significantly different from the lenis affricate at vowel onset and midpoint ($p < .001$). The fortis affricate is also found to be significantly different from both the aspirated and lenis affricate at vowel onset and midpoint ($p < .02$). The aspirated affricate is significantly different from all phonemes at both points except the plain fricative at vowel midpoint ($p \leq .02$). The lenis affricate is significantly different from all phonemes at both onset and midpoint of the following vowel ($p < .001$). The fortis affricate is significantly different only from the other two affricates at onset and midpoint ($p \leq .002$).

The F0 values at vowel onset and midpoint are shown in <Tables 5 and 6>, respectively. The non-significant F0 difference between the two fricatives indicates that F0 is not a strong cue to distinguish Korean fricatives. However, a significant F0 difference among affricates at vowel onset and midpoint indicates that F0 is a prominent acoustic cue to distinguish three types of affricates. A difference in F0 values for the Korean three-way laryngeal contrast has also been reported for stops in previous studies: lowest for the lenis stop, followed by the fortis and aspirated stops at onset of the following vowel. (Han & Weitzman, 1970; Kim, 1965; Kim *et al.*, 2002; Cho *et al.*, 2002, Lee & Jongman, 2012).

Table 5. F0 values (Hz) of the two fricatives in Korean at the onset of the following vowel. Standard deviations are in parenthesis.

	Male	Female	Total
/s/ (plain)	179 (26)	302 (33)	240 (69)
/s'/ (fortis)	177 (30)	304 (26)	240 (70)
/tsʰ/ (asp)	193 (28)	321 (32)	257 (72)
/ts/ (lenis)	129 (18)	226 (23)	178 (53)
/ts'/ (fortis)	177 (33)	302 (25)	240 (69)

Table 6. F0 values (Hz) of the two fricatives in Korean at the midpoint of the following vowel. Standard deviations are in parenthesis.

	Male	Female	Total
/s/ (plain)	182 (27)	315 (30)	248 (73)
/s'/ (fortis)	180 (31)	304 (25)	242 (68)
/tsʰ/ (asp)	192 (3)	329 (28)	261 (75)
/ts/ (lenis)	128 (18)	213 (14)	170 (45)
/ts'/ (fortis)	180 (32)	305 (29)	242 (70)

A significant main effect is found for Gender at onset (F(1, 290) = 1389.38, $p < .001$) as well as at midpoint (F(4, 290 = 1509.37, $p < .001$) of the following vowel. The female speakers show a higher value of F0 across all phonemes at onset as well as midpoint.

An interaction between Phoneme and Gender is reported at the onset (F(4, 290 = 3.35, $p = .011$) and at the midpoint (F(4, 290 = 9.32, $p < .001$). Female speakers produced a relatively higher F0 value than male speakers when producing the lenis affricate than non-lenis sibilants both at vowel onset and midpoint.

3.4. Ceptral Peak Prominence (CPP)

Cepstral Peak Prominence (CPP) is one of the common parameters to quantify voice quality. If the voice is produced with a periodic signal from the focal folds, the amplitude of the cepstral peak is larger than an aperiodic signal. When the vocal fold vibration becomes less periodic due to the production of breathy voice, the CPP values are smaller. In the same way, a modal voice produced with a more periodic signal yields larger CPP values

<Figure 1> shows that the plain fricative [s] has a smaller value of CPP (13.69 dB) while the fortis fricative [s'] has a bigger value than [s] (19.16 dB). In <Figure 2>, the fortis affricate [ts'] has the largest CPP value (29.24 dB), followed by the aspirated affricate (21.01 dB) and the lenis affricate (14.58 dB).

The higher CPP values of the fortis fricative and affricate indicate that they were produced with modal voice. On the other hand, the lower CPP values of the plain fricative, the aspirated affricate and the lenis affricate demonstrates they were produced with a relatively breathier voice.

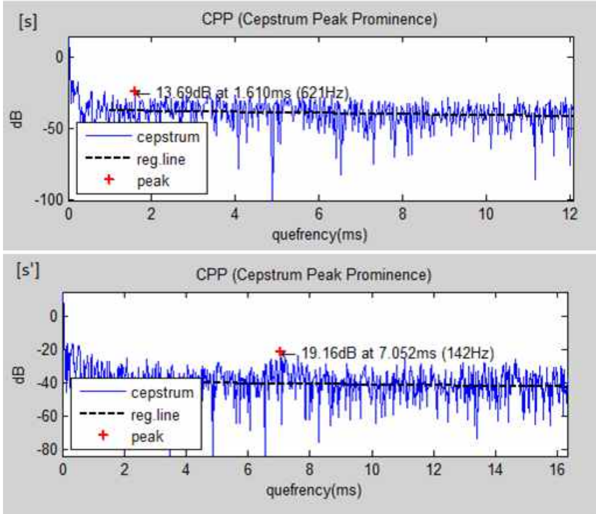

Figure 1. CPP values of plain fricative [s] and fortis fricative [s’] from a male speaker

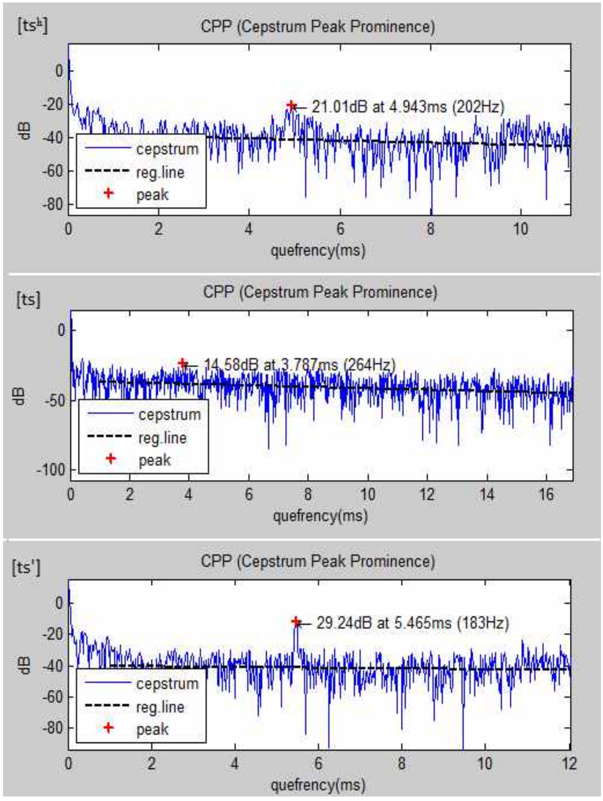

Figure 2. CPP values of aspirated affricate [ts^h], lenis affricate [ts], and fortis affricate [ts’] from a male speaker.

The result of the ANOVA indicates that the CPP value at the onset point has a main effect from phonemes (F(4, 290 = 22.62, *p* < .001). Bonferroni *post hoc* tests reveals that the plain fricative is significantly different than the fortis fricative and affricate (*p* < .001). The aspirated affricate is found to be significantly different than the fortis affricate (*p* < .001), but not with the lenis affricate (*p* = 1.00). ANOVA also reports a significant main effect by gender (F(1, 290 = 115.79, *p* < .001). Any interaction with gender and the phoneme type ((F(4, 290 = 1.14, *p* = .338) is not reported.

<Table 7> refers to the CPP values of the fricatives and the affricates from the vowel onset. For the fortis sounds [s’] and [ts’], the CPP values are higher than for the other sounds (21.31 dB for [s], 21.61 dB for [ts’]) at onset, which indicates that they are all produced with a periodic signal. For the non-fortis sounds, [s], [ts^h] and [ts], the CPP values at onset were smaller than those of the fortis sounds (17.06 dB for [s], 17.05 for [ts^h], 17.78 for [ts]). This implies that non-fortis sounds are produced with a breathy and less periodic signal.

Table 7. CPP values of the fricatives and the affricates from the onset point

	Male	Female	Total
/s/ (plain)	19.95 (4.93)	14.17 (2.52)	17.06 (4.85)
/s'/ (fortis)	23.20 (3.78)	19.43 (3.42)	21.31 (4.05)
/ts^h/ (asp)	19.55 (4.18)	14.54 (2.55)	17.05 (4.26)
/ts/ (lenis)	20.45 (4.84)	15.10 (2.61)	17.78 (4.70)
/ts'/ (fortis)	23.30 (3.75)	19.91 (3.96)	21.61 (4.19)

The result of the ANOVA shows that the CPP values at the midpoint are significantly affected by the phoneme type (F(4, 290 = 6.55, *p* < .001). Pairwise comparisons find no difference between the plain fricative and the other four phonemes. The fortis affricate is found to be significantly different than the aspirated affricate (*p* = .017) as well as the lenis affricate (*p* < .001). The ANOVA also finds no gender effect on the CPP values (F(1, 290 = 0.01, *p* = .969). No interaction between gender and the phonemes is found (F(4, 290) = 1.08, *p* = .37).

<Table 8> shows the CPP values of the fricatives and the affricates from the vowel midpoint. From the values of the midpoint, an increase in CPP values was observed across the five sounds; however, the non-fortis sounds showed a larger increase (9.64 dB for [s], 9.13 dB for [ts^h], and 7.37 dB for [ts]) than the fortis sounds (6.66 dB for [s’] and 5.19 dB for [ts’]). This indicates that non-fortis sounds exhibit a change in voice quality while the fortis sounds were produced with a periodic signal from the beginning and did not change.

As found in the H1-H2* values from Lee (2017), CPP values showed that both the aspirated and lenis affricates were produced with breathy voice, whereas the fortis affricate was produced with modal voice. Since the difference between aspirated and lenis affricates was not significant (*p* < .001), determining the categorization of the plain fricative based on the CPP differential values was challenging. <Figure 3> shows the CPP values at the onset and the midpoint of the vowel. Even though the gradient of the plain fricative more closely follows that of the aspirated affricate, it is still difficult to categorize the plain fricative since all non-fortis sounds ([s], [ts^h], [ts]) started from as breathy voice and changed to modal voice.

Table 8. CPP values of the fricatives and the affricates from the onset point

	Male	Female	Total
/s/ (plain)	26.86 (2.94)	26.55 (2.50)	26.70 (2.71)
/s'/ (fortis)	27.72 (4.11)	28.22 (2.32)	27.97 (3.32)
/tsʰ/ (asp)	26.83 (2.94)	25.53 (3.12)	26.18 (3.08)
/ts/ (lenis)	24.93 (3.25)	25.36 (2.92)	25.15 (3.07)
/ts'/ (fortis)	26.43 (3.19)	27.17 (3.40)	26.80 (3.29)

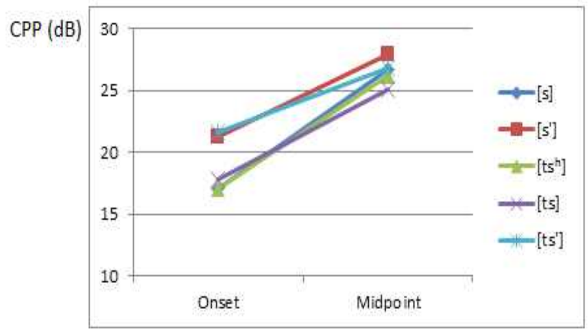

Figure 3. CPP difference between the onset and midpoint of the vowel

The plain fricative had a breathy voice at the onset and then changed into pressed voice along with the vowel. The same phenomenon was observed for the aspirated and lenis affricates. For the fortis fricative and affricate, the voice quality did not change throughout the vowel, remaining pressed.

4. Conclusion

The current study examined the acoustic characteristics of Korean fricatives and affricates in order to determine the phonation type of non-fortis fricative. In doing so, we measured rise time, intensity values, F0 values, and CPP values between fricatives and affricates.

With respect to rise time, categorizing the manner of the articulation (fricative vs. affricate) was possible based on the rise time (Howell & Rosen, 1983), but categorizing phonation type (aspirated, lenis, fortis) was not. Intensity was also found not to differentiate phonation type. Regarding F0 values, the lenis affricate was found to have significantly lower F0 values than the other two affricates. However, the fricatives had very similar F0 values. If the plain fricative patterns like aspirated sounds, the F0 would be slightly higher than that of the fortis fricative. If the plain fricative patterns like lenis, the F0 would be significantly lower than that of the fortis fricative. However, none of these results were found from the F0 values of the fricatives and affricates. Therefore, F0 values do not allow us to categorize the plain fricative as aspirated (Chang, 2008; Kang *et al.*, 2009; Park, 2002b) or as lenis (Cho *et al.*, 2002).

In addition, the CPP values of aspirated and lenis affricates exhibited a similar pattern in terms of aspiration with respect to COG and H1-H2* from Lee (2017). While the two fricatives patterned similarly in the acoustic parameters of F0 and rise time, the values indicating phontation type did not. The sounds accompanying aspiration – plain fricative [s], aspirated affricate [tsʰ], and lenis affricate [ts] – all showed not only a decline in COG but also a change in voice quality from breathy to modal voice. Even though these findings were not helpful in categorizing the plain fricative as aspirated or lenis, the parameters related to voice quality – H1-H2* and CPP – provided evidence that corresponded with COG in terms of aspiration. Therefore, based on the acoustic evidence collected from word-initial productions, definite categorization of the plain fricative as either aspirated or lenis is not possible. The fact that the acoustic parameters which are useful in distinguishing the three types of affricates do not robustly characterize the two types of fricatives leads us to entertain two possibilities. First, it could be the case that there are acoustic parameters which would allow us to definitively categorize the plain fricative as either aspirated or lenis that we have yet to uncover. Given the fact that this study has investigated a wide range of acoustic parameters, this seems unlikely, but it is nonetheless a possibility.

The other possibility is that the plain fricative need not be categorized as aspirated or lenis. Previous studies have also found that lenis stop has breathy voice quality while keeping F0 values low (Ahn, 2000). This is due to the fact that aspirated stops have been changed to have overlapping VOT with lenis stops while F0 is used as a strong cue to distinguish these two categories (Lee *et al.*, 2013). The same pattern has been also found affricates with respect to the COG values and H1-H2* values (Lee, 2017). Aspiration of the lenis affricate patterns similarly with aspirated affricates: COG values declined over the time course in the frication portion both in aspirated and lenis affricates. Consequently, all non-fortis sibalants (aspirated fricative, aspirated affricate, lenis affricates) had breathy voice quality with higher value of H1-H2*. The current study also found a consistent result that the CPP values of the non-fortis siblants were lower than fortis siblants, indicating that plain fricative, aspirated affricate, and lenis affricate all had breathy voice quality. Perception experiments on fricatives have also supported this pattern that breathy voice quality of the vocalic portion overrides the identification of fricatives than the consonantal portion (Lee & Jongman, 2014; 2016; Park, 1999; Yoon, 2002).

In addition, similarly with stops, we also found that the acoustic parameter that distinguishes between aspirated and lenis affricate was only F0 differences. Given this, it seems reasonable to posit that the acoustic cues distinguishing two fricatives might be different from those differentiating among three laryngeal category of affricates. Taken together, the current paper concludes that the fricatives should simply be analyzed as a distinct group rather than trying to fit them into the three-member grouping observed in the stops and affricates.

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