ISSN 2005-8063
2017. 6. 30.
Vol.9 No.2
pp. 31-38

말소리와 음성과학

Phonetics and Speech Sciences

한국음성학회지

http://dx.doi.org/10.13064/KSSS.2017.9.2.031

Examination of aspiration in Korean fricatives and affricates

Goun Lee*

Abstract

This study aims to examine the acoustic characteristics of Korean sibilant, especially aspiration in Korean fricatives (plain: /s/, fortis: /s'/) and affricates (aspirated: /tsʰ/, lenis: /ts/, and fortis: /ts'/). Duration values (closure duration, frication duration, aspiration duration), center of gravity (COG) (of the total duration, of the two portions, in 10 ms), H1-H2 values (at the vowel onset) were examined in order to investigate the phonetic feature of aspiration in frication noise. This study further discusses how to define criteria for identifying aspiration in sibilant sounds by adopting 3 visual criteria for assessing aspiration. This visually-designated aspiration onset points are further matched with the COG decline points in 10 ms windows. The result shows that all the non-fortis sounds (/s/, /tsʰ/, /ts/) contain aspiration, causing similar values of COG and H1-H2.

Keywords: aspiration, Korean fricatives, Korean affricates, acoustic features, onset of aspiration

1. Introduction

Korean has a typologically unusual three-way laryngeal contrast among voiceless consonants, referred to as aspirated, lenis, and fortis. While this distinction occurs at three places of articulation for both stops and affricates, it is not fully reflected in fricatives, which have only a two-way distinction between fortis and non-fortis (hereafter plain). While the fortis fricative /s'/ has a good agreement in its categorization, controversy still remains over the categorization of the plain fricative /s/ (Cho *et al.*, 2002; Chang, 2008, 2013; Chang, 2013; Holliday, 2012; Oh & Yang, 2015; Yoon, 1999, 2002).

Phonetically, various measurements such as frication duration, aspiration duration, Center of Gravity (COG), H1-H2 are measured in the literature; however, none of the measurements showed a consistent result regarding categorization of the plain /s/. For example, the stimuli used in previous research were limited to only a few vowel contexts such as [ɪ], [u], and [a]; and even the studies that used all vowel contexts were limited to the non-word stimuli (Kim *et al.*, 2010, 2011) with very limited number of speakers. Since voice quality can be highly affected by vowel height (Keating & Esposito, 2007), it is crucial to control vowel height. Therefore, this paper focuses on investigating the pattern of aspiration by matching the stimuli with mid-low and low vowels. Also, the current study compares the acoustic characteristics of the fricatives to those of the affricaties. Previous studies mostly compared the acoustic/aerodynamic parameters of fricatives with those of stop sounds. Since affricates involve stop closure, frication, and aspiration, it may be more productive to compare fricatives with affricates rather than stops.

In addition to controlling the vowel height of the stimuli, the current study examines the onset of aspiration very closely by looking at the COG differences in 10 min window. Previous research has failed to find a congruent result for the durational difference between the two fricatives, which may have been caused by the absence of a clear definition of aspiration. Not knowing the exact point of aspiration, finding strong evidence to make any conclusions is difficult because the results will vary depending on which portion of the fricative segment is subtracted from its total aperiodic noise. Hence, this paper only measured for comparison the

* Sungkyunkwan University, cconni@skku.edu
Received 30 April 2017; Revised 11 June 2017; Accepted 13 June 2017

frication noise from the onset of the aperiodic noise to the onset of the periodic voicing for the following vowel.

In measuring COG of affricates and fricatives, no studies have examined a gradual change in COG values to observe aspiration. Hwang (2004) adopted a 20 ms window from the midpoint of the fricative segments, and Kang (2009) measured the mean COG value of the total consonantal duration. With only one point for the COG value from the total consonantal segment, it is very difficult to capture the onset of aspiration since the measured part could or could not include the aspiration. Also, when measuring the COG value for the total consonantal segment, the COG value will include both the aspirated and unaspirated portions. Even though the COG value of the total consonantal duration could reflect aspiration by means of a lower COG value, it is still impossible to identify the exact onset point of aspiration.

Most importantly, none of the previous research defined the aspiration criteria explicitly. Since the presence or absence of aspiration plays a key role in determining the status of plain /s/, it is crucial that objective criteria for the detection of aspiration be used. There should be very clear acoustic criteria for aspiration to judge aspiration contained in the consonantal segment. Therefore, one of the goals of this study is to develop a way to designate the aspiration onset point. For a direct comparison of the acoustic parameters between fricatives and affricates, word-initial tokens from the same speakers were recorded and analyzed.

2. Methods

2.1. Subjects

To examine acoustic characteristics of Korean fricatives and affricates, recordings of 20 Korean native speakers (10 Females, 10 Males) in their mid-twenties to early-thirties were collected. None of them reported any articulatory or auditory impairment. To exclude dialectal influence, all participants were native speakers of Korean who were born and live in or near Seoul.

2.2. Stimuli

For acoustic analysis, two types of fricatives (/s/, /s'/) and three affricates (/ts^h/, /ts/, /ts'/) were collected in word-initial position. The present study examined the five target sounds (2 fricatives, 3 affricates) matched with mid and low vowels ([ɛ], [ʌ], [a]) in minimal or near-minimal pairs (See Appendix). We only used the tokens produced in mid- or low vowels, since Korean fricatives can undergo palatalization in high-vowel condition (Ahn, 1985; Jun, 1996), and aspiration duration declines substantially in high-vowel contexts (Kim *et al.*, 2010).

The target words were embedded in the carrier sentence [neka __ rago malhamnida] ("I say _______."). The experiment sentences were randomized with fillers, and one repetition of each sentence were recorded, yielding a total of 300 tokens ([3 affricates + 2 fricatives] x 3 vowels x 20 speakers).

The recording was conducted in a semi-soundproof room at one of the university in Seoul. A Sony Vaio Notebook with an external sound card and a Shure SM58 microphone were used. Recorded materials were digitized at a sampling rate of 44100 Hz and analyzed using Praat, Matlab, and VoiceSauce (version 1.11, 2011). Praat was used to measure the durations of consonants and vowels of the stimuli as well as the onset of the aspiration point by visual criteria. The value of H1-H2 was obtained with VoiceSauce, and COG values were measured by Matlab.

2.3. Measurements

For the consonantal segments, five measurements were examined for fricatives: (1) frication duration, (2) aspiration duration, and (3) center of gravity (COG) of the total frication duration. (4) The COG values of the consonantal part was divided into two portions according to the aspiration criteria. After gaining the COG values of the two portions, (5) the COG values of consecutive 10 ms windows throughout the entire frication were additionally measured to verify shift in COG with aspiration in the frication segments. For affricates, in addition to the five measurements mentioned above, (6) closure duration was also measured for the stop part.

For the vowel part, (7) H1-H2 values of 25 ms at onset of the vowel were analyzed.

2.4. Aspiration Criteria

To assess aspiration in fricatives and affricates, visual criteria as well as acoustic measurements were utilized to detect the aspiration of the fricatives and affricates. First, the point that satisfies criterion (1) Loss of high frequency and appearance of low frequency band was located on the spectrogram. Then, (2) the COG value of the 20 ms before and after this point was measured. At this stage, (3) the shape of the FFT spectrum was also monitored. Then, (4) the COG value of the successive 10 ms over the fricative was measured and the biggest drop point in COG values between consecutive windows was detected as the onset of the aspiration. When there was a systematic decline in the value of COG between these two windows, the point separating the windows was confirmed as the onset of the aspiration.

2.5. Analysis

Repeated measures Analyses of Variance (ANOVAs) were conducted for the statistical analysis. Phoneme (aspirated affricate, lenis affricate, fortis affricate, plain fricative, fortis fricative) and Gender (male, female) were considered as independent variables. Closure duration, frication duration, aspiration duration, COG, and H1-H2 were considered as dependent variables. In reporting the results of ANOVAs, p-values smaller than 0.05 were considered significant. As post-hoc analyses, Bonferron/Dunn analyses were conducted to evaluate the result within a factor (Phoneme).

3. Results

3.1. Duration values

Results of a two-way ANOVA (Phoneme × Gender) show that Phoneme affects closure duration ($F(4, 290) = 160.504$, $p < .001$), frication duration ($F(4, 290) = 127.587$, $p < .001$), aspiration duration ($F(4, 290) = 124.135$, $p < .001$), and total duration ($F(4, 290) = 17.5449$, $p < .001$). In terms of frication duration, Bonferroni post hoc tests reveal that the plain fricative is significantly different from the other four phonemes ($p < .001$) except the fortis fricative ($p = .249$). The aspirated affricate is also found to be significantly different from all phonemes ($p < .001$) but the lenis affricate ($p = .380$). The fortis affricate is significantly different from all phonemes ($p < .001$). With respect to the aspiration duration, a pairwise comparison shows that the plain fricative is significantly different from the fortis fricative and affricate ($p < .001$) as well as the lenis affricate ($p = .024$). However, no difference is found between the plain fricative and the aspirated affricate ($p = 1.000$). For the total duration (closure duration + frication duration), post hoc tests also show that the plain fricative is significantly different from the three affricates ($p < .001$ for the aspirated and lenis affricate; $p = .028$ for the fortis affricate). The fortis fricative is found to be significantly different from the aspirated affricate only ($p < .001$).

The ANOVA also indicates a main effect of Gender on the frication duration ($F(1, 290) = 11.854$, $p = .001$) as well as the total duration ($F(1, 290) = 4.830$, $p = .029$). The male speakers show a longer frication duration (86 ms) as well as total duration (128 ms) than female speakers (78 ms for frication duration, 120 ms for total duration).

There is also a significant interaction between Phoneme and Gender ($F(4, 290) = 5.349$, $p < .001$) for aspiration duration. As shown in <Figure 1>, while male speakers produce a shorter aspiration duration for the lenis affricate /ts/ than the aspirated affricate /tsʰ/ and the plain fricative /s/, female speakers show a longer aspiration duration for the lenis affricate /ts/ than for the other two phonemes.

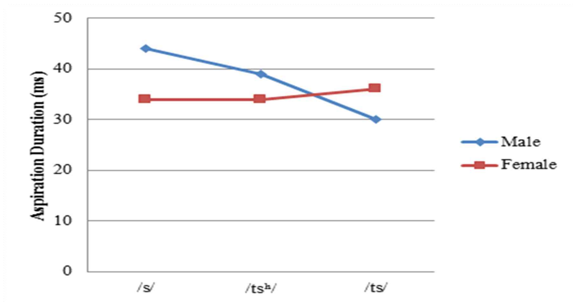

Figure 1. Interaction between Phoneme and Gender for aspiration duration.

<Table 1> represents the stop closure duration (CD), frication duration (FD), and aspiration duration (AD) of the fricatives and the affricates. Aspiration proportion (AD/FD) is defined as aspiration duration (AD) divided by frication duration (FD).

Table 1. Duration (ms) of the stop closure (CD), frication (FD), and aspiration of the fricatives and the affricates (AD). Standard deviation is in parentheses.

	CD	FD	AD	Aspiration Proportion
/s/ (plain)	-	104 (27)	39 (18)	38%
/s'/ (fortis)	-	113 (27)	0	0%
/tsʰ/ (asp)	67 (27)	85 (17)	37 (14)	24%
/ts/ (lenis)	51 (27)	77 (24)	32 (22)	26%
/ts'/ (fortis)	91 (41)	32 (11)	-	0%

3.2. COG values of the total consonantal segment

A two-way ANOVA (Phoneme × Gender) indicates that COG values are significantly influenced by Phoneme ($F(4, 290) = 82.457$, $p < .001$). Pairwise post hoc comparisons indicate that all phonemes are significantly different from each other at $p < .05$ except for the aspirated affricate from the lenis affricate and the plain fricative from the fortis affricate.

The results of the ANOVA also shows that there was a significant effect of Gender ($F(1, 290) = 53.774$, $p < .001$). Overall COG values for female speakers (6588 Hz) are significantly higher than those for male speakers (5881 Hz). No significant interaction between Phoneme and Gender is found. <Table 2> shows the COG values of the total consonantal segments of the fricatives and the affricates.

Table 2. Mean COG values (Hz) and standard deviation of the total consonantal segments of the fricatives and the affricates.

	Male	Female	Total
/s/ (plain)	6016 (894)	6455 (1063)	6236 (999)
/s'/ (fortis)	7422 (913)	8026 (608)	7724 (827)
/tsʰ/ (asp)	4941 (749)	5729 (811)	5345 (875)
/ts/ (lenis)	5135 (868)	5599 (1005)	5367 (960)
/ts'/ (fortis)	5890 (657)	7110 (651)	6500 (894)

3.3. COG values of the before and after the aspiration

First, to compare the COG values of sounds containing aspiration (aspirated affricate, lenis affricate, and plain fricative) with those of unaspirated sounds (fortis affricate and fortis fricative), the consonantal segments were divided into two parts and their COG values were measured. In the case of aspirated sounds, the portions before and after the onset of aspiration were examined. In measuring aspiration duration, the aspiration criteria described in section 2.3. is used.

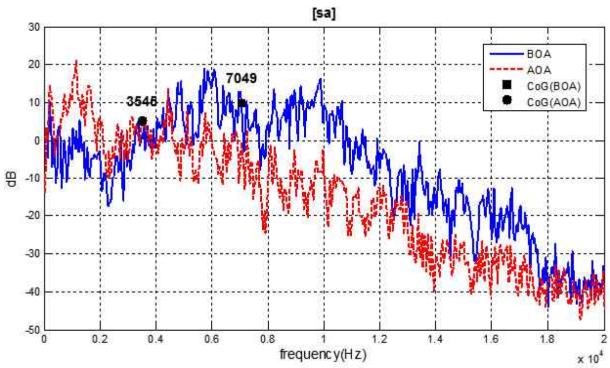

Figure 2. FFT spectra of the non-fortis fricative [sa] from a male speaker. (BOA = Before Onset of Aspiration, AOA = After Onset of Aspiration)

<Figure 2> is the spectrum of [sa] from a male speaker. The blue line indicates the spectrum of the frication before the aspiration (mean COG = 7049 Hz), and the red line indicates the spectrum of the aspiration (mean COG : 3545 Hz). The COG value showed a substantial decline after the onset of aspiration from 7049 Hz to 3545 Hz and the shape of the spectrum changed from rising-falling before aspiration to falling after the aspiration. These two acoustic

characteristics observed here — the sharp decline in COG value and the falling shape of the spectrum – matched the aspiration criteria described previously.

The two different spectral shapes and the decline in the COG value are also observed in the aspirated affricate and lenis affricate. <Figure 3> and <Figure 4> show the spectrum of the aspirated affricate [ts^ha] and lenis affricate [tsa]. Both the aspirated and lenis affricate showed a significant difference between the COG values before and after the onset of aspiration. The aspirated affricate [ts^ha] showed a drop of 2084 Hz in COG value after the onset of aspiration (from 5687 Hz to 3083 Hz) and the lenis affricate [tsa] showed a drop of 3230Hz in COG (from 5875 Hz to 2645 Hz).

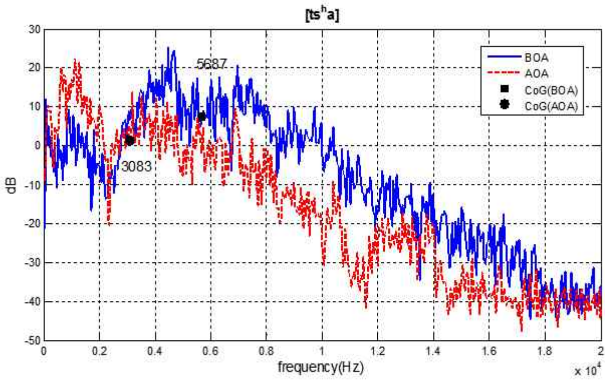

Figure 3. FFT spectrum of the aspirated affricate /ts^h/ from a male speaker. (BOA=Before Onset of Aspiration, AOA=After Onset of Aspiration)

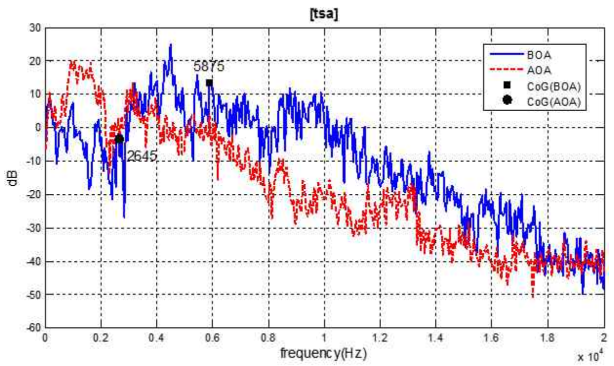

Figure 4. FFT spectrum of the aspirated affricate [tsa] from a male speaker. (BOA=Before Onset of Aspiration, AOA=After Onset of Aspiration)

As described in the Aspiration Criteria section, a significant decline in COG value and the falling shape of the spectrum, when they occur together, are taken as one of the pieces of acoustic evidence for the presence of aspiration. These features were observed in all the tokens of the plain fricative.

In contrast, in the case of unaspirated sounds such as the fortis fricative /s’/ and fortis affricate /ts’/, there was no difference in the spectral shape nor a substantial difference in COG values. <Figure 5> and <Figure 6> show the spectra of the fortis fricative and affricate. The blue spectrum is the COG of the first 60% of the frication, and the red spectrum is the COG of the final 40% of the frication. The point before and after aspiration is designated based on the averaged aspiration duration of the aspirated phonemes. The shape of the two spectra is almost identical, rising-falling, regardless of the point of thr measurement. In addition to the similar spectral shapes, <Figure 5> displays the close values of the two COG values for the fortis fricative /s’a/. (7102 Hz for the first 60%, 6666 Hz for the final 40%).

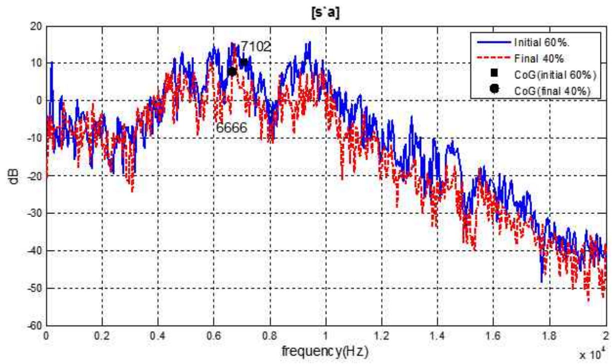

Figure 5. FFT spectrum of the fortis fricative /s’/ from a male speaker. (BOA=Before Onset of Aspiration, AOA=After Onset of Aspiration)

These two features are consistently shown in the fortis affricate as well. As shown in <Figure 6>, the fortis affricate /ts’/, has a COG value of 6613 Hz over the first 60%, and of 6307 Hz over the final frication portion.

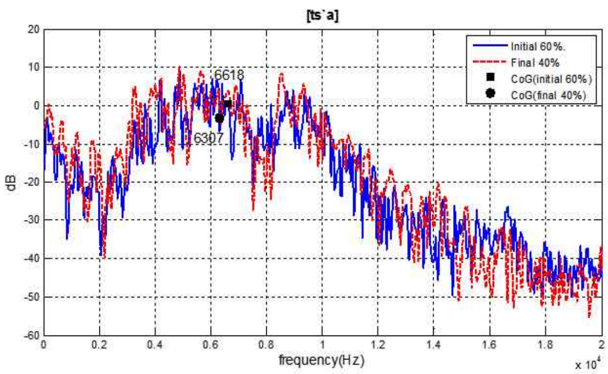

Figure 6. FFT Spectrum of the fortis affricate /ts’/ of a male speaker. (BOA=Before Onset of Aspiration, AOA=After Onset of Aspiration)

The difference of the COG values between these two portions are then statistically analyzed. The COG differences between the two portions are summarized in <table 3>.

Table 3. COG difference (Hz) between two portions of all phonemes

	Male	Female	Total
/s/ (plain)	3328	3801	3564
/s'/ (fortis)	-71	-203	-137
/ts^h/ (asp)	2360	3462	2911
/ts/ (lenis)	2221	3226	2723
/ts'/ (fortis)	641	775	708

A two-way ANOVA (Phoneme × Gender) shows a significant main effect of Phoneme ($F(4, 290) = 259.879$, $p < .001$) on the COG difference between two portions. Bonferroni post hoc tests reveal that the aspirated affricate is not significantly different from the lenis affricate (p = 1.000). The two fricatives and the fortis affricate were found to be significantly different from the other four phonemes (p <.001). The ANOVA also reports a main effect of Gender (F(4, 290) =34.584, p < .001), indicating that the COG difference for females (2212 Hz) was greater than for males (1696 Hz).

A significant interaction between Phoneme and Gender was also found (F(4, 290) = 0.485, p < .001). Male speakers showed a smaller COG difference between two portions for the aspirated and lenis affricates than female speakers.

3.4. COG variation over time

COG values obtained with successive 10 ms windows are presented to (1) examine the different pattern of COG variation for the five phonemes, and (2) pinpoint the exact onset of the aspiration and determine whether the COG drop matches the visually determined aspiration onset point.

In the plain fricative /s/, aspirated affricate /tsʰ/, and lenis affricate /ts/, the COG pattern can be described as consisting of five phases: (1) Rise in frequency until the peak point at around 5.5 to 8 kHz; (2) steady state at the higher frequency or smooth decline; (3) sharp decline with the onset of aspiration by about 1kHz for each frame until they reach to around 3-5 kHz; (4) Decreasing gradually until it reaches around 3kHz. (5) Sharp decline affected by the following vowel. The slope of each phase was calculated as follows:

$$\frac{(COG value\ of the\ last\ window) - (COG value\ of the\ first window)}{the\ number\ of the\ windows\ within\ a\ phase \times 5ms}$$

<Figure 7> represents a representative COG values of frication from /sa/, /tsʰ/ and /tsa/. Five phases were classified according to the variation in COG described above, and slopes were calculated. We can see that the COG value increases sharply in phase 1, then changes to increase gradually (36.2 Hz/ms) in phase 2 when it reaches to the higher frequency range. With the onset of aspiration, the COG value rapidly drops to the 3k Hz range in phase 3 (-209.5 Hz/ms), and then remains within the same range (-21.1 Hz/ms) in phase 4. Lastly, in phase 5, COG drops a little bit more sharply due to the following vowel (-144.8 Hz/ms).

The slope values of each phase from 20 speakers are summarized in <Table 4>. The slope shows the biggest drop at phase 3, which contains the onset of aspiration, across all three vowel contexts.

Table 4. 20 speakers' average slope values (Hz/ms) of each phase of the [s], tsʰ], and [ts]. Phase 3 includes the onset of aspiration.

	Phase1	Phase2	Phase3	Phase4	Phase5
[s]	263	8	-170	-18	-97
[tsʰ]	214	-28	-131	-34	-99
[tsa]	237	-18	-138	-45	-107

For fortis fricative and affricate, no substantial change in COG values was observed in the fortis fricative. The characteristics of the fortis phonemes can be described as following four phases: (1) Rapid rise in COG value (by more than 1 kHz per each window) to a higher frequency range of 7~8 kHz (2) a steady plateau in the high-frequency range; (3) a sharp decline due to the following vowel. (4) steady plateau in the low-frequency range at 1-2k Hz.

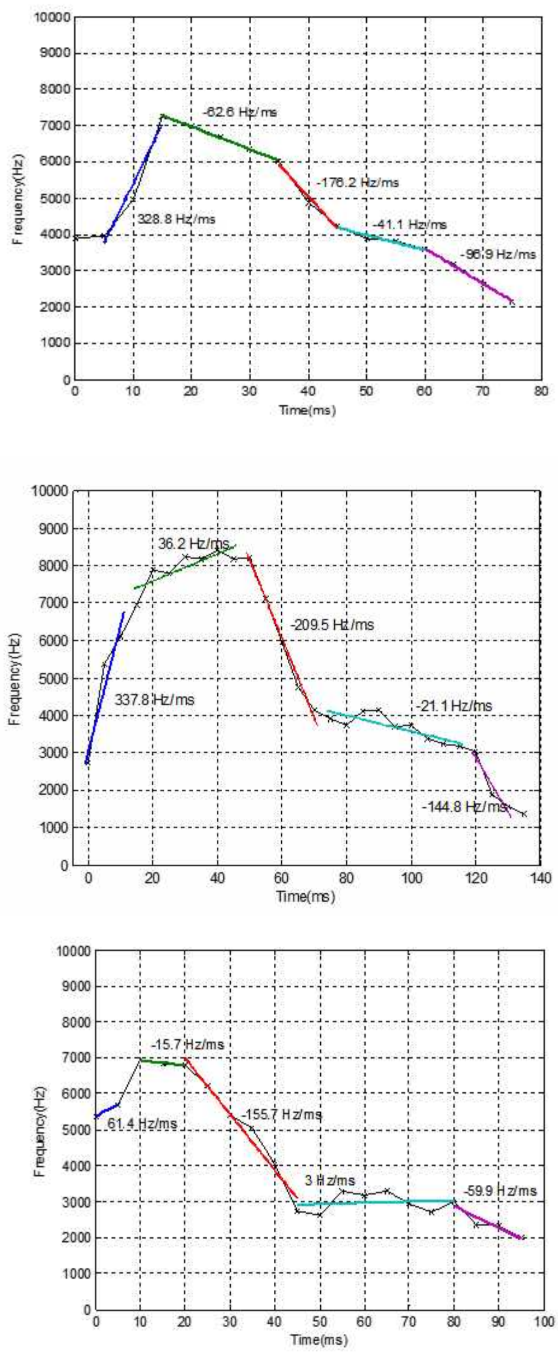

Figure 7. A female speaker's COG variation from frication of [sa] (top), [tsʰa](middle), [tsa] (bottom) classified into five phases.

<Figure 8> represent a representative COG variation in the fortis fricative [s'a] and fortis affricate [ts'a]. The average slope values of all 20 speakers' tokens across three vowel contexts are summarized in <Table 5>.

Table 5. 20 speakers' average slope values (Hz/ms) of each phase of the plain fricative. Phase 3 includes the onset of aspiration.

	Phase1	Phase2	Phase3	Phase4
[s']	255	6	-393	5
[ts']	256	-65	-558	-32

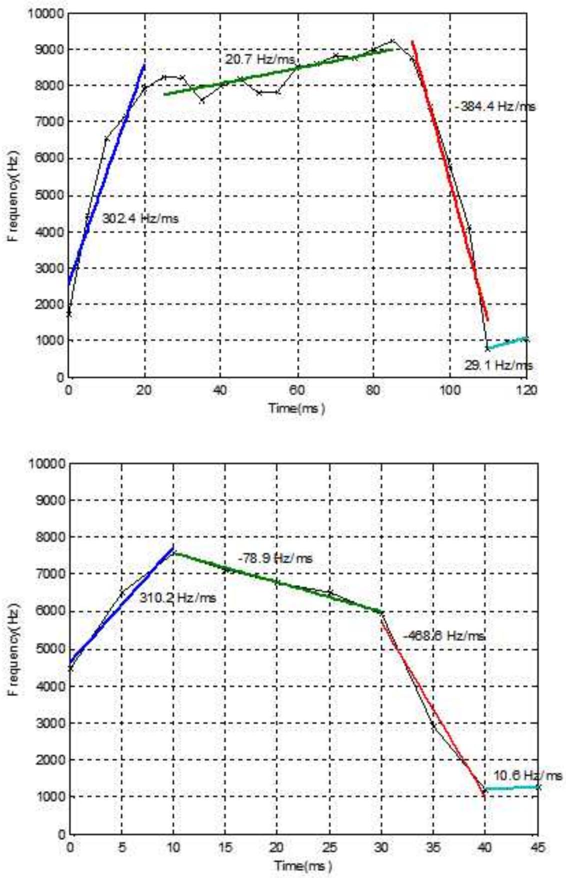

Figure 8. A female speaker's COG variation of frication from [s'a] (top) and [ts'a] (bottom) classified into four phases. Each phase is shown with different colored slope lines with its value next to it. (phase 1: blue, phase 2: green, phase 4 : aqua blue)

3.5. Accuracy of the visually determined aspiration onset point

To examine the accuracy of the visually designated onset point of aspiration, the COG values between adjacent windows were compared. Out of a total of 300 tokens analyzed for the experiment, 120 fortis tokens were excluded since the fortis group does not contain aspiration in the frication. Matlab computed the COG values for successive windows as well as the difference in COG between adjacent windows. Next, the time frames with the biggest and second biggest difference were obtained. These frames were cross-matched with the aspiration onset point that was visually determined by using the aspiration criteria described in 2.3. <Table 6> displays the number of tokens that matched the visual aspiration onset point within 10 ms (±5 ms) and within 20 ms (±10 ms). dCOG(1) refers to the biggest differential COG point and dCOG(2) to the second biggest differential COG point.

Out of 180 non-fortis tokens, 97 cases of the largest COG point (dCOG(1)) matched the visual point within 10 ms, yielding an accuracy of 54%. For the second biggest COG point (dCOG(2)), 89 cases were accounted for within 5 ms, a 49% accuracy. When considering whether either of these two points, (dCOG(1) or dCOG(2)), matched the visual point, 141 cases were counted as matching within 5 ms, yielding a 78% accuracy and 168 cases were counted with an accuracy of 93 %, respectively.

Table 6. Number of tokens and accuracy rate of the visually determined aspiration onset point compared with the biggest and second biggest differences in COG between adjacent windows.

	dCOG(1)		dCOG(2)		dCOG(1)OR(2)	
	# of Tokens	Accuracy	# of Tokens	Accuracy	# of Tokens	Accuracy
±5ms	97	54%	89	49%	141	78%
±10ms	148	82%	143	79%	168	93%

A comparison of the distribution of the dCOG(1) and dCOG(2) points with the visual aspiration onset point is shown in <Figure 9>, a histogram that depicts the first largest (dCOG(1): black bar) and the second largest COG values (dCOG(2): white bar) of the two frames. The x-axis indicates the temporal difference between visual aspiration onset points and the dCOG(1) and dCOG(2) values; the y-axis indicates the number of tokens matched for each point. This histogram (<Figure 9>) displays the points within a ±20 ms temporal difference; if the difference exceeds 20 ms, it is shown at -22ms and 22ms, respectively. Since Matlab pinpoints the point of the biggest differential COG values automatically, it sometimes counts the frame that is affected by a neighboring sound as the biggest COG decrease point. However, the sharp drop in COG values in this case at ±20 ms point is because of coarticulation, not the presence of aspiration. The black bar located at 0 ms on the x-axis indicates that the largest COG differential point was exactly the same as the visually determined point for 30 cases. If the largest COG difference occurred earlier than the visual point, this is represented by a negative value along the x-axis. Positive values indicate that the COG differential point occurred later than the visual point.

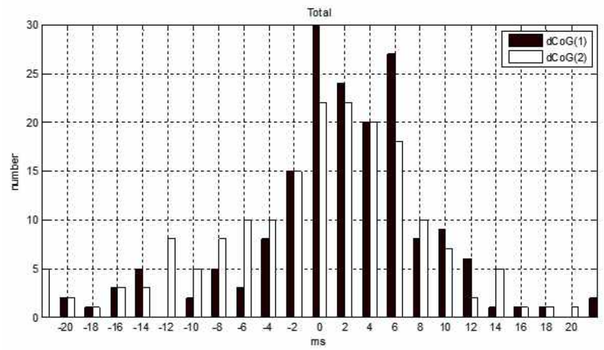

Figure 9. Visual aspiration onset points within a ±20ms temporal difference with the first and the second biggest COG differential point

3.6. H1-H2 values at vowel onset

A two-way ANOVA (Phoneme × Gender) shows a significant main effect of H1-H2 at onset of the following vowel (F(4, 290 = 13.954 p < .001). Post hoc analysis shows a significant difference between the plain fricative /s/ and the two fortis sounds, /s'/ and /ts'/. The fortis fricative /s'/ shows a significant difference with all other sounds except the fortis affricate /ts'/ at p < .05. However, the ANOVA shows no significant effect of Gender (F(1, 290 = .020 p = .887) and no significant interaction between Gender and Phoneme (F(4, 290 = 0.266 p = .900). <Table 7> shows the H1-H2 values at the onset of the vowel.

Table 7. H1-H2 values (dB) at the onset of the following vowel. Numbers in parenthesis indicate standard deviation.

	Male	Female	Total
/s/ (plain)	12.05 (5.15)	12.05 (6.45)	12.05 (6.45)
/s'/ (fortis)	5.61 (2.88)	4.70 (9.18)	5.15 (9.18)
/tsʰ/ (asp)	10.42 (5.36)	11.71 (10.56)	11.05 (10.56)
/ts/ (lenis)	12.02 (4.89)	12.11 (8.73)	12.07 (8.73)
/ts'/ (fortis)	6.57 (4.32)	5.52 (8.72)	6.05 (8.72)

4. Conclusion

In this research, the status of aspiration of non-fortis fricative and non-fortis affricaties were examined by analyzing duration values (stop closure, frication duration, aspiration duration) and Center of Gravity (COG) values. Since none of the previous studies have closely examined the onset of the aspiration, the current study examined the COG values that are computed over the entire consonant, over the portions with/without aspiration, and over successive 10 ms windows in order to assess aspiration.

Based on these aspiration criteria, aspiration was found not only in the aspirated affricate and the plain fricative (Yoon, 2002; Chang, 2008; Kim *et al.*, 2010), but also in the lenis affricate. This was an interesting finding since only aspirated affricates were expected to carry aspiration. The aspiration in lenis affricate is in line with the status of Korean stops such that VOT values of lenis stops are overlapping with aspirated stops, since younger Korean speakers are using both VOT and F0 values as cue to categorize the thee-way distinction in Korean (Lee & Jongman, 2012; Lee *et al.*, 2013; Silva, 2006).

Moreover, aspiration in the lenis affricate can also address the argument from the previous research on the categorization of the plain fricative. As aspiration gives the voice a breathy quality, all non-fortis phonemes (/tsʰ/, /ts/, and /s/), which include aspiration, were shown to have high H1-H2 whereas all fortis phonemes (/ts'/ and /s'/), which do not include aspiration, were shown to have low H1-H2. Although both the aspirated and the lenis affricate have a significantly different voice quality than the fortis affricate, and the plain fricative has a significantly different voice quality than the fortis fricative, no significant differences were found between the aspirated and lenis affricate. Therefore, based on the three acoustic measurements, it is conclusive that lenis affricate, aspirated affricate, and plain fricative all contain aspiration.

Also, the COG values in consecutive 10 ms windows successfully pinpointed the onset of aspiration. When considering the largest COG difference between two adjacent windows, automatic location of aspiration onset matched the visual aspiration point in 54% of all cases within 10 ms, and in 82% of all cases within 20 ms. With the second biggest difference, the accuracy was 49% within 10 ms, and 79% within 20 ms. When considering that the largest and second largest difference appeared almost adjacently, the rate at which either the biggest difference or second biggest difference appeared within 10 ms of the visual onset point was 78%.

With regard to the status of Korean fricatives in the categorization of three-way distinction, controversy still remained whether non-fortis fricative should be grouped as aspirated or lenis (Chang, 2013; Cho *et al.*, 2002; Holliday, 2012; Oh & Yang, 2015). The measures do not reveal whether the plain fricative is aspirated or lenis. However, the result of current study is in line with Holliday (2012) such that non-fortis fricative can be categorized as aspirated-lenis. Taken together, the current study was able to examine the acoustic characteristics of aspiration in Korean fricatives and affricates and was able to provide empirical evidence regarding designation onset of aspiration in sibilant sounds.

References

Ahn, S-C. (1985). *The Interplay of Phonology and Morphology in Korean.* Ph.D. Dissertation, University of Illinois at Urbana-Champaign, Champaign.

Chang, C. B. (2008). The Acoustics of Korean Fricatives Revisited. *Harvard Studies in Korean Linguistics*, 12, 137-150.

Chang, C. B. (2013). The production and perception of coronal fricatives in Seoul Korean: The case for a fourth laryngeal category. *Korean Linguistics*, 15(1), 7-49.

Cho, T., Jun, S. A., & Ladefoged, P. (2002). Acoustic and aerodynamic correlates of Korean stops and fricatives. *Journal of phonetics*, 30(2), 193-228.

Holliday, J. J. (2012). The acoustic realization of the Korean sibilant fricative contrast in Seoul and Daegu. *Phonetics and Speech Sciences*, 4(1), 67-74.

Hwang, H. K. (2004). Spectral characteristics of frication noise in Korean sibilants. *Proceedings of the KSPS conference* (pp. 133-137).

Jun, S-A. (1996). *The Phonetics and Phonology of Korean Prosody.* New York: Garland Publishing, Inc.

Kang, Y., Kochetov, A., & Go, D. (2009). The acoustics on Korean fricatives. *CRC-Sponsored Summer Phonetics/Phonology Workshop*. Department of Linguistics, University of Toronto. 6 August, 2009.

Keating, P., & Esposito, C. (2007). Linguistic voice quality. *UCLA Working Papers in Phonetics*, 105, 85-91.

Kim, H. (2005). Stroboscopic-cine MRI study of the phasing between the tongue and the larynx in the Korean three-way phonation contrast. *Journal of Phonetics*, 33(1), 1-26.

Kim, H., Maeda, S., & Honda, K. (2011). The laryngeal characterization of Korean fricatives: Stroboscopic cine-MRI data. *Journal of Phonetics*, 39(4), 626-641.

Kim, H., Maeda, S., Honda, K., & Hans, S. (2010). The laryngeal characterization of Korean fricatives: Acoustic and aerodynamic data. In S. Fuchs, M. Toda, & M. Zygis (Eds.), *Turbulent Sounds: An Interdisciplinary Guide* (pp. 143 – 166). New York: Mouton de

Gruyter.
Lee, H., & Jongman, A. (2012). Effects of tone on the three-way laryngeal distinction in Korean: An acoustic and aerodynamic comparison of the Seoul and South Kyungsang dialects. *Journal of the International Phonetic Association*, 42(02), 145-169.
Lee, H., Politzer-Ahles, S., & Jongman, A. (2013). Speakers of tonal and non-tonal Korean dialects use different cue weightings in the perception of the three-way laryngeal stop contrast. *Journal of phonetics*, 41(2), 117-132.
Oh, M., & Yang, H. (2015). An Acoustic Comparison of Korean Coronal Fricatives in the Seoul and Yanbian Korean Dialects. *Studies in Linguistics*, (34), 145-172.
Shue, Y.-L. (2010). *The voice source in speech production: Data, analysis and models*. Ph.D. Dissertation, UCLA. Retrieved from http://www.seas.ucla.edu/spapl/voicesauce/ [VoiceSauce. Version 1.11.] on June 23, 2011.
Silva, D. 2006. Acoustic Evidence for the Emergence of Tonal Contrast in Contemporary Korean. *Phonology*, 23, 287-308.
Yoon, K. (1999). *A study of Korean alveolar fricatives: An acoustic analysis, synthesis, and perception experiment*. M.A. Thesis, University of Kansas, Lawrence.
Yoon, K. (2002). A Production and Perception Experiment of Korean Alveolar Fricatives. *Speech Sciences*, 9(3), 169-184.

● **Goun Lee**
Department of English Language and Literature
Sungkyunkwan University
25-2 Sungkyunkwan-ro, Jongno-gu
Seoul 03063, Korea
Tel: 02-760-0912
Email: cconni@skku.edu
Fields of interest: Phonetics, Phonology, Psycholinguistics

Appendix. Minimal or near-minimal pairs and triplets in word-initial position used in this study

1. Plain fricative
[sɛta] ‘to count’
[sʌta] ‘to stop’
[sata] ‘to buy’

2. Fortis fricative
[s’ɛta] ‘strong’
[s’ʌta] ‘to subside’
[s’ata] ‘cheap’

3. Aspirated affricate
[tsʰɛhata] ‘to pretend’/‘to upset the stomach’
[tsʰʌnhata] ‘humble’
[tsʰata] ‘cold’/‘to kick’

4. Lenis affricate
[tsɛhata] ‘to exclude’
[tsʌnhata] ‘to deliver’
[tsata] ‘to sleep’

5. Fortis Affricate
[ts’ɛts’ɛhan] ‘stingy’
[ts’ʌnta] ‘awesome’
[ts’ata] ‘salty’