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Gendered spectral patterns of sibilant fricatives in Seoul Korean*

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Kong, Eun Jong and Jieun Kang. 2020. Gendered spectral patterns of sibilant fricatives in Seoul Korean. *Studies in Phonetics, Phonology and Morphology* 26.1. 1-19. The present study reports a preliminary acoustic analysis of sibilant fricatives (/s/, and /s'/) produced by young adults speaking Seoul Korean (F=17, M=15), focusing on gender-related spectral characteristics in frication noise. Fricative tokens in seven monophthong vowel contexts (/i a u o ʌ e ɨ/) were elicited word-initially and word-medially, using a picture-naming task. Acoustic patterns of spectral peak frequencies (SPFs) and variances yielded that male speakers tended to realize SPFs no lower than those of female speakers' (except before /i/ where palatalized variants were produced), and showed greater variance in spectral energy than female speakers. These gender characteristics observed in fricative acoustics might imply that Korean male speakers tend to make fricative lingual constrictions at relatively anterior locations and in a less tight manner compared to female speakers. In understanding the Korean-specific case of gendered pronunciations, we discussed a potential role of sibilant fricative consonants as a social-indexical marker. **(Korea Aerospace University, Associate Professor and Korea University, PhD Student)**

Keywords: Korean sibilant fricatives, spectral peak frequency, spectral moment analysis, gender difference

1. Introduction

While speakers' physiological attributes of sex are recorded in acoustic signals of speech, entire gendered properties in speech acoustics do not come from anatomical differences between male and female speakers. It has been well documented that biological differences in sizes and structures of resonant cavities and vocal cords

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differentiated males' speech from females' in terms of acoustic characteristics, e.g., lower fundamental frequencies (Whiteside, 1996), lower formant frequencies and lower spectral peak frequencies (e.g., Fox and Nissen 2005, Flipsen, Shriberg, Weismer, Karlsson and McSweeny 1999). However, gender-differentiated patterns recorded in the speech acoustics are not necessarily attributable to speakers' physiological characteristics, but sometimes are related to a function of gender as a social-indexical or stylistic marker (Perry, Ohde and Ashmead 2001, Li 2013, Li, Rendall, Vasey, Kinsman, Ward-Sutherland and Diano 2016, Fox and Nissen 2005). For example, regarding VOT, a temporal characteristic of stops, Li (2013) showed that sex-VOT interactions in unaspirated vs. aspirated stops manifested differently between Mandarin Chinese and American English (shorter vs. longer VOTs for females' unaspirated stops, respectively). This cross-linguistic difference pointed out that anatomical or physiological reasons are weak in accounting for sex-related acoustic properties of VOT in Chinese and English stops. Alternatively, Li offered that Mandarin-speaking females' shorter VOTs in unaspirated stops are for a stylistic reason: Females tend to make more distinct phonological contrast of unaspirated-aspirated stops than males.

Spectral frequencies of sibilant fricatives also illustrate the point that anatomical reasons are not enough to account for gender differentiated acoustic patterns. While various studies of English sibilant fricatives have demonstrated that adult females' fricative spectrum frequencies are higher than those of adult male speakers (e.g., Schwartz 1968, Jongman et al. 2000), some researchers have interpreted those acoustic variabilities as speakers' cultural modifications of articulations to resemble corresponding gender (Li et al. 2016, Fox and Nissen 2005, Fuchs and Toda 2010, Munson, McDonald, DeBoe and White 2006, Stuart-Smith 2007). Fox and Nissen (2005) investigated voiceless sibilant fricatives produced by English-acquiring children (aged from 6 to 14) to find out that even the youngest participants exhibited sex-related differences in fricative spectra (e.g., spectral peak locations, mean energy peaks). Considering minimal differences of vocal tract sizes and configurations between these young boys and girls, the authors suggested that the sex-related differences in children's fricative acoustics might not entirely be due to anatomical reasons but in part associated with learned behavior. Similarly, Stuart-Smith (2007) provided evidence of fricative acoustic differences within the same gender (i.e., female), which served to indicate a social identity of class in Glasgow English: Working-class females tended to produce lower spectral peak frequencies than

middle-class females in realizing /s/. This indicates that acoustic differences related to speakers' gender are not entirely rooted in biological differences of the speakers but are socially or stylistically motivated and manipulated.

Taking social and stylistic factors into consideration in understanding gendered acoustic patterns, the present study explores acoustic properties of Korean sibilant fricatives produced by young adult Seoul speakers. We aimed to examine whether and how acoustic spectra of fricatives pattern differently between male and female speakers. The Korean language has two distinctive sibilant fricatives /s s'/, which are contrastive in terms of laryngeal conditions (non-tense /s/ vs. tense types /s'/) (Lee 1996, Sohn 1999, Shin 2012). In terms of a lingual constriction location, most studies describe Korean sibilant fricatives /s s'/ as alveolar consonants with an allophonic variation of [ɕ, ɕ'] before /i/, while there are other studies defining Korean sibilant fricatives as alveolar-dental consonants (e.g., Sohn 1999). To our knowledge, acoustic studies of frication noise in Korean fricatives are rare and none of those rarely existing studies systematically investigated gender-related differences in frication spectra. Although studies reported overall frequency range differences of fricative spectra between male and female speakers (e.g., Sung and Cho 2010, Hahm 2007), they did not attempt to quantify the effect of gender on acoustic realizations of fricatives. The current study aims to present acoustic patterns of fricative frication noise by adult males and females to explore language-specific gender-related characteristics in Seoul Korean fricatives.

We applied two acoustic measures to analyze frication noise spectrum of Korean sibilant fricatives: (1) Spectral peak frequency (SPF) and (2) variance of spectral energy distribution (Jongman et al. 2000, Forrest et al. 1988). Among various acoustic measures, we chose these two in order to infer the location of lingual constriction (anterior or not) and the degrees of constriction (tightness). SPFs measuring the peak frequencies of spectral energy distributions are inversely correlated with the length of the front cavity, and thus would serve as an acoustic index of a lingual constriction location (i.e., place of articulation). Variances of spectral energy distribution are known to reflect tightness of lingual constriction in making fricative articulations. In English, this acoustic measure was useful in differentiating sibilant fricatives (smaller variances) from non-sibilant fricatives (greater variances) (Jongman et al. 2000). We apply this measure to the two Korean sibilant fricatives to understand the differential degrees of constrictions. Applications of these two acoustic measures to Korean fricative productions would help infer

whether or not male and female speakers realize fricatives differently in terms of how anterior lingual constriction locations are and how tight the lingual constrictions are.

To summarize, the goal of the current study is to provide acoustic evidence of a gender effect in Korean young adults' fricative realizations by investigating peaks and variances of spectral energy distributions. Filling the gap in describing gendered spectral characteristics of frication noises in Korean sibilant fricatives, this research would help us better understand a potential role of sibilant fricative segments as an indexical marker in the Seoul Korean speech community.

2. Methods

2.1 Stimulus words

Eighty one words (two or three syllabled nouns or adverbs) were chosen to elicit the target onset fricative consonants (ㅅ /s/, ㅆ /s'/) before seven vowel contexts (/i e ʌ ɨ o u a/). A condition of prosodic locations (word-initial vs. word-medial) was also considered in the word-list: 2 consonant types × 7 vowels × 2 prosodic conditions × 2 or 3 word types. Pictures that illustrate stimulus word items were selected to be presented to the speakers. While we tried to make sure the pictures were as unambiguous as possible, some pictures were presented with target words written in Hangul. Tense realizations after post-obstruent tensifications were classified as tense targets ([kuk.s'u] for /kuk.su/ 국수).

2.2 Participants, task, and procedures

The production data came from larger sets of speech corpus consisting of 80 speakers' various production tasks including picture naming, word-list readings and picture descriptions. We analyzed recordings of 32 Seoul Korean-speaking college students' picture naming task (17 females and 15 males) for this paper as a preliminary acoustic analysis of Korean fricative realizations. The speakers participated in the research project with monetary compensation. None of them reported a history of speech-, hearing- or language-related problems.

Sitting in front of the computer screen, participants were asked to name objects (nouns, e.g., 참새 /tɕʰam.se/ 'sparrow') or states (adverbs, e.g., /s'eŋ.s'eŋ/ 'vigorously') depicted in the pictures. While they completed the tasks with few misidentifications of the pictures, they sometimes produced synonyms (e.g., /kje.tan/

'계단' instead of /tɕiŋ.kje/ '층계' for the picture of stairs). Those off-target words were not necessarily corrected by a researcher during the task session, as we assumed that such interruptions might affect the naturalness of their pronunciations. The words were presented in a fixed order for all participants in order to make sure that the speakers did not pronounce identical CV combinations in a consecutive order. The picture stimuli were presented in E-prime 2 software (Psychology Software Tools). Recordings were made using a Marantz digital recorder (PMD661) and a hand-held unidirectional microphone (Shure SM81), digitalized at a 44,100 Hz sampling rate and 16-bit quantization. On average, it took participants approximately 15 minutes to complete this word-repetition task.

2.3 Analysis

Acoustic event markings: We obtained 2811 tokens (longer than 24ms) to analyze in total. Each analyzable token was processed to be ready for acoustic analysis of spectral energy distribution by being labelled at four locations of acoustic events of target CVs: (1) frication onset, (2) frication offset, (3) vowel onset, (4) vowel end. The onset and offset of frication signals were identified by the authors' visual inspections of spectrograms with the same dynamic range display settings. To cope with this subjective criterion of frication boundaries, two labelers consulted with each other over ambiguous acoustic events. Most often, ambiguous boundaries between frication and aspiration due to aspiration signals was discussed between the labelers. Vowel onset locations were determined by waveform as well as spectrogram evidence: A zero-crossing point of an upswing waveform accompanied by voicing bar in the spectrogram display. Finally, vowel end was defined as where F2 ends.

Analysis of spectral energy distribution: FFT frication spectrum was created based on a 25ms Hamming window centered at the midpoint of frication duration (frication onset ~ frication offset): 1,000Hz ~ 11,025Hz band pass filtered with pre-emphasis applied above 1,000Hz. We collected (1) frequencies at spectrum energy peak (Spectral Peak Frequency: SPF in Hz) and (2) variances of energy distribution (m2 in Hz: second moment). Both measurements were done in Praat (Boesma and Weeknik 2020) using a script (SPFs) or a built-in function in Praat (m2) (see <Figure 1>).

Statistical analysis: We made two types of mixed-effect regression models having SPFs and m2s as dependent variables, respectively: SPF models and m2 models. SPF

models were to explain variations of SPFs in terms of speakers' gender and phonation-type of fricative consonants: *Gender* (male vs. female) and *Phon.Type* (tense /s'/ vs. non-tense /s/ fricatives) as fixed effects, using a treatment coding scheme. Similarly, m2 models had the same fixed effects to explain m2 variations of fricative tokens. Random intercept and slope of *Phon.Type* were considered at individual speaker level. To make sense of model outputs, we divided fricative data into several sets by vowel context (/i e ʌ ɨ o u a/) and prosodic locations (word-initial (WI) and word-medial (WM)). The statistical analyses were implemented in R (R Core Team 2019), using *lmer* and *lmerTest* package (Bates, Maechler, Bolker, Walker 2015, Kuznetsova, Brockhoff, Christensen 2017).

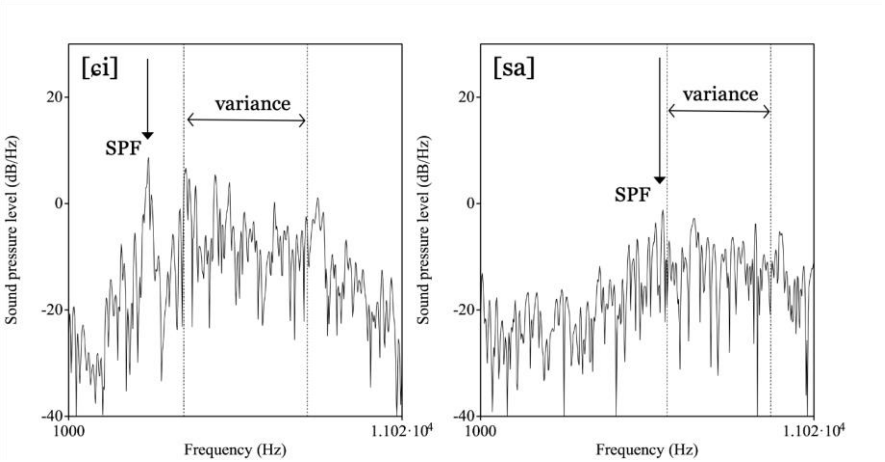

Figure 1. Illustrations of peak frequencies (SPF) and variances of /si/ (left) and /sa/ (right) spectrum.

3. Results

3.1 Spectral energy distributions: Peaks and Variances

<Figures 2 and 3> present distributions of spectral peak frequencies (SPF) and spectral variances (m2) by speaker's gender and phonation type of fricatives.

/s s'/ before /i/: Fricatives tended to have lower SPFs compared to those before other vowel contexts, as they were known to be realized at post-alveolar locations (i.e., at a more back place of articulation) before /i/ (e.g., Hahm 2007). In this vowel context, SPFs of male's fricatives were overall lower than those of females' fricatives,

which is expected from physiological differences of vocal tract sizes between sexes. This gender-differentiated pattern was observed both in word-initial (Fig.2) and word-medial positions (Fig.3).

/s s'/ before other vowels than /i/: Besides having overall higher SPFs than those before /i/, SPFs of fricatives before other vowels were also different from SPFs before /i/ by exhibiting less clear trends of gender differences. In terms of mean SPFs across vowel conditions and prosodic locations, males had similar or only slightly lower SPFs than females. For example, when examined within phonation types, males' mean SPFs of /sa/ tended to be only slightly lower than females, and males' mean SPFs of /s'a/ were as high as females'. Based on visual inspections, this lack of gender-difference in SPFs appears more consistent in word-medial locations (Fig.3). This finding is against what we would expect given the vocal tract size differences between genders, which yielded acoustic consequences of gender-differentiated patterns in fricative SPFs before /i/. The lack of gender differences in SPFs may suggest that male speakers produced fricatives at a much anterior place of articulation.

It is noted that fricatives before /o/ tended to have rather large variations of SPFs (top-rightmost panels in Fig.2 and Fig.3). The SPF distribution is characterized as bimodal: SPFs of some fricative tokens before /o/ were distributed at a low range (as low as SPFs of fricatives before /i/) and others were located at a high range. This tendency of bipolar SPF distributions was also observed in some other vowel contexts, e.g., word-initial /se/ and /sʌ/ tokens.

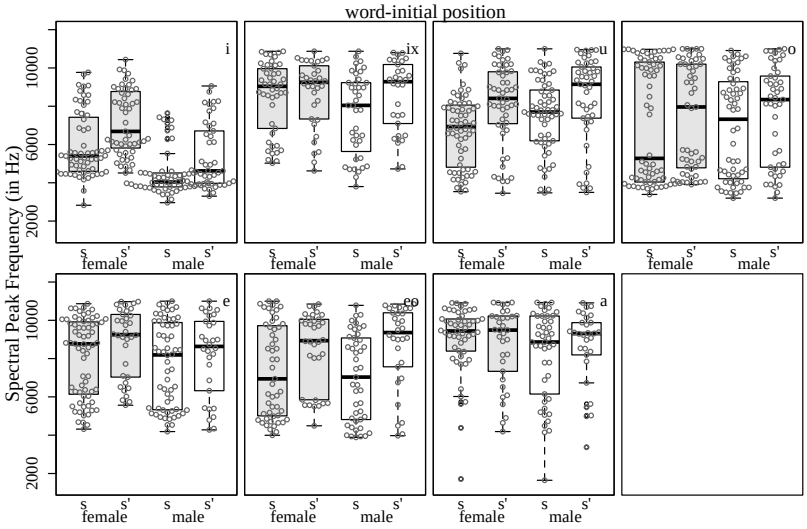

Figure 2. [Word-initial tokens] Boxplots of spectral peak frequencies (SPF) by speakers' gender (male and female) and phonation type (/s/ and /s'/). Panels are separated by post-consonantal vowel context: ix=/ɨ/, u=/u/, o=/o/, eo=/ʌ/, a=/a/.

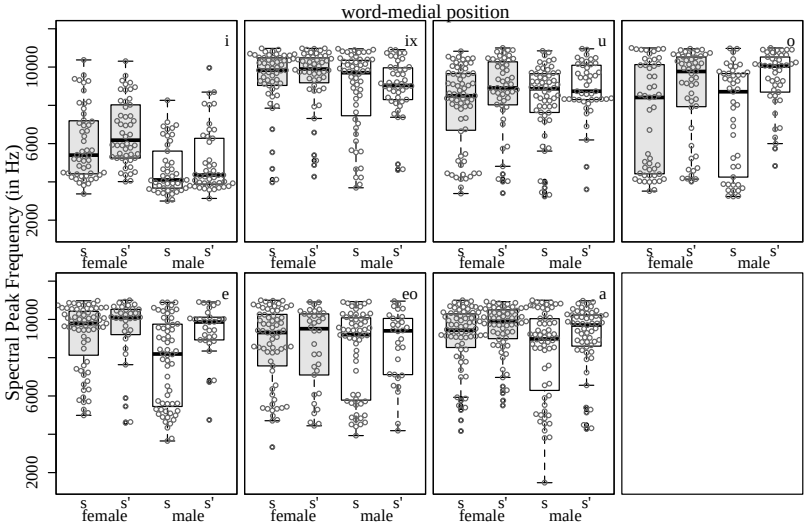

Figure 3. [Word-medial tokens] Boxplots of spectral peak frequencies (SPF) by speakers' gender (male and female) and consonants (/s/ and /s'/). Panels are separated by post-consonantal vowel context: ix=/ɨ/, u=/u/, o=/o/, eo=/ʌ/, a=/a/.

<Figures 4 and 5> display m2s of fricatives (variances of spectral energy concentration) separated by gender and phonation type in word-initial and word-medial positions, respectively. Across all vowel contexts, mean m2 values tended to be higher for males' fricatives than females', as best illustrated in the panel for /sa/ tokens in Fig.4. The tendency suggests that spectral energy was on average more diffused in the male speakers' fricatives than the females'. Within genders, non-tense /s/ tended to show higher m2 means than tense /s'/, indicating more diffused energy variances in /s/ than /s'/. This pattern is best illustrated in panels of /so/ and /sa/ in Fig.5. Although there were magnitude differences, the tendencies of gender and phonation-type differences were observed in both word-initial and word-medial contexts.

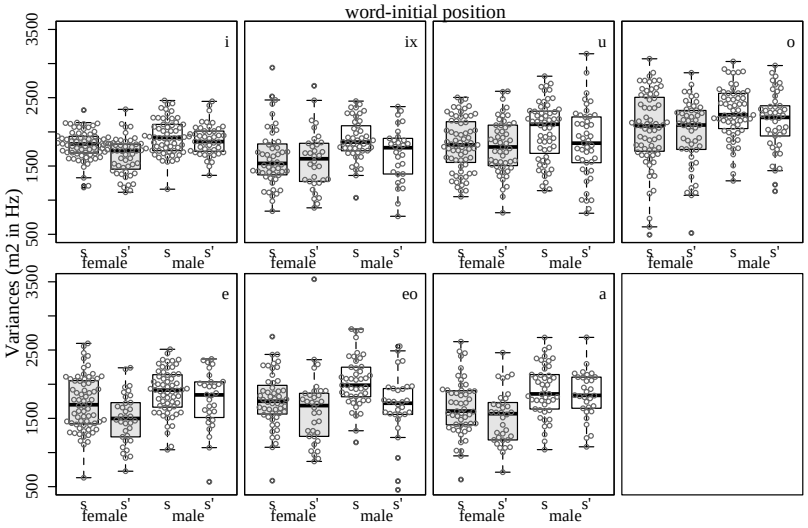

Figure 4. [Word-initial tokens] Boxplots of m2 (2nd moment: variances of spectral energy distribution) by gender (male and female) and phonation-type (/s/ and /s'/). Panels are separated by post-consonantal vowel context: ix=/ɨ/, u=/u/, o=/o/, eo=/ʌ/, a=/a/.

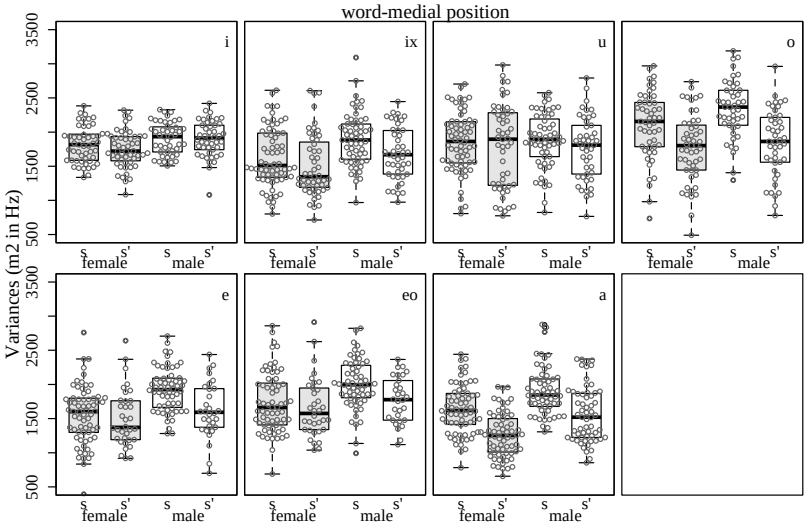

Figure 5. [Word-medial tokens] Boxplots of m2 (2nd moment: variances of spectral energy distribution) by gender (male and female) and phonation-type (/s/ and /s'/). Panels are separated by post-consonantal vowel context: ix=/i/, u=/u/, o=/o/, eo=/ʌ/, a=/a/.

In order to examine the relationship between SPFs and m2s across individual speakers, we plotted each speaker's average m2 values as a function of SPFs in word-initial position (Fig.6) and word-medial position (Fig.6). In both prosodic positions, fricatives (/s/ and /s'/) before /i/ were differentiated from those before the other vowels in that data-points were relatively compactly distributed: They were tightly clustered at a lower SPF range, confirming allophonic realization of fricatives before /i/. Bivariate plots of fricatives before /i/ also confirm gender-differentiated SPFs: Females' SPFs were greater than males' SPFs.

In other vowel contexts, gender-differentiated patterns were revealed along the m2 dimension. While male speakers could realize /s/ tokens as either low SPFs (as in word-medial /se/ or /so/) or high SPFs (as in word-medial /sʌ/ or /si/), male speakers produced /s/s consistently with higher m2 values across vowel contexts and prosodic positions. For example, panels of /e/ and /a/ vowel contexts, males' word-medial fricatives (more consistently /s/) tended to have higher m2 means and lower SPF means, whereas females' fricatives had lower m2 means and higher SPF means. This contrast confirms diffused versus compact energy distributions in male and female speakers' fricative realizations. To summarize, fricative acoustics differed between

male and female speakers in terms of SPFs before /i/ and in terms of m2s before vowels other than /i/.

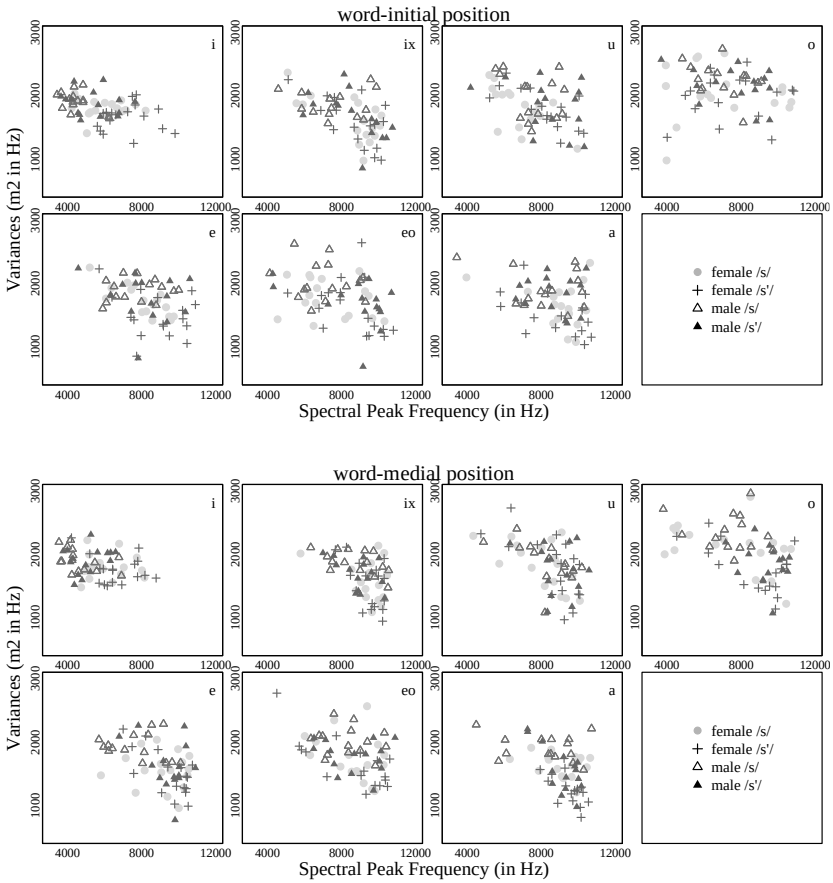

Figure 6. Scatterplots of individual speakers' m2s as a function of SPFs. Panels are separated by post-consonantal vowel context.

3.2 Statistical models: Effects of gender and phonation type

To quantify observations, statistical models were made with SPFs and m2s (variances of spectrum energy distributions) as dependent variables. Estimations of SPFs from mixed effects regression models are presented at <Table 1>, and those of m2s are summarized at <Table 2> separated by prosodic locations. Both tables

present outputs of models with male (vs. female) and /s/ (vs. /s'/) as base levels of *Gender* and *Phon.Type* variables.

Gender coefficients: In both prosodic positions, SPF models for fricative /s/ before /i/ yielded significant beta coefficients of *Gender* (a fixed effect variable) in explaining SPF variabilities (WI: β_{gender_i}=1342, WM: β_{gender_i}=1327, p<.05, as in Table 1): *Gender* coefficients were also significant when the base level was /s/ ([/s'/ as a base] WI: β_{gender_i}=1809, WM: β_{gender_i}=1499, p<.05). The results confirm that males' fricatives before /i/ had significantly higher SPFs than females'. This is an expected acoustic output given the vocal tract size difference between genders (Fox and Nissen, 2005; Flipsen et al., 1999). By contrast, *Gender* coefficients were *not* significant in the SPF models of other vowel contexts (with an exception of /se/: WM: β_{e}=1346, p<.05.), suggesting that SPF differences of /s'/ and /s/ between genders were not statistically meaningful.

Phon.Type coefficients: In the SPF model of word-initial fricatives before /i/ context, *Phon.Type* (/s/ vs. /s'/) coefficient was significant with male as a reference level: WI: $\beta_{Phon.Type\_i}$=-763, p<.05 as in Table 1. This means that males /s'/ tokens were realized as significantly higher SPFs than their /s/ tokens (This was the case in females' fricatives before /i/: WI: β $\beta_{Phon.Type\_i}$=-1229, p<.05). SPF models of word-medial fricatives before /i/ did not yield significant *Phon.Type* coefficients in both genders' productions.

Similar to the SPF models of word-initial fricatives before /i/, *Phon.Type* coefficients were also significant in the SPF models of males' fricatives before /u/ and /o/ vowel contexts in word-initial and word-medial positions (p<.1). Significantly lower SPFs of males' /so/ and /su/ tokens than those of /s'o/ and /s'u/ tokens indicate that male speakers' produced non-tense /s/s at a posterior place of articulation than tense /s'/s. It is noted that, *Phon.Type* coefficients were not consistently significant across all vowel contexts, although there was a consistent tendency where SPFs of males' /s/ were lower on average than those of /s'/. When the models have female as a base level of gender factor, *Phon.Type* coefficients were significant in the model of /u/ vowel context (WI: $\beta_{Phon.Type\_u}$=-1298, p<.05; WM: β $\beta_{Phon.Type\_u}$=-644, p<.05): SPFs of females' /su/ were significantly lower than /s'u/. Except in the models of /u/ context, SFPs of females' /s/ were not consistently lower than those of /s'/ before other vowels, which is not consistent with the male speakers' model outputs.

Table 1. Parameter estimations of fixed-effects from mixed-effects regression models predicting SPF variations: male (vs. female) and /s/ (vs. /s'/) as a reference level.

(a) word-initial tokens							
	/i/	/ɨ/	/u/	/o/	/e/	/ʌ/	/a/
(Intercept)	**4606**	**7722**	**7524**	**6749**	**7707**	**7013**	**8211**
Gender (base: male)	**1342**	*928*	-679	226	364	357	795
Phon.Type (base: /s/)	**763**	**859**	**855**	*866*	466	**1677**	427
Gender×Consonant	466	-823	442	-371	296	-547	-688
(b) word-medial tokens							
	/i/	/ɨ/	/u/	/o/	/e/	/ʌ/	/a/
(Intercept)	**4672**	**8819**	**8257**	**7403**	**7752**	**8319**	**8239**
Gender (base: male)	**1327**	413	-281	6	**1346**	323	825
Phon.Type (base: /s/)	409	122	*622*	**1958**	**1677**	347	**828**
Gender×Consonant	171	98	22	-665	**-1339**	-453	-386

<Table 2> presents outputs of m2 models with *Gender* and *Phon.Type* as fixed effect variables: male (vs. female) and /s/ (vs. /s'/) as reference levels. M2 models showed significant *Gender* coefficients, suggesting that m2s of male speakers' /s/ were significantly greater than those of females' /s/ productions: Word-initial /u/ context and word-medial /u/ and /i/ contexts were exceptions to this trend with coefficients not reaching a significance level of $p<.1$. This statistical pattern confirms that male speakers' /s/ productions had more diffused energy distribution than females' /s/ productions. When the models were set having /s'/ as a reference level, male speakers' /s'/ tokens had greater m2s across vowel conditions than those of females', but *Gender* coefficients were significant only in word-initial /i e a/ conditions and word-medial /i a/ conditions ($p<.1$).

Finally, the m2 models of word-initial and word-medial fricatives estimated higher m2 values for /s/ than /s'/ across vowel contexts, although m2 differences between /s/ and /s'/ were not always statistically meaningful as presented in <Table 2>.

Table 2. Parameter estimations of fixed-effects from mixed-effects regression models predicting m2 variations. The models set male (vs. female) and /s/ (vs. /s'/) as reference levels. Bold indicates p<.05 and italic p<.1.

<word-initial>							
	/i/	/ɨ/	/u/	/o/	/e/	/ʌ/	/a/
(Intercept)	**1930**	**1880**	**2008**	**2278**	**1889**	**2034**	**1909**
Gender (base: male)	**-119**	**-260**	-195	*-236*	**-165**	**-269**	**-248**
Phon.Type (base: s)	-49	**-200**	**-174**	-117	-113	**-348**	-67
Gender×Consonant	-111	165	148	59	-114	211	-76
<word-medial>							
	/i/	/ɨ/	/u/	/o/	/e/	/ʌ/	/a/
(Intercept)	**1909**	**1898**	**1872**	**2334**	**1922**	**2005**	**1903**
Gender (base: male)	-93	**-265**	-23	*-228*	**-362**	**-268**	**-265**
Phon.Type (base: s)	-5	**-212**	-104	**-491**	**-299**	**-235**	**-340**
Gender×Consonant	-60	88	50	156	*245*	157	-38

4. Discussion and Conclusion

The current study presented preliminary acoustic analyses of Korean sibilant fricatives (/s/, and /s'/) produced by 32 young adult males and females that explored gender-related acoustic patterns of spectral energy distributions. Acoustic analyses of spectral peak frequencies (SPF) and variances of energy distribution (m2: 2nd moment) revealed three notable findings related to speakers' gender in Korean fricative realizations. First, as physiological difference of vocal tract sizes between genders would predict, SPFs of the current post-alveolar fricatives (i.e., fricatives before /i/) were lower for male speakers than females. Second, in terms of SPFs, fricatives before the other vowel contexts than /i/ did not pattern differently between genders, which is contrastive with what post-alveolar fricatives showed with respect to the speakers' gender. Third, variances of spectral energy distributions, m2 values, of fricatives exhibited that male speakers realized their fricatives with greater m2s than female speakers did. The present findings suggest that gender-related differences in Korean fricatives are not necessarily explained by structural differences between genders but might be attributable to a role of gender as a social indexical value (potentially indicating casual or less-formal speech styles characteristic of male speakers).

A lack of gender differences in fricative SPFs (before non-/i/ vowels): Against common expectations related to male speakers' larger vocal tract sizes, the present study found no gender difference in SPFs of fricatives before non-/i/ vowels,

although post-alveolar fricatives produced by the same set of speakers conformed to the expectation by showing lower spectral frequencies in males than females. These inconsistent gender patterns of fricative SPFs might indicate that male Korean speakers realized their fricatives before non-/i/ vowels at far anterior lingual constriction locations, i.e., fronter places of articulation than where we would predict with a reference to males' post-alveolar fricative SPFs and proportionally to female speakers' fricative SPFs. Although limited in defining exact places of articulation (e.g., dental or alveolar-dental or alveolar), acoustic evidence is convincing that fronted variants of fricatives were observed in Korean male speakers but not female speakers.

Gender difference in fricative spectral energy variances: Another gender-related acoustic characteristic in fricatives (/s s'/) was that males' fricatives (both of fricative allophones) tended to be realized with relatively diffused energy distribution, which is less typical of the sibilant type of fricatives. Non-sibilant fricatives in English (e.g., /f θ/) are known to be realized with a relatively diffused energy spectrum due to broad and loose lingual constrictions (Jongman et al. 2000). This acoustic resemblance to the non-sibilant type of the fricatives might imply that Korean male speakers tend to articulate fricatives with less tight lingual constrictions which are somewhat deviant from standard phonetic forms of sibilant fricative consonants. It is also noted that the acoustic pattern of diffused energy was stronger in non-tense /s/ tokens than tense /s'/ tokens (even in females' productions as well as males'), indicating that tightness of lingual constrictions might in part be related to laryngeal gestures in fricative productions.

Potential sources of gender-differences in fricative acoustics: While the two major findings of the current study converge to describe fricative productions by Korean male speakers as fronted variants with less sibilant characteristics, the characteristics do not conform to cross-linguistically common observations of gender variants because fronted variants are associated with females (Hu 1991, Ohala, Hinton and Nichols 1997) and so are less conventional or new phonetic forms (Labov 1990, Eckert 1989). One may ascribe this unique gendered pattern in Korean fricatives to language-specific attitudes associated with fronted fricative consonants consciously shared in the Korean speech community. Fronted and less sibilant-like fricatives, which are often radically described as /θ/-like sounds, have negative connotation labelled as 'short-tongue sounds'. According to an unpublished survey report by Kong and Holliday (2018), laypeople's impression toward extremely fronted

fricatives by male speakers (strongly /θ/-sounding fricatives) supports that the pronunciations are socially stigmatized: Survey participants responded that (they think) they have heard of males producing /θ/-sounding fricatives and tended to associate male speakers' /θ/-sounding fricatives with articulation disorders related to the frenum of the tongue. Understanding this Korean-specific culture associated with fronted fricative uses, it is less likely that fronted and loosely constricted variants of Korean fricatives would be employed by female speakers, who are in general known to stay away from non-standard or stigmatized forms of speech (Labov 1990, Trudgill 1974). Therefore, this male version of fronted variants of sibilant fricatives in Korean seems differentiated from cross-linguistic observations of innovative phonetic variants without social stigma led by female speakers in the community. We emphasize that the current acoustic evidence from the production study alone cannot verify this speculation in the absence of perceptual evidence of Korean listeners' stigma toward fronted fricatives realized by male speakers. Therefore, possibilities are open regarding how to understand what the gender-differentiated fricative sibilants in the Seoul Korean imply. Further studies are called for to testify the argument and other alternatives (such as femininity and masculinity associated with gender-differentiated acoustic forms) through controlled experiments, which specifically investigate listeners' differential perceptual judgments of fronted articulations produced by male and female speakers in the Korean speech community.

To conclude, the present study demonstrated systematic acoustic differences associated with speakers' gender and phonation-type in realizing Korean sibilant fricatives. Spectral patterns of peak energy frequencies and variances illustrated that males' fricatives were differentiated from females' fricative tokens with their fronted place of articulation and less tight lingual constrictions. This acoustic variant of Korean fricatives observed in male speakers is deviant from typical acoustic characteristic of sibilant fricative consonants and is also meaningful in that they are associated with male speakers. Building on the current findings of gendered acoustic patterns, further studies should follow to discuss how phonetic variants of Korean sibilant fricatives are understood by speech communities as a linguistic and social indexical marker.

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