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The Effects of Following Vowel on Korean Fricatives

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Hahm, Hyun-Jong. 2007. The Effects of Following Vowel on Korean Fricatives. *Linguistic Research* 24(1), 57-82. This paper investigates the nature of the complementary distribution of Korean fricative acoustically. In this study, the fricatives preceding five different vowels [i, e, a, o, u] are compared in different speech rates – fast and slow – and in different positions in time domain – mid point and ending point. The study measures the spectral peak frequencies of the fricatives. The results seem to support the former idea, which is rather categorical than gradient and to imply Korean allophone [S] is by palatalization assimilation, which is a phonological process. **(Univ. of Texas at Austin)**

Keywords Korean fricative, alveolar fricative, alveopalatal fricative, palatalization, coarticulation, spectral property

1. Introduction

The fricative sound /s/ does vary according to the following vowel in Korean. The alveopalatal fricative [ʃ] occurs only before a high front vowel, and the alveolar fricative [s] occurs only elsewhere (e.g. [ʃi] 'poem' vs. [sa] 'four', [so] 'a cow', etc.). Thus, the alveopalatal fricative [ʃ] exists as an allophone of the alveolar fricative /s/, showing the complementary distribution.

Cross-linguistically there are instances of assimilation of different sounds brought about by the influence of a neighboring, usually adjacent, sound. Palatalization assimilation occurs when the consonant is neighboring a front vowel, a palatal semivowel, or a palatal or palatalized consonant and the sound resulted from the change is palatal sound or has a secondary palatal articulation (Bhat 1978).

However, palatalization can be a phonetic process, not only a phonological assimilation. The phonological process is categorical, which means that the output of the process looses the original quality completely. On the other hand, phonetic implementation process is gradient, which indicates absence of such a loss (Kim 1999).

In English, for example, palatalization occurs obligatorily at the lexical level (e.g. *confess/confession*, *habit/habitual*, etc.), and optionally at the postlexical level (e.g. *hit you*, *press your point*, etc.). Zsiga (1995, 2000) claims that in English the lexical palatalization is categorical, while the postlexical palatalization is gradient by coarticulation. Coarticulation is the overlap of articulatory gestures of adjacent segments. With her claim, she shows that spectral properties of lexically derived /ʃ/ (e.g. *impression*) does not differ from underlying /ʃ/ (e.g. *fresh*), while the spectral properties of /s +j/ sequences (e.g. *this year*) start from /s/- like at the beginning to more /ʃ/-like at the end because the postlexical change from /s/ to /ʃ/ is due to overlap between the /s/ and /j/ gestures.

The complementary distribution of Korean fricative has been expressed by a palatalization assimilation process that the alveolar fricative sound /s/ before the front vowel [i] changes into [ʃ], otherwise it keeps the sound [s] (Ahn 1985, Jun 1996). However, it has not been studied acoustically if this is a real phonological process or it is by the overlap between the fricative consonant and vowel gestures. If Korean allophone [ʃ] exists by a phonological rule, then it will be categorical as in English lexically derived [ʃ]. If it is by coarticulation, it will be like /s + j/ sequence in English based on the result of Zsiga (1995, 2000).

On the other hand, it has been known that the accelerated speech gives rise to increased coarticulation (Gay 1968, Gay et al. 1974). This fact can be explained on these grounds by an increased overlap of the "temporal domains" or "activation fields" of adjacent articulatory gestures (Bell-Berti and Harris 1981, Fowler and Saltzman 1993). By analogy, reduced coarticulatory effects are to be expected during reduced speech tempo. Hertrich and Ackermann (1995) shows that slowing of speaking rate resulted in a decrease of perseverative (left-to-right) coarticulation in the presence of unchanged anticipatory (right-to-left) effects.

In this study, therefore, to see if the complementary distribution of Korean fricative is phonological or phonetic, I compare them in the different speech rates. To maximize the differences of the fricatives by different speech rates, I choose to compare the fast speech rate, and slow speech rate rather than normal speech rate, because in the slow speech rate, the coarticulation may be decreased or be same with the one in the normal speech rate. If Korean fricative is by coarticulation, the effect will be greater in fast speech rate than in slow speech rate.

Fricatives are produced with a very narrow constriction in the oral cavity. A rapid flow of air through the constriction creates turbulence in the flow, and the random velocity fluctuations in the flow act as a source of sound (e.g. Stevens 1971). The acoustic properties of coronal fricatives have been investigated in a large number of studies, including Huges and Halle (1956), Heinz and Stevens (1961), Strevens (1960), Behrens and Blumstein (1988), and Nittrouer et al. (1989).

Hughes and Halle (1956) developed a procedure to distinguish between the American English fricatives [s], [ʃ], and [f] on the basis of their gross spectral shapes. The spectra were based on a 50 ms portion of the friction located somewhere in the middle of the fricatives. The metric used to distinguish [s] from [ʃ] was calculated by subtracting the energy (in dB) between 4.2 kHz and 10 kHz from the energy between 720 Hz and 10 kHz. A small value was characteristic of [s], a large difference indicated a [ʃ]. This is based on the observation that the frequency peaks for [s] are most often situated above 4 kHz, while the spectra of [ʃ] generally show peaks at lower frequencies. With this metric the authors classified 107 out of 125 (86%) fricative tokens produced by three speakers, both word-initial and word-final, and in the context of front, central and back vowels. On the basis of these findings, Heinz and Stevens (1961) performed a perception experiment, using synthesized versions of [f], [??], [s] and [ʃ]. They found that in comparison with the synthesized version of [s], synthesis of [ʃ] required a noise source with a relatively sharp cut-off for frequencies below 3 kHz.

Strevens (1960) provides an acoustic analysis of nine English fricatives, including [s] and [ʃ]. The comparison of the spectral characteristics was based on visual inspection of multiple broad-band spectrograms, taken from lengthened fricatives produced in isolation by 13 trained phoneticians. The difference between the alveolar [s] and alveopalatal [ʃ] turned out to be relatively clear-cut, residing mainly in the lower and upper limits of their noise frequency. For [ʃ], the lowest frequency at which energy was observable varied between 1.6 and 2.5 kHz, but it always exceeded 3.5 kHz for [s]. As for the upper limits, [ʃ] did not show energy above 7 kHz, while the spectrograms for [s] indicated that energy was present above 8 kHz.

Unlike the result of Hughes and Halle (1956), Mann and Repp (1980) shows the coarticulatory effect of following vowel on fricative noise spectrum. They recorded [sa], [ʃa], [su], and [ʃu] as part of a random list containing a number of other utterances from three male native speakers of American English. The averaged frequency of the lowest prominent energy peak was consistently lower in [-u] context than in [-a] context both for [ʃ] and for [s], although the extent of the context effect varied somewhat across speakers.

Soli (1981) also shows that the location of the spectral peaks in the frication noise is following vowel dependent. In his study, spectral analyses of the fricatives, as spoken in isolation and in initial position before the vowels [a, i, u], were performed. The mean LPC spectra revealed reliable anticipatory vowel coarticulation effects present at least 30-60 ms before vowel onset in the form of spectral peaks affiliated with the second formant of the vowel. Peak frequencies were between 1.5-2 kHz and were approximately 100-300 Hz higher before the front vowel [i] than before the back vowel [a, u].

In a study of the acoustic characteristics of American English voiceless fricatives, Behrens and Blumstein (1988) investigated spectral differences along with other acoustic parameters. They found that the individual sibilants did not differ systematically in duration and amplitude. Spectral information was measured at three different points in the fricative: at fricative onset, in the middle of the noise, and immediately preceding the voicing onset. However, the spectral characteristics turned out to remain relatively stable over the duration of the frication noise. The two sibilants could be reliably distinguished by major frequency peaks between 3.5-5 kHz for [s] and 2.5-3.5 for [ʃ].

Nittrouer et al. (1989) investigated the contrast between voiceless alveolar and alveopalatal fricatives and the amount of fricative-vowel coarticulation in productions of children and adults. They found that the so-called "centroid", or center of gravity of the DFT spectra (the first moment of the spectral distribution), distinguished between the spectral shapes of the two fricatives, yielding higher values for [s] than for [ʃ].

Evers, et al. (1998) tried to distinguish and characterize the fricatives /s, ʃ/ produced by two speakers each of English, Bengali and Dutch (12 real words). They used power spectra computed from a 40 ms window placed mid-fricative, and calculated the slopes of linear regression lines fit to spectra from 0 to 2.5 kHz and from 2.5 to 8 kHz. Their results showed that it was possible to separate [s] from [ʃ] by using the difference in slope below and above 2.5 kHz. Results also showed that there is no vowel influence in the discrimination and that there is a variation between speakers.

The papers mentioned above allow us to draw a number of conclusions. First, it turns out that amplitude and durational properties do not contribute to the differentiation of the coronal sibilants (Behrens and Blumstein 1988). Second, several studies have suggested that the sibilant [s] and [ʃ] are differentiated by the spectral properties of the friction itself (Hughes and Halle 1956, Evers et al. 1998). However, the result on the influence of the vowel context on the spectral properties of the fricative noise was different: the spectral properties of fricatives are also following vowel dependent (Mann and Repp 1980, Soli 1981), or following vowel independent (Hughes and Halle 1956, Evers et al. 1998). Third, it has been consistently observed that there is more low-frequency energy for the alveopalatal [ʃ] than for the alveolar [s].

The present paper aims to replicate and extend these findings with an acoustic study. The study examines the nature of the complementary distribution of Korean fricative acoustically. Here, the fricatives preceding five different vowels [i, e, a, o, u] are compared in different speech rates – fast and slow – and in different positions in time domain – mid point and ending point. The study measures the spectral peak frequencies of the fricatives.

The hypothesis in this paper is like the following: If the complementary distribution of Korean fricative is phonological, then the fricative group preceding high front vowel will have the significantly lower spectral peak frequencies than the ones preceding other vowels, regardless of speech rates or locations in time domain. If this is by coarticulation, the spectral peak frequencies of the group before the high front vowels will not be different from the other groups preceding [e, a, o, u] at the center point in time domain. However, at the ending point the group before high front vowel will have much lower spectral peak frequencies than other groups. This effect will be greater in fast speech than in slow speech. Also each fricative would be different depending on which vowel is following.

2. Method and Procedures

2.1 Participants

Three adult speakers (two males and one female) served as subjects. Their ages ranged from 24 to 31. All were native speakers of Korean, staying in Austin with the purpose of study, and they grew up in Seoul, Korea. They did not know the purpose of the study or what would be measured. No participants reported any known history of speech impairment. Participants were not paid for their participation.

2.2 Materials

The Korean fricative sound /s/ was recorded in CVCV(C) syllables in isolation. The fricative sound was in the first syllable initial position, followed by each of five vowels /i, e, a, o, u/. Each group had 4 words. The initial consonant of second syllable was one of the voiced stops /b, d, g/[1]. All words were repeated 4 times and presented in random order. Each token was shown in Korean orthography in each slide of PowerPoint file. None of the target consonants was marked or underlined. First, the subjects were instructed to read each word in citation form, and to speak clearly in the slow speech rate, and each slide was shown every 5 sec. automatically by using the PowerPoint slide show. Then, they were asked to read the same whole set of tokens in

[1] The materials are appended at the end of this paper.

the fastest speech rate, and each slide was shown every 3 sec. Thus, each subject produced a total of 160 tokens (5 vowels * 4 words * 4 repetitions * 2 speech rates).

2.3 Procedure and Analysis

Speakers were recorded in the Phonetic Laboratory (CAL 518) at the University of Texas at Austin, in a soundproof booth, with a Samson S12 HyperCardioid Dynamic Microphone, microphone pre-amp (ART Tube MP Studio), and Macintosh computer with External A/D converter (RolandED VA-30 USB) to transfer the signal in to the computer. The microphone was placed at approximately a 45-deg angle and 15 cm away from the speaker's mouth, to prevent turbulence due to direct airflow from impinging on the microphone. All recordings were sampled at 22.05 kHz, using the Macquirer software.

In this study, the highest spectral peak frequencies of the fricatives preceding the high front vowel are compared with the ones of fricatives preceding other vowels in two different locations (mid and ending points) and two different speech rates (fast and slow). In deciding the measuring location in fricative noise, the simultaneous consultation of waveform and wideband spectrogram was involved. Following Jongman et al. (2000), fricative onset was defined as the point at which high-frequency energy first appeared on the spectrogram or waveform. Frication offset for voiceless fricative was defined as the intensity minimum immediately preceding the onset of vowel periodicity.

The ending point of fricative, one of the measurement points here, was defined as the point of 20 ms before the fricative offset[2]. The mid point of fricative was defined as the mid point between the fricative onset and its offset. In Korean, many cases showed the aspiration after fricative. If there is aspiration, the mid point of noise was defined as the mid point of the fricative onset and the intensity minimum immediately preceding the aspiration. This case, not considering the aspiration, gave more reasonable results. The reason that I did not measure the beginning point of the

[2] As explained below, the window size of spectrum was set as 40 milliseconds. To be independent from the vowel formant, the measuring point had to be as least half of the window size before the fricative offset.

fricative was because in the small pilot study that the beginning point was defined as the point of 20 ms after the frication onset due to the large window size, the beginning point was too close to the mid point, especially in fast speech rate, and the result was very similar to each other.

A spectrum was computed for each token using a 40 ms window size, using a 1024 point frame, following Evers et al. (1998), Jongman et al. (2000), and Gordon et al (2002). This larger window size yields better resolution in the frequency domain. Spectral peak estimation was based on spectra generated by means of FFT (fast Fourier transform) and LPC (linear predictive coding). For LPC, 26 poles were used. LPC spectra were computed to examine if their peaks matched those of the FFT. Spectral peak is defined here as the highest-amplitude peak of the FFT spectrum in 0-11 kHz range.

Fig 1 shows the sample display of waveform and spectrogram indicating the center location point in fricative noise. Fig. 2 shows the sample display of waveform and spectrogram indicating the end point in fricative noise, which is 20 ms before the fricative offset. In both figures, the vertical lines are placed by the cursor in waveform (the top one) and spectrogram (the bottom one), to get the spectrum in those positions over time. Fig. 3 shows the spectrum resulted from the waveform or spectrogram. This shows the peak amplitude location in FFT spectrum (smoothly curving wave line is LPC, and the sharp lines are FFT). The vertical line in spectrum is by cursor placement to get the frequency value at the peak amplitude location in FFT spectrum. The spectral peak frequency is shown at the bottom on the rightmost side in spectrum window.

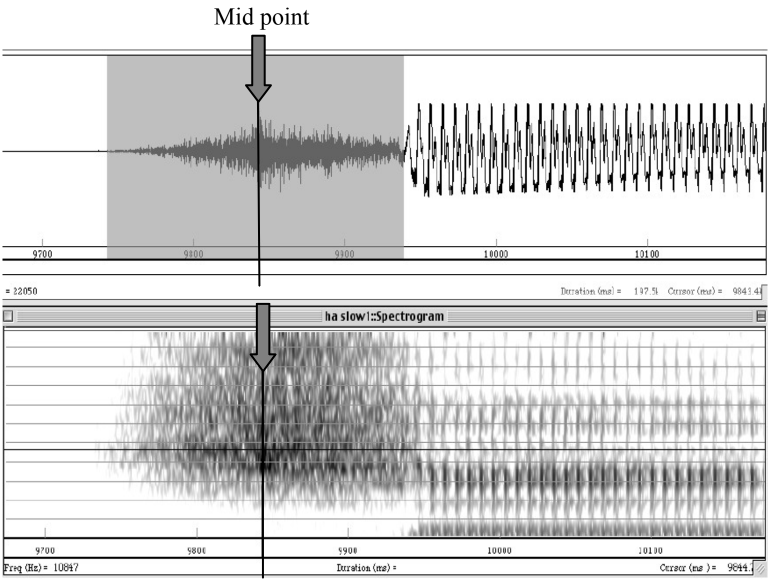

Figure 1. Sample display with the mid point in the waveform and spectrogram

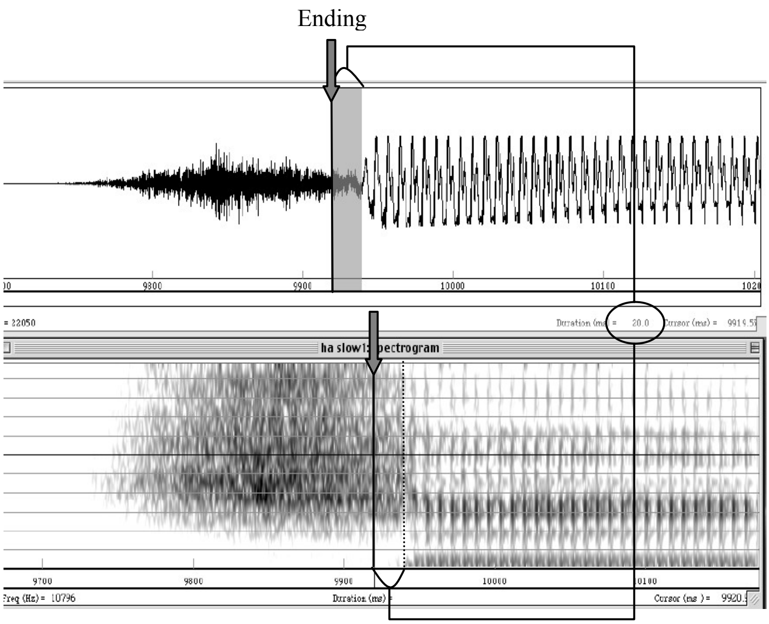

Figure 2. Sample display with the ending point in the waveform and spectrogram

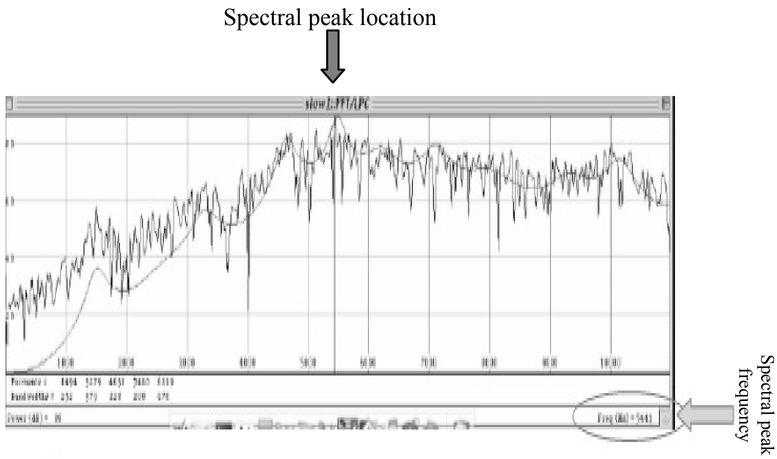

Figure 3. Sample display with the FFT spectral peak location in the spectrum
The amplitude of FFT spectrum is shown at the bottom on the left side in the spectrum window.

3. Results

The factorial ANOVA statistical tests were performed. First, in order to determine how different spectral peak frequency the speakers showed in each of fricative groups in each context (at slow and fast speech rates and at the mid and end point in fricative segment), one-way ANOVAs with post-hoc analyses were conducted for each individual. In one-way ANOVAs, the dependent variable was the spectral peak frequency and the independent variable was the following vowel context. Then, two-way ANOVAs were performed for the independent variables (following vowel * speech rate) and for the independent variables (following vowel * location in fricative) with dependent variable, the spectral peak frequency.

3.1 The Results for the Subject F (female)

1) In Fast speech rate

(1) Mid point

A one factor ANOVA revealed the highly significant effect of the following vowel on the mean spectral peak frequency:[df(4, 75), F(124.7), and P(<.0001)]. Post-hoc test results indicated that a) The mean spectral peak frequency of the group preceding high front vowel [i] was significantly different from any other groups (P<.0001), which had the lowest mean frequency; b) The group before [e] was significantly different from the group before [a, u], but not from the group before [o]; c) The group before [a] was not different from the groups before [o, u].

(2) Ending point

A one-way ANOVA showed the significant effect on the following vowels: [df(4,75), F(18.0), and P(<.0001)]. Post-hoc test results showed that a) The group before [u] did not have difference from the group before [i], but it had significantly higher mean frequency than groups before [e, a, o]; b) The group before [o] also had quite significantly higher mean than the group before [o].

(3) A two-way ANOVA (Following vowel * Location in Fricative) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(18.5), and P(<.0001)], of location in fricatives [df(1,158), F(570.0), and P(<.0001)], and of a following vowel * location in fricative interaction [df(4,155), F(51.527), and P(<.0001)] (refer Fig. 4 below).

2) Slow speech rate

(1) Mid point

A one factor ANOVA revealed the highly significant effect of the following vowel on the mean spectral peak frequency:[df(4, 75), F(113.1), and P(<.0001)]. Post-hoc test results indicated that a) The mean spectral peak frequency of the group preceding [i] was significantly lower from all of the other groups; b) The mean frequency of groups before [e, o] were significantly higher than the one of groups before [a, u]; c) The ones of between groups before [e, o] and between groups before [a, u] did not show the differences.

(2) Ending point

A one-way ANOVA showed the significant effect on the following vowels: [df(4,75), F(34.2), and P(<.0001)]. Post-hoc test results showed that a) The mean spectral peak frequency for the group before [u] was the highest; b) The mean spectral peak frequency of the group before [i] was the second highest and it was significantly different from the one of the groups before [e, a, u]; c) The rest three groups before [e, a, u] did not have any difference.

(3) A two-way ANOVA (Following vowel * Location in Fricative) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(37.0), and P(<.0001)], of location in fricatives [df(1,158), F(644.4), and P(<.0001)], and of a following vowel * location in fricative interaction [df(4,155), F(66.5), and P(<.0001)] (refer Fig. 5 below).

3) Mid point

At this point I put the location in fricative as the dependent variable for the mid point only by the two-way ANOVA (Following vowel * speech rate). The tests revealed a highly significant effect only of following vowels on spectral peak frequency [df(4,155), F(237.1), and P(<.0001)]. The tests indicated that there was no difference for the speech rate [df(1,158), F(.3), and P(.5847)], and of a following vowel * speech rate interaction [df(4,155), F(.3), and P(.8406)] (refer Fig.65 below).

4) Ending point

The two-way ANOVA (Following vowel * speech rate) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(46.2), and P(<.0001)] and a significant effect of a following vowel * speech rate interaction [df(4,155), F(3.2), and P(.0145)]. But, the test indicated there is no difference in speech rate again [df(1,158), F(2.7), and P(.0997)] (refer Fig. 7 below).

3.2 The Results for the Subject M1 (male 1)

1) In Fast speech rate

(1) Mid point

A one factor ANOVA revealed the highly significant effect of the following vowel on the mean spectral peak frequency:[df(4, 75), F(25.2), and P(<.0001)]. Post-hoc test results indicated that a) The mean spectral peak frequency of the group preceding high front vowel [i] was significantly different from the one preceding other vowels; b) The latter groups also showed the differences each other. The mean frequency of the groups before [e] or [u] was significantly higher than the one of groups before [a] or [o]; c) Between [e] and [u] groups or between [a] and [o] groups there were no difference.

(2) Ending point

A one-way ANOVA showed the significant effect on the following vowels: [df(4,75), F(12.5), and P(<.0001)]. Post-hoc test results showed that a) The groups before [i] and before [e] had significantly higher mean frequency than other groups; b) The groups before [a, o, u] showed no difference.

(3) A two-way ANOVA (Following vowel * Location in Fricative) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(11.0), and P(<.0001)], of location in fricatives [df(1,158), F(488.4), and P(<.0001)], and of a following vowel * location in fricative interaction [df(4,155), F(24.9), and P(<.0001)] (refer Fig. 8 below).

2) Slow speech rate

(1) Mid point

A one factor ANOVA revealed the highly significant effect of the following vowel on the mean spectral peak frequency:[df(4, 75), F(19.7), and P(<.0001)]. Post-hoc test results indicated that a) The mean spectral peak frequency of the group preceding [i] was significantly different from all of the other groups; b) Other groups before [e, a, o, u] did not show the differences.

(2) Ending point

A one-way ANOVA showed the significant effect on the following vowels: [df(4,75), F(10.7), and P(<.0001)]. Post-hoc test results showed that a) The mean spectral peak frequency for the group before [e] was the highest; b) The mean spectral peak frequency of the group before [i] was the second highest and it was significantly different from the one of the groups before [a, o, u]; c) thus the highest ranked group before [e] of course showed the significant difference from all of other groups; d) The rest three groups did not have any difference.

(3) A two-way ANOVA (Following vowel * Location in Fricative) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(6.5), and P(<.0001)], of location in fricatives [df(1,158), F(374.3), and P(<.0001)], and of a following vowel * location in fricative interaction [df(4,155), F(22.2), and P(<.0001)] (refer Fig. 9 below).

3) Mid point

At this point I put the location in fricative as the dependent variable for the mid point only by the two-way ANOVA (Following vowel * speech rate). The tests revealed a highly significant effect only of following vowels on spectral peak frequency [df(4,155), F(44.0), and P(<.0001)]. The tests indicated for the speech rate [df(1,158), F(.2), and P(.6448)], and of a following vowel * speech rate interaction [df(4,155), F(.4), and P(.7436)] (refer Fig. 10 below).

4) Ending point

The two-way ANOVA (Following vowel * speech rate) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(18.2), and P(<.0001)] and a significant effect of a following vowel * speech rate interaction [df(4,155), F(2.5), and P(.0429)]. But, the test indicated there is no difference in speech rate again [df(1,158), F(2.6), and P(.1075)] (refer Fig. 11 below).

3.3 The Results for the Subject M2 (male 2)

1) In Fast speech rate

(1) Mid point

A one factor ANOVA revealed the highly significant effect of the following vowel on the mean spectral peak frequency:[df(4, 75), F(6.910), and P(<.0001)]. This subject shows the strangest pattern. Post-hoc test results indicated that a) The mean spectral peak frequency of the group preceding [e] was significantly higher than other groups; b) The rest groups did not show any difference.

(2) Ending point

A one-way ANOVA showed the significant effect on the following vowels: [df(4,75), F(24.6), and P(<.0001)]. Post-hoc test results showed that a) The groups before [i] and before [u] had significantly higher mean frequency than other groups; b) Those two groups did not have difference; c) The group before [e] was second highest, thus was significantly higher than the rest two groups; d) The group before [a] was significantly higher than the group before [o] as [P<.0316].

(3) A two-way ANOVA (Following vowel * Location in Fricative) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(9.1), and P(<.0001)], of location in fricatives [df(1,158), F(385.4), and P(<.0001)], and of a following vowel * location in fricative interaction [df(4,155), F(25.4), and P(<.0001)] (refer Fig. 12 below).

2) Slow speech rate

(1) Mid point

A one factor ANOVA revealed the highly significant effect of the following vowel on the mean spectral peak frequency:[df(4, 75), F(5.9), and P(.0003)]. Post-hoc test results indicated that a) The mean spectral peak frequency of the group preceding [i] was significantly different from all of the other groups; b) Other groups before [e, a, o, u] did not show the differences.

(2) Ending point

A one-way ANOVA showed the significant effect on the following vowels: [df(4,75), F(32.8), and P(<.0001)]. Post-hoc test results showed that a) The mean spectral peak frequency for the group before [i] was the highest, and was significantly different from other groups; b) The mean spectral peak frequency of the group before [u] was the second highest and it was significantly different from the one of the groups before [e, a, o]; c) the group before [e] was significantly higher than group before [o].

(3) A two-way ANOVA (Following vowel * Location in Fricative) revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(7.4), and P(<.0001)], of location in fricatives [df(1,158), F(502.6), and P(<.0001)], and of a following vowel * location in fricative interaction [df(4,155), F(30.7), and P(<.0001)] (refer Fig. 13 below).

3) Mid point

At this point I put the location in fricative as the dependent variable for the mid point only by the two-way ANOVA (Following vowel * speech rate). The tests revealed a highly significant effect of following vowels on spectral peak frequency [df(4,155), F(7.9), and P(<.0001)], of the speech rate [df(1,158), F(28.8), and P(<.0001)], and of following vowel * speech rate interaction [df(4,155), F(4.7), and P(.0013)]. Only this subject shows the speech rate difference (refer Fig. 14 below).

4) Ending point

Unlike the mid point, the two-way ANOVA (Following vowel * speech rate) for ending point revealed a highly significant effect only of following vowels on spectral peak frequency [df(4,155), F(56.0), and P(<.0001)]. The test indicated no differences in speech rate [df(1,158), F(.2), and P(.6471)] and of a following vowel * speech rate interaction [df(4,155), F(1.9), and P(.1125)] (refer Fig. 15 below).

The following graphs confirm the results of two-way ANOVA tests for the three subjects as shown in the following:

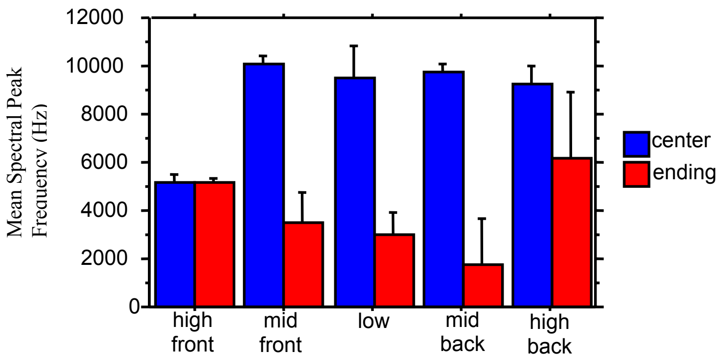

Figure 4. Mean spectral peak frequency in fast speech for Subject F

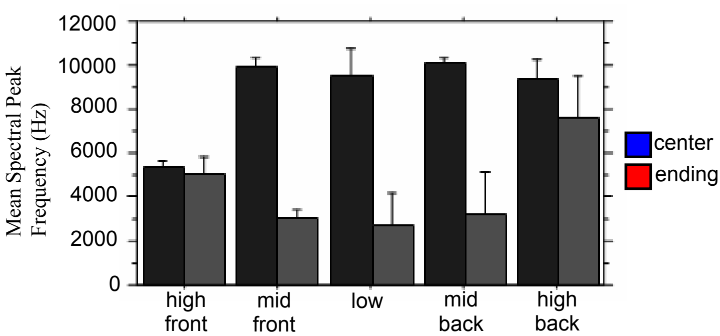

Figure 5. Mean spectral peak frequency in slow speech for Subject F

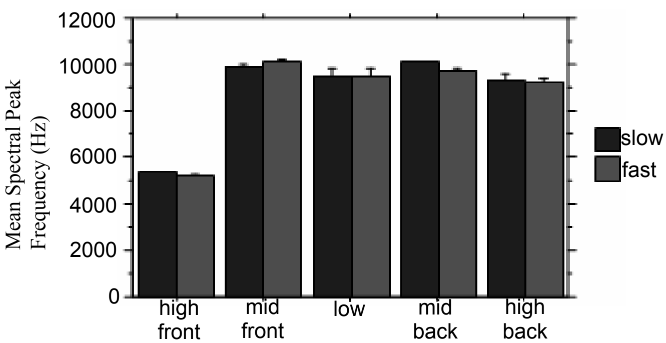

Figure 6. Mean spectral peak frequency in center location for Subject F

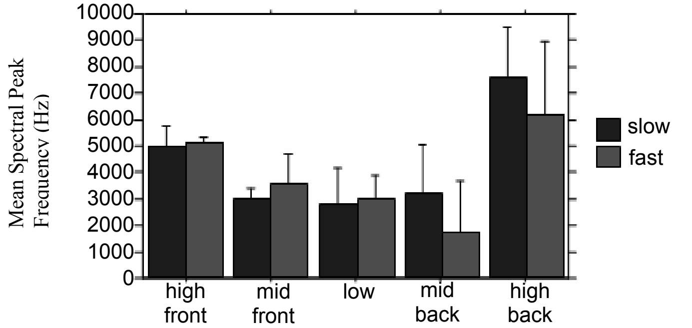

Figure 7. Mean spectral peak frequency in ending location for Subject F

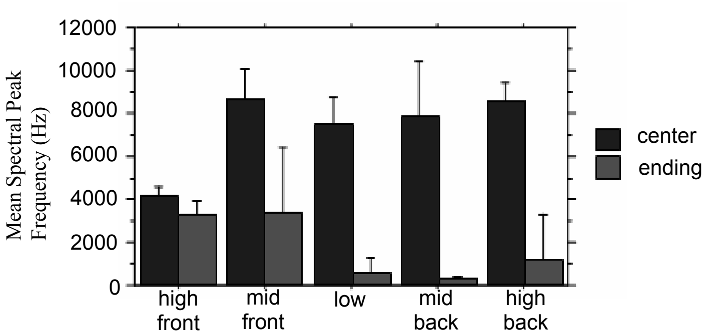

Figure 8. Mean spectral peak frequency in fast speech for Subject M1

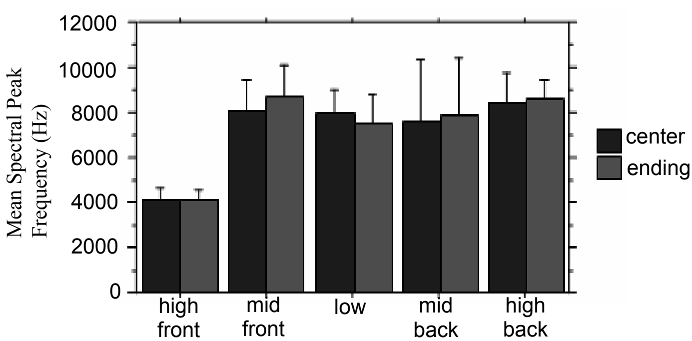

Figure 9. Mean spectral peak frequency in slow speech for Subject M1

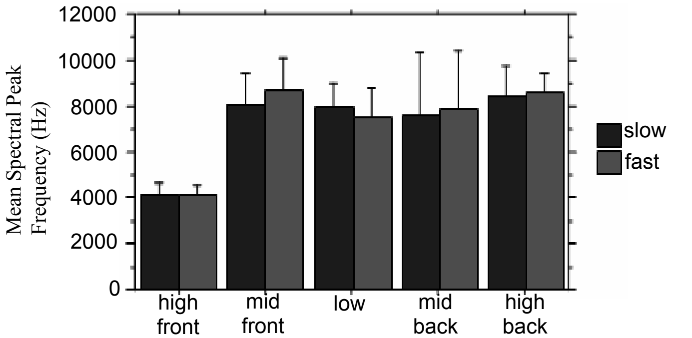

Figure 10. Mean spectral peak frequency in center location for Subject M1

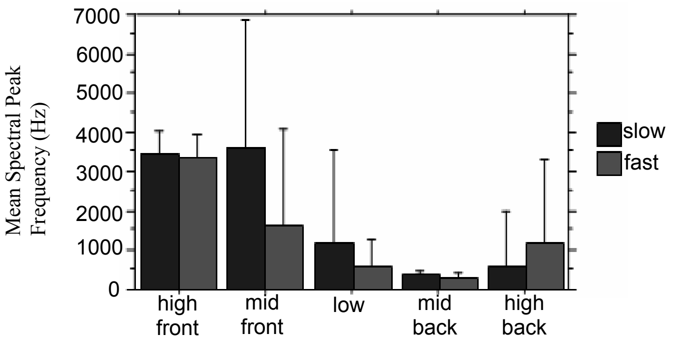

Figure 11. Mean spectral peak frequency in ending location for Subject M1

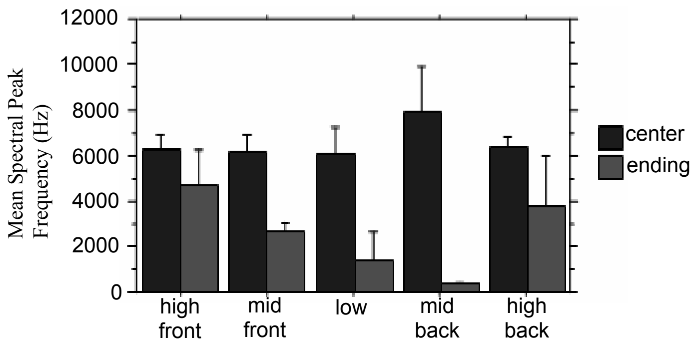

Figure 12. Mean spectral peak frequency in fast speech for Subject M2

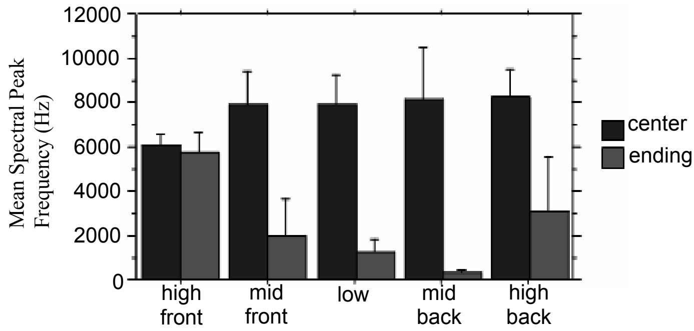

Figure 13. Mean spectral peak frequency in slow speech for Subject M2

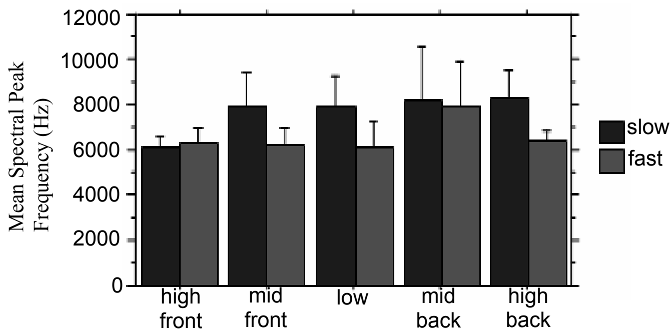

Figure 14. Mean spectral peak frequency in center location for Subject M2

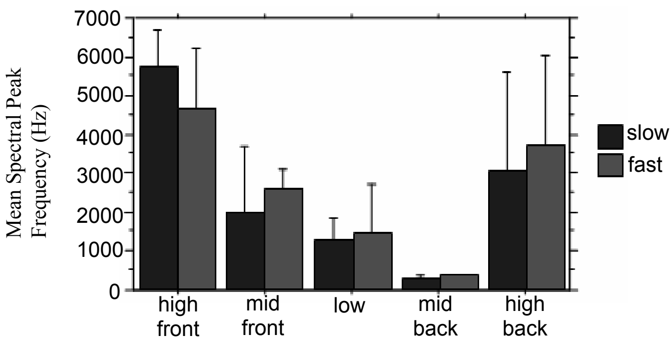

Figure 15. Mean spectral peak frequency in ending location for Subject M

3.4 Mean Spectral Peak Frequencies

The following table 1 shows the mean spectral peak frequencies of each subject in each different context. It indicates the several properties of the mean spectral peak frequencies in each condition in Korean:

As shown in Table 1, all subjects showed the significant differences between the /si/ group and others. All subjects do not show the significant differences in between fast and slow speech rates. However, they show the significant differences in the different locations in fricative in most cases. Especially the spectral peak frequencies of /si/ group are usually stable regardless of the context. The female subject has significantly higher frequency than male subjects.

Table 1. Mean spectral peak frequency values for each subject by the speech rate and the position in fricative over time. **(**Subject F means female subject, while M1 and M2 indicate two male subjects. Groups are shown as the target fricative segment with following vowel in phoneme here.)

Subject	Group by following Vowel	Mid point in Fricatives		Ending point in Fricatives	
		Slow speech (kHz)	Fast speech (kHz)	Slow speech (kHz)	Fast speech (kHz)
F	/si/	5.3	5.2	5.0	5.1
	/se/	9.9	10.0	3.0	3.5
	/sa/	9.5	9.5	2.7	3.0
	/so/	10.0	9.8	3.2	1.7
	/su/	9.3	9.2	7.6	6.2
M1	/si/	4.1	4.1	3.5	3.3
	/se/	8.0	8.7	3.6	3.4
	/sa/	7.9	7.5	1.2	0.6
	/so/	7.6	7.8	0.4	0.3
	/su/	8.4	8.6	0.6	1.2
M2	/si/	6.1	6.3	5.7	4.7
	/se/	8.0	6.2	2.0	2.6
	/sa/	7.9	6.1	1.2	1.4
	/so/	8.2	7.9	0.3	0.4
	/su/	8.3	6.3	3.1	3.7

4. Conclusion

This study departed from the question of whether Korean palatalization is categorical or gradient. The current results seem to support the former idea, which is rather categorical than gradient. Except Subject M2's fast case, all subject showed the significant difference between the fricative sound before [i] and others at the center position. Also when we compare the spectral peak frequencies between the mid point and the ending position, all subjects showed the no or very little lowering for the group preceding [i], regardless of the speech rates, while other groups showed significantly different lowering of the mean frequencies over time. These results seem to imply Korean allophone [S] is by palatalization assimilation, which is a phonological process. Jonman et al. (2000) reported that the spectral peak location of /s,z/ did vary as a function of vowel context, but other fricatives were not affected by the vowel context. And, they claimed that the spectral peak for /s,z/ was significantly lower in the context of the back-rounded vowels.

My result also showed way too big lowering of the spectral peak frequencies of the fricatives preceding especially the back vowels. On the other hand, the spectral peak frequencies of fricatives before [i] were rather static, which is identical to the study of Jongman et al. If it was by coarticulation, in the center position of fricative in time, the spectral peak frequency of one group is expected not be different from others. And, by time they become different. The current results here do not look like supporting that the Korean palatalization is by coarticulation.

In the current experiment, the speech rate does not show the differences on the spectral peak frequency, while the time domain shows the significant differences. Hertrich and Ackermann 1995 shows that the slowed speech tempo had a differential influence on perseverative and anticipatory vowel-to-vowel coarticulation, giving rise to consistently decreased perseverative effects in the presence of unaltered or even “increased” articulatory anticipation. The complementary distribution of Korean fricative seems to have a coarticulation effect, especially anticipation, because the spectral peak frequency was heavily affected by the following vowel context in the time domain. If in Korean, CV anticipatory coarticulation is increased by the “slow” speech rate as well as by the fast speech rate, the result might be explained to be affected by a coarticulation in both fast and slow rates although it is difficult to explain how the degrees of coarticulation can be similar between two speech tempos. Then, the choice of the two speech rate –fast and slow – was wrong. The future study at normal speech rate is needed.

In the pattern of coarticulation all the subjects did not show the consistent result or patterns. In general, coarticulation phenomena may exhibit considerable inter-speaker or even intra-speaker variability (Hoole et al. 1993, Johnson, et at. 1993, Hertrich and Ackermann 1995, etc.) Unlike the English result from Behrens and Blumstein (1988), the acoustic characteristics of the frication noise of Korea varied across speakers, words, and vowel contexts. This study also shows lots of variability, which we can see the big size of standard deviation. What I could not understand most in my result was that the subject shows variability showing very high frequency before rounded back vowels.

It is well established that the acoustic characteristics of /s/ differ in male and female speakers, with females typically showing higher frequency energy than males (e.g. Flipsen et al. 1999). These differences are often accounted for by referring to the observation that female speakers are likely to have a shorter resonance cavity in front of the fricative constriction than males (e.g. Stevens 1998). In my result also female subject shows the female subject had higher mean frequency except Subject Male2's case for the fricative before [i]. Other than that, the male subjects did not have more than 8 kHz mean in any group, while the female subject's mean frequency went more than 8 kHz many times. The future work is required with the bigger size of tokens and subjects to reduce variability.

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Appendix: Materials used in this experiment

- Alveolar fricative followed by high front vowel

ʃigak 'sight'	ʃigi 'jealousy'
ʃibi 'a dispute'	ʃido 'a trial'

- Alveolar fricative followed by mid front vowel

sega 'a powerful family'	segi 'a century'
sebi 'annual expenditure'	sedo 'authority'

- Alveolar fricative followed by high back vowel

sugap 'handcuffs'	sugi 'a note'
subi 'defense'	sudo'a capital'

- Alveolar fricative followed by low vowel

sagak 'a square'	sagi 'trickery'
sabi 'private expense'	sado 'an evil way'

- Alveolar fricative followed by mid back vowel

sogak 'destruction by fire'	sogi 'expectation'
sobi 'consumption'	sodo 'a small island'