Coarticulation effects of Korean sibilant /s/ before a high front segment*

Hyunsook Kang
(Hanyang University)

Kang, Hyunsook. 2010. Coarticulation effects of Korean sibilant /s/ before a high front segment. *Studies in Phonetics, Phonology and Morphology* 16.1. 3-18. This paper investigates acoustic characteristics of Korean /s/ before a high front segment and argues that Korean /s/ shows acoustic characteristics of a palatalized segment due to the coarticulation with the following high front segments. In Experiment, it is shown that the first 30 msec of /s/ before /i, ye, ya/ shows spectral peaks around 4 kHz whereas /s/ before open vowels like /e, a/ shows peaks around 6 kHz. We suggest that this is due to the tongue body position at the palatal area placed at the beginning of /s/ when it is followed by /i/ or /y/. Center of gravity frequency, and band energy difference also show differences of Korean /s/ in different contexts. Based on the results of this experiment, we argue that Korean /s/ is modified from its beginning due to the coarticulation with the following segments if articulators of /s/ are compatible with those of the following segments. Interestingly, this paper also shows that in case /s/ is followed by /yu/ or /yo/, its spectral shape shows significant differences from /s/ followed by /ya/ or /ye/. It raises the question that in Korean the domain of coarituclation may be larger than the target and its immediately surrounding segment**. (Hanyang University)**

Keywords: Korean /s/, coarticulation, spectral peaks, center of gravity frequency, band energy difference

1. Introduction

Sibilant fricatives have long been studied for their wide range of acoustic characteristics. Their acoustic characteristics are mainly determined by the noise source at the constriction and by the front cavity resonances (cf. Heinz and Stevens 1961). The spectra of English alveolar fricative /s, z/ show a major peak near 5-6 kHz, and those of English palatal fricatives /ʃ, ʒ/ a peak near 2.5 kHz if produced by a male speaker (cf. Heinz and Stevens 1961, Hughes and Halle 1956, etc.). Other characteristics like spectral moments and amplitude were also studied (cf. Forest et al. 1988, Jongman et al. 2000).

Acoustic properties of sibilant fricatives may also change at the function of time due to varying degree of coarticulation with the adjacent segments. Though earlier studies assumed that sibilant fricatives are minimally influenced by surrounding segments (Liberman et al. 1967), others (e.g.,

* This paper was presented on the 18th International Congress of International Linguistics 2008. This work was supported by the research fund of Hanyang University research (HY-2007-G).

Repp and Mann 1981, Yeni-Komshian and Soli 1981) have convincingly shown that noise frication of sibilant fricative contains sufficient perceptual cues which make listeners quite correctly identify the phonological context in which it occurred. That is, sibilant fricatives are coarticulated with the upcoming segments and listeners are able to decompose the coarticulation effect from the acoustic properties of the stimuli (Mann and Repp 1980).

Coarticulaton occurs as the result of the gestural overlap of articulators involved in the execution of the target with those of its nearby segments when they are compatible. Beckman and Shoji (1984) claim that assimilation and coarticulation can be regarded as the same thing and that the difference is merely of degree, not by the type. For example, Japanese sibilant /s/ before /i/ is realized as a palatalized segment by assimilation whereas English sibilant /s/ before /i/ shows coarticulatory effects only on the last few centiseconds of /s/. They argue that this difference can be understood as different phonetic timing of articulators in the execution of /s/ before /i/, which is strictly determined by each particular language.

Korean sibilants, /s, S*/[1], also show different effects of coarticulation in different contexts. It is known that they undergo palatalization before a high front vowel /i/ just as in Japanese: overlapping of the articulators of the target and the following /i/ begins from the start of the fricative. Other than this process, however, variations regarding Korean fricative are not well studied since they are not actively involved in any other interesting phonological processes.

Recent introduction of English loanwords into Korean, however, have shown that many interesting coarticulation processes may in fact be occurring in Korean fricative, which were previously unknown. Consider loanword forms in (1) in which English palatal fricative /ʃ/ is adapted as /s/ in a variety of phonological contexts. Korean does not have an independent palatal fricative.

(1)

a. (leader)ship	/sip/[2]	/swip/
b. shoot	/syut/	
c. show	/syo/	/S*yo/[3]

---

[1] /s/ represents plain fricative and /S*/ represents tense fricative in this paper.

[2] The representation inside the slant lines in these examples represent the psychological reality of phonemes which Korean listeners have in their lexicon. The exact acoustic characteristics are somewhat different depending on the context. For example, /w/ may show different acoustic characteristics like high front round glide or mid front round glide before a high front vowel and a mid front vowel, respectively. However, all these front round glides are psychologically realized as round segment /w/ by Korean speakers (cf. Kang 2006).

[3] Many Koreans produce tense /S*/ instead of plain /s/ as the first segment of this loanword. The tendency to use a tense segment often occurs if the segment is the first segment of the loanword such as ‘boy’ /P*oi/ and ‘gum’ /G*Am/.

d. (milk)shake /swyeik^{h}ɨ/[4] /syeik^{h}ɨ/
e. (sun)shine /swyain/ /syain/

In (1a), English /ʃɪp/ is adapted as /sip/ or /swip/ in Korean. Since English /ɪ/ and /p/ corresponds with Korean /i/ and /p/ in other loanwords, we can easily conjecture that English /ʃ/ is adapted as either /s/ or /sw/ in Korean. In (1b), English /ʃut/ is adapted as /syut/. Since English /u/ and /t/ are adapted as Korean /u/ and /t/, respectively, again we can safely assume that English /ʃ/ is adapted as Korean /sy/. The forms in (1d) and (1e) show that English /ʃ/ can be sometimes adapted as /swy/ in Korean as well. Thus, English /ʃ/ has many correspondents in Korean.

One-to-many correspondence in (1), however, throws the question of what principle determines this type of correspondence. The answer to this question would show why English /ʃ/ corresponds with Korean /s/ in the environment in (1a) but not in other phonological environments. In order to answer this question, we need to investigate the acoustic features of Korean /s/ in a variety of phonological environments. We expect that this investigation will show what acoustic characteristics Korean /s/ in (1) has in common with one another, but not with others. It will also show why Korean /s/ in the environments of (1) is selected as a correspondent of English /ʃ/.

Among these questions, this paper will specifically focus on the first question, namely what acoustic features Korean /s/ in (1) has in common with one another but not with others. The second question will be investigated in the future study. Since spectral shapes are important in understanding acoustic properties of fricative (Harris 1958, Yeni-Komshian and Soli 1981), this study examines the spectral shapes of Korean sibilant /s/ with various upcoming segments. In particular, this study will examine the spectral shapes of Korean /s/ when it is followed by a high front segment, /i/ or /y/ in comparison with /s/ before other segments.

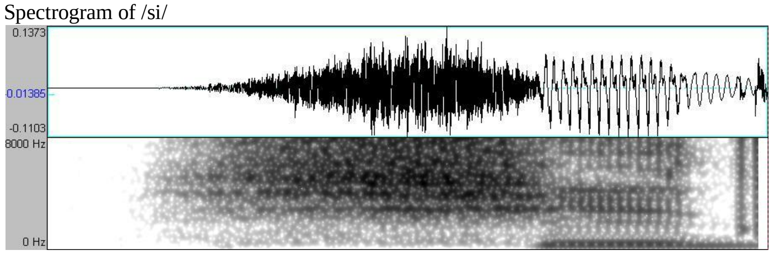
2. Experiment

Informal observation of the spectrograms of fricative /s/ in Korean suggests that different frequency areas are excited from the very beginning of the fricative depending on the characteristics of the upcoming segment. As we can see in the spectrograms in Figure 1, different frequencies of the fricative seem to show concentrated energy depending on the following segments. Furthermore, it seems to occur from the very start of the fricative.

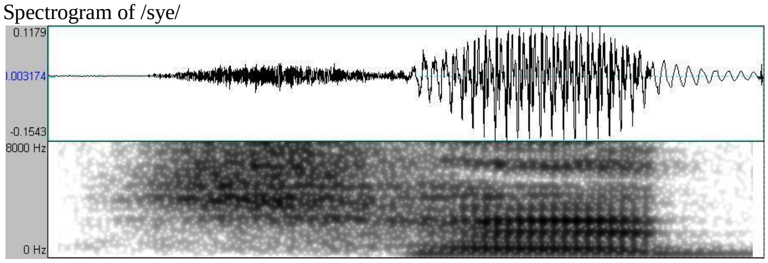
---

[4] Korean writing system does not allow two glides as onset. This does not mean that Koreans cannot produce nor perceive the combination of two glides. To represent two glides in this instance, Korean listeners made a new spelling for this sound.

a. Spectrogram of /si/



b. Spectrogram of /sye/



c. Spectrogram of /se/

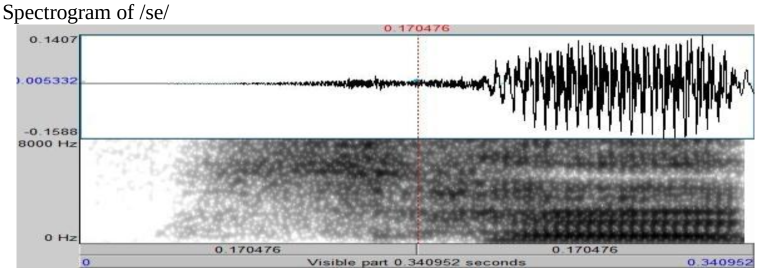


Figure 1. Spectrograms of /s/ in various contexts

The fact that concentrated energy occurs in different frequencies of fricative /s/ from its very start suggests that some articulatory components of upcoming segments are coarticulated with those of sibilant /s/ from the beginning of /s/. In order to examine the extent of the coarticulation of sibilant /s/ with the upcoming segments more in detail, the following experiment is conducted.

2.1 Procedures

For the experiment in this paper, four male speakers from Seoul (age 20-25) read a list of sentences[5] in the normal speed. The list contained words beginning with the sibilant fricative /s/ and /S*/ in AP-initial position. The words we analyzed are given in Table 1 as they occurred in the wordlist.

[5] The list of sentences was written in Korean.

Table 1. List of sentences

1. ikɨldʒanɨn syetayeyo.
2. ikɨldʒanɨn switayeyo.
8. ikɨldʒanɨn sutayeyo.
9. ikɨldʒanɨn sitayeyo.
12. ikɨldʒanɨn syatayeyo.
17. ikɨldʒanɨn satayeyo.
18. ikɨldʒanɨn syutayeyo.
19. ikɨldʒanɨn sotayeyo.
22. ikɨldʒanɨn syotayeyo.
24. ikɨldʒanɨn setayeyo.
27. ikɨldʒanɨn swyetayeyo.

Four subjects read the list three times. No subject reported any hearing or speech problem and they were paid a small amount of money. The recording is done in a sound attenuated booth using a dynamic microphone SHURE KSN44 and a digital recorder Tascam HD-P2 at the Hanyang Phonetics and Psycholinguistics Lab.

Several acoustic analyses have been conducted using Praat (Boersma and Weenink, 2002, Version 5.1.07). For the spectral analyses, all the sibilant fricatives were low-pass filtered at 8 kHz and were Fourier transformed. The time window for the dft was a 30-ms Hamming window from the start of the sibilant fricative and all the fricatives from which the samples were taken are longer than 30-msec. The excised 30-msec samples did not include the aspiration part of /s/.

For the excised frication noise, LPC spectral smoothing with 9 peaks (18 coefficients) was computed, and the precision with which the frequency of a peak in an individual spectrum was measured was in the range 50 Hz and no preemphasis was used. The amplitude of each peak was also measured. For each 30-msec Hamming windowed frication noise, then, we obtained measures of the frequencies and amplitudes of several major spectral prominences in the frequency range 0-8 kHz. Other phonetic analyses include the measurement of center of gravity frequency, and band energy difference in specific frequency range. This paper analyzed /sV/, and /syV/ sequences to focus on the palatalized characteristics shown in /s/. The results of other /s/- or /S*/-initial sequences will be reported in other papers.

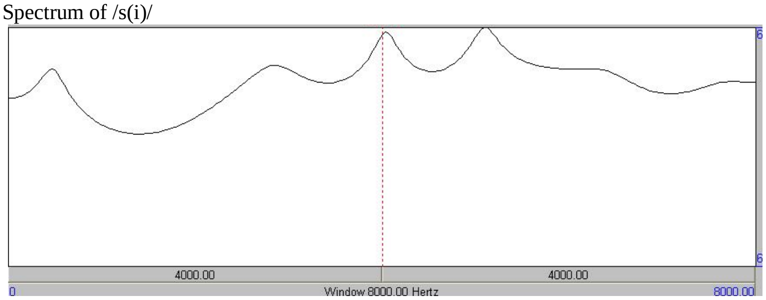
2.2 Spectral shapes

As is shown in Figure 1, major peaks of some /s/ appear to be contiguous with certain formants of the upcoming segment if the upcoming segment is high front. More specifically, the frequencies near the third and the fourth formants of the upcoming segment seem to have high amplitude in /s/ if the following segment is high front /i/ or /y/. If the following segment is open vowels like /e/ or /a/, no distinctive major peak seems to occur in the frequency below 5 kHz.

We consider this that the source or sources of turbulence noise of the upcoming high segment excite certain resonances of the vocal tract during the production of the fricative. That is, the tongue position of an upcoming high front segment begins at the beginning of the production of /s/ since the articulator for a high front segment is compatible with the narrow opening required for fricative /s/ in Korean and this articulatory shape excites frequencies reserved for palatal segments. No extensive coarticulation with the preceding /s/ occurs if the following vowel is an open vowel like /e/ or /a/ since the degree of opening for open vowels is non-compatible with the narrow opening required for sibilant fricative. Let us examine these differences more in detail since spectral shapes are important in characterizing sibilant fricative (cf. Hughes and Halle 1956, Harris 1958, Heinz and Stevens 1961, Beckman and Shoji 1984, Behrens and Blumstein 1988, Yeni-Komshian and Soli 1981).

The spectra of sibilant /s/ before /i/ and before /y(V)/ show that major peaks occur in the region of around 4 kHz and that some other fairly strong peaks also occur around this frequency as shown in Figure 2. The spectra we show in this paper come from the tokens produced by Subject 1. The description we supply here, however, applies to all the /s/ in the same environment regardless of the talker with small variations on the exact frequency of the high peaks. In these spectra, the line in the middle represents 4 kHz.

a. Spectrum of /s(i)/



b. Spectrum of /s(ye)/

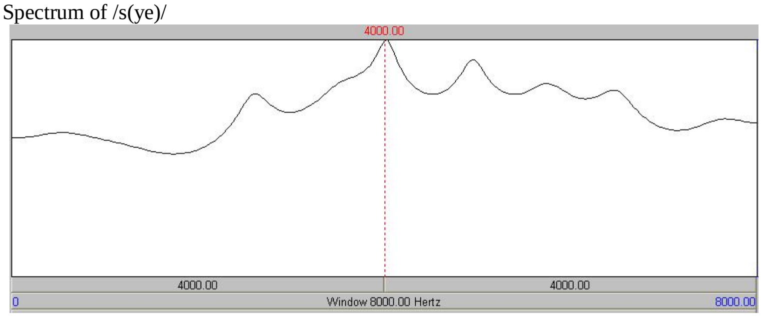
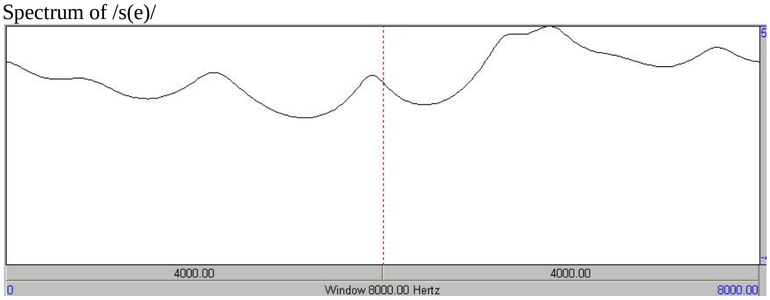


Figure 2. Spectrum of /s/ before a high front segment

Some minor difference occur between the spectra of /s(i)/[6] and /s(yV)/: the major peaks of /s/ occur in higher frequencies before /i/ compared with those before /y/. For /s/ before open vowels like /e/ and /a/, major peaks seem to occur in higher frequencies around 5-6 kHz as in Figure 3, though there might be some small peaks occurring in lower frequencies.

a. Spectrum of /s(e)/



b. Spectrum of /s(a)/

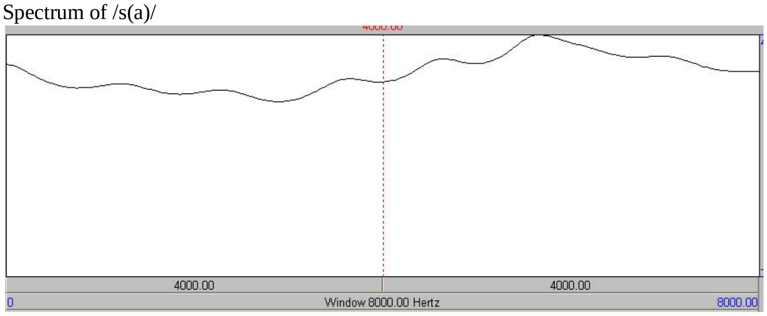


Figure 3. Spectrum of /s/ before an open vowel

---

[6] In this paper, we will use the notation of /s(i)/, for example, to indicate /s/ segment before /i/.

As one can see in Figure 3, there is clear difference between spectral shapes of /s(i, yV)/ and /s(e, a)/. For /s(i, yV)/, major peaks occur in around 4 kHz whereas for /s(e, a)/, they occur in 5-6 kHz. Note that major peaks of /s/ before /e, a/ do not occur in frequencies reserved for /s/ before a high front segment.

Since the spectral shapes of /s/ in Figures 2-3 are for the first 30 msec of /s/, they support the fact that Korean /s/ is influenced by the following high front segment from the beginning of its production and that it is the tongue position of the following high segment that modifies the sibilant fricative /s/.

2.3 Center of gravity

Spectral moments analysis is commonly used to distinguish fricative noise from one another. The spectral moment, or center of gravity frequency, for example, well distinguishes /s/ from /ʃ/ in English (cf. Forrest et al. 1988, Jongman et al. 2000): it roughly shows where the constriction is made relative to the length of the oral cavity.

In this paper, we calculated center of gravity frequency of the first 30 msec of Korean sibilant in various environments to examine whether Korean sibilant /s/ is also distinguished from one another depending on the contexts. Table 2 shows center of gravity of /s/ computed from the power spectra between 0-10 kHz which did not undergo LPC transformation.

Table 2. Center of gravity

Subject 1

Token	Average of center of gravity
sye	4364
si	5002
sya	4451
syu	4786
syo	4668
sa	6849
se	5745
cf.) swi	5002

Subject 2

Token	Average of center of gravity
sye	4314
si	4842
sya	4263
syu	4645
syo	4316
sa	6082
se	5693

Subject 3

Token	Average of center of gravity
sye	4631
si	4979
sya	4720
syu	4314
syo	4661
sa	6625
se	6597

Subject 4

Token	Average of center of gravity
sye	4903
si	5776
sya	5265
syu	4280
syo	3607
sa	7617
se	7235

Center of gravity frequency in Table 2 shows that /s(i, yV)/ is very different from /s(e, a)/ even at the very beginning of the production of /s/. Center of gravity of /s/ before /e, a/ is 1-2 kHz higher than that of /s/ before a high front segment. This difference supports the suggestion that /s/ is affected by the following high front segment from the beginning of its production in Korean. Specifically, we suggest that the difference occurred due to the tongue position at the palatal area during the production of /s/ due to the following palatal vowel: High segments do not disrupt the narrow constriction sibilant fricative requires, and in Korean the tongue position of a high front segment begins from the start of fricative.

It is also shown that in general, center of gravity frequency of /s/ before /i/ is higher than that before /y/. High energy is spread over the higher frequency area of the palatalized frequency zone for /s(i)/ than for /s(yV)/. This tendency was also observed in the spectra shown in Figure 2. Since the location for the concentrated energy for sibilant has to do with the cavity length in front of the constriction, we tentatively assume that tongue body position for /s/ before /yV/ might be slightly further back than /s/ before /i/ due to the coarticulation of /y/ with following open vowel. This speculation, however, needs to be confirmed by other acoustic measurements.

Table 2 also reports that the average center of gravity frequencies of /s(wi)/ of Subject 1 is similar to /s(i)/ and /s(yV)/, even if /s/ is immediately followed by a totally different segment /w/ in /s(wi)/. This raises the question of what similar environments fricative /s/ has in common in these two sequences.

2.4 Band energy difference

Center of gravity frequency seems to clearly segregate /s/ in different phonological contexts from one another. However, it is not certain whether center of gravity frequency is the quality which listeners pay attention to in perceiving a segment. Rather, it has been argued that spectral shapes are the ones that affect the perception of listeners (cf. Harris 1958, Yeni-Komshian and Soli 1981).

As we have seen, peaks of /s/ in Korean occur in different frequency area of the spectra depending on the contexts in which it occurs. To precisely measure the frequencies of the major peaks in each spectrum, however, is quite difficult: High energy is spread over some wide frequency area with small valleys interwoven, and thus reading the frequencies of the most prominent peak off the spectrum is not easy. Phoneticians often LPC transform the spectrum with certain number of coefficients to get around this problem. However, the number of main peaks in the LPC transformed spectra depends on the number of coefficients and selecting the proper number of coefficients is not easy. Even with the proper number of coefficients, how to interpret several peaks in certain frequency area is another problem. For example, if major peaks with similar amplitude are spread over some wide frequency area with small valleys interwoven, should we choose just one of them as the major peak or should we average all the peaks for the major peak? And what if the frequency of the most prominent peak of /s/ in a certain context may overlap with /s/ in another context? Furthermore, there is always possibility that the amplitude of the major peak and the valley of the spectra of /s/ may be different in magnitude for each particular fricative /s/ due to different talker and some other reasons, we needed some reference point to make the energy we measured to be objectively compared. Therefore, in this paper we computed the difference of energy of two critical frequency areas of each /s/ and compare it with that of another /s/. By comparing the relative strength of two frequency areas in each spectrum, we can reduce any token-particular idiosyncrasy and locate the frequency area where important peaks are located in each spectrum.

To distinguish /s(i, yV)/ from /s(e, a)/, we computed energy difference between the frequency area of 5-7 kHz and the frequency area of 3-4 kHz in each spectrum of /s/ in Korean. We expect positive value for the spectra of /s/ before open vowels since it has high peaks in 5-7 kHz but not in 3-4 kHz, and negative or minimally positive value for the spectra of /s/ before high front segment since palatalized fricative has high peaks in 3-4 kHz but not in 5-7 kHz, though the exact frequency areas for the measurement may differ from speaker to speaker due to the different size of the front cavity. Thus, for three subjects, we measured the energy difference between 5.5-6.5 kHz and 3-4 kHz and for subject 2, we measured the energy difference between 5.0-6.0 kHz and 3-4 kHz. The results are given in Table 3.

Table 3. Band energy difference

Subject 1

Token	Average
sye	-9.5
si	1.2
sya	-7
syu	6.6
syo	-2.8
sa	15.5
se	12.3
cf. swi	6.9

Subject 2 (energy difference between 3-4 and 5-6 kHz)

Token	Average
sye	-7.8
si	-3.9
sya	-9.2
syu	-7.9
syo	-7.5
sa	3.1
se	3.7

Subject 3

Token	Average
sye	-3.9
si	-1.7
sya	-3.9
syu	3.9
syo	-1.1
sa	13.7
se	11.3
cf.) s(wy)e	-0.7

Subject 4

Token	Average
sye	-1.1
si	2.2
sya	-3.9
syu	1
syo	-6
sa	15.8
se	19.6
cf.) s(wy)e	-10.1

The results show that band energy difference between the area near 6 kHz and the one near 4 kHz clearly distinguishes palatalized fricative from fricative before open vowels: palatalized fricative such as /s(ye)/, /s(i)/, /s(ya)/, /s(yu)/ or /s(yo)/ show negative or minimally positive value whereas /s/ before open vowels like /s(e)/ and /s(a)/ show positive value: Band energy difference of any palatalized token never showed higher value than that of any non-palatalized token. Though the exact frequency area for peaks of each /s/ may differ per talker, this is the general frequency area in which high energy occurs.

3. Conclusion

This paper examined characteristics of the spectral shapes of the fricative noise in various phonological contexts and showed that these characteristics can be represented by different acoustic features like the location of the main peak, center of gravity frequency, and the band energy difference.

We suggest that the differences among various /s/ in Korean occur due to the coarticulation of Korean fricative /s/ with the upcoming segments which begins from the very start of the production of fricative. Coarticulation with the upcoming segments occurs only if the articulators of /s/ and those of the upcoming segments are compatible. Specifically, when Korean /s/ is followed by a high front segment, the articulatory component of an upcoming segment, the tongue body position, can be overlapped with that of the fricative since it does not disrupt the most important characteristics of fricative, namely narrow constriction between the roof of the mouth and the tongue body. As the result, the modified front cavity of the constriction amplifies the frequencies in palatal area. The extent of the coarticulation between /s/ and the following high segment is complete as can be called total assimilation.

At the beginning of this paper, we mentioned that English /ʃ/ is adapted as Korean /s(yV)/ or /s(i)/ sequence in some of the loanwords. The correspondence between English /ʃ/ and its Korean /s/-initial sequence shown in (1) can be well explained if we compare the spectral shapes of English /ʃ/ and its corresponding Korean /s/-initial sequence. Kang (2010b) shows that /ʃ/ produced by English female talker was mostly perceived as Korean /si/ sequence. The spectrum of English /ʃ/ from the word ‘shade’ by this talker is given in Figure 4. It shows high peaks around 4 kHz similar to Korean /s/-initial sequence of /s(i)/ or /s(yV)/ shown in Figure 2. The line in the middle of the spectrum represents 4 kHz.

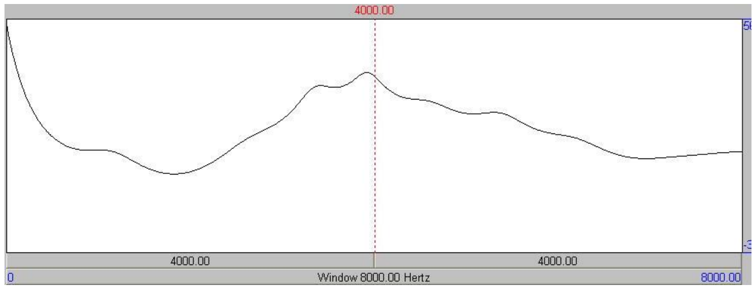
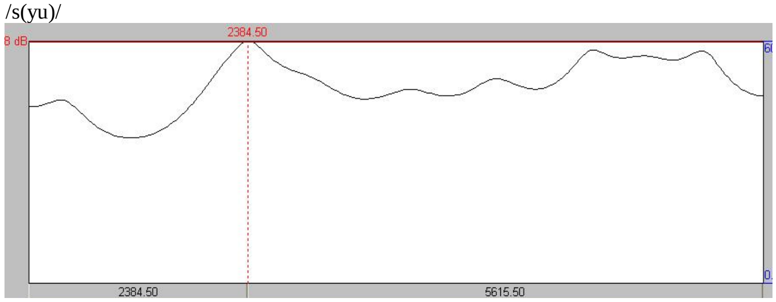


Figure 4. English /ʃ/ of Subject 1 in ‘shade’

There is another type of correspondence between English /ʃ/ and its Korean /s/-initial sequence. As is shown in (1), English /ʃ/ often shows /w/ in its Korean correspondent as in ‘ship’ /swip/. This may have something to do with the rounding effect that we did not mention in this paper. While examining spectral shapes and center of gravity frequency of /s/ in various positions, it is observed that some /s/ before a high front segment show high peaks around 2.3 kHz, not around 4 kHz as expected. Consider Figure 5.

a. /s(yu)/



b. /s(yo)/

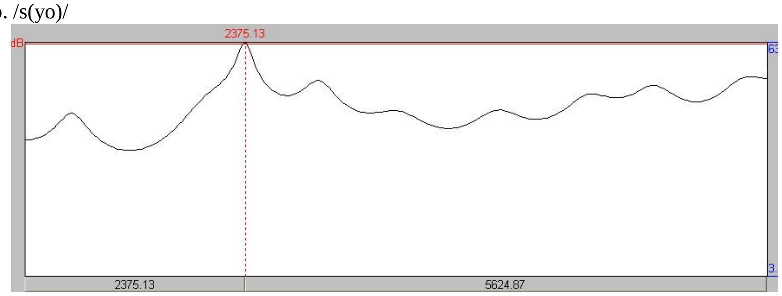
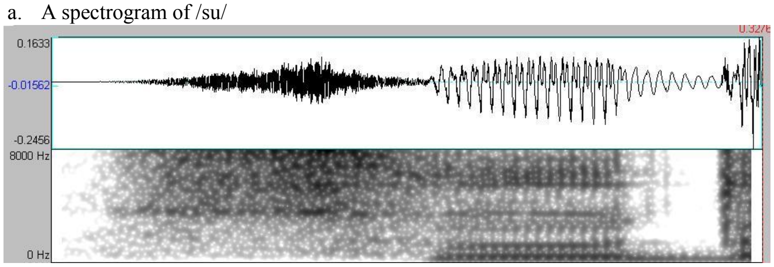


Figure 5. Spectrum of /s/ before /(yu)/ and /(yo)/

Interestingly, in this case /s/ is followed by /yu/ and /yo/, and the shared phonological context for /s/ is that it is followed by a high front segment and a round segment. The effect of rounding on /s/ is certainly caused by a following round segment (cf. Bell-Berti and Katherine 1979, Daniloff and Moll 1968). As we see in Figure 6, energy is concentrated on the frequency area around 4 kHz from the start of /s/ when followed by /u/. Note that the amplitude of frication noise rises fairly rapidly to its maximum value at approximately 3.7 kHz for sibilant /s/ before /u/. Importantly, no distinctively strong spectral energy is observed in the palatalized fricative frequency range, especially in 2.5-3.3 kHz and 4-5 kHz.

a. A spectrogram of /su/



b. The spectrum of /s(u)/

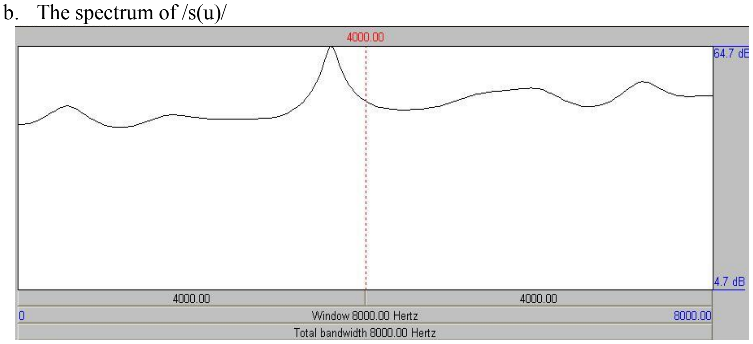


Figure 6. A spectrogram and a spectrum of /s(u)/

The detailed effect of rounding and fronting on /s/ and its implication on Korean phonology will be examined in another paper (Kang 2010a).

REFERENCES

BECKMAN, M. and A. SHOJI. 1984. Spectral and perceptual evidence for CV Coarticulation in devoiced /si/ and /syu/ in Japanese. *Phonetica* 41, 61-71.

BEHREN, SJ. and S. BLEUMSTEIN. 1988. Acoustic characteristics of English voiceless fricatives: A descriptive analysis. *Journal of Phonetics* 16, 295–298.

BELL-BERTI, F. and S. KATERINE. 1979. Anticipatory coarticulation: some implications from a study of lip rounding. *Journal of the Acoustical Society of America* 65, 1268-1270.

BOERSMA, P. and D. WEENINK. 2002. Version 5.1.07 Praat: doing phonetics by computer (Version) [computer program].

DANILOFF, R. and K. MOLL. 1968. Coarticulation of lip rounding. *Journal of Speech and Hearing Research* 11, 707-721.

FORREST, K., WEISMER, G., MILENKOVIC, P. and R. N. DOUGALL. 1988. Statistical analysis of word-initial voiceless obstruents: Preliminary data. *Journal of the Acoustical Society of America* 84, 115-123.

HARRIS, K. 1958. Coarticulation of lip rounding. *Journal of Speech and Hearing Research* 11, 707-721.

HEINS, J. M. and K. STEVENS. 1961. On the properties of voiceless fricative consonants. *Journal of the Acoustical Society of America* 33, 589-596.

HUGHES, G. W. and M. HALLE. 1956. Spectral properties of fricative consonants. *Journal of the Acoustical Society of America* 28. 303-310.

JONGMAN, A., WAYMAN, R., and S. WONG. 2000. Acoustical characteristics of English fricatives. *Journal of the Acoustical Society of America* 108, 1252-1263.

KANG, H. 2006. An acoustic study of the perceptual significant of F2 transition of /w/ in English and Korean. *Speech Sciences* 13, 7-21.

KANG, H. 2010a. Coarticulation effect of Korean /s/ before a high front and a round segment and its implication of the domain of coarticulation in Korean. Ms. Hanyang University.

KANG, H. 2010b. Coarticulation effects and perceptual neutralization of Korean sibilant fricative /s/ in various contexts. Ms. Hanyang University.

LIBERMAN, A. M., COOPER, F. S., HARRIS, K. S., MACNEILAGE, P. F. and M. STUDDERT-KENNEDY. 1967. Some observations on a model for speech perception. In W. Wathen-Dunn (ed.), *Models for the perception of speech and visual form* pp. 68-87. Cambridge, MA: MIT Press.

MANN, V. and B. REPP. 1980. Influence of vocalic context on perception of the [ʃ]-[s] distinction. *Perception and Psychophysics* 28, 213-228.

REPP, B. and V. MANN. 1981. Perceptual assessment of fricative-stop coarticulation. *Journal of the Acoustical Society of America* 69, 1154-1163.

SOLI, S. D. 1981. Second formants in fricatives: The acoustic consequences of fricative-vowel coarticulation. *Journal of the Acoustical Society of America* 70, 976-84.

YENI-KOMSHIAN, G. H. and S. D. SOLI. 1981. Recognition of vowels from information in fricatives: Perceptual evidence of fricative-vowel coarticulation. *Journal of the Acoustical Society of America* 70. 966-975.

Hyunsook Kang
Department of English Language and Culture
Hanyang University
Sa-3 dong, Ansan-si Sangnok-gu Gyunggi-do
426-791 Republic of Korea
e-mail: hskang@hanyang.ac.kr

received: February 17, 2010
accepted: April 10, 2010