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Korean Sibilant /s/ before a High Front and a Round Segment

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ABSTRACT

In this paper, we investigate acoustic characteristics of Korean /s/ when it is followed by both a high front and a round segment regardless of their order to one another. We show that Korean /s/ in this environment has characteristics of a labio-palatalized segment, being affected by both a high front and a round segment if they occur within the domain of a syllable. In the experiment, we show that Korean /s/ before a high front and a round segment shows a spectral shape different from that in other environments. Specifically, it is different from /s/ before a high front segment only, showing peaks around 2.5 kHz. Furthermore, it shows a rapid decrease of amplitude in 4-5 kHz, and sometimes another plateau of high peaks in 5-6 kHz. We also examined center of gravity frequency and band energy difference. Based on the results of this experiment, we argue that Korean /s/ is affected by the following segments within the domain of coarticulation, a syllable and that the degree of coarticulation is different from language to language.

Keywords: spectral shapes of /s/ in Korean, center of gravity, band energy difference, coarticulation, spectra

1. Introduction

Korean has two alveolar sibilant fricatives, aspirated /s/ and tense /S*/. One of these alveolar fricatives, /s/, substitutes English alveolar fricative /s/ and alveopalatal fricative /ʃ/ in loanwords as examples in (1) and (2) show.

(1) English Loanwords
 a. smile [sɨmail]
 b. studio [sitʰudio]
 c. spy [sɨpʰai]

(2) English Loanwords
 a. (leader)ship [sip][swip]
 b. shoot [syut]
 c. show [syo][S*yo][2)]
 d. (milk)shake [swyeikʰɨ][3)] [syeikʰɨ]
 e. (sun)shine [swyain] [syain]

Kang (2010a) noted that the substitution of English /s/ and /ʃ/ with Korean /s/ is due to acoustic similarities among these corresponding sounds or sequences. For example, 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 when produced by a male speaker (cf. Heinz & Stevens, 1961; Hughes & Halle, 1956.). English does not show extensive degree of coarticulation between /s/ and the following segment. According to Beckman & Shoji (1984), English /s/ before an /i/ show spectral peaks near the frequencies which are dominant in the spectra of an /ʃ/ only on the last few centiseconds of /s/. On the contrary, Korean /s/ showed peaks in various locations depending on the phonological contexts it occurs in. Specifically, Kang (2010a) showed that that Korean /s/ before a high front

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2) The examples in (2) are from Kang (2010a). Many Koreans produce tense /S*/ instead of plain /s/ as the first segment of this loanword.

3) Korean writing system does not allow two glides as onset. However, Koreans made a new spelling to represent two glides for this loanword.

segment showed peaks around 4 kHz, the palatalized frequency zone, unlike /s/ before an open vowel like /e/ or /a/, which shows peaks near 5-6 kHz.

While considering /s/ before a high front segment, Kang noticed that some /s/ before a high front segment as in /syu/ seems to show quite different acoustic characteristics from other typical palatalized /s/. Rather, she noted that /s/ in /syu/ shows a similar spectral shape as that in /swi/ in which the segment that immediately follows /s/ is /w/, a round segment.

Since the common phonological environments of /s/ in /syu/ and /swi/ are a high front and a round segment even if their order is reversed in these two sequences, this paper attempts to investigate the acoustic characteristics of /s/ in various environments to see how important the order of segments that follow /s/ in the /s/-initial sequence is and what the phonological implications of the order of segments are in phonology.

2. Experiment

2.1 Methods

For the experiment in this paper, we used the data which was recorded and used for Kang (2010a). Four male speakers from Seoul (age 20-25) read a list of sentences containing /s/ and /S*/ in various positions in the normal speed. The word list is given in Table 1. We analyzed stimuli beginning with plain /s/.

Table 1. List of sentences

1. ikɨlʤanɨn syetayeyo.
2. ikɨlʤanɨn switayeyo.
3. ikɨlʤanɨn sutayeyo.
4. ikɨlʤanɨn sətayeyo.
5. ikɨlʤanɨn swatayeyo.
6. ikɨlʤanɨn S*yetayeyo.
7. ikɨlʤanɨn swətayeyo.
8. ikɨlʤanɨn S*atayeyo.
9. ikɨlʤanɨn sitayeyo.
10. ikɨlʤanɨn S*witayeyo.
11. ikɨlʤanɨn S*utayeyo.
12. ikɨlʤanɨn syatayeyo.
13. ikɨlʤanɨn S*yotayeyo.
14. ikɨlʤanɨn S*etayeyo.
15. ikɨlʤanɨn S*ətayeyo.
16. ikɨlʤanɨn S*watayeyo.
17. ikɨlʤanɨn satayeyo.
18. ikɨlʤanɨn syutayeyo.
19. ikɨlʤanɨn sotayeyo.
20. ikɨlʤanɨn syətayeyo.
21. ikɨlʤanɨn S*yatayeyo.
22. ikɨlʤanɨn syotayeyo.
23. ikɨlʤanɨn S*wyetayeyo.
24. ikɨlʤanɨn setayeyo.
25. ikɨlʤanɨn S*otayeyo.
26. ikɨlʤanɨn S*itayeyo.
27. ikɨlʤanɨn swyetayeyo.
28. ikɨlʤanɨn S*watayeyo.
29. ikɨlʤanɨn S*yutayeyo.

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

For the acoustic analyses in this paper, we used the same procedures used in Kang (2010a). Praat (Boersma and Weenink, 2002, Version 5.1.07) was used for the acoustic analyses. For the spectral analyses, all the sibilant fricatives were low-pass filtered at 8 kHz and were Fourir transformed. The time window for the dft was a 30-msec Hamming window from the beginning of the sibilant fricative and all the fricatives which we used in this paper were longer than 30-msec. The excised 30-msec samples did not include the aspiration part of /s/.

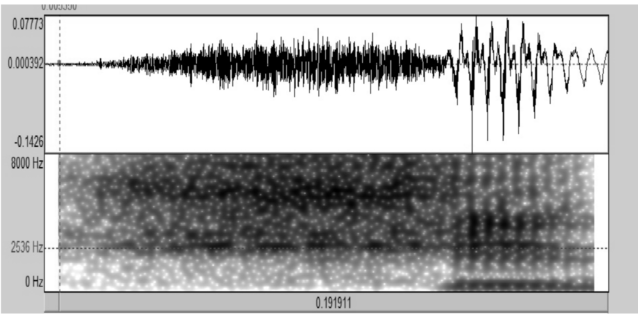
For the excised frication noise, LPC spectral smoothing with 9 peaks (18 coefficients) was computed. The precision with which the frequency of a peak in an individual spectrum was measured was in the range 50 Hz and no pre-emphasis was used. The measurement of center of gravity frequency, and band energy difference in specific frequency range were also calculated.

2.2 Spectrograms

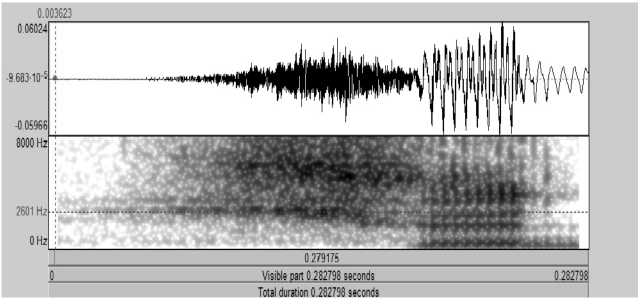
In Figure 1a through Figure 1d, the spectrograms of /s/ that are followed by both a high front and a round segment are shown. These tokens were produced by Subject 1. Only the token in Figure 1d, /swye/[4], is produced by Subject 3. Note that the spectrograms of /s/ if followed by both a high front and a round segment look similar to one another, regardless of which segment

4) After recording two speakers, it came to my attention that Koreans use special spelling system to represent /swye/ sequence. The order of glides /wy/ after /s/ is insignificant since each glide symbol represents a feature, and thus, /wy/ is the combination of [+high, -back, +rnd] features.

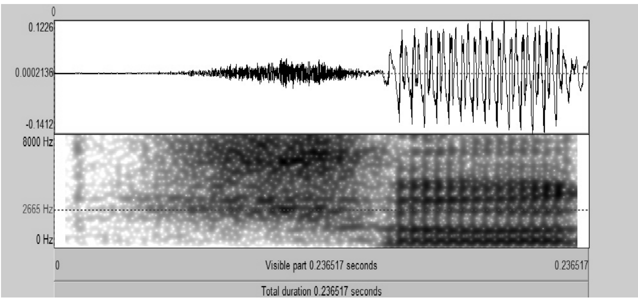
is closer to /s/. Also note that if a round segment is a vowel, it does not matter whether it is a high or a mid vowel.



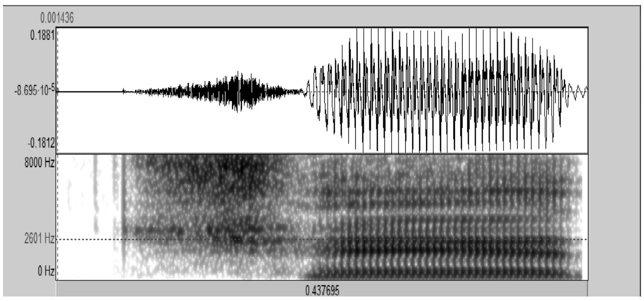
(a) /swi/



(b) /syu/



(c) /syo/

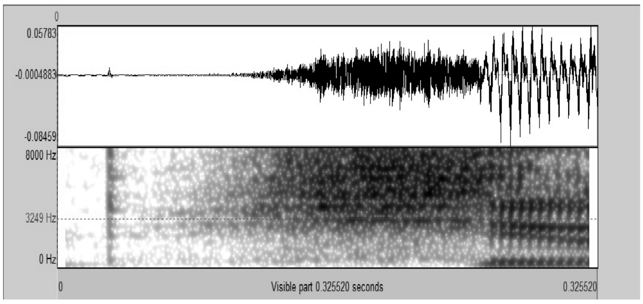


(d) /swye/

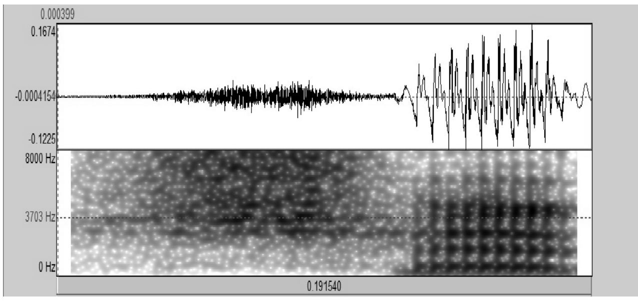
Figure 1. Spectrograms of /s/ before a high front and a round segment

In Figures 2a and 2b, the spectrograms of /s/s which are followed by a high front segment, but not a round segment, are shown.

The difference of spectrograms in Figures 1a-d and 2a-b can be generalized as that those in Figure 1a-d show strong energy in lower frequency than those in Figure 2.



(a) /si/



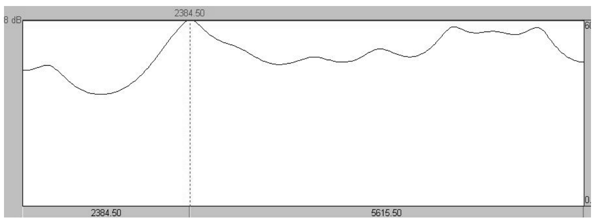
(b) /sye/

Figuire 2. Spectrogram of /s/ before a high front segment

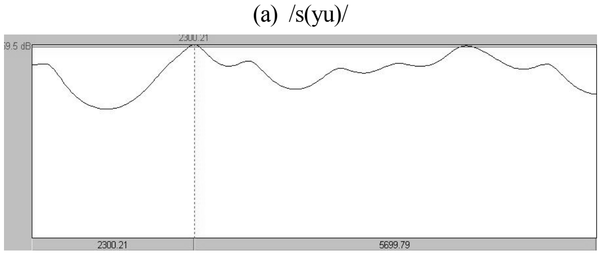
2.3 Spectral Shapes

In order to examine clear differences between these two types of /s/, we examined the spectral shapes of various /s/. In Figure 3a through 3d, spectral shapes of /s/ which are followed by a high front and a round segment regardless of their order to each other are given. In Figures 4a and 4b, spectral shapes of /s(i)/ and /s(ye/) are given (cf. Kang 2010a).

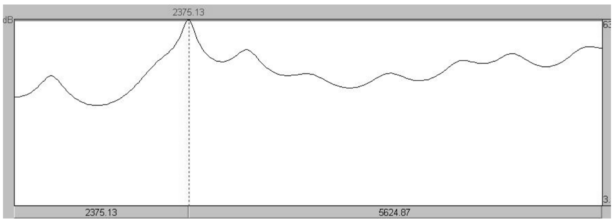
However, the spectra in Figure 3a-3d and Figure 4a-4b are similar to one another in the sense that their peaks are in lower frequency range than those which are followed by an open vowel shown in Figure 5a-5b (cf. Kang, 2010a).



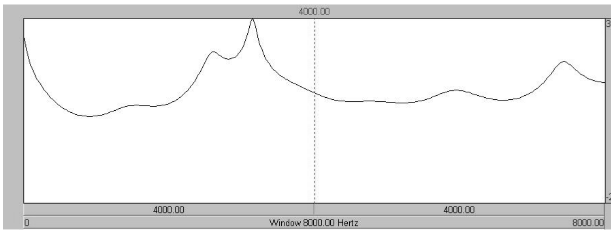
(a) /s(yu)/



(b) /s(wi)/

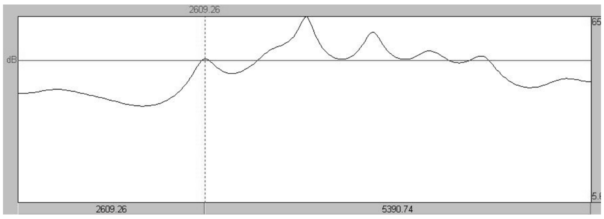


(c) /s(yo)/

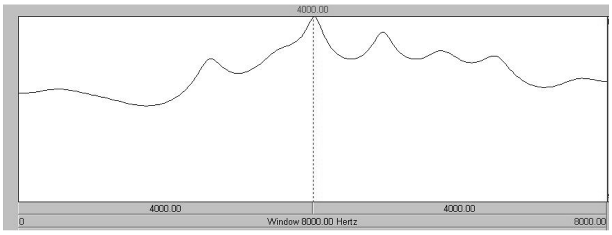


(d) /s(wye)/

Figure 3. Spectra of /s/ before a high front and a round segment

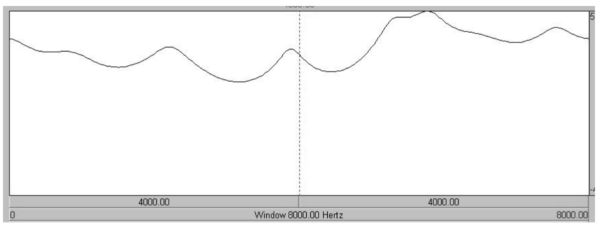


(a) /s(i)/

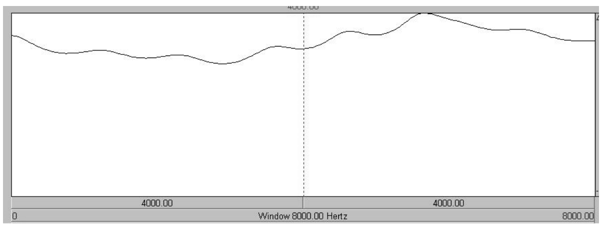


(b) s(ye)/

Figure 4. Spectra of /s/ before a high front segment



(a) /s(e)/



(b) /s(a)/

Figure 5. Spectra of /s/ before an open vowel

Therefore, we conjecture that the /s/s in Figure 3a-3d and in Figure 4a-4b show similarities to one another since they occur before a high front segment even if it may not immediately follow /s/. At the same time, /s/s in Figure 3a-3d and in Figure 4a-4b show spectral differences since fricative /s/ in Figure 3a-3b is also followed by a round segment whereas the one in Figure 4a-4b is not.

Another interesting difference among the spectral shapes of Figure 3 is that depending on speakers and tokens, there is a second plateau of high peaks that occur in the frequency range of 5-6 kHz, though its exact location depends on the cavity length of each speaker. More importantly, there is a rapid dip from the first plateau of high peaks in the spectrum starting at approximately 4 kHz before there is the rise for the second plateau of peaks. This rapid decrease of the amplitude around 4 kHz occurs in all the tokens regardless of whether the second plateau of high peaks occurs or not, and thus, it is in a marked contrast with /s/ in /s()i/ or /s(yV)/ which maintains a stable high peaks in this frequency range.

2.4 Center of Gravity

Since the spectral shapes of palatalized fricative, /s(i)/ and /s(yV)/, and labio-palatalized fricative, /s(wi)/, /s(yu)/, /s(yo)/ and /s(wyV)/, are different from one another, we expect that center of gravity frequency may well distinguish these two types of /s/ (cf. Forest et al, 1988; Jongman et al, 2000). However, for center of gravity frequency to play a role in distinguishing these two variants of /s/, it is important to compute center of gravity within a certain frequency range. This is due to the second plateau of high peaks that may occur in the frequency range of 5-6 kHz for the labio-palatalized fricative. After examining the spectral shapes of four speakers, we conclude that 5 kHz seems to be the appropriate frequency that divides the first plateau of high peaks from the second one for labio-palatalized fricative. The results are given in Table 2. As one can verify, center of gravity of labio-palatalized /s/ is several hundred Hz lower than that of palatalized /s/.

In fact, all the tokens of labio-palatalized /s/ show lower center of gravity frequency than all the tokens of plain palatalized /s/ for each speaker.

Table 3 shows that if center of gravity is not limited between 0-5 kHz and allowed up to 10 kHz, the spectral difference between these two variants of /s/ cannot be distinguished from one another.

Table 2. Center of Gravity between 0-5kHz

Token	Average of Center of Gravity
sye	3796
si	4019
sya	3804
Average of palatalized fricative	3873
swi	3025
syu	2926
syo	2937
swye	3021
Average of labio-palatalized fricative	2977

Table 3. Center of Gravity between 0-10kHz
Sub 1

Token	Average of Center of Gravity
sye	4364
si	5002
sya	4451
swi	5002
syu	4786
syo	4668

Note that in Table 3 center of gravity of labio-palatalized /s(wi)/ is as high as palatalized /s(i)/, and is higher than that of plain palatalized /s/ in /s(ya). No consistency can be found.

Again, the results in Table 2 show that the segments that may not immediately follow /s/ affects the acoustic characteristics of /s/ and thus, the domain of coarticulation in Korean is the domain of a syllable. Furthermore, in measuring center of gravity, it is necessary to take the spectral shapes into consideration for it to play a role in distinguishing different types of /s/.

2.5 Band Energy Difference

Band energy difference may also capture the differences among /s/s in various contexts. The spectral shapes have shown that the first plateau of high peaks occur around 2.3 kHz, and a valley of amplitude around 4.5 kHz in the spectra of labio-palatalized /s/ whereas the peaks of palatalized /s/ occur near 4.5 kHz. To capture these different characteristics of the spectral shapes, we used band energy difference between two critical frequency areas, the frequency area of 4.5-5.0 kHz in which energy is low for labio-palatalized /s/ whereas it is still high for palatalized /s/ and the frequency area of 2.3-2.8 kHz in which energy is high for labio-palatalized /s/ whereas it is comparatively low for plain palatalized /s/. Thus, we expect negative value for labio-palatalized /s/ and positive or minimally negative value for palatalized /s/ if we compute the energy difference between these two frequency bands. The results are given in Table 4.

Table 4 Band energy difference
(a) Sub 1(difference of energy between 2.3-2.8 kHz and 4.5-5.0 kHz)

Token	Average of Band Energy Difference
sye	4.7
si	9.8
sya	6.8
swi	-5.5
syu	-10.7
syo	-15.5

(b) Sub 2 (difference of energy between 2.3-2.8 kHz and 4.5-5.0 kHz)

Token	Average of Band Energy Difference
sye	5.8
si	10.7
sya	4.2
swi	-8.1
syu	-1.85
syo	-4.4

(c) Sub 3 (difference of energy between 2.3-2.8 kHz and 3.7-4.2 kHz)

Token	Average of Band Energy Difference
sye	0.8
si	10.4
sya	2.7
swi	-6.9
swye	-5.2
syu	-8.7
syo	-7.3

(d) Sub 4 (difference of energy between 2.3-2.8 kHz and 4.5-5.0 kHz)

Token	Average of Band Energy Difference
sye	8.0
si	12.8
sya	9.1
swi	-5.2
swye	-10.8
syu	-8.6
syo	-16.8

As we predicted, band energy difference between the two critical frequency areas show the expected results. There was no instance of any labio-palatalized /s/ which shows higher value than any token of plain palatalized /s/ for each talker. This shows that characteristics of these two frequency areas for labio-palatalized and plain palatalized spectra are very significant ones that separate one from the other.

3. Conclusion

The Experiment in this paper began with the question why different acoustic characteristics occur between /s/ in /s(yu)/ and /s/ in /s(ye)/ even if both /s/s were immediately followed by a high front segment. Results showed that contra to the general assumption that a segment is affected by the immediately following segment, /s/ in /s(yu)/ show similar acoustic characteristics such as spectral shapes, center of gravity and band energy difference to those of /s/ in /s(wi)/, /s(yo)/ and /s(wye)/ even if the immediately following segment may be different. The closer inspection shows that all these /s/s share certain phonological contexts. That is, all these /s/s are followed by both a palatal and a round segment regardless of their order to one another in the domain of a syllable unlike /s/s in /s(ye)/, /s(ya), and /s(i)/ which are followed only by a palatal segment.

It is well known that phonological contexts are important since nearby segments affect the target due to the coarticulation. In particular, it is the immediately surrounding segment that affects the preceding or following target. However, the Experiment in this paper showed that it is not the immediate segment but the segments in the Onset-Nucleus domain that affect the target /s/ in Korean. This raised questions regarding what the domain of coarticulation is in Korean. We suggested that the coarticulation domain for palatalization and labialization is Onset-Nucleus, or rather a syllable in Korean.

This type of the extensive coarticulation of Korean palatalization and labialization in the domain of syllable can be explained with two principles: articulatory compatibility, that is, articulators of an upcoming segment begin earlier if they are compatible with those of the preceding segment (cf. Daniloff & Hammarberg, 1973), and language particular phonetic timing relationship of articulators which explains the time course of anticipatory coarticulation (cf. Beckman & Shoji, 1984). Specifically, Korean language particular phonetic timing of articulators requires the articulators of the onset and the nucleus to begin from the very start of the syllable if they are compatible.

Compatibility among articulators and language particular phonetic timing need to be clearly defined in each particular language. In Korean, tongue position of the following high front segment begins from the very beginning of sibilant /s/ unlike English (cf. Beckman & Shoji, 1984). That is, the tongue position of a high front segment replaces the neutral tongue position of /s/ from the beginning and this replacement does not interfere with the narrow opening necessary for the fricative, the most important aspect of the fricative /s/. In this sense, the tongue position of a high front segment is compatible with /s/. Lip rounding may also start at the beginning of /s/ in Korean if the round segment is in the domain of syllable[5]. Lip rounding does not interfere with any articulatory actions of /s/ (cf. Daniloff & Moll, 1968; Bell-Berti & Harris, 1979). Thus, articulators of a high front segment and lip rounding may affect /s/ from the very beginning of the preceding /s/ in Korean.

What is the degree of overlapping of gestures of a target and the following segments in Korean? Korean glide does not seem to show its distinctive duration. Kang (2006) showed that Korean /w/, when it occurs after a consonant, modifies the burst frequency, the frequency of concentrated energy in the aspiration period and the frequency of the following vowel but does not have its own distinctive segmental duration unlike English /w/. Specifically, Kang (2006) showed that spectrograms of Korean /t^hwin/ or /T*win/ are very different from that of English /twin/: Korean glide /w/ is realized as flat transition from the release period to the following vowel /i/, whose formants were lower than regular /i/ and there is no distinctive period which can be specifically designated as /w/ whereas English /w/ has its own target frequency and its own duration (cf. Sussman, 1994).

The different degrees of overlapping of gestures explain why Korean /s/ replaces English /s/ and /ʃ/ in various contexts. The correspondence between English /ʃ/ and its Korean /s/-initial sequence shown in (2) 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 /s(i)/ sequence. Figure 6[6] shows the spectrum of English /ʃ/ from the word 'shade' by this talker. High peaks occur around 4 kHz similar to Korean /s/-initial sequence of /s(i)/ or /s(yV)/ in Figure

5) Lip rounding affects the preceding /s/ with different degree depending on the speaker, though most speakers show the full rounding effect from the very beginning of /s/. We will talk about the degree of rounding in another paper.
6) Figure 6 comes from Kang (2010a, b).

4. The line in the middle of the spectrum indicates 4 kHz.

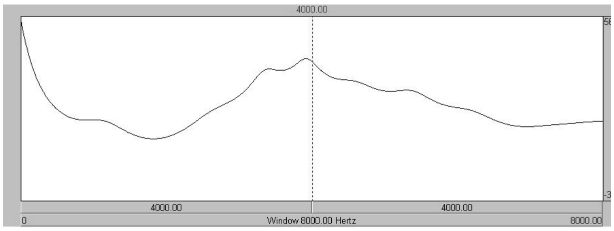


Figure 6. English /ʃ/ in ‘shade’ by Subject 1

The spectrum of /ʃ/ from ‘shone’ spoken by an English male talker is given in Figure 7[7]. We can see peaks occur around 2.3 kHz, a valley of amplitude around 4-5 kHz and another plateau of high peaks around 5-6 kHz. These characteristics are very similar to those of Korean labio-palatalized /s/-initial sequence. According to Kang (2010b), most Korean listeners perceived this token as Korean /syu/ and a few perceived it as /swi/ sequence, but no one perceived it as /si/. The line in the middle of the spectra represents 4 kHz.

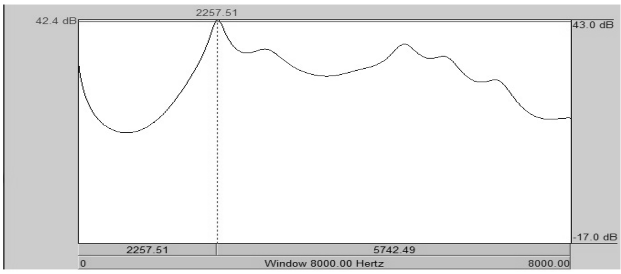


Figure 7. English /ʃ/ in ‘shone’ by Subject 2

The acoustic similarities between English /ʃ/ and its corresponding Korean /s/-initial sequence show that similar acoustic features are categorized differently in different languages due to different degrees of coarticulation of each particular language.

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7) Figure 7 comes from Kang (2010a, b).