The Place of Articulation of Korean Affricates Observed in LPC Spectra

Hyunsoon Kim*

ABSTRACT

This paper attempts to acoustically examine the place of articulation of Korean affricates. In order to pursue an acoustic analysis of where Korean affricates are articulated, we resort to LPC spectra of the Korean plain affricate /c/ in intervocalic position, based on theoretical assumptions (e.g., Stevens 1993a), and compare the data to that of the Korean alveolar consonants /t, s/ in the same context. Our phonetic results show that in intervocalic position, the Korean plain affricate is alveolar just like the Korean alveolar consonants /t, s/, supporting the articulatory studies of Skaličková (1960) and Kim (1997).

Keywords: Korean affricates, stops, fricatives, LPC spectra

1. Introduction

In the literature there is no consensus about the place of articulation of the Korean affricates. Many linguists have considered Korean affricates as post-alveolar with no further theoretical or experimental investigation. W. Huh (1964), K.-M. Lee (1972, 1978), C.-W. Kim & S.-C. Ahn (1983), S.-C. Ahn (1985), Sohn (1987), Cho (1990) and H.-B. Lee (1993), among others, refer to the Korean affricates as palato-alveolar affricates /tʃ, tʃʰ, tʃ'/. Kim-Renaud (1974) and S.-G. Kim (1976) classify them as palatal affricates whose place of articulation they simply assume is the same as that of the palatal glide /j/ (e.g., Kim-Renaud 1974). On the other hand, Hume (1990, 1992) proposes that Korean affricates are alveolo-palatals, based on her consultation of a single native speaker that in the Kyŏngsang dialect, only affricates block Umlaut, while noncoronal consonants and the other coronal consonants are transparent to vowel fronting. Regarding phonetic studies of the place of articulation of the Korean affricates, we can refer to Skaličková (1960) and Kim (1997). Skaličková (1960) offers articulatory data consisting of her own X-rays, palatograms and linguograms from nine Korean speakers: three from South Korea and the other six from North Korea. In thearticulatory study of Skaličková (1960) Korean affricates in word-initial and intervocalic positions are proposed as alveolars, not as post-alveolars. Recently Kim (1997) offers palatograms and linguograms of Korean obstruents, and confirms the results of Skaličková (1960).

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Since there is still much disagreement in the literature over how the Korean affricates are characterized in terms of place of articulation, this paper attempts to acoustically examine the place of articulation of the Korean affricates. Though the articulatory data of Skalicčková (1960) and Kim (1997) shows that the place of articulation of the stop phase of the Korean plain affricate /c/ is alveolar like the alveolar consonants /t, s/, it does not tell us whether, if it is an affricate, its fricative portion is articulated at the alveolar ridge just like its complete oral closure. This is because it captures only the first phase of an affricate, that is, its oral closure. Thus, articulatory data based on static X-ray tracings, palatograms and linguograms cannot tell us whether or not a segment in question is internally complex, i.e. involves internal movement, though it can tell us where oral contact occurs and what articulator is involved.

The inherent limitations of the static articulatory data concerning the place of articulation of an affricate can be overcome by investigating acoustic cues for the place of articulation of the two articulatory phases of an affricate by means of LPC spectra, as we will discuss in the following section. Thus in this paper we will look into our acoustic data of LPC spectra of the Korean plain affricate /c/ in intervocalic position in order to identify the place of articulation of Korean affricate and compare it with that of the Korean consonants /t, s/ in the same context. Note that since our main focus is on the place of articulation of Korean affricates, only the plain affricate /c/ will be discussed, on the assumption that its aspirated and tense counterparts /c^h, c'/ have the same place of articulation as their plain counterpart.1)

Before looking into acoustic data, we will first introduce some theoretical background for why we depend on LPC spectra to examine the place of articulation of Korean affricates.

2. Theoretical Considerations

Our interpretation of the acoustic cues for place of articulation in the Korean coronal obstruents /t, s, c/ is based on the theory that these acoustic cues lie in the relation between the spectral peak of a consonant at a specific point and the formant values of a following vowel in its steady-state, because the relation of spectral peaks to vowel formants provides a relatively stable method of cross-speaker comparison (e.g., Stevens 1972, 1985, 1989; Dorman et al. 1977; Soli 1981; Kewley-Port 1983; Lahiri et al. 1984; Ohde & Stevens 1983; Sereno et al. 1987; Hedrick & Ohde 1993).2)

As acoustic cues for place of articulation of obstruents, it has been proposed that the spectral peaks of obstruents at their release correspond to the formants of following vowels,

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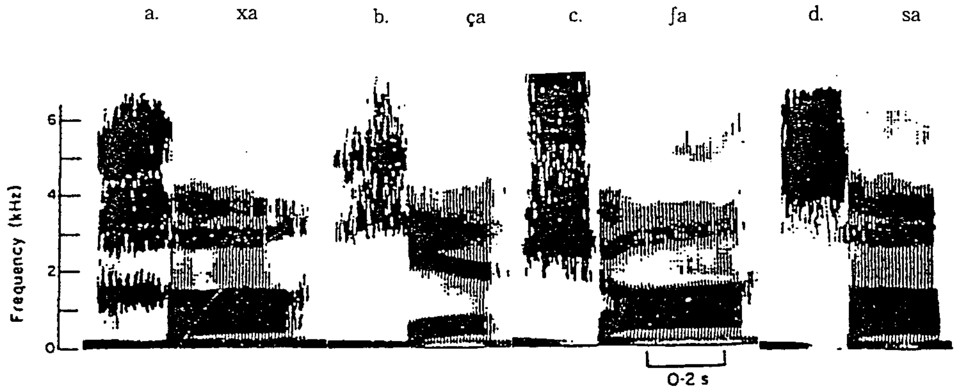
1) Since we have not yet demonstrated the exact place of articulation of the Korean affricates, we will provisionally use letters /c, c^h, c'/ for the affricates. Elsewhere we will employ IPA transcriptions for the purpose of consistency, throughout this study.

2) Another assumption for acoustic cues for place of articulation of obstruents is the hypothesis of an absolute spectral frequency peak. According to the hypothesis, there are invariant acoustic properties that are independent of the vowel context for each place of articulation (e.g., Halle et al. 1957; Heinz & Stevens 1961; Jakobson et al. 1963).

though this correspondence can be expected to vary, depending on vowel contexts.[3] Regarding spectral peaks of obstruents in relation to the formants of following vowels, Stevens (1989:26) provides a good example of the acoustic correlates of fricatives in different places of articulation. As shown in Figure 1, fricatives produced with constrictions at several points along the vocal tract are acoustically manifested differently when followed by the vowel /a/.[4]

Figure 1. Wide-band spectrograms taken from Stevens (1989:26)



In these spectrograms, the velar fricative /x/ has its highest spectral peak at the region close to F_2 of the following vowel /a/ in Figure 1 (a), and according to Stevens, this spectral peak is "affiliated with the front cavity"; the palatal fricative /ç/ formed in the region of the hard palate has its highest spectral peak at the region close to F_3 of the following vowel, as in Figure 1 (b); the palato-alveolar fricative /ʃ/ occurring in "the palatal region with a space under the tongue blade" has its highest spectral peak at F_3 of the following vowel with some irregularly striated friction noise distributed over the region of F_2, as in Figure 1 (c); the fricative /s/ occurring near the alveolar ridge has its highest spectral peak at the region close to F_4 or F_5 of the following vowel, as in Figure 1 (d).[5] The relation of the spectral peak for the palato-alveolar to the formant of a following vowel is lower than that of the alveolar fricative /s/, because the front cavity of the palato-alveolar is longer, due to the palato-alveolar place of articulation and due to the occurrence of slight lip rounding and protrusion (e.g., Fant 1960).

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3) See Fant (1973), Sereno et al. (1987), Keating & Lahiri (1993), etc. for the different formant correspondence of velar consonants in different vowel context.

4) Stevens (1989) does not mention to which language the fricatives in Figure 1 belong.

5) Note that there is little difference in the spectral peaks between the palatal fricative /ç/ and the palato-alveolar fricative /ʃ/ in Figure 1. In addition, according to Kudela (1968), all three types of Polish fricatives, [ʃ, ʒ], [ʃʲ, ʒʲ] and [ɕ, ʑ] have their strongest spectral peaks in the F_3-F_4 range. To distinguish these Polish fricatives, Dogil (1994) proposes the perceptual properties of hushing and hissing closely related to the presence/absence of lip protrusion.

As for a perception test of the distinction of /ʃ/ from /s/ in relation to the amplitude of the third formant of a following vowel, we can refer to Stevens (1985) and Hedrick & Ohde (1993) among others. For instance, in a continuum of consonant-vowel stimuli ranging from /sa/ to /ʃa/, Stevens found that when the amplitude of a prominence in the noise spectrum was weak at the third formant frequency of the following vowel /a/, listeners identified the consonant as [s], whereas when it was strong, they identified it as [ʃ].

Adopting the hypothesis of a relative spectral frequency peak, thus, we will examine the correspondence of the highest spectral peak of a consonant to the formant structure of the following vowel in its "steady-state" portion, as the major acoustic cue to consonantal place of articulation. For the fricative /s/ in our experiment, we will see to which formant values of a following vowel the spectral peak at its "steady-state" frication portion corresponds. The reasons why we look at the "steady-state" portion of the fricative are in the following: a) since the fricative /s/ in our test words is placed intervocalically, the fricative may have local vowel-coarticulatory effects in its onset and offset; and b) /s/ has acoustic cues for its own place of articulation in its steady-state portion rather than its transition into a vowel.[6] In the case of the stop /t/, we will depend on the spectral peak at the consonantal release to the formant of a following vowel for acoustic cues for its place of articulation (e.g., Blumstein & Stevens 1979).

Affricates can also be understood in the same framework. Recall that as complex segments, affricates consist of both an oral closure just like in stops and an oral release followed by frication noise just like in fricatives. As shown in Figure 2 (a) taken from Stevens (1993a), the articulatory movements involved in the English palato-alveolar affricate [tʃ] form an oral closure at the alveolar ridge (dashed line) before the release and a narrow oral constriction 20-30 ms following the release (solid line), along the palate. Figure 2 (b) illustrates an idealized configuration of the vocal tract for this affricate in reversed (back-to-front) orientation: the oral closure and the oral constriction of the affricate are schematized as a narrowing near its anterior end (A1), and as a longer, less narrow section behind it (A2), respectively.

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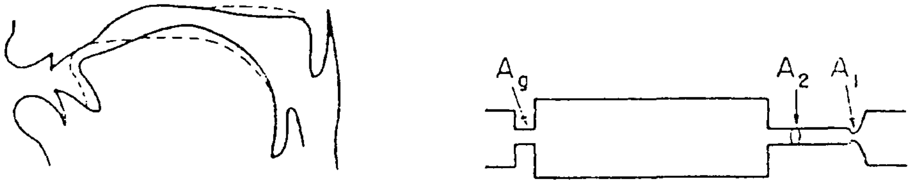
[6] Hughes & Halle (1956) report a perception experiment of English fricatives /f, s, ʃ/ wherein the isolated friction parts of the fricative plus vowel sequences were identified quite well when presented to listeners. Harris (1958) and Heinz & Stevens (1961) report from their perceptual experiments of fricatives that the second formant transition into a following vowel does not have an appreciable effect on /s/ and /ʃ/ responses, in a fricative and vowel sequence, through they provide acoustic cues for the distinction of /f/ from /θ/. According to them, /s/ and /ʃ/ have acoustic properties in the spectrum of their steady-state friction noise portion, supporting Hughes & Halle (1956).

Figure 2. The English palato-alveolar affricate /tʃ/ (Stevens 1993a:35)



a. X-ray tracing

b. an idealized configuration

(Ag : the cross-sectional area of the glottal opening)

From his phonetic experiment based on the schematized model of the vocal tract for an affricate consonant, as in Figure 2 (b), Stevens (1993a:33) claims that "the constriction that is formed by the major articulator to produce an affricate has two parts that can be manipulated somewhat independently": an anterior section denoted as A1 and a posterior section denoted as A2 in Figure 2 (b). Between the two-part constriction at A1 and A2 in Figure 2 (b), Stevens (1993a) proposes that the acoustic cue for the place of articulation of the frication part of an affricate is associated with the second release at A2, at least 20-30 ms after the initial release at A1:

> The spectrum during the early part of the release of the palato-alveolar affricate is not unlike the spectrum that is observed at the release of an alveolar stop consonant [t]. The shape of the constriction posterior to the point of release does not become evident in the sound until 20-30 milliseconds have passed and the cross-sectional area of the anterior part of the constriction becomes sufficiently large.
> (Stevens 1993a:41)

Figure 3, taken from Stevens (1993a:38), shows the spectra calculated at several points during the release of the English palato-alveolar affricate /tʃ/ followed by a neutral vowel, using the model in Figure 2 (b). The spectral peak at the release of the affricate, as indicated by T, corresponds to the fourth formant of a following neutral vowel (V). The spectrum of frication noise about 50 ms following the release, as indicated by a solid line F2, also has its highest spectral peak at around 3,500 Hz corresponding to the fourth formant of a following neutral vowel (V).7)

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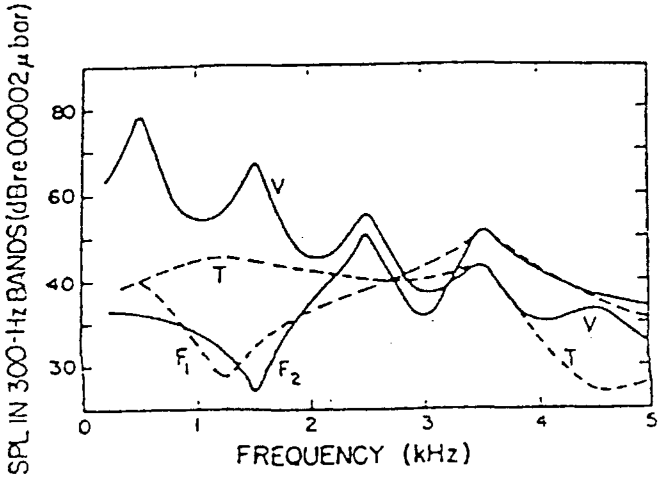
7) According to Stevens, the spectral peak corresponding to the third formant of a following neutral vowel (V) is "the negligible coupling to the palatal channel".

Figure 3. The spectra during the release of the English /tʃ/ (Stevens 1993a:38)



T: Transient source at initial consonant release

F1: Spectrum of frication noise about 15 ms following the initial release

F2: Spectrum of frication noise about 50 ms following the release

V: Spectrum of neutral vowel (male speaker)

Following Stevens (1993a), then, we will depend on the spectral peaks both at the initial release and at least 20-30 ms after the initial release for acoustic cues for place of articulation in our examination of the Korean affricate /c/.

In sum, we assume here that acoustic cues to place of articulation of stops, fricatives and affricates lie in the highest spectral peak in relation to the formant of a following vowel in its "steady-state" portion: at the consonantal release for stops, at the steady-state frication part for fricatives, and at both in the case of affricates. Thus the question of whether the Korean plain affricate /c/ is alveolar or post-alveolar can be closely associated with the question of to which formant of the following vowel the highest spectral peak corresponds at (a) initial release, for the stop phase; (b) a point at least 20-30 ms after the initial release, for the fricative phase. Based on the assumptions laid out so far, we can make a hypothesis about the place of articulation of the Korean coronal obstruents as follows:

(1)

In the case of a stop before __ *a*:

A spectral peak at the release burst of a stop, above F_4 or corresponding to a higher formant of the following vowel, is taken to be a cue to alveolar occlusion; such a peak corresponding to F_4 or a lower formant of the following vowel is taken to be a cue to a post-alveolar occlusion (e.g., Stevens 1993b).

In the case of a fricative before __ *a*:

A spectral peak at the steady-state part of a fricative, corresponding to F_4 or a higher formant of the following vowel, is taken to be a cue to alveolar constriction; such a peak corresponding to F_3 of the following vowel is taken to be a cue to a post-alveolar constriction.

In the case of an affricate before __ *a*:

A stop portion is interpreted like alveolar stops if its spectral peak at the release is above F_4 or corresponds to a higher formant of the following vowel. Or it is interpreted like post-alveolar stops if its spectral peak at that initial release corresponds to F_3 of the following vowel.

A fricative portion is interpreted like alveolar fricatives if its spectral peak at least 20-30 ms after the initial release is above F_4 or corresponds to a higher formant of the following vowel. Or it is interpreted like post-alveolar if its spectral peak at the same points is at F_4 or corresponds to a lower formant of the following vowel.

3. Experiment

3.1 Methods

In our acoustic experiment, a list of words with two open syllables was prepared with target consonants in intervocalic contexts, *a__a*, *a__i* and *a__u*, first within a morpheme and then across a morpheme boundary as presented in (2a) and (2b). The test words in this experiment began with a labial consonant in most cases. When minimal pairs beginning with a labial consonant do not exist, we used lexical items beginning with the consonant /c/.[8]

(2)

/mati/	'knot'
/casi/	'the first of 12 doubled-hours'
/paci/	'pants'
/mata/	'every'
/casa/	'one's own company'
/paca/	'network of wooden stripes'
/catu/	'plum'
/casu/	'self-surrender'
/macu/	'face to face'

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8) We observed in our experiment that a vowel in the first syllable had a higher F_2 formant when preceded by the consonant /c/ than when preceded by labial consonants /p, m/. But since our target consonants were in the second syllable, we assume that possible coarticulatory effects on our target consonants can be ignored.

All the target words were embedded in the frame sentence / əsə ____ haseyo/ 'Say ____ please.' On each page, sentences with target words were randomized with two filler sentences on the top and the bottom to reduce any bias in pronunciation. The four native speakers --two male and two female in their 20's and 30's -- took part in this experiment. Each subject familiarized him/herself with test words by reading them a few times before recording and was asked to read them as naturally as possible during recording. They were then asked to read the sentences five times at normal speed, and were tape-recorded in a sound-treated room at the Institute of Phonetics, ILPGA, University of Paris III. The total of 180 tokens obtained in this way (9 test words x 4 subjects x 5 repetitions) were then analyzed.

3.2 Analysis

Among the target words in (2), only those in the context *a__a* -- /mata/ 'every', /casa/ 'one's own company', /paca/ 'network of wooden stripe' -- were examined, given that a target consonant may have the least vowel-coarticulatory effect when flanked by the vowel /a/ than by any other vowel.[9] The total of the target words in the *a__a* context was then 60 (3 tokens x 4 subjects x 5 repetitions). Each utterance was digitized at 16 kHz to better examine spectral peaks.

The analysis of LPC spectra at a few points within each target consonant was carried out. For an affricate, one spectrum was computed at the stop release by centering a cursor at the burst onset; another was computed for the frication 25-35 ms after the release. In order to compare spectra of consonants to those of following vowels, an LPC spectrum of a vowel was also computed by positioning a cursor at the steady-state part of the vowel. A 25.6-ms Hamming analysis window was used for the LPC analysis of burst onset in vowel.

Figure 4 illustrates these cursor placements in a wide-band spectrogram of the affricate /c/ in /paca/ 'network of wooden stripe': (a) for the stop release spectrum; (b) for the fricative spectrum 25-35 ms after initial release; (c) for the spectrum of the following vowel /a/ in its middle part.

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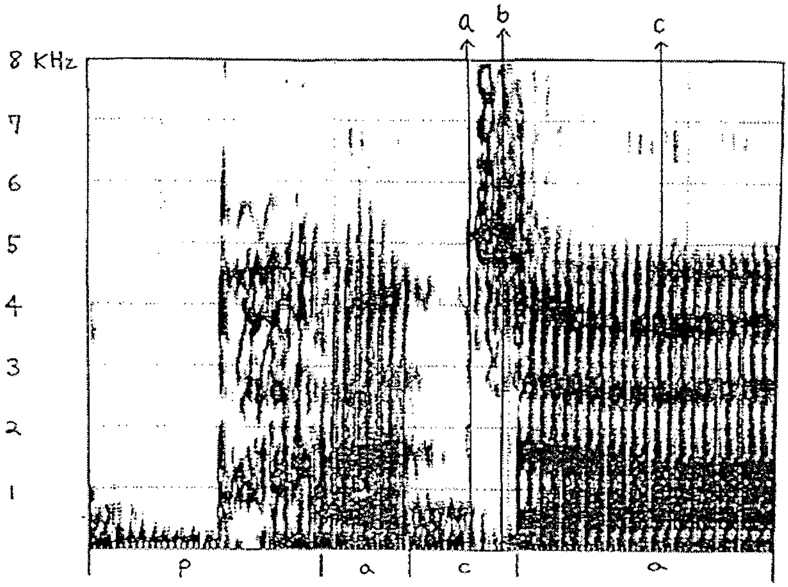
9) According to Soli (1980) and Yeni-Komshian & Soli (1981), the English fricatives /s, z, ʃ, ʒ/ in initial position had the least vowel-coarticulatory effects before the low vowel /a/ than before the high vowels /i, u/. For instance, spectral peaks of fricatives were 100-300 Hz higher before the vowel /i/ than before the back vowels /a, u/. Before /u/, peak frequencies of the fricatives became lower due to the lip rounding effect throughout the consonants.

Figure 4. Cursor Placements for an LPC analysis of the affricate /c/ in /paca/ 'network of wooden stripe'



For the stop /t/, one spectrum was computed (a) at the center of the stop release, and another was computed for the vowel at the middle of its steady-state, as in Figure 5.

Figure 5. Cursor Placements for an LPC analysis of the stop /t/ in /mata/ 'every'

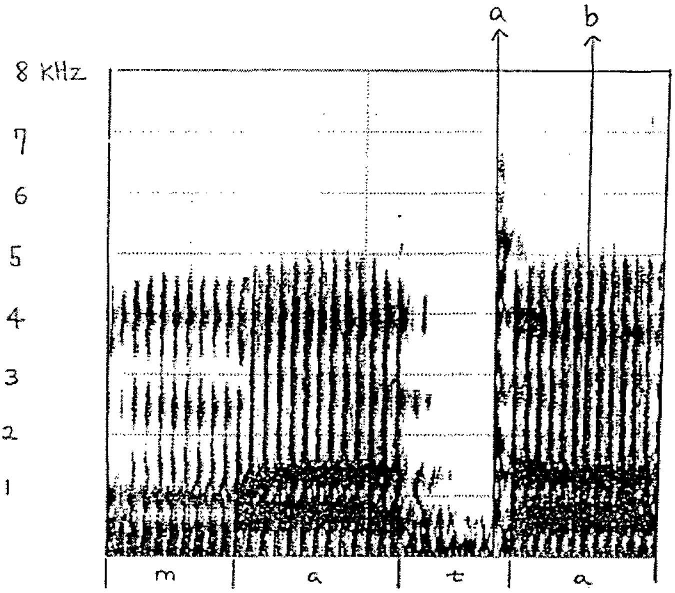
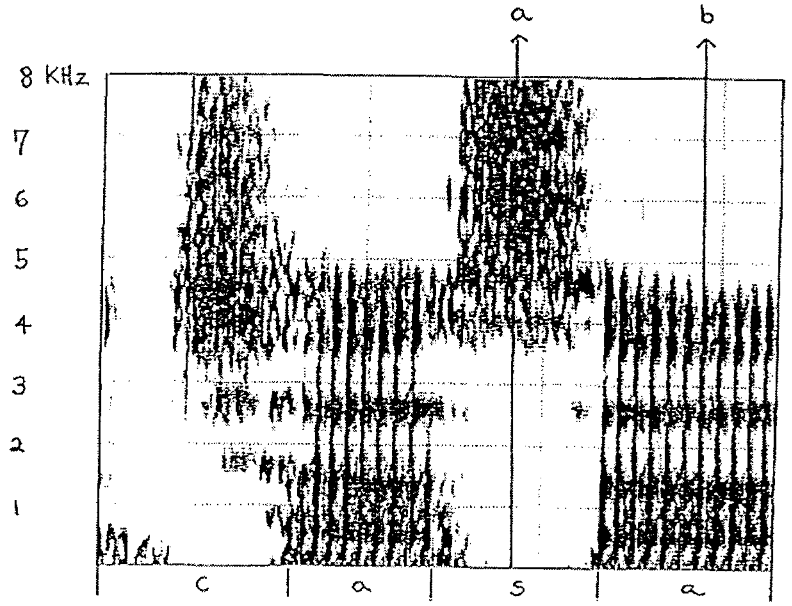


Figure 6 shows cursor placement (a) for the fricative /s/ in the middle of its steady-state and (b) for the following vowel in the middle of its steady-state.

Figure 6. Cursor Placements for an LPC analysis of the fricative /s/ in /casa/ 'one's own company'

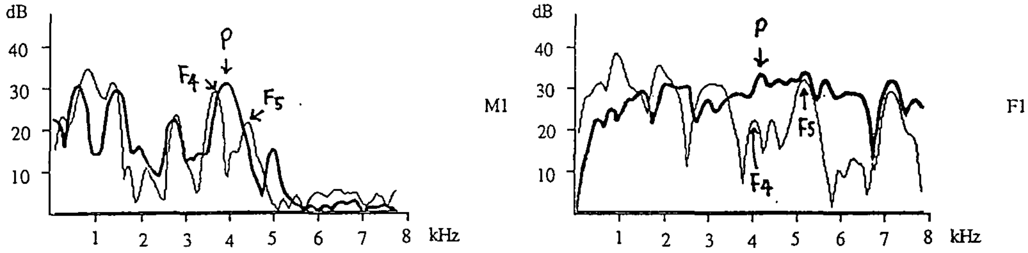


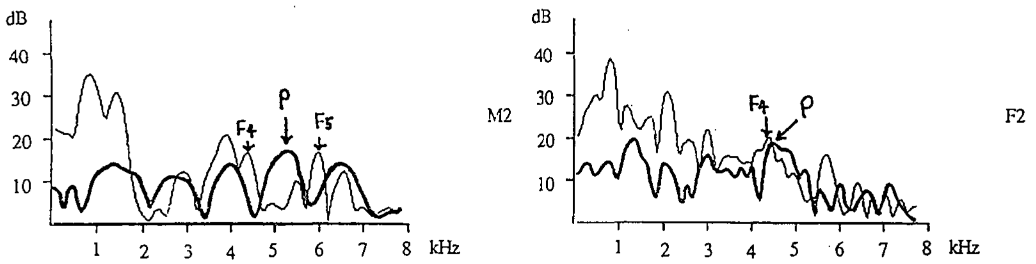
3.3 Results

The representative spectral peaks of /t, s, c/ from our four subjects -- two male, M1 and M2, and two female, F_1 and F_2 -- are presented from Figure 7 to Figure 9 in the context *a*__*a* where the target consonants are within a morpheme. The spectra in those figures are arrayed in the following order: the male subject from Taeku, Kyŏngsang (M1), the other male subject from Taecŏn, Ch'ungch'ŏng (M2), the female subject from Seoul (F1), and the other female subject from Pusan, Kyŏngsang (F2).

Figure 7 superimposes one spectrum at the release of the target consonant /t/ in the context *a*__*a*, and another spectrum at the steady state of the following vowel /a/. The former is represented by the thicker dark line, and the latter is represented by the thinner dark line. For visual clarity, we have marked spectral peaks of the consonants by P and the fourth and fifth vowel formants by F_4 and F_5, respectively, in Figures 7, 8 and 9.

Figure 7. LPC Spectra of the stop /t/ and the following vowel in /ata/

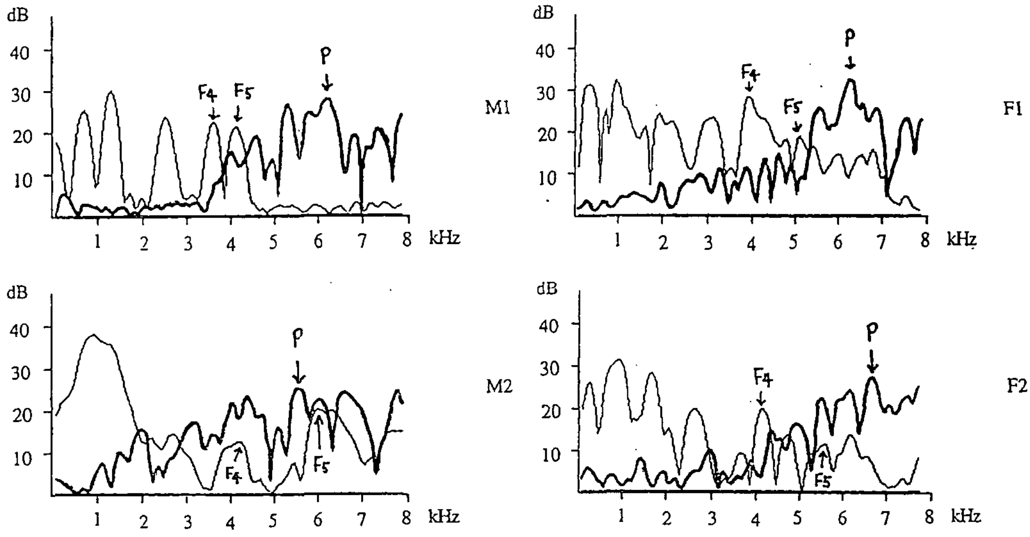




Our male subject M1 had the spectral peak of the stop /t/ at 3,937 Hz, which is between F_4 and F_5 of the following vowel /a/. In the other male subject M2, the spectral peak of the stop is located at 5,312 Hz, which is also between F_4 and F_5 of the following vowel. In our female subject F1, the first strong spectral peak of the stop is in the frequency of 4,187 Hz, also between F_4 and F_5 of the following vowel. In the case of the other female subject F2, the spectral peak of the consonant is located at 4,500 Hz which is a little higher than the frequency of F_4 (4,437 Hz) of the following vowel.

Figure 8 displays one spectrum at the steady state of the fricative, /s/, in the context *a__a*, and the other spectrum at the steady-state middle part of the following vowel /a/ as superimposed. As in Figure 7, the spectrum of a consonant is represented by the thicker dark line, and that of a vowel is represented by the thinner dark line.

Figure 8. LPC Spectra of the fricative /s/ and the following vowel in /asa/



In the male subject M1, the highest spectral peak of the fricative is at 6,250 Hz which is far above the frequency of the F_5 (4,125 Hz) of the following vowel. In the case of subject M2, the spectral peak of /s/ is at 5,562 Hz which is between the F_4 and the F_5 of the following vowel. Our female subjects had the same spectral pattern as that in the male subject M1: in our female subject F1, the spectral peak of the fricative is at 6,312 Hz which is far above the frequency of the F_5 (5,125 Hz) of the following vowel; in the other female subject F2, the spectral peak of /s/ is at 6,875 Hz which is also above the frequency of the F_5 (5,687 Hz) of the following vowel. In short, the male subject M2 had the spectral peak of /s/ between F_4 and F_5 of the following vowel, and the other three subjects had the spectral peaks of /s/ above F_5 of the following vowel.

Figure 9 shows the superimposed spectra of the affricate /c/ and the following vowel /a/. To include more detail, two displays are shown for each token. In Figure 9 (a), the spectrum at the consonant release of the affricate, represented by the thicker dark line, was displayed together with that at the steady state of the following vowel which is represented by the thinner dark line. An additional figure is given in Figure 9 (b) in which the spectrum of a point taken 25-35 ms after the initial release of /c/, represented by the thicker dark line, was displayed together with the spectrum at the steady state of the following vowel represented by the thinner dark line.

Figure 9 a. LPC Spectra at the release of /c/ and the following vowel in /aca/

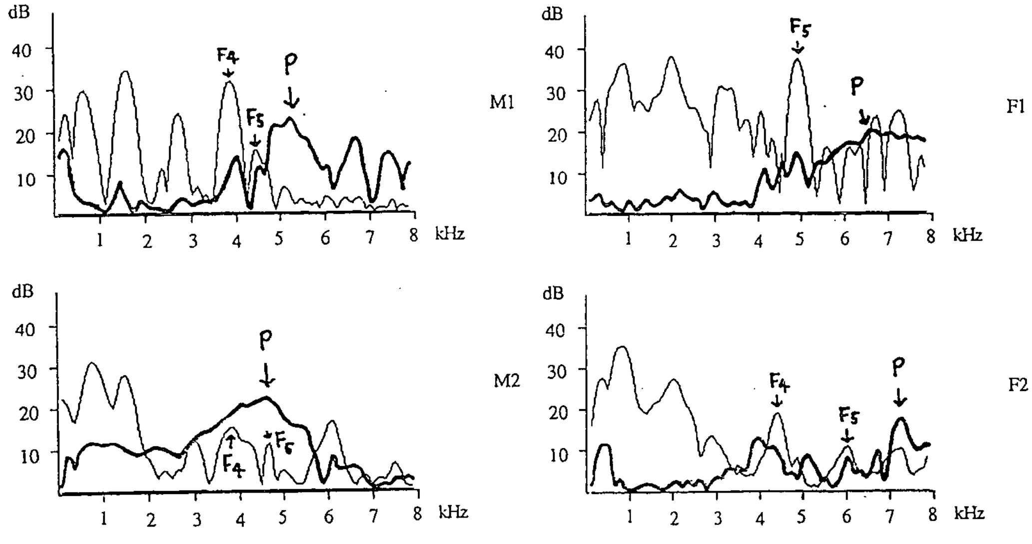
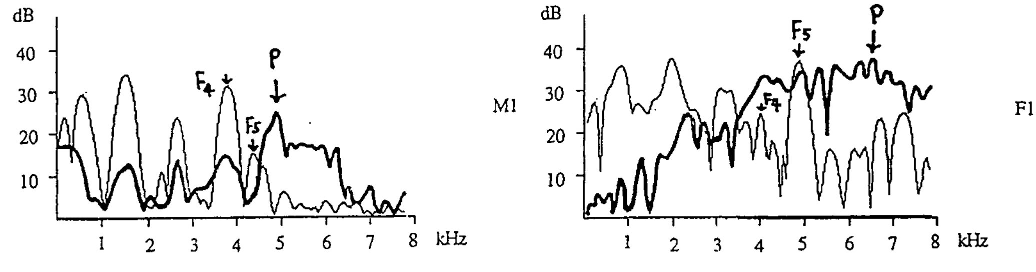
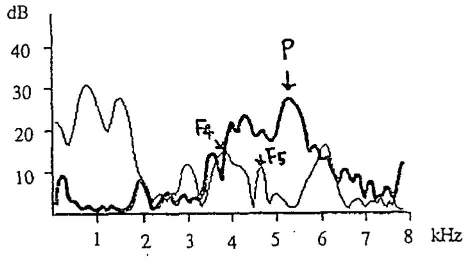
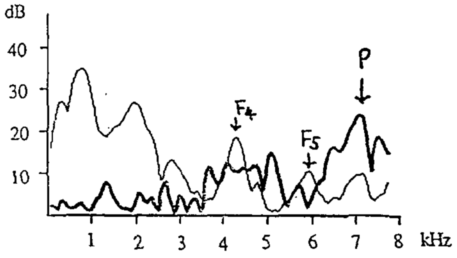


Figure 9 b. LPC Spectra at a point 25-35 ms after the release of /c/ and the following vowel in /aca/





M2



F2

In Figure 9 (a), the male subject M1 had the spectral peak at the consonant release at 5,250 Hz which is above the frequency of the F_5 (4,437 Hz) of the following vowel /a/. The other male subject M2 had the spectral peak at the release at 4,687 Hz which is the same frequency value of the F_5 of the following vowel. Our female subjects had the same spectral pattern at the consonant release as that of the male subject M1: in the female subject F1, the spectral peak at the release is located at 6,625 Hz which is above the frequency value of the F_5 (4,937 Hz) of the following vowel; in the other female subject F2, the spectral peak at the release is at 7,312 Hz which is above the frequency value of the F_5 (6,062 Hz) of the following vowel. In short, our four subjects had the spectral peak at the consonant release at or above F_5 of the following vowel.

In Figure 9 (b), our male subject M1 had the spectral peak of a point taken 25-35 ms after the initial release of /c/ at 4,937 Hz which is above the frequency value of the F_5 (4,437 Hz) of the following vowel. We can see the same spectral pattern in the other male subject M2: the spectral peak of the same point of /c/ is located at 5,250 Hz which is above the frequency value of the F_5 (4,687 Hz). We can also note the same spectral pattern in our female subjects. In the female subject F1, the spectral peak of a point taken 25-35 ms after the initial release of /c/ is located at 6,625 Hz which is above the frequency value of the F_5 (4,937 Hz) of the following vowel. The other female subject F2 had the spectral peak of the same point after the release of /c/ at 7,250 Hz which is also above the frequency value of the F_5 (6,062 Hz) of the following vowel.

Table 1 shows the average spectral peaks of /t/ and /s/ at release and those of the affricate /c/ both at the release and 25-35 ms after the release in relation to the following vowel's F_4 and F_5 in the context *a__a*.

Table 1 Spectral Peaks in the context a __ a across speakers:

a)

F_4	F_5	/t/ at release	
M1	3700	4424	5237
M2	3802	4575	5337
F1	3625	4700	4725
F2	3575	4350	4675

b)

F_4	F_5	/s/ at steady-state	
M1	3725	4425	6500
M2	3925	4800	6362
F1	3887	4577	6587
F2	3837	4475	7300

c)

F_4	F_5	/c/ at release	25-35 ms after initial release	
M1	3737	4462	5300	5300
M2	3500	4487	5012	4812
F1	3737	4850	6637	5812
F2	3762	4437	5987	6537

Across speakers, spectral peaks of the consonants are all above the fifth formant of a following vowel, regardless of whether an intervocalic consonant is /t/, /s/ or /c/.

4. Conclusion

In our analysis of LPC spectra of the Korean consonants /t, s/ in intervocalic position, we found that the spectral peaks at the consonant release of the stop /t/ and at the steady state of the fricative /s/ were either between F_4 and F_5 or above F_5 of the following vowel across our subjects. As for the Korean plain affricate /c/ in the same context, we also found that the spectral peaks at the release of /c/ and at a point taken 25-35 ms after the release were above F_5 of the following vowel across our subjects. Based on the assumptions in (1), then, we can conclude that for these examples, a) the place of articulation of the stop /t/ is alveolar; b) the place of articulation of the fricative /s/ is also alveolar; c) the affricate /c/ is also alveolar throughout its articulation, that is, both for its stop part and for its frication part.

These acoustic results are consistent with the results of Skaličkovás (1960) and Kim's (1997) articulatory study. Therefore, we can transcribe the Korean plain, aspirated and tense affricates as /ts, ts^h, ts'/, especially in intervocalic position.

REFERENCES

Ahn, S.-C. 1985. *The Interplay of Phonology and Morphology in Korean*. Ph.D. dissertation, University of Illinois, Urbana, Illinois.

Bladon, R. Anthony W., and Francis J. Nolan. 1977. "A video-fluorographic investigation of tip and blade alveolars in English." *Journal of Phonetics,* 5 :185-193.

Blumstein, S.E., and K.N. Stevens. 1979. "Acoustic invariance in speech production: Evidence from measurements of the spectral characteristics of stop consonants." *Journal of the Acoustical Society of America,* 66, 1001-1017.

Blumstein, S.E., and K.N. Stevens. 1980. "Perceptual invariance and onset spectra for stop consonants in different vowel environments." *Journal of the Acoustical Society of America,* 67, 648-662.

Blumstein, S. E. 1991. "The relation between phonetics and phonology." *Phonetica,* 48, 108-119.

Cho, Y.-M. 1990. *Parameters of Consonantal Assimilation.* Ph.D. dissertation, Stanford University.

Dogil, G. 1994. "Hissing and Hushing Fricatives: A Comment on Non-Anterior Spirants in Polish." To appear in AIMS-Phonetik, Stuttgart: Institut für Maschinelle 2.

Dorman, M. F., M. Studdert-Kennedy, and L. J. Raphael. 1977. "Stop-consonant recognition: Release bursts and formant transitions as functionally equivalent, context-dependent cues." *Perception Psychophysics,* 22, 109-122.

Fant, G. 1960. *Acoustic Theory of Speech Production.* The Hague: Mouton.

Fant, G. 1973. *Speech sounds and features.* Cambridge: MIT Press.

Firth, J. R. 1948. Word-palatograms and Articulation (BSOAS 1948). In reprinted in *Papers in Linguistics,* 1934-1951, 148-155. Oxford 1957.

Halle, M., G.W. Hughes, and J.P.A. Radley. 1957. "Acoustic properties of stop consonants." *Journal of the Acoustical Society of America,* 29, 107-116.

Halle, M. 1959. *The Sound Pattern of Russian.* The Hague: Mouton.

Halle, M., and K. N. Stevens. 1979. Some Reflections on the Theoretical Bases of Phonetics. In *Frontiers of Speech Communication Research.* Edited by B. Lindblom and S. Ohman. London: Academic Press.

Harris, Katherine S. 1958. "Cues for the Discrimination of American English Fricatives in Spoken Syllables." *Language and Speech,* 1, 1-7.

Hedrick, M.S., and R.N. Ohde. 1993. "Effect of relative amplitude of frication on perception of place of articulation." *Journal of Acoustic Society of America,* 94(4), 2005-2026.

Heinz, J.M., and K.N. Stevens. 1961. "On the properties of voiceless fricative consonants." *Journal of the Acoustical Society of America,* 22, 589-596.

Hughes, G., and M. Halle. 1956. "Spectral Properties of Fricative Consonants." *Journal of Acoustical Society of America,* 28, 303-310.

Huh, W. 1964. "Chiŭmko (the study of Korean dentals)." *Kukŏkukmunhak,* 27.

Jakobson, R., G. Fant, and M. Halle. 1963. *Preliminaries to Speech analysis.* Cambridge, Mass.: MIT Press.

Keating, P., and A. Lahiri. 1993. "Fronted Velars, Palatalized Velars and Palatals." *Phonetica,* 50, 73-101.

Kewley-Port, D. 1983. "Time-varying features as correlates of place of articulation in stop consonants." *Journal of the Acoustical Society of America,* 73(1), 322-335.

Kim, Chin-Wu, and S.-C. Ahn. 1983. "Palatalization in Korean Revisited." paper presented at the 58th Annual Meeting of the Linguistic Society of America, Minneapolis, MN.

Kim, H. 1997. *The Phonological Representation of Affricates: Evidence from Korean and Other languages.* Ph.D. dissertation, Cornell University, Ithaca, NY.

Kim-Renaud, Y.-K. 1974. *Korean Consonantal Phonology.* Ph.D. dissertation, University of Hawaii.

Kim, S.-G. 1976. *Palatalization in Korean.* Ph.D. dissertation, University of Texas at Austin.

Kudela, K. 1968. Spectral analysis of Polish fricative consonants. In *Speech analysis and synthesis.* Edited by W. Jassem. Warsaw: Panstwowe Wydawnictwo Naukowe.

Lee, H.-B. 1993. "Illustrations of the IPA: Korean." *Journal of International Phonetic Association,* 23(1), 28-31.

Lee, K.-M. 1972. *Kukoŭmunsa Yŏnku* (the historical study of Korean Phonology). Seoul: Tower Press.

Lee, K.-M. 1978. *Kukŏsa Kaesŏl* (Introduction to the history of Korean). Seoul: Minchungsŏkwan.

Ohde, R.N., and K.N. Stevens. 1983. "Effect of burst amplitude on the perception of stop consonant place of articulation." *Journal of the Acoustical Society of America*, 74, 706-714.

Purcell, E. 1979. "Formant frequency patterns in Russian VCV utterances." *Journal of the Acoustical Society of America*, 66, 691-1702.

Sereno, J., S. Baum, G. C. Marean, and P. Lieberman. 1987. "Acoustic analyses and perceptual data on anticipatory labial coarticulation in adults and children." *Journal Acoustic Society of America*, 81(2), 512-519.

Shinn, P. 1984. *A Cross-language investigation of the stop, affricate and fricative manner of articulation.* Brown University.

Sohn, H.-S. 1987. *Underspecification in Korean Phonology*. Ph.D. dissertation, University of Illinois at Urbana-Champaign.

Skaličková, A. 1960. *The Korean Consonants*. Prague: Rozpray, CSAV.

Soli, S. 1981. "Second formants in fricatives: Acoustic consequences of fricative-vowel coarticulation." *Journal of the Acoustical Society of America*, 70, 976-984.

Stevens, K. N. 1972. The quantal nature of speech: Evidence from articulatory-acoustic data. In *Human communication: a unified view*. Edited by E. E. David and P. B. Denes. 51-66. New York: McGraw-Hill.

Stevens, K. N. 1985. Evidence for the role of acoustic boundaries in the perception of speech sounds. In *Phonetic linguistics: essays in honor of Peter Ladefoged.* Edited by V. A. Fromkin, 243-255. London: Academic Press.

Stevens, K. N. 1989. "On the quantal nature of speech." *Journal of Phonetics*, 17, 3-45.

Stevens, K. N. 1993a. "Modelling affricate consonants." *Speech Communication*, 13, 33-43.

Stevens, K. N. 1993b. "Models for the production and acoustics of stop consonants." *Speech Communication*, 13, 367-375.

Stevens, K. N., and S. E. Blumstein. 1981. The search for invariant acoustic correlates of phonetic features. In *Perspectives on the study of speech.* Edited by P. D. Eimas and J. L. Miller. New Jersey: Erlbaum.

Yeni-Komshian, G., 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.

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