A STUDY OF KOREAN ALVEOLAR FRICATIVES AN ACOUSTIC ANALYSIS, SYNTHESIS AND PERCEPTION EXPERIMENT

Kyuchul Yoon

Department of Linguistics, Ohio State University

I INTRODUCTION

Korean has two types of voiceless alveolar fricatives One is called aspirated and the other tense (Kagaya, 1974) The aspirated fricatives have also been called lax fricatives because phonologically they act like a lax obstruent, undergoing a set of processes that lax stops do For example, Korean lax stops and /s/ undergo post-obstruent tensing (Sohn 1999) Aspirated stops (e g , c^h), however, do not undergo this process and tense stops (e g , k') remain tense This process is shown in (1)

(1) Post-obstruent tensing lax stop → tense stop / obstruent___

t → t' / k___	/pak#ta/ → [pakt'a]	*drive* as in *drive a nail*
k → k' / k___	/tok#ki/ → [tokk'i]	*poison*
c → c' / p___	/c^h p#ca/ → [c^h pc'a]	*a spy*
c^h → c^h / k___	/pak#c^ha/ → [pakc^ha]	*spur*
k' → k' / k___	/pak+k'oc^h/ → [pakk'ot]	a kind of flower
s → s' / k___	/pak#sa/ → [paks'a]	*a doctor*
s → s' / p___	/c^h p#sa/ →[c^h ps'a]	*an affix* (# syllable juncture, + compound juncture)

However, /s/ acts like aspirated stops with regard to lack of intervocalic voicing Lax stops become voiced intervocalically but neither aspirated stops nor /s/ do

Korean alveolar fricatives, aspirated or tense alike, have palatalized allophones before the vowel /i/ by assimilation to the vowel's place of articulation The allophonic variant of the aspirated fricative before /i/ is palatalized, resembling the IPA alveolo-palatal fricative [ ] The allophonic variant of the tense fricative before the vowel /i/ is a tense version, ['] As can be seen in Figures 1 and 2, the allophonic variation has an effect on the distribution of the acoustic energy of the frication segments As the place of articulation changes from the original alveolar region to the assimilated alveo-palatal region, causing the front cavity to lengthen, the frequency region with the highest energy moves downward, resulting in a lower frequency range This is because the sound source is located behind the front cavity and the acoustic filtering action of the vocal tract in fricatives is mainly determined by the resonant frequencies of the front cavity

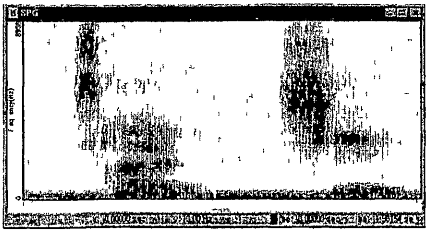

Figure 1 Spectrogram of Korean /sal/ and /si/ [i]

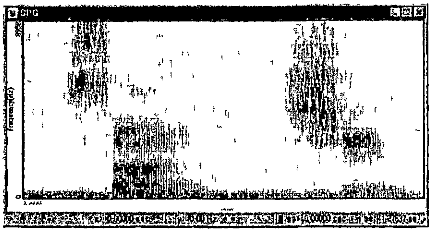

Figure 2 Spectrogram of Korean /s'al/ and /s'i/ ['i]

A number of investigations have been made of Korean stop consonants, which are divided into three types depending on their manner of articulation lax (/p t k/), aspirated ($/p^h\ t^h\ k^h/$), and tense stops (/p' t' k'/) Various parameters have been put forward as cues to the manner distinction Some of them are voice onset time (VOT), fundamental frequency at voicing onset, and energy build-up rate The first parameter looks at the time it takes for the voicing onset to begin after the consonant release The other two parameters look at differences at the beginning of the vowel following the stop consonant

Lisker and Abramson (1964) claimed that VOT provides the single best basis for the physical discrimination of Korean stop manner categories Han and Weitzman (1970) suggested, however, that VOT only differentiates lax and tense stops from aspirated stops and that the energy build-up rate at voicing onset of the following vowel distinguishes lax stops from tense ones It has also been found that the fundamental frequency (F0) at voicing onset is higher after the tense stops than after the corresponding lax stops (Han and Weitzman, 1970, Kim, 1965, Hardcastle, 1973)

Studies with fiberoptics, electromyogram (EMG), and palatography showed that tense stops involve greater muscular activity of the oral structure as well as of the vocal cords (Hirose et al , 1974, Kagaya, 1971 and 1974, Kim, 1965) During the tense stop closure, the vocal folds were in complete contact from 80 to 100 msec before release Hirose showed a marked increase in lateral cricoarytenoid and vocalis muscle activity just before the release of a tense stop, which means that the glottis was tightly closed before release Kim's EMG and palatograph study reported greater muscular activity of the lips for tense bilabials and more area of contact between the tongue and the hard palate for tense alveolars

The glottal width during the stop closure and at the stop release was largest for aspirated stops, intermediate for lax stops, and smallest for tense stops If we assume that aspiration is a function of the glottal opening at the time of release (Kim, 1970), we can explain why VOT values increase in order of tense, lax, and aspirated stops

It is not clear whether VOT can also be used to distinguish aspirated fricatives from tense ones since VOT is defined with reference to the stop release, which fricatives do not have Fricatives do have a frication segment and sometimes aspiration depending on the type of the fricative Therefore the start of the voicing can be measured either from the start or end of the frication

Before we go on, it would be in order to mention the difference between frication and aspiration Frication differs from aspiration both in articulatory and acoustical aspects Aspiration is a breathy noise created as air passes through the vocal cords Frication involves turbulence noise which is generated when air passes through a narrow constriction somewhere in the vocal tract at a suitable rate of flow Both aspiration and frication are noise, but articulatorily, they are different in terms of their place of generation

Acoustically, aspiration differs from frication in terms of intensity, duration, and frequency distribution Spectrogram analysis shows that aspiration following a word-initial voiceless stop consonant is usually seen as having less intensity and shorter duration than a word-initial fricative

For native speakers of Korean, it is not hard to pronounce each type of alveolar fricative with varying frication duration and the frication duration does not affect their perception Therefore, if we assume that the duration of the frication segment does not play a crucial role in distinguishing fricative types, at least for the alveolar fricatives of Korean, it is not hard to see the importance of the aspiration that follows the frication segment If we assume that aspiration of the fricatives is produced concomitantly as the speech organs prepare to pronounce the following vowel, we can see aspiration duration as another way of expressing voice onset time

Some previous studies have touched on the properties of Korean fricatives and affricates Kagaya (1974) showed that the vocal cords are still open after the end of the fricative segment of aspirated alveolar fricatives, which seems to cause the period of aspiration before the onset of the following vowel This is one of the reasons for calling the non-tense Korean alveolar fricatives aspirated By contrast, for tense fricatives, the vocal cords were narrowed for voicing even before the frication ended

Various acoustic parameters have been suggested as correlates of the force of articulation of consonants One of them concerns the rise time, which can be represented as the rate of amplitude change of the frication segment It has been mainly used to deal with affricates and fricatives (Howell and Rosen, 1983) Affricates are known to have a shorter rise time than the fricatives Rise time of the postconsonantal vowel has also been noted by some researchers as an acoustic correlate of the force of articulation of the preceding consonant (Debrock, 1977) Based on his data of Korean, Dutch, and French stops, Debrock suggested that the rise time of the postconsonantal vowel is inversely proportionate to the force of the consonant articulation

Investigations involving synthesis and perception tests have been made of Korean stop consonants Lee (1990) synthesized Korean alveolar lax and tense stops based on previous findings She manipulated parameters that control the voicing amplitude, fundamental frequency, spectral tilt of voicing, aspiration amplitude, and duration of open phase of the glottal pulse Her perception experiment showed that the four listeners did not perceive the stimuli categorically and that their identification boundary was not very sharp The unexpected results led her to assume that all the parameters she employed may not work equally in perceiving Korean lax and tense stops

The role of VOT in stop consonant perception was investigated by Han and Weitzman (1970) They reported that listeners' judgment switched from an aspirated stop to a lax stop and then from a lax stop to a tense stop as VOT decreased They added that the transition from a lax stop to a tense stop also involved the removal of portions of the voice onset

To find consistent parameters that act as cues to the aspirated/tense distinction of Korean alveolar fricatives, I examined such parameters as the duration, frequency distribution, energy, and fundamental frequency of the words containing each type of fricative produced by twenty native speakers of Korean (Yoon 1999) This analysis showed that only the duration of the aspiration segment was consistent across all speakers in differentiating the fricatives in mid and low vowel contexts In this paper I will show that the aspiration between the frication and vowel segments can act as the major perceptual cue to differentiating aspirated from tense fricatives

II METHOD

In an informal pilot perception experiment, I and another Korean speaker listened to all twenty tokens of /sada/ 'buy' analyzed in Yoon (1999) from which aspiration intervals were removed For some of the words, perception shifted from /sada/ to /s'ada/ Utterances from four of the speakers whose tokens caused perception shift when aspiration was removed and utterances from four other speakers whose recordings did not cause perception shift were selected for the perception experiment The aspiration was removed in 10msec increments starting at the center to avoid removing any acoustically significant information that might be found at the beginning and end of the aspiration segment The prepared tokens were duplicated eight times and presented to listeners in random order for identification

In a separate section, a synthesized CV syllable /sa/ with and without aspiration was also duplicated eight times and presented to listeners for identification

1 Subjects

Twenty native speakers of Korean (eleven males L1 – L11 and nine females L12 – L20), all with normal speech and hearing, served as listeners All were either graduate or undergraduate students at the University of Kansas The mean age and standard deviation were 28 5 and 5 7 years

Potential listeners for the experiment were screened by having them listen to natural /sada/ and /s'ada/ utterances from all twenty speakers (2 x 20 = 40) used for analysis in order to eliminate listeners who because of dialect differences did not reliably distinguish the aspirated and tense fricatives Out of twenty-one potential listeners, only one listener with a Pusan dialect failed to correctly identify 95% of the words The remaining twenty listeners served as subjects Seventeen listeners were speakers of Seoul dialect, two male listeners spoke Kyungsang-namdo and Cholla-bukdo dialects, and one female listener spoke Taegu dialect

Among the male listeners, ten had made recordings for the previous analysis and consequently some of them heard their own voices among the stimuli presented

2 Stimuli

The word /sada/ containing an aspirated alveolar fricative and the vowel /a/ as spoken by eight speakers (A, B, C, D, E, F, G and H) was used in the experiment Four of the speakers (A, B, G and H) seemed to use the aspiration duration as a primary cue for aspirated/tense distinction and the others did not

Session 1 – 4 The tokens of the first four sessions were prepared by removing sections in 10msec increments from the center of the aspiration Depending on the aspiration duration in the original utterance, 5 to 10 tokens with different durations were prepared for further duplication For example, if a speech sample from a speaker had 75 msec of aspiration, 8 tokens with durations of –5, 5, 15, 25, 35, 45, 55, and 65 msec would be prepared The minus sign indicates that a small portion of the beginning of the voicing and the ending of the frication were also cut out since the cutting started from the center of the aspiration

The aspiration durations for each of the Speakers A, B, C, D, E, F, G, and H were 74, 87, 45, 61, 98, 81, 72, and 77msec respectively Therefore, 64 tokens (8 + 9 +5 + 7 + 10 + 9 + 8 + 8) of varying aspiration duration were prepared These tokens were duplicated 8 times and evenly divided into four sessions Natural /sada/ and /s'ada/ utterances from the eight speakers (2 x 8 = 16) were added to each of the sessions in order to compare judgments of unaltered speech with those from which aspiration had been removed With 16 natural utterances included, each session had 144 tokens presented in random order The total number of items to be identified in the four sessions was 576 (144 x 4 = 576)

Session 5 The syllable /sa/ was synthesized in three segments frication, aspiration, and vowel segments based on measurements taken from analysis of natural productions as a starting point The segments were 150 msec, 70 msec and 200 msec long respectively Some modifications of measured values were made to make the syllable sound more natural or to accommodate to the limitations of the synthesizer Formant frequency values of the fricative segment were adjusted so that the center frequency was located above 5kHz The frication amplitude parameter was also adjusted so that it gradually increased at the onset and then decreased to the aspiration amplitude following the fricative segment, avoiding an abrupt change in amplitude The vowel amplitude and the fundamental frequency at the beginning of the vowel were also adjusted to make it sound natural

The Klatt Synthesizer parameters and their values for each segment are given below in Tables 1, 2 and 3

Parameters	Frequency	Parameters	Bandwidth	Parameters	Amplitude
F5	4500Hz	b5	500Hz	a5	65dB
F6	4990Hz	b6	500Hz	a6	65dB
F7	6500Hz	b7	500Hz		
F8	7500Hz	b8	600Hz		
Af	75dB From 40 to 75 dB (first 30 msec) From 75 to 40 dB (last 15 msec)				
Av	0dB				

Table 1 Parameters and their values used in the synthesis of the fricative segment of the syllable /sa/ F5, F6, F7, and F8 stand for fifth, sixth, seventh, and eighth formants, b5, b6, b7, and b8, their respective bandwidths, and a5 and a6, fifth and sixth formants' amplitudes af and av stand for frication and voicing amplitudes respectively

Parameters	Frequency	Parameters	Bandwidth
F1	770Hz	b1	160Hz
F2	1200Hz	b2	160Hz
F3	2830Hz	b3	120Hz
ah	45dB		
av	0dB		

Table 2 Parameters and their values used in the synthesis of the aspiration segment of the syllable /sa/

Parameters	Frequency	Parameters	Bandwidth
F1	770Hz	b1	80Hz
F2	1200Hz	b2	80Hz
F3	2830Hz	b3	60Hz
av	55dB with an increase from 40dB to 55 dB (first 15 msec)		
f0	70Hz with a decrease from 80Hz to 70Hz (first 15 msec)		

Table 3 Parameters and their values used in the synthesis of the vowel segment of the syllable /sa/

The syllable was synthesized with and without the 70 msec asprration segment Wave forms and spectrograms of the two synthesized stimuli are presented in Figures 3 and 4

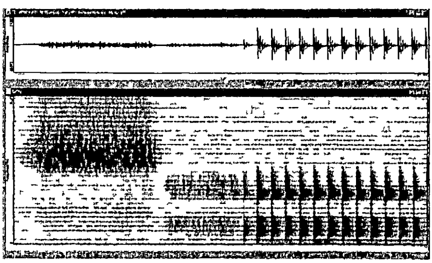

Figure 3 Spectrogram of the synthesized syllable /sa/

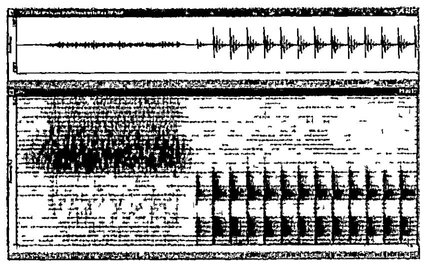

Figure 4 Spectrogram of /sa/ with its aspiration removed

The perception experiment for the synthesized syllable was not focused on where the shift in perception starts, but on whether the shift in perception to its tense counterpart occurs at all The syllable with and without aspiration was duplicated eight times, resulting in a total of 16 tokens They were presented in a session given after the four sessions of modified natural tokens

The total number of tokens from spoken and synthetic stimuli was 592 (144 x 4 + 16 = 592)

3 Procedures

The 592 tokens described above were presented to the twenty native speakers of Korean (L1 – L20) for identification Each listener was tested individually using the Auditory Stimulus Preparation and Presentation software from Kay Elemetrics© Each listener sat in front of a computer, was given instructions, and listened to the tokens that came from a JBL© Pro III speaker hooked up to the CSL Model 4300B from Kay Elemetrics Co

The instructions given in Korean were as follows

You are to listen to the words from the speaker and to choose one of the two buttons on the computer screen, one for [sada] 'buy' and the other for [s'ada] 'cheap' For synthetic stimuli, choose one that corresponds to the first syllable of the two buttons If what you hear is neither of the two choices, please let me know by raising your hand Each word is given only once You will have a one-minute break between sessions Thank you

None of the listeners indicated hearing anything but one of the two choices

III RESULTS

1 Natural stimuli

As expected, reduction in the amount of aspiration shifted perception from aspirated to tense The results of identification tests for sessions 1 through 4 for two representitive speakers are given in Tables 4 and 5 and shown graphically in Figures 5 and 6 Each cell in the tables represents the number of /sada/ identifications for each stimulus in a total of eight presentations

A beginning point of perception shift will be defined as the place where the majority of the responses start to show fewer than 100% [sada] responses and a complete perception shift is defined as the place where most listeners give fewer than 25% [sada] responses

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20	AVG
-10	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	100
-20	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	8	8	8	8	99
-30	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	100
-40	8	8	8	8	8	8	8	5	6	8	8	8	8	6	8	3	8	8	7	8	92
-50	6	8	5	6	4	4	7	2	3	6	5	5	2	2	5	0	6	4	3	0	52
-60	0	8	1	4	2	3	4	0	1	1	1	1	1	0	2	0	2	0	1	0	20
-70	0	3	0	2	2	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	6
-80	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4
/sada/	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
/s'ada/	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	

Table 4 Identification responses for /sada/ for tokens from Speaker A The horizontal axis represents each listener and the vertical axis the amount of aspiration removal (-) in msec The two rows at the bottom indicate the number of wrong answers for the original utterances of the speaker AVG column represents the average percent correct answers for all listeners

As can be seen in Table 4 , all listeners correctly identified all presentations of the natual utterances Listeners began to identify words with an aspirated fricative as ones with a tense fricative when the original aspiration of 74 msec was reduced by 50msec and they shifted to predominantly tense identifications when aspiration reduction was 60msec

Since the aspiration duration for the natural /sada/ of speaker A was 74msec, 60 msec of aspiration reduction means that the token had only 14msec of aspiration and aspiration was totally removed at –80 msec Comparing this with the 7 msec aspiration for the natural /s'ada/ of the same speaker , we can see that aspiration duration plays a major role in differentiating his aspirated alveolar fricatives from tense ones

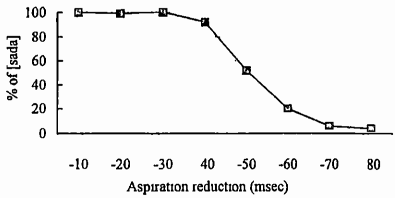

Figure 5 Listeners' average responses for tokens from Speaker A

As shown in Table 5 and Figure 6 below, perception for tokens from Speaker G began to shift at 50msec of aspiration reduction Most listeners reported a complete perception shift when the aspiration reduction was greater than 70msec For this speaker, the aspiration durations for unmodified natural /sada/ and /s'ada/ were 72 and 18msec respectively Aspiration of 2msec or less was required before most listeners identified the stimulus overwhelmingly as containing the tense fricative even though the speaker actually had 18msec of aspiration in his natural /s'ada/ This implies that there might be some other parameters, besides aspiration duration, that influence perception shift

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20	AVG
-10	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	100
-20	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	8	8	8	8	99
-30	8	8	8	8	8	8	8	8	8	8	8	8	6	8	8	8	8	8	8	7	98
-40	8	8	8	7	5	7	8	8	8	8	8	8	7	8	8	8	8	8	7	8	96
-50	3	8	3	7	3	6	7	7	1	6	5	6	5	8	8	5	8	5	4	4	68
-60	0	8	0	3	1	2	3	5	0	1	1	4	1	6	4	1	7	1	5	3	35
-70	0	7	0	4	1	0	2	3	0	1	0	0	0	1	1	0	2	0	0	0	14
-80	0	3	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	4
/sada/	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
/s'ada/	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 5 Identification responses for /sada/ for tokens from Speaker G The horizontal axis represents each listener and the vertical axis the amount of aspiration removal (-) in msec The two rows at the bottom indicate the number of wrong answers for the original utterances of the speaker AVG column represents the average percent correct answers for all listeners

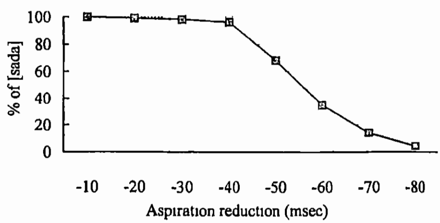

Figure 6 Listeners' average responses for tokens from Speaker G

The approximate aspiration durations where perception began to shift for each speaker are given in Table 6 Combined responses for all listeners to each reduction in aspiration are given in Figure 7

	Speaker A	Speaker B	Speaker C	Speaker D	Speaker E	Speaker F	Speaker G	Speaker H
Listeners	34 (74)	37 (87)	15 (45)	11 (61)	28 (98)	21 (81)	22 (72)	27 (77)

Table 6 Aspiration duration in msec for each speaker at which listeners' perception shifted from aspirated to tense The numbers in parentheses indicate the amount of aspiration in the original /sada/ utterances

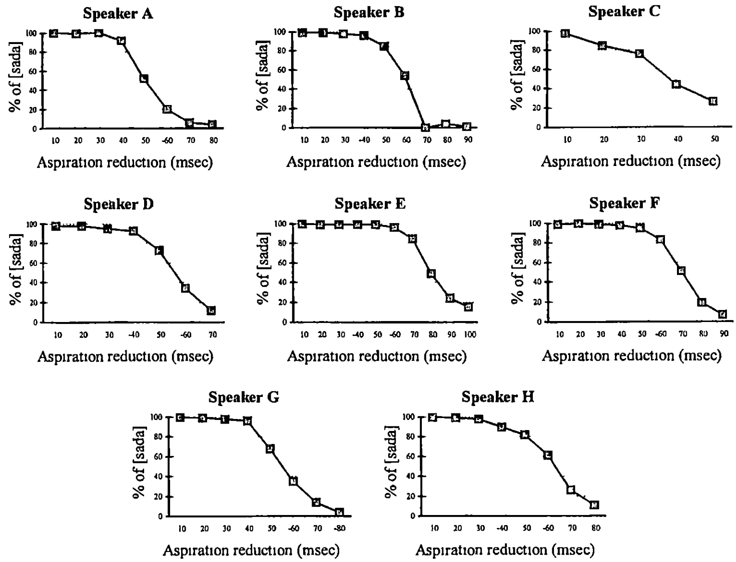

Figure 7 Average scores of all listeners for each speaker

Table 6 and Figure 7 show that, depending on the speakers, an aspiration duration of 11 to 37msec or less in the natural utterances cause perception to begin to shift from aspirated to tense In other words, less than 37msec of aspiration causes listeners to judge the tokens as belonging to the tense category

2 Synthetic stimuli

Individual listener responses to synthetic stimuli in session 5 are given below in Table 7 and shown graphically in Figure 8

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
/sa/ response when aspiration present	8	5	8	8	8	8	8	8	8	8
/s'a/ response when aspiration absent	6	8	8	8	7	7	8	8	8	6
	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
/sa/ response when aspiration present	7	8	5	8	3	8	8	6	7	7
/s'a/ response when aspiration absent	8	8	8	8	4	8	8	8	8	8

Table 7 Identification of synthetic stimuli Cells give the number of times the intact synthetic syllable /sa/ with aspiration was identified as /sa/ and the number of times /sa/ without aspiration was identified as /s'a/

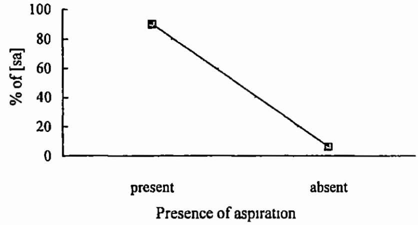

Figure 8 Average responses for synthetic /sa/ with and without aspiration

As mentioned earlier, session 5 consisted of 16 tokens of synthetic /sa/ Half of the tokens contained aspiration and the other half did not Depending on the presence of the aspiration, listeners' responses fell into two groups In general, when the tokens had aspiration, they were perceived as containing aspirated fricatives, but when they did not, they were reported as containing tense fricatives One female listener deviated from other listeners Her responses were random and she may simply have been having a problem with unnatural synthetic speech that prevented her from using normal speech cues to discriminate the syllables Her responses to the manipulated natural speech did not differ markedly from those of other listeners Although they differ in degrees, most listeners experienced perception shift in perception tests with both natural tokens and synthetic tokens

3 Summary

All listeners showed perception shift from aspirated to tense as the aspiration duration decreased Perception began to shift when 54% to 82% of the aspiration was removed from natural utterances Since some aspirated words required more aspiration deletion to be heard as tense than the aspiration found in their natural tense counterparts, we infer the presence of other parameters that aid aspirated/tense distinction of Korean alveolar fricatives Some of these parameters may be energy, fundamental frequency, etc

With the synthetic /sa/, listeners showed perception shift from aspirated to tense with the removal of the aspiration segment Noting the fact that the tokens prepared from the synthetic /sa/ differed only in the presence of aspiration duration, we can say that aspiration plays a very important perceptual role in differentiating the two types of Korean alveolar fricatives

IV DISCUSSION

The results of acoustic analysis (Yoon 1999) showed that among the duration parameters that were measured, only the aspiration duration in mid and low vowel contexts was an invariant acoustic cue to the aspirated/tense distinction of the voiceless Korean alveolar fricatives This was true not only in terms of overall statistical significance, but also in terms of every instance of individual measurements In general, the aspiration duration of the words with tense fricatives was much shorter (less than 21 msec) compared to that of the words with aspirated fricatives

For words with high vowels /i, u/, aspiration was usually short so that the differences in duration between tense and aspirated were very small In fact, in a few instances (e g Speaker D) there were no differences at all Furthermore, sometimes there was no aspiration because the vocal cords started to vibrate even before the end of frication It is probable, then, that some parameters other than the aspiration duration play a major role in a high vowel context

The fricative in the low vowel context had more aspiration than in the other vowel contexts possibly because the lower articulators had to move a greater distance in the transition from consonant to vowel The allophonic variants of the two type of fricatives and the high vowels following the allophones require little change in the position of the lower articulators Therefore, it seems natural that aspiration duration does not play a primary perceptual role in the distinction

There does not seem to be any invariant parameter for the aspirated/tense distinction in high vowel contexts As Han and Weitzman's (1970) study with Korean stops suggested, the VOT parameter together with other parameters associated with the voice onset quality (e g intensity build-up and fundamental frequency) may play important roles It is probable that two or more parameters are simultaneously involved in the case of the high vowel contexts To prove this, further study of different combinations of two or more parameters at the same time would be useful

The role of the aspiration duration for the distinction of the two Korean voiceless alveolar fricatives in mid and low vowel contexts supports Lisker and Abramson's (1964) conclusion that different languages use different areas in the VOT continuum As the three types of Korean alveolar stops in their study did, both types of Korean alveolar fricatives also had positive values of the aspiration duration (see Table 8) The aspiration duration for fricatives is generallly similar in average and range to the voice onset time of stops if we call the end of frication the articulatory release of the fricative

		Aspirated alveolar stop		Tense alveolar stop	
	Vowel context	Average	Range	Average	Range
Lisker & Abramson (1964)	Unknown	94	75 – 105	11	0 – 25
Han & Weitzman (1970)	/a/	104	45 – 190	8	3 – 25
Hardcastle (1973)	/a, , u/	80	55 – 98	5	3 – 9
		Aspirated alveolar fricative		Tense alveolar fricative	
This study	/a/	69	45 – 98	13	3 – 18

Table 8 Aspiration duration in msec of Korean alveolar fricatives compared with the VOTs of the stops in other studies

Aspiration duration is not only related to vowel height, but also to vocal cord configuration If the vocal cords are adducted for voicing immediately after the release of the frication, we get a tense fricative provided that the aspiration duration is the principal parameter for aspirated/tense perception If the vocal cords are open following the release, we hear the sound as aspirated The glottis related muscles are also involved in the production of the fricatives and are known to be used in the production of tense sounds (Hirose et al , 1974)

The similarity of aspirated stops and fricatives in terms of the interval between the articulatory release and the start of voicing helps us to explain the failure of Korean /s/ to voice in an intervocalic position Aspiration can be associated with the relative openness of the glottis at articulatory release (Kim, 1970) Kagaya (1974) reported that the aspirated fricative in intervocalic context had a glottal width about half of the maximum opening word-initially while the glottal width for the intervocalic aspirated stop was slightly narrower than the maximum opening in the word-initial position Iverson (1983 explained the failure of Korean /s/ to voice intervocalically in terms of the fact that the glottis is still open just as it is open for the intervocalic aspirated stops

Spectral peak measurements failed to reveal any significant pattern that might differentiate the types of frication segments The frequency distribution for the alveolar fricatives and their palatal allophones, however, generally agreed with previous studies on other languages The major peaks of the frication segment for the words with unround low or mid vowels /a, e/ were located between 4500-8200Hz, which roughly corresponds to the frequency range of the English /s/ reported by Heinz and Stevens (1961) Manrique and Massone (1981) also showed that / / was related to a peak at about 2500Hz When Korean alveolar fricatives were followed by round or high vowels /o, i, u/, the resonance frequencies of the preceding fricatives were lowered due to either lip rounding or place assimilation, leading to the appearance of a relatively low energy peak around 2800-2900Hz The measurements of the aspiration formants indicated that most were close in frequency to the steady-state vowel formants that followed

When presented with either synthetic or natural tokens of varying aspiration duration, most listeners experienced perception shift from aspirated to tense when aspiration was either completely absent or less than 37msec Provided that the VOT for fricatives is measured from the start of the aspiration segment, this finding for Korean alveolar fricatives agrees with a previous perceptual experiment (Lisker and Abramson, 1970) where they showed that VOT delays for English alveolar stops of 35 2msec or less were not heard as aspirated by human subjects Kuhl and Miller (1977) demonstrated that animals like chinchillas also did not discriminate VOT delays of 33 3msec or less for the same type of English stops, suggesting that the ability to detect VOT boundaries is not language related

The responses of the perception experiment support the concept that certain acoustic continua produce categorical perception where small acoustic changes are not perceived until a threshold is reached that produces an abrupt perceptual change A relatively small change in the amount of the aspiration duration for one type of fricatives resulted in two qualitatively different responses However, the perception experiment has a limitation in that it was performed only with the low vowel /a/ To show that the aspiration plays a major role in the aspirated/tense distinction in Korean alveolar fricatives in mid vowel contexts as claimed earlier, further perception experiments with the mid vowels /e, o/ are necessary

The manipulation of one of the parameters involved in the perception of the Korean alveolar fricatives has advantages over manipulating more than two parameters at the same time as Lee (1990) suggested in her perceptual study with Korean lax and tense stops She synthesized a lax and a tense stop and varied several parameters (voicing amplitude, glottal open quotient and spectral tilt, fundamental frequency, and aspiration amplitude) in equal steps Her Korean listeners did not perceive the stimuli categorically She suggested that the parameters employed in producing the continuum might not work equally and that further research was needed where we synthesize stimuli, changing each parameter separately My perception experiment is in line with her suggestion in that I focused on the one parameter which seemed to be the most influential based on measurements of utterances She also predicted the presence of a hierarchy among the parameters involved in the lax and tense distinction If her prediction is right and if there is a parametric hierarchy in Korean alveolar fricative system, aspiration duration will rank highest It would also be intriguing to fill out the rest of the fricative parametric hierarchy by doing experiments with other parameters controlled one at a time

The perception study by Han and Weitzman (1970) reported that the progressive removal of the VOT from the Korean aspirated stops resulted in an increasing identification of the lax stops, and the perception shift from the lax to the tense stops resulted either when some of the voice onset was removed or when the voice onset quality was appropriate such that the intensity build-up after voice onset was relatively rapid The present perception experiment showed a similar pattern with regard to aspiration except that because there is no third (lax) category of fricatives, perception shifted to tense rather than lax In some cases, as the graphs in section III showed, some of these judgments were responses to stimuli from which some of the voice onset of the following vowels had been removed

A comparison between the amount of aspiration in the perception test and the actual aspiration from the natural utterances leads us to the assumption that other parameters may exist It was sometimes the case that perception did not shift from aspirated to tense even when the same amount of aspiration as for the tense fricative was present In cases such as this, more aspiration reduction was necessary for the expected perception shift, indicating that the aspiration duration was not the only parameter for the aspirated/tense distinction The discovery of the other parameters requires further research

	Tense	Lax	Aspirated
Stops	**p' t' k'**	**p t k**	**p^h t^h k^h**
	ㅃ ㄸ ㄲ	ㅂ ㄷ ㄱ	ㅍ ㅌ ㅋ
Affricates	**tʃ'**	**tʃ**	**$tʃ^h$**
	ㅉ	ㅈ	ㅊ
Fricatives	**s'**	s (?)	
	ㅆ	ㅅ	

Table 9 Classification of Korean stops, affricates, and fricatives according to manner of articulation along with corresponding Korean spellings

As can be seen in Table 9, traditional Korean orthography bases the representation of the tense and aspirated stops on the symbols for the lax stops Tense stops are represented by putting the corresponding lax symbol twice side by side and aspirated stops by adding a horizontal bar over the symbol for the corresponding lax stop Note that the symbol for the aspirated fricative is represented in the same way as lax stops, i e single symbol without the horizontal bar

The double vertical line in Table 9 dividing tense and lax segments from aspirated ones represents the argument by Han and Weitzman (1970) in terms of classifying the three types of segments The tense and lax stops are not distinguished by VOT When it comes to the fricatives, however, it is not easy to draw a clear line between the lax and aspirated columns On the basis of the evidence presented so far, aspirated fricatives have phonetic properties like aspirated stops in that, in mid and low vowel contexts, they can always be differentiated from their tense counterparts by the aspiration duration Although in some ways the phonological behavior of Korean aspirated fricatives is similar to that of Korean lax stops as pointed out in section I, we can also find some phonological similarity between aspirated fricatives and aspirated stops They are similar in that both do not undergo intervocalic voicing, while lax stops do On the basis of the phonetic evidence and this phonological behavior, we classify the aspirated fricative [s] as belonging to the same category as aspirated stops

This claim is also supported by the historical fact that Korean once had an alveolar voiced fricative /z/ represented by the symbol Δ Huh (1990) claimed that the voiced fricative was used either as an independent phoneme or as an allophonic variant of the aspirated fricative in intervocalic position From the fact that Δ was voiced in intervocalic contexts just as the current lax stops are, we might well classify the sound written with the letter Δ as having belonged to the lax category

The arguments of Kuhl and Miller (1977), Lisker and Abramson (1970) above and the findings of the present perception experiment have implications for the classification of Korean stop and fricative system The ability of non-humans as well as humans to categorically discriminate different VOTs suggests the presence of genetic predispositions in those species that in turn control the markedness or unmarkedness of a sound segment Let us suppose that unmarked sounds are relatively frequent and resist replacement or disappearance due to the ease of articulation and perception Suppose also that unmarked sound segments are produced with the least effort both in terms of articulation and perception The least amount of effort in perception can be seen as having the fewest parameters involved in distinguishing the sounds in a particular phonemic system The sounds in Table 9 can be grouped into two aspirated and non-aspirated (tense and lax) Let us assume that the aspirated group of sounds is unmarked both articulatorily and perceptually because only one parameter of VOT distinguishes it from the other and there is no subgroup in it Then the non-aspirated sounds (i e tense and lax sounds) are marked because some other parameters such as fundamental frequency and intensity build-up parameters as well as VOT are required to distinguish them If we classify the aspirated fricative as belonging to the lax category as some phonological processes suggest, we end up removing the unmarked aspirated fricatives contrary to the markedness assumptions above

However, the markedness argument has limitations because the aspiration duration for the fricatives was not invariant across all vowel contexts The aspiration duration only worked for mid and low vowel contexts

The fact that aspiration duration is the most noticeable and reliable parameter for the aspirated/tense distinction of Korean alveolar fricatives has significance for classifying them in terms of the phonological features Ladefoged (1996) proposed that, in addition to the features Fricative and Sibilant, the phonological classification of fricatives will require the feature Shape (with possible values grooved, flat, domed, and palatalized) to specify different tongue shapes to represent various types of sibilant fricatives of many languages He argues that the tongue shape feature can be used to distinguish the grooved alveolars like English /s/, laminal flat post-alveolars like Chinese retroflex / /, laminal domed post-alveolars like English / /, and laminal palatalized post-alveolars like Polish / /

This new feature is not relevant in distinguishing the two Korean alveolar fricatives because, based on spectral characteristics, the two fricatives do not appear to have any articulatory difference I am unable to distinguish the two sounds by any feature associated with the oral tract Their primary difference is one of the glottal configuration at the time of articulatory release Halle and Stevens (1971) employed the features Spread glottis and Constricted glottis with reference to Korean consonants I propose, based on the acoustic analysis and perceptual experiment, that the feature Spread (with possible values + or -) be used to distinguish the two types of Korean alveolar fricatives The feature [+spread] will specify the aspirated fricative and [-spread] the tense fricative The two fricatives are, of course, [-voice]

We may be able to get additional insights when we look at the fricatives spoken at normal speed and embedded in a variety of contexts such as word-medial and word-final as well as word-initial position

REFERENCES

Debrock, M 1977 An acoustic correlate of the force of articulation Journal of Phonetics 5 61-80

Halle, M and Kenneth N Stevens, 1971 A Note on laryngeal features Quarterly Progress Report Research Laboratory, Electronics, M I T No 101

Han, M S, and R S Weitzman 1970 Acoustic features of Korean /P, T, K/, /p, t, k/, and /p^h, t^h, k^h/ Phonetica 22 112-28

Hardcastle, W J 1973 Some observations on the tense-lax distinction in initial stops in Korean Journal of Phonetics 1 263-72

Heinz, J M, and K N Stevens 1961 On the properties of voiceless fricative consonants Journal of the Acoustical Society of America 33 589-96

Hirose, H, C Y Lee, and T Ushijima 1974 Laryngeal control in Korean stop production Journal of Phonetics 2 145-52

Howell, P, and S Rosen 1983 Production and perception of rise time in the voiceless affricate/fricative distinction Journal of the Acoustical Society of America 73 976-84

Huh, Ung 1990 The phonological system of the 15th century Korean CNU Series in Linguistics 3 Understanding Hunmin-jong um Chonnam National University 87-106

Iverson, Gregory K 1983 Korean *s* Journal of Phonetics 11 191-200

Kagaya, R 1971 Laryngeal gestures in Korean stop consonants Annual Bulletin 5 Research Institute of Logopedics and Phoniatrics University of Tokyo

Kagaya, R 1974 Fiberscopic and acoustic study of the Korean stops, affricates and fricatives Journal of Phonetics 2 161-80

Kim, Chin-woo 1965 On the autonomy of the tensity feature in stop classification (with special reference to Korean stops) Word 21 339-59

Kim, Chin-woo 1970 Theory of aspiration Phonetica 21 107-16

Kuhl, P K, and James D Miller 1977 Speech perception by the chinchilla Identification functions for synthetic VOT stimuli Journal of the Acoustical Society of America 63(3) 905-17

Ladefoged, P and Ian Maddieson 1996 The sounds of the world's languages Cambridge and Oxford Blackwell Publishers

Lee, Sook-hyang 1990 Korean lenis and fortis stops Synthesis and categorical speech perception task Ohio State University Working Papers in Linguistics 38 105-20

Lisker, L, and A S Abramson 1964 A cross-language study of voicing in initial stops Acoustical measurements Word 20 384-422

Lisker, L, and A S Abramson 1970 Discrimination along the voicing continuum Cross-language tests Proceedings of the 6th International Congress of Phonetic Science, Prague, 1967 (Academic, Prague) 569-73

Manrique, A M B, and M I Massone 1981 Acoustic analysis and perception of Spanish fricative consonants Journal of the Acoustical Society of America 69 1145-53

Sohn, Joong-Sun 1999 Tensing and aspiration in Korean compounds (To appear) Kansas Working

Papers in Linguistics 24 University of Kansas

Stevens, Kenneth N 1971 Airflow and turbulence noise for fricative and stop consonants Static considerations Journal of the Acoustical Society of America 50 1180-92

Yoon, Kyuchul 1999 A study of Korean alveolar fricatives An acoustic analysis, synthesis, and perception experiment Unpublished master's thesis University of Kansas