An Acoustic and Aerodynamic Study of Consonants in Cheju

Taehong Cho, Sun-Ah Jun & Peter Ladefoged*

ABSTRACT

Acoustic and aerodynamic characteristics of Cheju consonants were examined with the focus on the well-known three-way distinction among stops (i.e., lenis, fortis, aspirated) and the two-way distinction between s and s*. Acoustic parameters examined for the stops included VOT, relative stop burst energy, Fo at the vowel onset, H1-H2, and H1-F2 at the vowel onset. For the fricatives s and s*, acoustic parameters were fricative duration, Fo, centroid of the fricative noise, RMS energy of the frication, H1-H2 and H1-F2 at the onset of the following vowel. In investigating aerodynamics, intraoral pressure and oral flow were included for the bilabial stops. Results indicate that, although Cheju and Korean are not mutually intelligible, acoustic and aerodynamic properties of Cheju consonants are very similar in every respect to those of the standard Korean. Among other findings there are three crucial points worth recapitulating. First, stops are systematically differentiated by the voice quality of the following vowel. Second, stops are also differentiated by aerodynamic mechanisms. The aspirated and fortis stops are similar in supralaryngeal articulation, but employ a different relation between intraoral pressure and flow. Finally, our study suggests that the fricative s is better categorized as 'lenis' than as 'aspirated' in terms of its phonetic realization.

Keywords: Cheju, Korean, stops, fricatives, acoustics, aerodynamics

1. INTRODUCTION

Cheju is spoken on Cheju Island, which is located about 100 km south of the Korean Peninsula, and 160 km west of Japan. The island is 73 km from east to west, 41 km from north to south in the space of an oval, with a total area of 1,845 km2. Politically, Cheju Island is an integral part of South Korea, one of the eight provinces of the country. It differs from the other provinces in its tropical weather and plants, which attract many tourists. The population of Cheju has been increased rapidly in past

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* Phonetics Laboratory, Dept. of Linguistics, UCLA, USA.

decades due to the migration from the mainland Korea. As of 1997, there were approximately 540,000 people in Cheju Island. Due to the high level of education and the influence of mass media, it is not easy to find a pure native speaker of Cheju. Cheju is spoken more commonly in the inland, rural, areas.

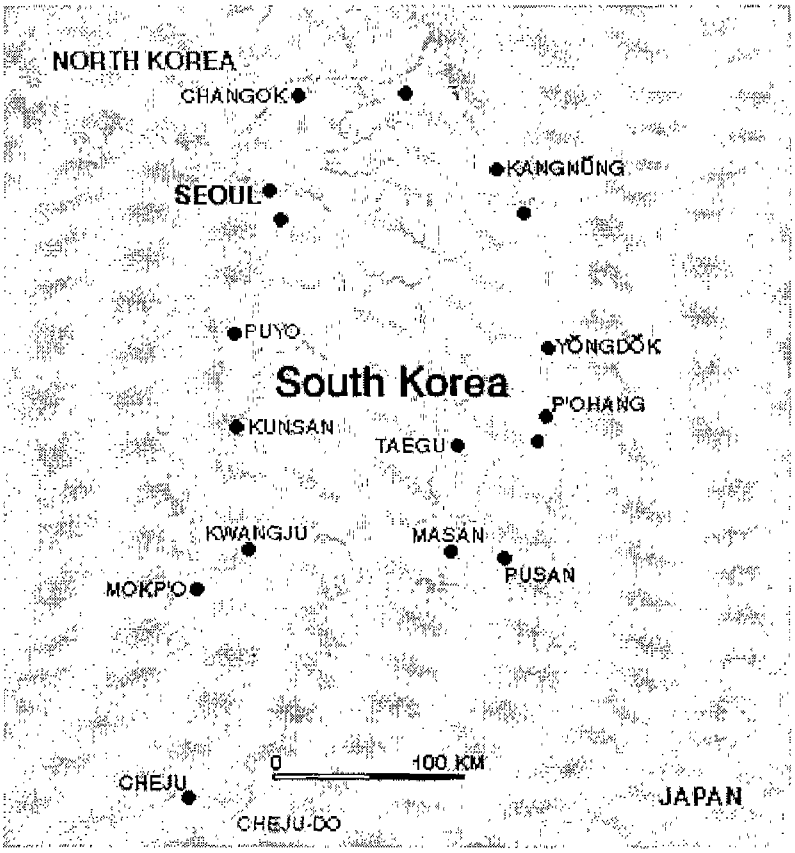


Figure 1. The location of Cheju Island

Cheju can be considered to be simply a dialect of Korean. It shares the same morphosyntactic structure and the same writing system as other dialects of Korean. It is, however, not mutually intelligible with the rest of Korean, and might be considered to be a separate language. However, in this paper, we will take no stand on this issue. Instead, we will simply compare the consonants of Cheju, whenever necessary, with those of the standard Korean spoken in Seoul, which we will refer to as Korean in this paper.

This paper is based on recordings of eight male speakers of Cheju. Three speakers (S1-S3) were recorded in Cheju city, aged 55, 61 and 68, and the other five speakers (S4-S8) were recorded in the more mountainous area of southern Cheju (Namchejukun), in two villages: Shinrye-ri and Uikwi-ri. The five men in this region were between 66 and 74 years old. All the speakers understood Korean, were literate, and above average in their socioeconomic status. We also recorded eight female speakers, three in Cheju city (aged 62, 66 and 75) and five in the rural area (aged between 68 and 78). Data from these speakers will be considered in a later paper.

Each of the speakers was recorded using a close-talking, noise-canceling Shure microphone and a Sony DAT recorder. The recordings were made in the home of one of the speaker's, or in a quiet part of the village community center. The word list consisted of 80 Cheju words, each of which was written on an index card in Korean orthography reflecting the sounds of Cheju as close as possible. To help speakers produce each word more naturally, a word triggering the context was written next to the target word on the index card. For example, a word for 'baby' was written for the target word 'to give a birth'; a word for 'ground' was written for the target word 'to dig'. Speakers produced each word twice after being prompted by one of the authors, S-A. Jun, or by a Cheju-native linguist (see Acknowledgements). The word list was rehearsed with each speaker before the recording was made.

2. CHEJU OBSTRUENTS

A great amount of work has examined the acoustic and articulatory properties of Korean consonants, especially the typologically unusual system of Korean stops. Cheju is like Korean with respect to its stop system. Both Cheju and Korean stops occur at three places of articulation, bilabial, denti-alveolar, and velar. At each place of articulation, stops fall into three different categories, often called lenis, fortis and aspirated. The lenis stops have been described as lax and slightly aspirated, the fortis stops as tense and unaspirated, and the aspirated stops as being strongly aspirated. Along with the stops, both Cheju and Korean distinguish post-alveolar affricates with a similar three-way distinction, lenis, fortis and aspirated. In addition, there is a two-way distinction in denti-alveolar fricatives: plain vs. fortis. The plain s is sometimes categorized as lenis, and sometimes as aspirated. In this paper, we will refer to this s as a 'plain' s in order to avoid any unnecessary confusion brought about by the terminology, lenis vs. aspirated. Table 1 shows all the Cheju and Korean obstruents. In this table, s is categorized as lenis for the sake of simplicity. The diacritic '*' is used to mark fortis obstruents in this paper. Table 2 gives minimal triplets (or, in the case of the denti-alveolar fricatives, a minimal pair) for the Korean sounds. We were not able to find equally minimal contrasts for Cheju, but all these oppositions exist, as will be demonstrated below.

Table 1. Obstruents in Cheju and Korean: lenis, fortis, and/or aspirated distinctions

lenis series	p	t	ʧ	k	s
fortis series	p*	t*	ʧ*	k*	s*
aspirated series	p^h	t^h	$ʧ^h$	k^h	

Table 2. Minimal contrasts for Korean obstruents in word-initial position

Lenis		Fortis		Aspirated	
paŋ	'room'	p*aŋ	'bread'	p^haŋ	'bang'
tal	'moon'	t*al	'daughter'	t^hal	'mask'
ʧata	'to sleep'	ʧ*ata	'to squeeze'	$ʧ^h$ata	'to kick'
kæta	'to fold up'	k*æta	'to break'	k^hæta	'to dig up'
sata	'to buy'	s*ata	'to wrap'		

3. PREVIOUS INVESTIGATIONS OF KOREAN OBSTRUENTS

In this section, we will review acoustic and articulatory properties of Korean obstruents, focusing on stops and fricatives. Acoustic and articulatory properties of the three way manner distinctions in the affricates are similar to those of stops, except that affricates have a frication component after stop closure.

3.1 Stops

In most of the world's languages, the voicing feature for syllable-initial stops can be specified quite well in terms of the three categories, voiced, voiceless unaspirated and aspirated (e.g., Lisker and Abramson 1964; Klatt 1975). However, Korean does not have a voicing distinction among stops phonologically, though it does phonetically in an intervocalic word-medial position. They are all voiceless. Nevertheless, there are consistent three-way differences in VOT among the three stop categories. The fortis stops are unaspirated, the lenis stops moderately aspirated, and the aspirated stops are strongly aspirated (Abberton 1972; Lisker and Abramson 1964, *inter alia*). However, other acoustic and physiological studies have suggested that VOT alone does not fully account for the observed three-way phonemic distinction of Korean stops (C. Kim 1965, 1970, Han and Weitzman 1970, Hardcastle 1973, Hirose et al. 1974; M. Kim 1994, Y. Kim 1995, Han 1996, Cho 1996).

As VOT is not the only distinguishing feature of the manner distinction of Korean stops, some phonologists and phoneticians have proposed different ways of identifying these stops in initial position. Han and Weiztman (1970) noted that, in addition to the differences observed in VOT among these stops, different acoustic features can be observed in the onset phase of voicing following the stop release. They reported that the onset value of fundamental frequency and the intensity characteristics of the initial phase of voicing also contribute to the manner distinction. In general, Fo after aspirated or fortis stops is relatively higher than after lenis stops. Similar results were found by Hardcastle (1973), Kagaya (1974), M. Kim (1994) and Cho (1996). These studies indicate that Fo contrasts serve as a supplementary cue to distinguish lenis stops from fortis and aspirated stops, but not necessarily to distinguish aspirated and fortis stops. Furthermore, Jun (1993, 1996) found that the Fo difference is not simply due to the phonetic perturbation that has been noticed in other languages (Lehiste and Peterson 1961, Lieberman 1963, Ladefoged 1964, Hombert 1978, Hombert, Ohala, William 1979, *inter alia*,), but is phonologically encoded in the intonation system in most dialects of Korean (including Seoul dialect), so that a phrase-initial syllable beginning with a fortis or an aspirated obstruent is realized with a high (H) tone.

Han and Weitzman (1970) also reported that the harmonic components are weaker for lenis stops, intermediate for aspirated stops, and stronger for fortis stops. They further argued that these observations are indicative of a difference in the intensity build-up following the voice onset associated with each stop: relatively more time is needed for glottal intensity to build up following a lenis stop or an aspirated stop than that following a fortis stop.

The duration of the stop closure has been considered as another acoustically distinctive feature associated with Korean stops - in general, the stop closure is shortest for lenis stops, intermediate for aspirated stops, and longest for fortis stops (Silva 1993; M. Kim 1994; Han 1996). But an electropalatographic (EPG) study by Cho & Keating (1999) showed that there is no significant difference between aspirated and fortis stop closure durations, all else being equal. Cho & Keating (1999) also examined linguopalatal contact (the contact between the tongue and the roof of the mouth) for different stops and found that lenis stops have less linguopalatal contact than aspirated or fortis ones. The longer duration and the greater linguopalatal contact associated with both the aspirated and the fortis stops indicate that they are articulatorily 'strong' stops, compared to the lenis stop.

The nature of the aspirated and the fortis stops has been a long term research topic. One of the earlier studies, C. Kim (1965), characterized the stops in terms of two features: 'tension' of the articulation, which served to distinguish aspirated and fortis stops from lenis stops; and 'aspiration', which served to distinguish aspirated stops from fortis stops (and lenis stops). Some of the supportive findings for 'tension' associated with fortis and aspirated stops were a faster rate of vocal fold vibration after release, greater amplitude of pressure, longer duration of increased pressure, faster pressure build-up, greater linguopalatal contact, greater lip muscle activity (for bilabial stops). In line with C. Kim, on the basis of results of VOT, frequency of glottal cycles at vowel onset and air-flow rate, Hardcastle (1973:271) suggested that "a feature 'tensity', defined in terms of isometric muscular tension in the vocal cords and pharynx, can usefully be employed to explain some of these properties".

As techniques developed for examination of the glottal area, researchers started investigating vocal fold configurations that may contribute to the production of the contrasting stops. C. Kim (1970), using cineradiographic evidence, reported that the glottal opening is larger for aspirated stops, intermediate for lenis stops, and narrower for fortis stops, arguing that the degree of aspiration is proportionally correlated with the degree of glottal opening at the time of release of the oral closure. Kagaya (1974), in a fiberscopic study, found that fortis stops have approximated vocal folds well before the articulatory release, while the glottis is quite open for the lenis stop but not as open as for the aspirated stop at the time of the release. Kagaya suggested that both the fortis and aspirated stops are characterized by some intrinsic laryngeal gestures. In his view, fortis stops can be characterized by (1) a completely adducted state of the vocal folds before the articulatory release, (2) stiffening of the vocal folds, (3) abrupt closure of the vibrating vocal folds near the voice onset, (4) increasing subglottal pressure, and (5) lowering of the glottis immediately before the release. Aspirated stops are associated with positive abduction of the vocal folds and heightened subglottal pressure. On the other hand, none of these positive laryngeal gestures are observed for lenis stops. More recently, Jun, Beckman, & Lee (1998), in their fiberscopic study of vowel devoicing, found a similar result in terms of the timing and size of the glottal opening for the three stop types. They also found that the glottal opening area is greater when the stop is in phrase (i.e., Accentual Phrase) initial than in phrase medial position, suggesting that there is domain-initial strengthening associated with the glottal gesture. (See Cho, 1998; Cho & Keating, 1999; Keating, Cho, Fougeron & Hsu, 1999 for further discussion on domain-initial strengthening.)

The glottal state in these stops was further examined by the Electromyography (EMG), which allows us to investigate the activities of the intrinsic laryngeal muscles. Hirose, Lee, and Ushijima (1974) in an EMG study, reported that fortis stops are characterized by a sharp increase in thyroarytenoid activity before the stop release, which presumably resulted in increased tension of the vocal folds and constriction of the glottis during or immediately after the stop closure. In aspirated stops, all activity of the adductor muscles of the larynx was suppressed immediately after the articulatory release. A steep increase in activity of the adductor muscles always followed this suppression, presumably due to the movement into the position for voicing. In lenis stops, the suppression of adductor muscle activity is not significantly involved as compared with aspirated stops, and there is no transient increase in thyroarytenoid activity before the articulatory closure. These results suggest that a simple dimension of adduction-abduction of the vocal folds in characterizing Korean stops, implied in the studies of C. Kim (1970) and Kagaya (1974), is not sufficient, and another dimension is required.

Dart (1987) investigated the different aerodynamic properties of fortis and lenis stops in Korean. She measured intraoral air pressure and oral flow associated with the fortis and lenis stops in prevocalic position. One of the main results in her study is that the production of fortis stops is characterized by "a higher intraoral pressure before release, yet a lower oral flow after release," which is counterintuitive since in general higher intraoral pressure is associated with greater oral flow. Dart's aerodynamic modeling accounted for the pressure-flow relations by modeling fortis stops with tightly adducted vocal folds before the articulatory release and greater vocal tract wall tension.

As it became clear that the different types of stops are associated with different glottal configurations in the production of not only the stops themselves but also the onset of the following vowel, researchers began to raise the question of whether the voice quality of the vowel is influenced by the preceding consonant. They hypothesized that the voice quality of the vowel is similar to a breathy voice after the lenis stop and to a laryngealized or 'pressed' voice after the fortis stop. A laryngographic study by Abberton (1972) showed that the onset of vowels after fortis stops has some of the characteristics of creaky voice with a long closed phase and a slow opening phase. Han (1998) reported that vowels after lenis stops have a breathy voice as indicated by positive H1-H2 values (the difference in amplitude between the first and the second harmonics). On the other hand, vowels after fortis stops do not always have negative H1-H2 values, which, if present, would have indicated a laryngealized or pressed voice quality.

3.2 Fricatives

There are three fricatives in Korean, s, s*, h. As in the stops, there is no voicing contrast among fricatives, but unlike stops, there is only a two way contrast between denti-alveolar fricatives, s and s*. s* is a tense or fortis fricative, but the categorization of s has been controversial. Korean orthography regards it as lenis and it behaves that way in phonological processes. But its behavior in phonetic processes and its phonetic realizations are generally believed to be similar to stops in the aspirated category. For example, s becomes tense after a lenis stop (e.g., /paksa/ → [paks*a] 'Ph.D') as does the lenis stop (e.g., /pakta/ → [pakt*a] 'to pin down'). However, s is not likely to become phonetically voiced between voiced segments as lenis stops do, and it generally triggers a high tone in the beginning of an Accentual Phrase as does the aspirated stop (Jun 1993).

In its phonetic realization, s consists of two parts, frication and aspiration, as has been shown in spectrograpic studies (Yoon 1998, Park 1999). Fiberscopic data in Kagaya (1974) and Jun et al. (1998) showed that s has a glottal opening configuration similar to aspirated stops, and Jun et al. further showed that s has a larger glottal opening than s*. Park (1999) reported that plain s has greater H1-H2 values than fortis s*, suggesting that the vowel onset after plain s is breathier than after fortis s*. However, the relative breathiness associated with plain s cannot be a direct metric for whether plain s has the characteristics of an aspirated segment, since the lenis segment, as noted earlier, can also be associated with breathy voicing in the following vowel onset.

4. CHEJU DATA

In this section, we will describe the procedures employed to investigate the acoustic and aerodynamic properties of Cheju consonants, and the measurement criteria for both stops and fricatives. For stops, we will examine VOT, burst energy, Fo, H1-H2, H1-F2 (the second formant), and oral pressure and flow data. (Affricates were included only for VOT measurement.) For fricatives, we will examine the duration, centroid of fricative noise, RMS energy, Fo, H1-H2, and H1-F2, with particular reference to the contrasting nature of s and s*.

All nine stops and three affricates were examined in the acoustic study. Each consonant was placed in initial and medial positions in the word, and was followed (and preceded, for word medial tokens,) by the open vowel a. In this paper, we will discuss word initial tokens only. Table 3 shows the word list in a phonemic transcription. Note that for the lenis t, two different words were used because some speakers were more familiar with one than the other.

The fricatives s, s*, h were recorded in initial and medial position, in the words shown in Table 4. As will be discussed in section 7, we also recorded all the other consonants of Cheju. Here we will simply note that the approximant l in word initial position (i.e., /latio/ 'radio') was used to provide a base line when comparing the voice qualities of vowels conditioned by the type of preceding consonant.

Table 3. Stops and affricates recorded for acoustic measurements

p^h	p^hamtʃə	to dig
p*	p*amtʃə	to squeeze oil
p	pataŋ	sea
t^h	t^hamtʃə	to get (shy)
t*	t*api	ground
t	t*alkwatʃəmtʃə	to heat iron
	t*ɐlanamtʃə	to run away
$tʃ^h$	$tʃ^h$amtʃə	to kick
tʃ*	tʃ*amtʃə	to conspire
tʃ	tʃamtʃə	to sleep
k^h	k^hamtʃə	to get burned
k*	k*amtʃə	to peel
k	kamtʃə	to go

Table 4. Fricatives recorded for acoustic measurements

Word initial			Word medial		
s	salamtʃə	to live	s	asakatʃə	to take away
s*	s*alamtʃə	to wrap	s	phasak	breaking noise
h	hata	many/much	h	nahan	(from) 'opek nahan'

For the aerodynamic study, a corpus with only bilabial stops was designed as shown in Table 5. Four sets of data were constructed to make the target consonants (p, p^h, p*) vary in four prosodic positions - word-initial vs. word-medial in isolation, and word-initial (i.e., phrase initial) vs. word-medial within a sentence.

Table 5. Word list for aerodynamic study

Word in isolation, word initial			Word in isolation, word medial	
p	pe	ship	tʃapamtʃə	to catch
p^h	p^he	card	ap^{h}amtʃə	sick
p*	pe	bone	pap*amtʃə	busy
Sentence medial, word initial			**Sentence medial, word medial**	
p	ikəsi petʃu	This is a ship	kaitʃapamtʃə	He catches (object)
p^h	ikəsi p^hetʃu	This is a card	kaiap^{h}amtʃə	He is sick
p*	ikəsi p*etʃu	This is a bone	kaipap*amtʃə	He is busy

For the acoustic study, each word in Tables 3 and 4 was read twice by each speaker. For the aerodynamic study, the items in Table 5 were read four times each by each speaker (except for one male speaker in the rural area). Recorded materials were digitized at a sampling rate of 22,050 Hz and analyzed using the Kay Elemetrics's Computerized Speech Lab (CSL).

4.1 Measurements for stops

■ Voice Onset Time: VOTs for all stops and affricates were taken from the point of the stop release to the voice onset of F_2 and higher formants in the following vowel, as seen in spectrograms. Thus for the lenis stops, any breathy voicing with only low-frequency harmonics was included in the VOT, and for the affricates, frication after stop release was included in the VOT because there was no clear cut between frication and aspiration.

■ Relative Burst Energy: The acoustic energy at the burst and in the middle of the vowel were measured from an acoustic energy profile, using a 10 ms window. The percentage value of the burst energy relative to the energy at the midpoint of the vowel was employed to examine the characteristics of the stop release for the different types of stops. Greater burst energy for a stop can be expected in two cases - when a consonant (i.e., t) has a relatively small amount of linguopalatal contact, resulting in a fast release (Stevens, Keyser, & Kawasaki, 1986) and when the air flow is greater at the release (which is presumably due to a greater air pressure behind the constriction immediately before the release).

■ Fundamental Frequency (Fo): Fo was measured at the onset and the midpoint of the vowel, using the pitch track along with the first harmonic values from an FFT with a 25 ms window as supplementary checks. From the Fo differences, we would infer some physical information about the vocal folds (e.g., tension or stiffness) associated with different consonant types.

■ H1-H2 and H1-F2: Energy values (dB) for the first (H1) and second (H2) harmonics, and the peak harmonic forming the second formant (F2) were taken at the onset of the vowel, using FFT spectra with a 25 ms window. All nine stops were included in this measure. In addition, harmonic values were also measured at the midpoint of the vowel after the liquid l, which was used as a control data representing modal voicing. The difference in amplitude between H1 and H2 has been frequently used to distinguish between breathy and modal voicings (e.g., Bickely 1982, Ladefoged 1983, Huffman 1987, Klatt & Klatt 1990, Blankenship 1997). Breathy voicing is produced with a relatively larger open quotient with the vocal folds remaining closed for a shorter time (e.g., open for 80-100 % of the cycle for breathy phonation, vs. 65-70 % for modal phonation (Childers & Lee, 1991)). As a result, the spectrum is dominated by the energy at the fundamental frequency, resulting in the amplitude of H1 being markedly higher than that of other harmonics. On the other hand, laryngealized vowels with creaky voicing (or 'pressed voicing' in Stevens' (1999) term) would have the opposite result, as they are produced with a smaller open quotient with the vocal folds remaining closed for a longer time (Blankenship, 1997). Thus, a greater H1-H2 would indicate breathiness of the vowel and a smaller or negative H1-H2, would indicate creakiness.

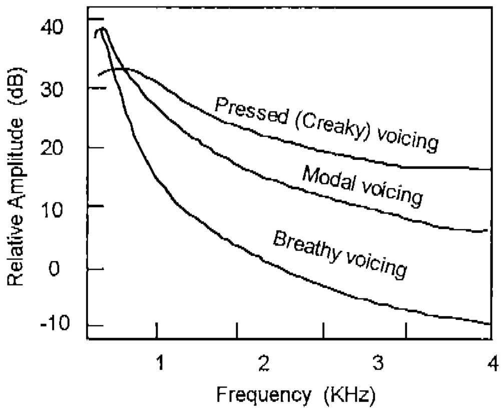


Figure 2. Schematized spectra for different phonation types, based on Stevens (1999:86, 90).

The spectral slope, as obtained from H1-F2, is an indicator of the abruptness of vocal fold closure. Blankenship (1997:17) explains that a gradual adduction of the vocal folds excites mainly the lower resonances of the vocal tract and, as a result, the sound wave is nearly sinusoidal with most energy near Fo. The resulting spectrum has a steep downward slope from which a greater H1-F2 is expected. We expect that any breathy voicing should be associated with a gradual adduction with a greater H1-F2. On the other hand, when there is an abrupt adduction with the vocal folds coming together all at once, which is one of the characteristics of pressed or creaky voicing, the abruptness of the closure excites a wider range of frequencies. As a result, the sound wave has a spectrum with energy spread across a higher range of frequencies. Schematized spectra for different types of voicing are shown in Figure 2, based on Stevens (1999:86, 90).

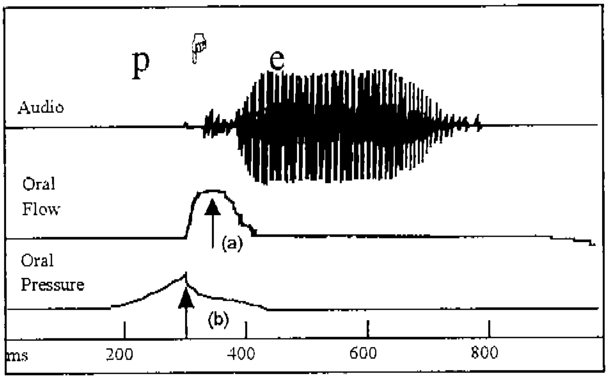


Figure 3. Waveforms of audio, oral airflow and oral pressure.
The points marked by arrows indicate peak oral flow (a) and oral pressure (b).

■ Oral Pressure and Flow: Oral airflow and pressure were recorded using the Macquirer X16 system. Speakers held a face mask against the lower part of the face, below the nose, capturing all the oral airflow. They also held a tube (internal diameter 2 mm) between their lips to record the pressure of the air in the mouth. A microphone within the face mask recorded the audio signal. The flow and pressure signals were sampled at a rate of 2 kHz and the audio signal was sampled at 10 kHz. Speakers found little difficulty in producing the required phrases in these conditions, and the audio signal indicated that the utterances sounded reasonably natural. Only bilabial stops, as shown in Table 5, can be investigated in this way. (The speakers were too elderly and unaccustomed to phonetic experimentation to ask them to pass a tube through the nose so that pressures behind dental and velar closures could be recorded.) The maximum flow after the release of the closure and the peak oral pressure during the closure were measured, as indicated by the arrows (a) and (b) in Figure 3, respectively.

Oral pressure and flow provide information about the degree of glottal constriction (Ladefoged, Maddieson & Jackson 1987). Other things being equal, the ratio of flow to pressure in a voiced sound should be constant. The ratio of flow to pressure will be higher if the vocal folds are held together more loosely, as in a breathy voiced vowel, and lower when the vocal folds are more tightly together as in a pressed or creaky vowel. As we have noted, Dart (1987) and others using these measures have found indications of differences in phonation type in the vowel onsets after the different Korean stops. We wanted to determine whether similar variations occurred in Cheju.

4.2 Measurements for fricatives

■ Fricative duration: Duration measurements were made from the spectrograms of each token for s and s* both in word-initial and word-medial positions. For s, we also measured the duration of both frication and aspiration, separately and combined.

■ Centroid of the fricative noise: The centroid is the center of gravity of a defined part of the spectrum, each frequency being weighted according to its amplitude. Centroid values were taken from FFT spectra in the frequency range from 500 Hz to 10,000 Hz, using a 25 ms window centered around the midpoint of the fricative portion of s*, h, and the midpoint of the fricative and the following aspiration for the plain s. Due to the low-frequency characteristics of h (Stevens 1999), we expect that h would be associated with a lower centroid. On the other hand, for denti-alveolar fricatives, s and s*, a higher centroid is expected as the source is filtered by the front cavity resonance, resulting in a spectrum peak in the vicinity of F_4 or F_5 (Stevens 1999). We were particularly interested in determining whether there was a difference in the centroid frequency of s and s*.

■ RMS energy: The acoustic energy at the center of the frication was measured from an FFT spectrum giving the RMS value over all frequencies. A 25 ms window was centered around the midpoint of the frication for s and s*.

■ H1-H2 and H1-F2: As measured for stops, H1-H2 and H1-F2 were measured at the onset of the vowels that follow s and s*.

■ Fundamental Frequency (Fo): As measured for stops, Fo was taken at the onset and the midpoint of the following vowel.

Along with these parameters that were analyzed quantitatively, qualitative observations of the spectrographic characteristics were made for each token.

5. RESULTS AND DISCUSSION FOR STOPS

5.1 VOT

We found a significant effect of consonant type on VOT ($F(2, 180) = 280.571$, $p < .0001$). Pairwise Fisher's PLSD post hoc comparison showed that VOT is shortest for the fortis stop, intermediate for the lenis stop, and longest for the aspirated stop ($p < .0001$ for each comparison). This finding is true across all places of articulation, as summarized in Figure 4. It remains true for stops at each place of articulation taken separately, except that there is no significant difference in VOT between the lenis and the fortis post-alveolar affricates, presumably because there was a trade off between the aspiration and the frication periods (Note that the frication component of an affricate was included as VOT).

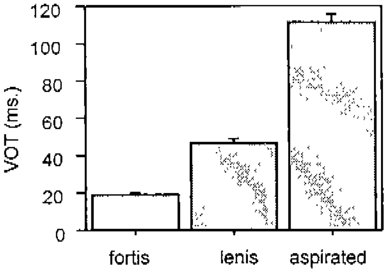


Figure 4. VOT for different types of stops and affricates. Data are pooled across stops/affricates, speakers and place of articulation. Error bars refer to standard errors.

Figure 5 shows the variation in VOT due to place of articulation. There is a significant effect of place of articulation on VOT (F(3, 180) = 15.253, p < .0001). Pair-wise Fisher's PLSD post hoc comparison showed that VOT of the velar stop is significantly longer than that of either the bilabial or the denti-alveolar stops. There was no significant difference between the bilabial and the denti-alveolar or between the post-alveolar and the velar VOT's. This is in general agreement with the tendencies noted in other languages, notably that the further back the closure, the longer the VOT (Fischer-Jørgensen 1954; see also Cho & Ladefoged, 1999, for an extended discussion on VOT).

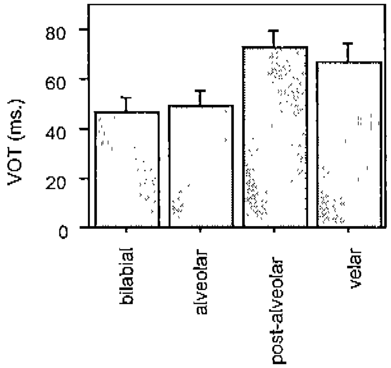


Figure 5. Variation in VOT depending on place of articulation.

5.2 Relative burst energy

We found a significant effect of the consonant type on the relative burst energy (F(2, 135) = 11.091, p < .0001). Fisher's PLSD pairwise post hoc comparisons revealed that the aspirated stop has significantly greater burst energy than the other two types of stops while there is no difference between the fortis and the lenis stops, though there is a trend for the lenis stop to have a greater burst energy than the fortis stop, as shown in Figure 6.

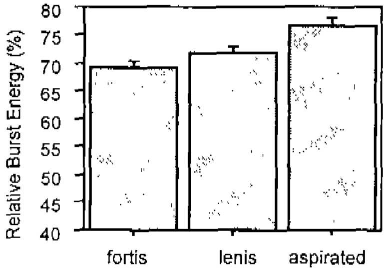


Figure 6. Relative burst energy (dB) for different types of stops.

As mentioned earlier, a greater burst energy is due either to a smaller linguopalatal contact (Stevens et al. 1986) (and, therefore, a greater speed of movement) or a greater air flow at the release. Cho and Keating (1999) found that both fortis and aspirated Korean stops have greater linguopalatal contact than the lenis stops while there is no difference between the fortis and aspirated stops. If the greater contact induces slower release, which is in turn associated with lesser burst energy, then both fortis and aspirated stops should have lesser burst energy than lenis stops, all else being equal. Our data, however, show that only fortis stops have lesser burst energy than lenis stops. This indicates that the amount of the contact itself is not the primary source for the greater burst energy.

Dart (1987) found that the lenis stop has a greater air flow at the release than does the fortis one, though the fortis stop has a greater air pressure before the release. (A similar result was found in our own aerodynamic study. See below.) This explains why the lenis stop tends to have a greater burst energy than the fortis stop in our data. The lenis stop has a greater air flow at the release which is responsible for the greater burst energy. We can also expect that the aspirated stop is produced with a greater oral pressure and a greater flow than the lenis stop at the release, which would lead to a greater burst energy. In fact, our aerodynamic data show that the aspirated stop is produced with the greatest air flow at the release (see Fig. 11).

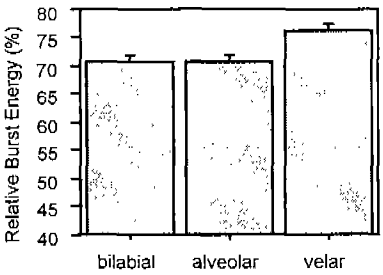


Figure 7. The relative burst energy (%) at different places of articulation.

This aerodynamic explanation of the burst energy is supported by the observation that there is a significant effect of place of articulation (F(2, 141)=6.787, p =.0015 across speakers). The burst energy for the velar stop is significantly greater than that for both the bilabial and denti-alveolar stops (p < .001, Fisher's PLSD posthoc comparisons) between which there is no difference, as shown in Figure 7. The velar stop, which is usually produced with a relatively greater linguopalatal contact, might be expected to have smaller burst energy. This would be the case if the amount of linguopalatal contact and its consequent slow speed of the release movement is the primary factor responsible for the burst energy difference. But the cavity behind the constriction of the velar closure is relatively smaller than those of other stops, and, as a result, will have relatively greater air pressure buildup before the release. The greater air pressure would give higher air flow volume velocity, which appears to be responsible for the greater burst energy for the velar stop. However, we should not ignore the possibility that the difference may be due to the shape of the constriction just after the release.

5.3 Fo differences

We found that Fo in both the onset and the midpoint of the vowel is significantly influenced by the type of preceding consonants (F(2, 135) = 27.999, p < .0001 for the onset; F(2, 116) = 13.461, p < .0001 for the midpoint). Each consonant type is associated with significantly distinctive Fo in the onset of the following vowel at least at the p < .05 level while, in the midpoint of the following vowel, a significant difference is maintained between the lenis and the other two stops, but not between the fortis and the aspirated stops. As shown in Figure 8, for the vowel onset, lenis stops have smaller Fo values than fortis stops which in turn have smaller Fo values than aspirated stops. Note, however, that the difference between the fortis and the aspirated stops is smaller than that between the lenis and the other stops. For the vowel midpoint, similar patterns are observed except that the difference between the fortis and the aspirated stops is not significant.

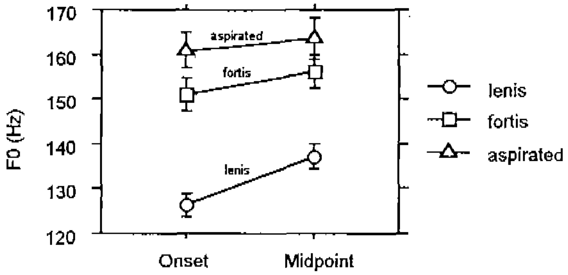


Figure 8. Fo differences in the onset and the midpoint of the following vowels.

The substantial difference in Fo between the lenis and other stops cannot be understood in terms of the phonetic pitch perturbation caused by the voicing of the preceding consonant (i.e., microprosody) as found in many other languages (Hombert 1978, Hombert et al. 1979). The Fo difference between the groups shown in Figure 8 is substantially greater than that found in other languages, and the Fo difference is still present at the mid point of the syllable. Furthermore, all three stops are voiceless.

The same Fo pattern was found in Seoul Korean (Jun 1996a). Jun (1996b) claims that this segmentally triggered Fo distinction in Seoul Korean is phonologized in the intonation system of Seoul Korean as described by Jun (1993, 1996a, 1998). In this intonation system, the Accentual Phrase is realized in two distinct tonal patterns, LHLH and HHLH, where the phrase initial tone (L vs. H) is determined by the type of the consonant occurring in the onset of the phrase initial syllable. When there is a fortis or aspirated obstruent in the onset, the Accentual Phrase starts with H, and otherwise (i.e., when there is a lenis obstruent, a sonorant consonant, or a vowel), it starts with L. This phonologization of microprosody seems to occur in Cheju, though we do not yet know the detailed intonation system of Cheju.

5.4 H1-H2 and H1-F2

There is a significant effect of consonant type on H1-H2 (F(2, 135) = 27.419, p < .0001). Pairwise posthoc comparisons by Fishers PLSD showed that stops differ significantly from each other at p < .05. H1-H2 is greater (positive) for lenis stops, intermediate for aspirated stops, and smaller (negative) for fortis stops, as shown in Figure 9. In other words, the onset of the vowel (the first 30 ms. period) has a more breathy voicing with a larger open quotient of the vocal folds immediately after the lenis stop, and more pressed (creaky) voicing with a smaller open quotient after the fortis stop. The voice quality of the vowel after the aspirated stop is close to the modal voice. Its H1-H2 value is about the same as the control (modal) value taken from the midpoint of the vowel after l which has no known effect on the phonation type of the following vowel. What is especially interesting about this finding is that it indicates that both the fortis and the lenis stops are associated with non-modal phonation.

Now let us consider the spectral slope (H1-F2), a hypothesized indicator of the abruptness of vocal fold closure. Results show that there is a significant effect of consonant type on H1-F2 ($F(2, 135) = 9.939$, $p < .0001$). The fortis stop has negative H1-F2 while the lenis and aspirated stops have positive H1-F2, as shown in Figure 10. This indicates that the closing gesture of the vocal folds during the voicing is more abrupt for the fortis stop than for the other stops. The folds come together more rapidly after the fortis stop, providing more energy in the second formant region, presumably because they are under greater tension. Interestingly, however, the expected higher H1-F2 associated with the breathy voicing for the lenis stop was not observed as compared to H1-F2 for the aspirated stop. This indicates that the H1-H2 (an indicator of the open quotient) and the H1-F2 (an indicator of the abruptness) do not necessarily go hand in hand. In fact, there is only modest correlation between the two parameters ($R = .466$).

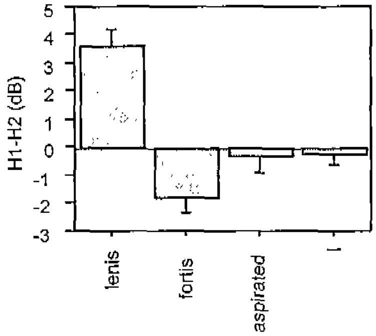


Figure 9. Difference between the amplitudes (dB) of the first harmonic (H1) and the second harmonic (H2) for different stop types and /l/. Error bars indicate standard errors.

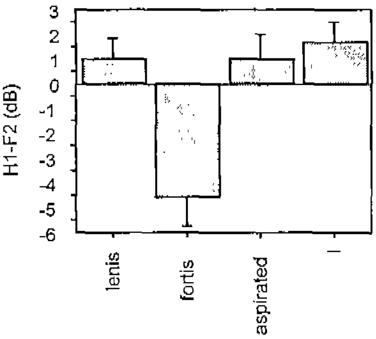


Figure 10. Difference between the amplitudes (dB) of the first harmonic (H1) and the second formant (F2). Error bars indicate standard errors.

5.5 Oral Pressure and Flow

Both oral pressure and flow were found to be significantly influenced by the consonant type (F(2, 317) = 28.985, $p < .0001$ for oral pressure; F(2, 317) = 87.257, $p < .0001$ for air flow). As shown in Figure 11a, the peak oral pressure during the closure is smaller for the lenis stop than for the fortis and aspirated stops, while there is no difference between the latter two. On the other hand, the lenis stop is produced with a slightly greater flow than the fortis stop, as found by Dart (1987), but with a much smaller flow than the aspirated stop, as shown in Figure 11b.

The fact that the fortis stop has greater oral pressure but little flow can be accounted for by several factors such as the glottal impedance (which depends largely on the glottal area), the vocal tract wall tension, and a possible increase in the subglottal pressure, as discussed in Dart (1987). The smaller glottal opening area (Kagaya 1974, Jun, Beckman, and Lee 1998) would have the effect of decreasing flow through the glottis. A greater degree of vocal tract wall tension (C. Kim, 1965; Hardcastle, 1973) also contributes to an increase in oral pressure. Dart posited that the pressure increase is due to stiffening the wall, which presumably reduces passive vocal tract expansion. The suppression of the vocal tract expansion is effectively the same as reducing the supraglottal cavity volume which otherwise would be expanded under normal circumstances. The stiffened vocal tract wall can also result in a decrease in the volume velocity of air flow since the reduction in the elasticity of the walls would also reduce the amount of elastic recoil of the walls, which would in turn cut down the initial flow volume velocity at release. Finally, the pressure increase can be understood as the result of heightened subglottal pressure, as suggested by C. Kim (1965) and Kagaya (1974). Dart's model suggested that the heightened subglottal pressure is primarily due to a larynx raising caused by a more rapid increase in respiratory muscle force, although it is also possible that any subglottal pressure increase can be a result of larynx lowering, caused by expanding the supraglottal cavity.

Now let us look at aerodynamic characteristics of the aspirated stops, which were not included in Dart's study. Aspirated stops are characterized by an increase in both oral pressure and flow, as shown in Figure 11. The greater oral pressure and flow can be accounted for by a larger vocal fold opening (Kagaya 1973, Jun et al. 1998) and a greater subglottal pressure due to an increase in the respiratory muscular force. As C. Kim (1965) noted, there may be a greater vocal tract wall tension during the closure of the aspirated stop as in the case of the fortis stop, which will contribute to an increase in the oral pressure. However, as discussed above, the greater wall tension would counteract the increase in flow velocity immediately after the stop release. It is conceivable that the effect of glottal area function and the respiratory muscular force is large enough to override that of the vocal tract wall tension, if there is any.

To examine the position effect on aerodynamic parameters, the data were submitted to three-way ANOVAs with factors, Consonant Type, Position-in-Word (initial vs. medial), Position-in-Sentence (word in isolation vs. word inside a sentence). First, the results show that there is a significant effect of Position-in-Word on flow ($F(1, 308) = 33.535$, $p < .0001$) - air flow was significantly greater for word-initial stops than for word-medial stops. But, there is no significant effect of Position-in-Word on oral pressure. Second, there is no effect at all of Position-in-Sentence on either oral pressure or flow - i.e., no difference between the word in isolation and the word inside a sentence. In addition, there is no significant interaction between Position-in-Word and Position-in-Sentence. Third, a significant interaction between Consonant Type and Position-in-Word is found for both oral pressure ($F(2, 308) = 12.568$, $p < .0001$) and flow ($F(2, 308) = 18.788$, $p < .0001$). The effect of Position-in-Word and its interaction with Consonant Type is illustrated in Figure 12. Note that since there is no effect of Position-in-Sentence (word in isolation vs. word inside a sentence), we present data for the word-initial stops pooled across Position-in-Sentence.

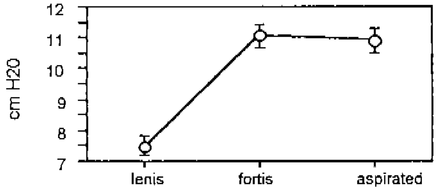
The word-initial lenis stop has a greater oral pressure and flow than the word-medial one, regardless of where it occurs in isolation or sentence-medially. The lower oral pressure and flow for the word medial lenis stop can be accounted for by the intervocalic voicing for the lenis stop. This clearly suggests that there is an effect of weakening in medial position. Seen from a different angle, however, this effect can be understood as strengthening in initial position. The glottal opening gesture is larger in word-initial position, which explains the greater oral pressure and flow, compared to word-medial position, where there is voicing. This agrees with Jun et al.'s (1998) fiberscopic study of glottal configurations of Korean obstruents, where they found that Accentual Phrase initial lenis and aspirated stops are produced with a larger glottal aperture than Accentual Phrase medial ones. A similar case was found for English by Cooper (1991).

For both fortis and aspirated stops the oral pressure is smaller for word-initial stops than for word-medial ones. This appears to be due to the geminate characteristics of the fortis and aspirated stops word-medially. In Korean, it has been reported that word-medial tense and aspirated stops in general lengthen (e.g., Silva, 1992; Han, 1996; Cho, 1998; Cho & Keating, 1999). Cho & Keating (1999) also found that linguopalatal contact for the fortis and aspirated stops tends to be greater word-medially than word-initially (but Accentual Phrase medially), which could perhaps be correlated with more forceful articulation, compared to word-initial ones.

For the air flow, there is no significant difference between initial and medial fortis stops, as shown in Figure 12b. This is presumably because the glottal aperture is too small to be effectively different between the word-initial and word-medial positions.

This is also supported by the fact that there is no significant difference in VOT between word-initial and word-medial fortis stops (Cho & Keating, 1999). For the aspirated stops, however, the word initial stops have a greater flow than word medial ones. This is presumably because the glottal aperture is larger at word initial position than medial position (Kagaya 1974, Jun et al. 1998).

(a) Oral Pressure (cm H20)



(b) Air Flow (1/msec.)

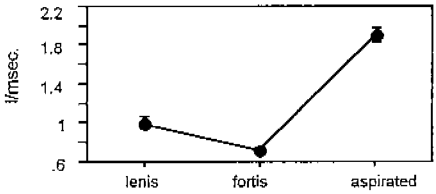
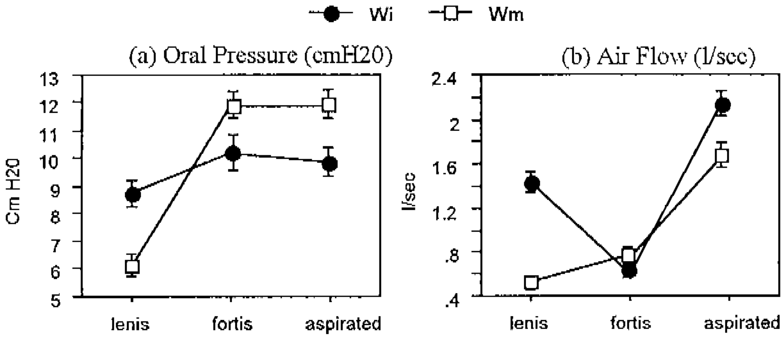


Figure 11. (a) Oral pressure (cm H20) and (b) air flow (l/msec) with data pooled across prosodic positions and speakers. Error bars indicate standard errors.



(a) Oral Pressure (cmH20)

(b) Air Flow (l/sec)

Figure 12. Difference between word-initial (Wi) and word-medial (Wm) positions for oral pressure (a) and flow (b) for three stop types, pooled across Position-in-Sentences and speakers.

6. RESULTS AND DISCUSSION FOR FRICATIVES, S AND S*

Let us first examine the acoustic characteristics for s and s* that can be qualitatively observed in the spectrograms. Spectrograms of word-initial s and s* are given in Figure 13. The plain s consists of both frication and aspiration, making it a complex, aspirated segment. This complex nature of the plain s was observed in most of the tokens examined. This suggests that the plain s is phonetically aspirated, agreeing with the previous studies (e.g., Kagaya, 1974; Jun et al, 1998; H. Park, 1999). However, it does not behave like the aspirated stops in that it does not retain a period of aspiration word-medially. The plain s is unaspirated when it occurs word-medially, as shown in Figure 14a. In these circumstances it has intervocalic weakening, like the lenis stops. Furthermore, although it is commonly supposed that s in general does not become voiced intervocalically, we observed about 38 % of tokens for s being voiced in this position-further evidence that s behaves as a lenis segment. Two examples of the fully voiced s between vowels are given in Figure 15.

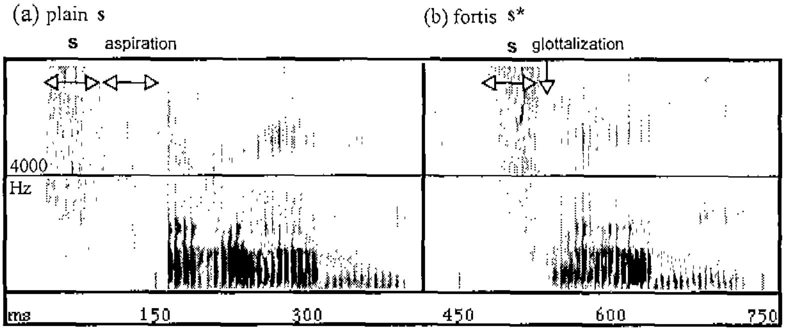


Figure 13. Spectrograms of s and s* in word-initial positions (speaker S6)

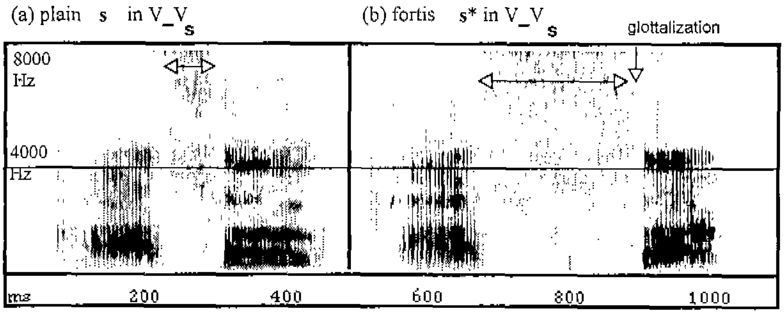


Figure 14. Spectrograms for s and s* word-medially between vowels.

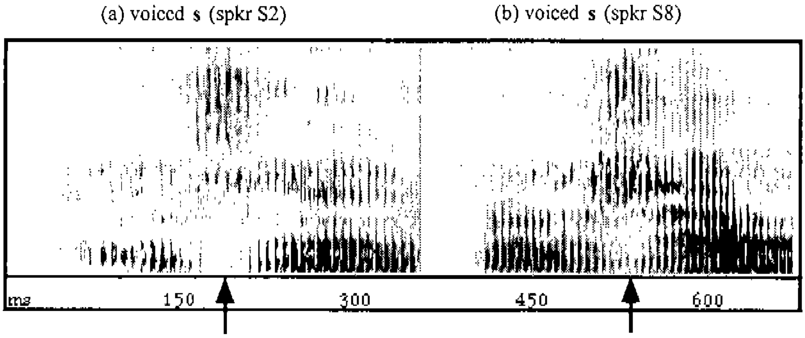

(a) voiced s (spkr S2) (b) voiced s (spkr S8)

Figure 15. Spectrograms for fully voiced intervocalic s.

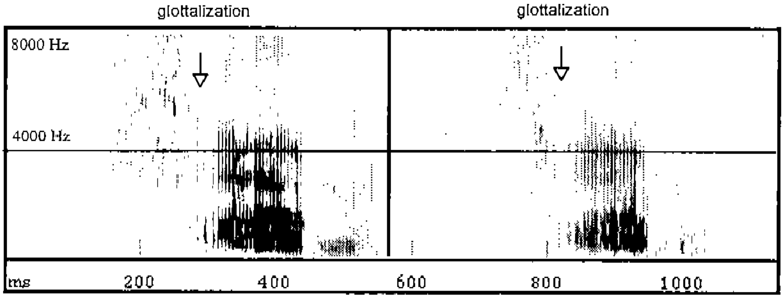


Figure 16. Spectrographic evidence of glottalization for s* in word-initial positions in s*amʧə, produced twice by speaker S4.

The fortis s* also has two components. As shown in Figures 13b and 14b, it has a frication portion similar to that of the plain s, followed by a vertical gap immediately before the vowel onset. The gap appears to be an indication of the glottalization for s*. Figure 16 shows examples of glottalization spanning over the first several cycles of the following vowel. There were a total of 9 out of 16 tokens showing a clear gap at word-initial position. A similar gap was found for word-medial tokens in 8 out of 16 tokens.

Such a glottalization gap was not generally observed when we examined fortis stops. In fortis stops the vocal folds close just before the oral release and start vibrating immediately for the following vowel, as implied by a short VOT. However, as noted by Jun et al. (1998), for the Korean fortis fricative (as well as the plain one) the glottis must remain open to a certain degree in order to permit sufficient air flow for the frication noise. Consequently it seems that it is only in the last part of s* that the glottal characteristics of a fortis consonant are present.

6.1 Fricative duration

For the word-initial position, the duration of the plain s (frication plus aspiration) is significantly longer than that of the fortis s* (F(1,30) = 11.097, p = .0023), as shown in Figure 16. This is the opposite of the difference in closure duration between the lenis and the fortis stops; that is, the closure of the fortis stop is longer than that of the lenis stop at word initial position (Cho & Keating, 1999). However, if we exclude the aspiration period, the difference becomes insignificant as shown in the figure. When the data were separated by the speaker, only two of eight speakers (S4, S6) show a significant duration difference between the plain s (excluding aspiration) and the fortis s*. This is contradictory to Yoon (1998) who found that the fortis s* is significantly longer than the plain s in non-high vowel context.

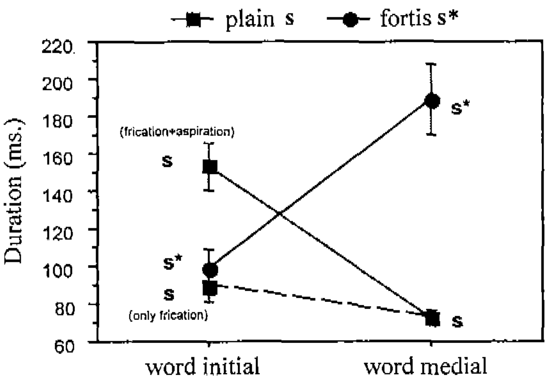


Figure 17. Duration of the plain s and the fortis s* in word-initial and word-medial positions. For the word-initial plain s, the duration with and without aspiration is shown together, with the latter marked by a dashed line. Error bars indicates standard errors.

The duration difference between s and s* is even larger in word-medial position (F(1, 30) = 36.415, p < .0001), but in the opposite direction, as also shown in Figure 17. The word-medial, intervocalic s* is about twice as long as the word-initial one, showing the geminate nature of the fortis segment, which is phonetically realized with a longer duration intervocalically (see Cho & Keating, 1999, for the seal closure duration difference between word-initial and word-medial fortis stops in Korean). In contrast to the increase in duration for the word-medial fortis s*, there is a decrease in duration for the plain s. The decrease is primarily due to the absence of the aspiration intervocalically. The duration of the word-medial s is not significantly longer than that of the word-initial s excluding the aspiration period.

6.2 Centroid Frequency

There is a trend toward a higher centroid frequency for s* than for s, as can be seen in Figure 18. However, there is also a substantial speaker variation -- only four out of eight speakers produce s* with a higher those who show this difference, s* is produced with a relatively smaller front cavity, which presumably results in a higher centroid frequency. An interesting fact lies in the similarity between **h** and the aspiration portion for s, (i.e. **h** in s) as can be seen in the figure. This indicates that the plain s in Cheju (as well as most of dialects in Korean) has two components, frication and aspiration, and has a similar acoustic pattern as other aspirated obstruents.

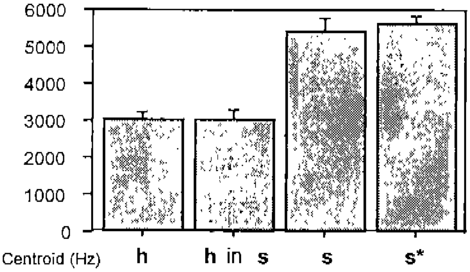


Figure 18. Centroid frequencies for h, h in s, s, and s* in word-initial positions.

6.3 RMS Energy of frication

There is no RMS energy difference between the plain s and the fortis s*.

6.4 Fundamental Frequency (Fo)

Fo in the onset of the vowel is significantly higher after the fortis s* than after the plain s (t=-2.242, p <.05), as shown in Figure 19. However, there is no significant difference at the midpoint of the vowel. As we have seen, the plain s is often aspirated, but it does not have a high Fo as other aspirated obstruents (see Figure 9). It also has a lower Fo than fortis s*, unlike the higher Fo for aspirated stops than fortis stops. Although the effect of the aspiration of plain s on Fo is not as great as that of the aspiration in aspirated stops, there still remains some effect of the aspiration in plain s. In a separate t-test comparing the fricative and stops, Fo after the plain s is significantly higher than that after the lenis stop (t=2.411, p < .05). Fo values after the plain s are closer to the fortis s* in Jun (1999) where Seoul Korean female speakers, in their 20s and 30s, produced fricatives and stops in an Accentual Phrase initial position. Jun also shows that the average Fo of both fricatives is higher than that of fortis stops. A low Fo value after the plain s in Cheju may be due to a dialect and/or an age difference.

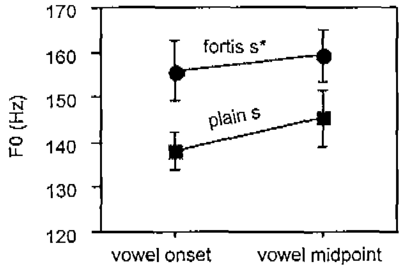


Figure 19. Fo difference between s and s* in the onset and the midpoint of the following vowel. Error bars indicate standard errors.

6.6 H1-H2 and H1-F2

As shown in Figure 20, there is a significant H1-H2 difference between s and s* in the onset of the vowel (t=4.04, p =.0003) - H1-H2 is positive after s and negative after s*. This suggests that the vowel onset has breathy voicing after s but 'pressed' voicing after s*. The average H1-H2 value after the plain s (2.5 dB) is closer to that after the lenis stop (3.5 dB) than that after the aspirated stop (-0.3), showing that the plain s has breathy voicing in the onset of the vowel in common with the lenis stop, not with the aspirated stop. There is no difference in H1-H2 between s and s* in the midpoint of the following vowel.

The plain s and the fortis s* differ also in H1-F2, an indicator of the abruptness of the vocal fold closure - H1-F2 is positive after s and negative after s*. The difference is maintained significantly in both the onset and the midpoint of the vowel (t= 2.745, p =.0101 for the onset; t=2.499, p = .0194 for the midpoint). Put differently, vowels after the fortis s* are produced with abrupt vocal fold closure as are vowels after fortis stops, and the abruptness after s* continues into the middle of the vowel. That is, the pressed nature of the vowel seems to be more evident after s* than after fortis stops.

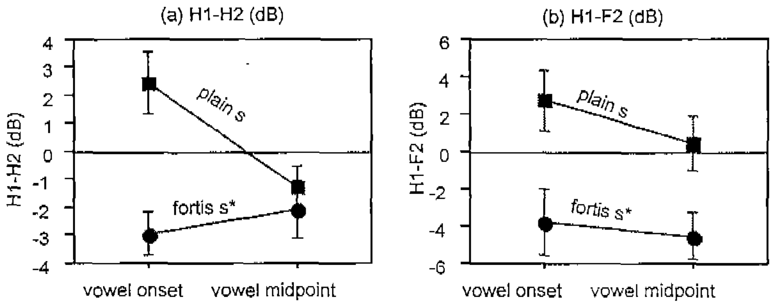


Figure 20. (a) difference in dB between the first and the second harmonic (H1-H2) and (b) difference in dB between the first harmonic and the second formant (H1-F2). Error bars indicate standard errors.

6.7 Summary on phonetic natures of s and s*

We have examined some phonetic properties that may contribute to distinguishing the contrasting segments s and s* in Cheju. The phonetic nature of the fortis s* is rather straightforward: it is produced with (1) frication and glottalization immediately before the vowel, (2) higher Fo in the vowel onset, (3) 'pressed' voicing (negative H1-H2) at the vowel onset, and (4) abrupt vocal fold closure during the following vowel (negative H1-F2).

The phonetic nature of the plain s is quite complex and ambiguous. It is produced with frication, aspiration, and Fo at the vowel onset relatively high as compared to a lenis stop. This might make one believe that it is an aspirated s appropriately transcribed as [s^h]. However, we claim that the plain s may well be categorized as a lenis segment for several reasons. First, its counterpart lenis stop is also produced with a fair amount of aspiration. Second, the onset of the vowel after s has a similar breathy voice quality to vowels after the lenis stop. Third, there is a relatively low Fo in the vowel onset after s, compared to Fo in the vowel onset after an aspirated stop, though higher compared to Fo after a lenis stop. Fourth, interestingly enough, the plain s loses its aspiration word-medially as does the lenis stop. Finally, though in general it does not become voiced, we have observed about 38 % of tokens fully voiced word-medially. Considering all these observations, it seems that the plain s can be better labeled as a lenis fricative, rather than an aspirated fricative.

The phonetic nature of the frication is much the same for both plain and fortis fricatives in word-initial positions. There is no significant difference in centroid frequency, RMS energy, or the duration of frication. Yoon (1998) reports inconsistency in parameters such as the acoustic energy of the frication and the frequency distribution of the spectral peaks. It appears that the substantial difference then lies only after the frication period and in the onset of the following vowel, as just discussed above.

7. OTHER CONSONANTS

The Cheju segments that we have not yet discussed are the nasals and the lateral exemplified in Table 6, and the glides exemplified in Table 7. The velar nasal ŋ occurs only in coda position, and the same is true for the lateral l, except for its occasional occurrence initially in loan words. The lateral is usually realized as a flap word-initially and intervocalically. We did not find any unusual phonetic features specific to Cheju nasals and lateral.

Table 6. Word list for nasals and lateral

	Wd initial		Wd medial	
m	mataŋ	ground	samɨla	to weave straw
n	naamʧə	to give a birth	anla	to hug
ŋ			paŋe	grinding tool
l	latio	radio	ɑlamʧə tallɨʧu	to know different

The glides are similar to those in Korean. We recorded each of the glides w, j, ɰ before each of the vowels, as permitted by the phonological constraints. (In Korean, glides are sometimes analyzed as a consonant and sometimes as part of the vowels. In this paper we take no stand on either of these positions.)

As in nasals and lateral, there is nothing particularly noteworthy about these glides except for the back unrounded glide, ɰ, a rare glide in the languages of the world. The back unrounded glide occurs only with i, as shown in Table 7. In casual speech, however, ɰi is usually monophthongized as either i or ɨ by most speakers. A few rural speakers in the experiment produced this glide and the labio-velar glide, w, distinctively as shown in Figure 20. In Figure 20a, for wi 'stomach,' formants (F_2, F_3, F_4) are lowered at the beginning, an indication of the rounded glide w, followed by the steady state of i. In Figure 20b, for ɰi in ɰikwili 'name of a village,' there is a much lowered F_2 at the beginning but no observable lowering of the higher formants. A clear transition in F_2 from ɰ to i is shown in the figure.

Table 7. Word list for glides

wi	wi	stomach
we	we	cucumber
wæ	wæullɨmsə(ke) wæullɨmʧə	to shout
wə	wəllamɐl	horse(colorful)
wa	wa	to stop(to horse)
je	jesun	sixty
jæ	jæja	child!(vocative)
jə	jə	stone
ja	jakaʧi / jakeki	neck
jɐ	jɐtap	eight
jo	jo	blanket
ju	jukʧi	land
ɰi	ɰisa / ɰiʦa ɰikwili	doctor / chair name of a village

8. CLOSING REMARKS

Cheju and Korean are not mutually intelligible, but the consonants of the two languages seem to be the same in every respect. The opposition between the fortis, lenis and aspirated obstruents is realized in the same way, and the phonetic realization of all consonants are the same as those found in Korean.

Among findings reported in this paper, three points are particularly worth recapitulating. First, the voice quality of the vowel varies systematically depending on the preceding consonant type. This suggests that the voice quality may be one of the strong perceptual cues for listeners to use in differentiating the three way contrast in Korean stops. This finding is in agreement with Cho (1995, 1996) who reported that Korean listeners were able to identify the stop category at a far better than chance level by only listening to vowel stimuli following the stop. Second, the Cheju stops can be differentiated by aerodynamic characteristics. While two 'strong' strops (i.e., aspirated and fortis) are equally strongly articulated on a supralaryngeal level (cf. Cho & Keating, 1999), aerodynamics suggests that different mechanisms are employed in producing these stops. Finally, our study suggests that the fricative s is closer to a lenis category than an aspirated category in terms of its phonetic realization. The breathiness of the vowel onset after s and the property of intervocalic lenition are most appealing evidence in favor of the lenis category.

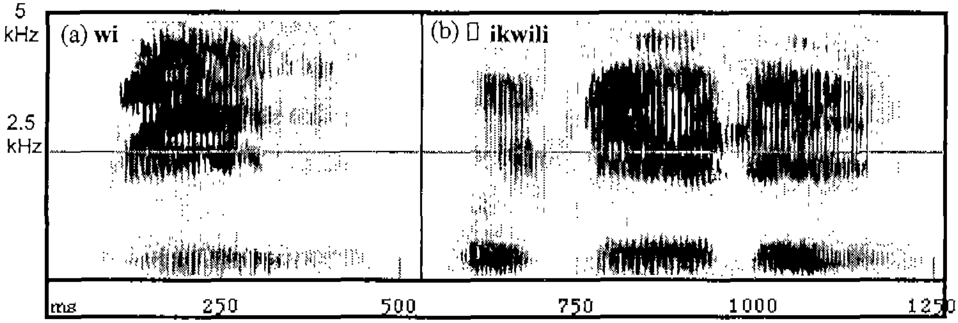


Figure 20. Spectrograms of (a) wi 'stomach' and (b) ɰikwili 'name of a village.'

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▲ Taehong Cho
Phonetics Lab, Dept. of Linguistics
405 Hilgard Ave. UCLA
Los Angeles, CA 90095, USA
Phone: +1-310-206-2808; Fax: +1-310-206-5743
e-mail: taehong@humnet.ucla.edu

▲ Sun-Ah Jun
Phonetics Lab, Dept. of Linguistics
405 Hilgard Ave. UCLA
Los Angeles, CA 90095, USA
Phone: +1-310-206-7818; Fax: +1-310-206-5743
e-mail: jun@humnet.ucla.edu

▲ Peter Ladefoged
Phonetics Lab, Dept. of Linguistics
405 Hilgard Ave. UCLA
Los Angeles, CA 90095, USA
Phone: +1-310-825-0829; Fax: +1-310-206-5743
e-maol: oldfogey@ucla.edu