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An Investigation of the Manner Contrast in Inter-vocalic Korean Stops

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1. Introduction

Korean has nine stop consonants that are all phonemically voiceless. They occur in three different places of articulation, i.e. bilabial, alveolar, and velar. The alveolar stops are also described as alveo-dental since they are produced with the front of the tongue touching the back of the upper teeth. Three different manners of Korean stops have been referred to in various ways by phonetic researchers. Type I, which is produced with a strong puff of air, is described as heavily aspirated or aspirated. Type II, which is produced with little aspiration, is described as slightly aspirated, lax, or lenis. Type III, which is produced with a tight glottal constriction, is described as reinforced, tense, or fortis. We will refer the Korean stops as aspirated, lax, and tense, hereafter.

All nine stops occur in word-initial position as voiceless. Since it is rather unusual having all voiceless stops, the word-initial Korean stops have received much attention from phonetic researchers over the past several decades. Those languages with three (or more) different types of manner, such as Thai and Hindi, often have voiced, voiceless unaspirated, and voiceless aspirated stops (Ladefoged & Maddieson, 1996). While both aspirated and tense Korean stops remain as voiceless in inter-vocalic position, the lax Korean stops become voiced inter-vocalically. In word-final position, all three types of Korean stops are neutralized to their homorganic lax stops and they are often unreleased. Bilabial and alveolar tense stops do not occur in word-final position.

The present study investigates the acoustic characteristics of the inter-vocalic Korean stops. Phonemically, the inter-vocalic stops can occur either in the coda position of the first syllable followed by the vowel (VC.V) or in the onset position of the second syllable which is preceded by the vowel (V.CV). In either case, the actual utterances have a V.CV structure within the same word via the resyllabification process. The present study provides absolute physical measurements of the inter-vocalic Korean stops to re-examine the previous impressionistic or phonological treatment of the allophonic variations of Korean stops. Even though many acoustic characteristics of inter-vocalic stops can be found both in the stop portion of the utterance and in the neighboring segment due to the coarticulation process, we focus on three acoustic features, Closure duration, Voice Onset Time and Fundamental frequency of the following vowel.

2. Acoustic Characteristics of Korean Stop Consonants

Figure 1 shows the sound waveform and the spectrogram display of the Korean aspirated stop, [k^h]. The arrows are placed both in the beginning and at the end of the stop production. The complete momentary blockage of the vocal tract results in a stop closure that is virtually blank, like a pause between utterances. The voiced stops are characterized by the presence of the voice bar during the interval of articulatory closure. Halle et al. (1957) reported that silence (closure) is the only necessary cue for stop identification. Without the silence, a stop is not perceived. The burst that follows the closure represents the release of the airstream. A lower amplitude of burst energy is often associated with lax stops. The release burst also provides important information

regarding the place of articulation of the stops. The burst associated with the bilabial stops is fairly faint with a primary concentration of energy in the low frequencies,

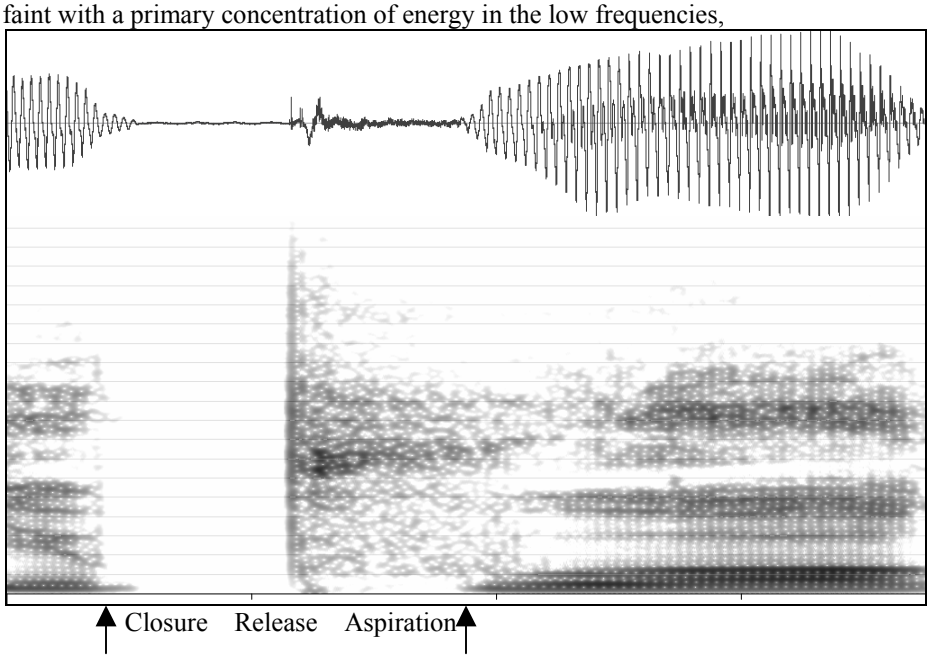

Figure 1. Sound Waveform and Spectrogram of Korean Aspirated Stop [k^h].

from about 500 – 1500 Hz. The burst associated with the alveolar stops has relatively high-frequency concentrations of energy above 4 kHz. The burst associated with the velar stops has strong concentrations of energy in the intermediate frequency range of about 1500 - 4000 Hz (Ladefoged, 2001; Kent & Read, 2002). Voice Onset Time (VOT) is the interval between the articulatory release of the stop and the onset of vocal fold vibration of the following segment. It can be measured acoustically as the duration between the release burst and the onset of periodicity (Kent & Read, 2002). VOT is considered the major acoustic feature that can differentiate many different types of stop articulation. In what follows, findings on acoustic characteristics of mostly word (or syllable)-initial Korean stops are summarized, including measurements that were obtained in a recent study using an empirical design similar to the one utilized in the present study.

In Korean stops, the closure duration is longest for the tense stops, intermediate for the aspirated stops, and shortest for the lax stops. It ranged from 68.8 ms to 143.2 ms for the tense stops, from 69.8 ms to 140.9 ms for the aspirated stops, from 43.0 ms to 107.9 ms for lax stops (Kim & Lotto, 2002).

VOT clearly differentiates the aspirated stops from the other two types of Korean stops. Even though some researchers found an overlap in VOT between lax stops and tense stops (Lisker & Abramson, 1964; Kim, 1965), it is generally agreed that the average VOT is longest for aspirated stops, intermediate for lax stops, and shortest for tense stops. The measured VOT ranged from 71.2 ms to 100.9 ms for aspirated stops, from 14.6 ms to 94.8 ms for lax stops, and from 7.0 ms to 22.4 ms for tense stops (Kim & Lotto, 2002). Kim (1965) claimed that since there is a certain amount of overlap in VOT between lax stops and tense stops, the [tensity] feature should also be considered as an autonomous feature, which can distinguish stop categories. The fiberscopic study of Kagaya (1974) claimed that the glottal width is almost linearly correlated with the length of voicing lag, not showing any overlap in the values of glottal width in Korean stop productions. The glottal opening is largest for aspirated stops, intermediate for lax stops, and smallest for tense stops.

The overall mean fundamental frequency (f0) of the following vowel also differs significantly depending on the manner of the preceding stops. Keating(1984) found that in many languages, the f0 of the vowels following voiceless stops is higher than for vowels following voiced stops. In word-initial Korean stops, which are all voiceless, f0 is highest after aspirated stops, intermediate after tense stops, and lowest after the lax stops (Han & Weitzman, 1970). The average f0 of the aspirated stops ranged from 147.2 Hz to 163.3 Hz for male subjects and from 272.2 Hz to 309.9 Hz for female subjects. The f0 of the tense stops ranged from 142.5 to 150.9 for male subjects and from 239.9 Hz to 285.9 Hz for female subjects. The f0 of the lax stops ranged from 114.3 Hz to 138.4 Hz for male subjects and from 210.9 Hz to 225.3 Hz for female subjects (Kim & Lotto, 2002).

Several researchers have investigated other characteristics related to the manner distinction of Korean stops. Kagaya (1974) investigated the Korean stops in terms of the laryngeal gesture. The aspirated types showed an increase of glottal width in the initial phase of utterance followed by rapid closure of the glottis for the following voiced segment. And the articulatory explosion occurred around the moment when the glottal width reached its maximum value. In lax types, the glottis began to close gradually with some fluctuations in glottal width. A rapid adduction took place for the following voiced segment right after the articulatory explosion. For the tense (forced) types, the vocal folds were completely adducted before the articulatory explosion. After the articulatory explosion, the glottal width decreased monotonically. Cho (1996) also found that the vowel length after a stop was systematically different depending on the preceding stop categories. The vowel length was inversely related to VOT. The vowel after tense stops was longest, intermediate after lax stops, and shortest after aspirated stops. Several more recent studies have investigated the voice quality of the vowel after Korean stops. Ahn (1999) reported that vowels after lax stops had a breathy voice with positive *H*1-*H*2 values, which represent the difference in amplitude between the first and the second harmonics. Kim, Beddor and Horrocks (2002) reported that the vowel portions after lax stops were necessary and largely sufficient for the perception of the lax stops. Even though the tense stops were expected to have negative *H*1-*H*2 values due to laryngealization, the results for the tense stops were inconclusive in both production experiments (Ahn, 1999) and perception experiments (Kim, Beddor & Horrock, 2002).

Kim and Jongman (1996) investigated the neutralization of manner of articulation of the word-final coronal obstruents in Korean. They investigated whether neutralization of Korean obstruents, which changes underlying /t^h, t, s/ into the homorganic lax stop, is complete or incomplete. The test results indicated that there were no significant differences in terms of preceding vowel duration or closure duration of the surface lax stops, which represent the different underlying Korean phonemes, thus indicating complete neutralization.

Most of these earlier studies have concentrated on stop manner in a single context, i.e. syllable initial. The study presented here examined several acoustic variables (closure duration, VOT and f0) in relation to manner of stops in an inter-vocalic context.

3. Experiment

3.1 Subjects

Twelve native speakers of Korean, six males and six females, participated in this experiment. In order to avoid possible dialectal variations, only Seoul dialect speakers were chosen. Seoul dialect is considered standard Korean. The subjects ranged from 27 to 32 years in age. They were either graduate students at the University of Georgia or the spouse of a graduate student. The subjects had lived in the U.S. for 6 months to 4 years at the time of recording. All subjects reported having normal speaking and hearing ability.

3.2 Stimuli

For the data collection, a reading list containing three tokens for each of nine stops (three manners at three places of articulation) was prepared. Most of the tokens were nouns with (C)V.CV syllable structure. The inter-vocalic stop occurred in the onset position of the second syllable within the same word. For the measurement of stop closure, the nouns were embedded in a carrier sentence, "i (this) + kes (thing) + i (nominative particle) NOUN ipnita (is)" (in the Yale romanization system), which means "This is a noun" in English. Four sentences were slightly changed in order to make them more meaningful.

3.3 Procedure

The recording was made using a noise-canceling Shure SM48-LC microphone and a Sony Digital Audio Tape recorder at a 48-kHz sampling rate. The distance of the microphone from the mouth was approximately 4 inches. The recordings were made in four different places. Four subjects were recorded in a quiet chapel on the University of Georgia (UGA) campus, two subjects in a quiet room in their homes, two subjects in the Digital Language Laboratory at UGA, and four subjects in a quiet classroom. Each subject was given a reading list and instructed to read the sentences as naturally as possible. The subject was also asked to keep speech rate constant. In order to collect six tokens for each stop, all of the sentences were read twice.

3.4 Acoustic Analysis

Upon completion of recordings, all recorded data were digitized at a sampling rate of 22 kHz. In total, 648 tokens (9 stops x 3 nouns x 12 subjects x 2 repetitions) were acoustically analyzed from the spectrographic and waveform display from the TF32 program which is implemented in CspeechSP (Milenkovic & Read, 2000). For the closure duration, the silence between the last glottal pulse of the preceding vowel and the release of the stop burst was measured. For the measurement of VOT, since the burst is often not distinct from the aspiration, the distance from stop release to the point at which the waveform shows the first sign of periodicity was measured. For the fundamental frequency of the following vowel, the average fundamental frequency of the first five glottal periods was measured. When the vowel was too short to have five glottal periods, the average fundamental frequency of the whole vowel was measured.

3.5 Statistical Analysis

For each of the three acoustic measures, the mean of the six tokens (3 nouns x 2 repetitions) were calculated for each subject. These means served as the dependent variables for 2x3x3 (Gender x Place of Articulation x Manner) mixed-model ANOVA (Analysis of Variance). For all three measures, there was a significant interaction between manner and place ($p<.05$). As a result, separate analyses were run for each place of articulation in order to examine the individual patterns. For closure duration and VOT, there was no main effect of gender nor an interaction of gender with manner or place. Therefore, gender was not included in the separate analyses for these two variables. For f0, there was both a predicted main effect of gender [$F(1,10) = 63.05$, $p< .001$] as well as a significant three-way interaction ($F(4,40) = 3.63$, $p<.05$). For this measure, analyses were separated by place and gender. Significant effects of manner were investigated further with *post-hoc* comparisons with a Bonferroni adjustment of significance levels.

3.6 Results

3.6.1 Closure Duration

Table 1 presents the mean closure durations with attendant standard deviations for the three manners at each of the three places of articulation. Closure duration differed significantly for changes in manner at all three places of articulation ($p<.001$). The pattern is similar for each place. For bilabial stops, closure durations were greatest for tense stops, smaller for aspirated stops and smallest for lax stops, that is, tense > aspirated > lax. For alveolar stops there was no significant ($p > .05$) difference between tense and aspirated stops but both had longer closure durations than did lax stops, i.e. tense = aspirated > lax. The velar pattern matched the bilabial pattern: tense > aspirated > lax. These patterns are consistent with the changes in closure duration found for differences in manner of bilabial and velar syllable-initial stops (Kim & Lotto, 2002). The patterns obtained for both syllable initial and inter-vocalic alveolar stops tend to be more variable.

Table 1. Mean and standard deviation (in parentheses) of closure duration (in ms).

Manner	Bilabial	Alveolar	Velar
Aspirated	98.75 (14.33)	97.78 (17.41)	81.07 (15.54)
Lax	46.66 (10.51)	48.36 (12.16)	40.86 (9.79)
Tense	134.07 (21.49)	92.42 (14.18)	94.47 (11.98)

3.6.2 Voice Onset Time (VOT)

Table 2 presents the mean VOT with attendant standard deviations for the three manners at each of the three places of articulation. VOT differed significantly for changes in manner at all three places of articulation ($p<.001$). The pattern is similar for each place. For bilabial stops, aspirated > tense = lax. For alveolar and velar stops, aspirated > tense > lax. For both syllable initial and intervocalic stops, the aspirated manner is associated with the longest VOT(Kim & Lotto, 2002). However, unlike syllable-initial stops, lax inter-vocalic stops have the shortest VOTs. This is consistent with previous descriptions of the lax stop as voiced in intervocalic position. Note that there is still a positive average VOT for these stops, which suggests that they are not completely voiced. This is in agreement with Jun's (1996) claim the voicing of lax stops is graded in Korean.

Table 1. Mean and standard deviation (in parentheses) of VOT (in ms).

Manner	Bilabial	Alveolar	Velar
Aspirated	48.21 (11.75)	45.56 (11.63)	55.82 (10.09)
Lax	13.47 (5.67)	18.49 (5.84)	19.32 (8.42)
Tense	13.78 (5.77)	31.84 (10.35)	27.59 (7.78)

3.6.3 Fundamental Frequency of the Following Vowel (f0)

Table 3 presents the mean f0 with attendant standard deviations for the three manners at each of the three places of articulation for male speakers. Table 4 presents the same data for female speakers. For each gender by place condition, there was a significant effect of manner ($p<.01$). The relationship between manner and f0 was not straightforward. For bilabial stops, the pattern for male and female speakers was: aspirated > lax = tense. For alveolar stops, the male speaker pattern was: aspirated > tense = lax. For female speakers, the female pattern was: aspirated > tense > lax. For velar stops, the male speaker pattern was: aspirated = tense > lax. For female speakers, the pattern was: aspirated > tense >lax. The patterns for syllable-initial stops also

differed by place and gender (Kim & Lotto, 2002), but those patterns were dissimilar from the inter-vocalic patterns. Overall, it doesn't appear that f0 provides a reliable cue to manner.

Table 3. Mean and standard deviation (in parentheses) of f0 (in Hz) for male speakers.

Manner	Bilabial	Alveolar	Velar
Aspirated	152.62 (29.40)	156.74 (30.90)	152.93 (29.68)
Lax	131.87 (21.36)	139.75 (26.55)	142.47 (28.53)
Tense	135.57 (27.09)	149.00 (29.89)	149.54 (30.42)

Table 4. Mean and standard deviation (in parentheses) of f0 (in Hz) for female speakers.

Manner	Bilabial	Alveolar	Velar
Aspirated	278.67 (15.75)	279.85 (28.74)	273.03 (24.07)
Lax	228.44 (17.03)	240.49 (16.74)	245.54 (22.99)
Tense	235.44 (19.10)	269.29 (24.54)	256.56 (20.64)

4. Discussion

The present study examined the role of three acoustic features, closure duration, VOT, and f0 of the following vowel, in the manner contrast in intervocalic Korean stops. All three features were found to vary as a function of manner in word-initial Korean stops (Kim, 1994; Kim & Lotto, 2002). The findings from this study were consistent with the previous findings in that all three acoustic features varied with the manner contrast of Korean stops in intervocalic position as well.

In general, the closure duration of lax stops is shorter than that of both aspirated stops and tense stops. In turn, the closure duration of tense stops is longer than that of aspirated stops for bilabial and velar stops. Although we expected a consistently longer closure duration for tense stops, no significant difference between aspirated stops and tense stops was found for alveolar stops. This is partly due to the individual (or dialectal) differences among the subjects in the production of alveolar tense stops. Ten out of twelve subjects pronounced the intervocalic tense stops with shorter closure duration and longer VOTs. Because of this, the tokens were similar to aspirated stops.

As expected, VOT of lax stops is shorter than the other types of Korean stops. This is partly due to the voicing of the intervocalic lax stops. When the lax stops become voiced, the stop release is nearly simultaneous with the vocal cord vibration. However, the voicing of inter-vocalic lax stops showed a great deal of both intra and inter speaker variation. Generally, the inter-vocalic Korean lax stops showed three different patterns: voiceless, partly voiced, fully voiced. In partly voiced lax stops, only the initial portion of the closure duration showed vocal cord vibration, which can be attributed to the coarticulation of preceding vowels.

For f0, the patterns were not consistent across place of articulation. The overall mean f0 after lax stops is lower than that of the other stops. This finding was consistent with the previous results from the acoustic measurements of word-initial Korean stops (Kim, 1994). The average f0 of aspirated stops was the highest. The f0 of tense stops did not show significant difference with either aspirated stops or lax stops.

Several researchers have investigated the effect of prosodic position on Korean stop articulation. The edge of a phonological phrase (word-initial position) is considered strengthening environment, while the position further away from the edge, that is, a word-medial position, is considered a weakening environment (Silva, 1992). The findings from the previous studies, however, are not consistent. The lax stops, in general, undergo the weakening process in word-medial position (Silva, 1992; Jun, 1996). On the contrary, the recent study by Cho & Keating (2001) found that tense and aspirated consonant oral articulations were longer and stronger word-medially than word-initially, which are indicative of a strengthening process.

Since we cannot compare the absolute acoustic measurements from this study with the previous measurements from the word-initial stops, it is very hard to draw conclusions about the effect of prosodic structure on Korean stop articulation. Instead, we conclude that all three acoustic features played important roles interacting with each other as a function of the manner contrast for Korean stops both in word-initial and in intervocalic position.

References

Ahn, H. (1999). *Post-release phonatory processes in English and Korean: acoustic correlates and implications for Korean phonology*. Doctoral dissertation, University of Texas at Austin.

Cho, T. & Keating, P. A. (2001). Articulatory and acoustic studies on domain-initial strengthening in Korean. *Journal of Phonetics*, 29, 155-190.

Cho, T. (1996). *Vowel correlates to consonant phonation: an acoustic-perceptual study of Korean obstruents*. MA thesis, University of Texas at Arlington.

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

Han, M. S. & Weitzman, R. S. (1970). Acoustic features of Korean /P,T,K/, /p,t,k/, and /p^h,t^h,k^h/. *Phonetica*, 22, 112-128.

Jun, S.-A. (1996). *The phonetics and phonology of Korean prosody: intonational phonology and prosodic structure*. New York: Garland.

Kagaya, R. (1974). A fiberscopic and acoustic study of the Korean stops, affricates, and fricatives, *Journal of Phonetics*, 2, 161-180.

Keating, P. A. (1984). Phonetic and phonological representation of stop consonant voicing. *Language*, 60, 286-319.

Kent, R. & Read, C. W. (2002). *The acoustic analyses of speech* (2nd ed.). San Diego: Singular Publishing.

Kim, C.-W. (1965). On the autonomy of the tensity feature in stop classification (with special reference to Korean stops). *Word*, 21, 339-359.

Kim, H. & Jongman, A. (1996). Acoustic and perceptual evidence for complete neutralization of manner of articulation in Korean. *Journal of Phonetics*, 24, 295-312.

Kim, M.-R., Beddor, P. S., & Horrocks, J. (2002). The contribution of consonantal and vocalic information to the perception of Korean initial stops. *Journal of Phonetics*, 30 (1), 77-100.

Kim, M.-R. Cho & Lotto, A. J. (2002). Acoustic characteristics of Korean stops produced by non-heritage learners. *The Korean Language in America*, 7, 177-187.

Kim, M.-R. Cho (1994). *Acoustic characteristics of Korean stops and perception of English stop consonants.* Doctoral dissertation, University of Wisconsin, Madison.

Ladefoged, P. (2001). *Vowels and Consonants: An introduction to the sounds of languages*. Oxford, UK: Blackwell.

Ladefoged, P. & Maddieson, I. (1996). *The sounds of world's languages*. Oxford, UK: Blackwell.

Lisker, L. & Abramson, A. S. (1964). A cross-language study of voicing in initial stops: acoustical measurements. *Word*, 20, 384-422.

Milenkovic, P. H. & Read, C. (2000). CSpeechSP [Computer software]. Madison, WI:Author.

Silva, D. (1992) *The phonetics and phonology of stop lenition in Korean*. Doctoral dissertation, Cornell University, Ithaca, New York.