AN ACOUSTIC AND AERODYNAMIC STUDY OF STOPS IN TONAL AND NON-TONAL DIALECTS OF KOREAN

BY

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ABSTRACT

This study investigates the acoustic and aerodynamic properties of well-known three-way distinction of Korean voiceless stops in two dialects, which differ in their tonal systems: non-tonal Seoul Korean (standard Korean) and tonal South Kyungsang Korean (spoken in Southern part of Korea). Several issues are addressed in the current study: (i) the acoustic cues (e.g. VOT, *f0*, *H1-H2*) that each dialect mainly uses to distinguish the three Korean stops, (ii) the effect of *f0* as a function of distinguishing three stop categories and as a function of distinguishing the High vs. Low tonal contrasts in the tonal South Kyungsang dialect, (iii) dialectal variation in aerodynamic area (e.g., oral airflow, oral air pressure) as well as acoustic area. These issues are examined with 16 Korean speakers, eight Seoul Korean and eight South Kyungsang Korean speakers. Along with the results replicating previous findings, the experimental results report several noteworthy new findings. First, the acoustic and aerodynamic pattern differently in the two dialects; Seoul speakers primarily use *f0* as an acoustic cue for three laryngeal gestures of Korean stops, while South Kyungsang speakers are more likely to use VOT as a main acoustic cue. Second, the use of tonal contrasts to distinguish High vs. Low tone for South Kyungsang speakers makes *f0* an unreliable acoustic cue for the three Korean stops. Third, the dialectal differences on VOT to mark the three laryngeal distinctions support the notion of the diachronic transition that the VOT difference between the lenis and aspirated stops is decreasing over the past 50 years. Finally, the results of aerodynamic study make it possible to postulate the articulatory state. Hence, based on the acoustic and aerodynamic results, this study suggests the possible phonological representations in the two dialects which differ in their tonal systems.

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Chapter1. Introduction and Literature Review

1.1. Introduction

Korean stops with the unusual three-way laryngeal distinction have long drawn the attention to a number of phoneticians since Lisker and Abramson's landmark cross-language study in 1964. Most of the world's languages categorize the stop in terms of voicing (e.g., Spanish, Dutch) and aspiration (e.g., Thai, Hindi) and the feature of aspiration is used to distinguish the stop in the voiceless region (Lisker and Abramson, 1964). However, Korean stops have a three-way distinction in the voiceless region and are categorized in terms of the force of articulation as well as aspiration. Therefore, various terms to describe the three categories of Korean stops have been used by many phoneticians. For example, the following terms have been used: 'fortis', 'tense', 'laryngealized' or 'unaspirated' for category 1, 'lenis', 'plain', 'lax', 'breathy', or 'slightly aspirated' for category 2, and 'aspirated' or 'heavily aspirated' for category 3. All three categories of stops are phonetically voiceless in word-initial or phrase-initial position, and each of these occurs at three places of articulation: bilabial, alveolar, and velar. Table 1 shows an example of minimal contrasts for Korean stops in word-initial position. In the present study, the terms 'fortis', 'lenis', and 'aspirated', which distinguish Korean stops in terms of 'tension of vocal folds' and 'aspiration', will be used for categories 1, 2, and 3, respectively.

Category 1		**Category 2**		**Category 3**	
p'ul	"horn"	pul	"fire"	p^hul	"grass"
t'al	"daughter"	tal	"moon"	t^hal	"mask"
k'ul	"honey"	kul	"oyster"	k^hul	"sleeping sound" (an onomatopoeic word)

Table 1. Minimal contrasts for three-way phonemic distinction of Korean stops in word initial position

A considerable number of phonetic studies have explored the acoustic cues for Korean stops with the three-way distinction in the fields of acoustics, perception and articulation. Previous research (e.g., Lisker and Abramson 1964; Han and Weitzman 1970; Choi 2002), has proposed VOT as one of the main acoustic cues, reporting that the mean length of VOT is longest for the aspirated stop, intermediate for the lenis stop, and shortest for the fortis stop. However, Choi (2002) suggested that VOT alone cannot be a sufficient cue to distinguish the three stops because of the overlapped values of VOT in fortis and lenis or in lenis and aspirated stops. Consequently, a number of subsequent acoustic, perception and aerodynamic studies (e.g., Kim 1965, 1970; Kagaya 1974; Dart 1987; M-R Kim 2002) have revealed that the properties of the following vowel after the stop release are also primary acoustic cues along with VOT of the stop segments themselves. More specifically, the fundamental frequency (*f0*) of the onset of the following vowel also distinguishes laryngeal gestures, with the lowest value of *f0* for the lenis stops, and relatively high value of *f0* for the aspirated and fortis stops in the following vowel. That is, *f0* distinguishes Korean lenis stops from aspirated and fortis stops. Along with *f0* at vowel onset, phonation type of the following vowel has also been examined by measuring the amplitude differences between the first harmonic (*H1*) and the second harmonic (*H2*). A recent comprehensive study on Korean stops by Cho *et al.* (2002) reported that vowels after fortis stops showed the lowest value of *H1-H2*, and the highest value after lenis stops. The researchers suggested that the lowest value for the fortis stop indicated more pressed or creaky voice for the vowel after the fortis stop while the highest value for the vowel after the lenis stop indicated the breathier voice for the vowel after lenis stops (see section 1.2. for more discussion).

Acoustic cues to Korean stops have also been examined with respect to dialect variation. Particularly, previous studies (e.g., Choi 2002; Kenstowicz and Park 2006) have focused on the dialectal variation of *f0*: Choi (2002) investigated the acoustic cues for the Korean stop in two dialects with different intonational systems, namely the standard Seoul dialect and the Chonnam dialect. She reported well-separated values of *f0* for the three Seoul dialect speakers, but overlapping values of *f0* for the three Chonnam dialect speakers. Based on this, Choi (2002) suggested that the different intonational systems have an influence on *f0* as an acoustic cue to Korean stops. Kenstowicz and Park (2006) investigated the laryngeal features and tone in the Kyungsang dialect, where lexical pitch contrasts are preserved. The researchers reported that like the vowel correlate in the Seoul dialect, the laryngeal gestures of stops have a significant influence on *f0* values of the following vowel even in the Kyungsang dialect. Aerodynamic studies also support the distinctive Korean stops through measuring air pressure and airflow and give us the information on the subglottal and supraglottal systems. Dart (1987) studied the aerodynamic properties of the Korean fortis and lenis stops and reported that the lenis stops had a greater airflow rate despite having a lower pressure than the fortis stops. Cho *et al*. (2002) confirmed this, reporting that intraoral airflow (Uo) was highest for the aspirated, intermediate for the lenis and lowest for the fortis stop while the rate of intraoral air pressure (Po) was lowest for the lenis and the same for the aspirated and fortis stops, which was in line with Dart's study.

The findings from previous studies indicate that the atypical Korean stop contrasts cannot be distinguished only by the consonant durational property of VOT, but the voice quality (e.g., *f0, H1-H2*) after the stop is also required to signal the three-way distinction of stops. Moreover, several studies considering dialectal variation (e.g., Choi 2002; Kenstowicz and Park 2006) have suggested that different dialects affect the three-way distinction differently, particularly with respect to *f0*. Therefore, the current study aims to examine the three categories of Korean obstruents in two different dialects of Korean, namely the Seoul standard dialect and the South Kyungsang dialect. Since South Kyungsang Korean preserves the lexical pitch contrasts (e.g., High vs. Low), the main focus in this study will be on the tonal contrasts. This study will explore to what extent the lexical pitch contrasts influence the three-way laryngeal distinction by investigating the following vowel quality as well as the consonant properties. Along with the acoustic study, the current study also examines aerodynamic properties by measuring intraoral airflow (Uo) and intraoral air pressure (Po) in both dialects. Since none of the aerodynamic studies on Korean stops investigated the aerodynamic properties of the South Kyungsang dialect, it is hoped that the present study will be able to contribute more details on aerodynamic characteristics of the tonal dialect Korean (South Kyungsang) as well as to re-evaluate previous findings of the non-tonal dialect Korean (Seoul).

1.2. Literature Review

1.2.1. Acoustic and Aerodynamic Characteristics of Korean Stops

From the pioneering study by Lisker and Abramson (1964) “A cross-language study of voicing in initial stops: acoustical measurements” to the recent comprehensive review study by Cho, Jun and Ladefoged (2002) “Acoustic and aerodynamic correlates of Korean stops and fricatives,” the atypical Korean stops have been investigated for the last 40 years in the field of acoustic, aerodynamic, articulatory, and auditory phonetics. In this section, some of these studies on Korean stops are reviewed.

1.2.1.1. *Voice onset time* (VOT)

Voice onset time, the time interval between stop release and onset of voicing, is the main acoustic cue for categorizing stops in terms of voicing and aspiration. For example, in languages like Cantonese or Eastern Armenian with a two-way distinction of stops in the voiceless region, the VOT alone clearly separates the two stop categories (Lisker and Abramson, 1964). Lisker and Abramson (1964) have examined voice onset time as a single dimension to distinguish the stop categories in languages including Korean, and suggested that VOT sufficiently separates stop categories. Their study, in which one Seoul Korean speaker produced the three categories of stops, reported that the average duration of VOT in Korean stops was shortest for the fortis, intermediate for the lenis, and longest for the aspirated stops in word initial position. Several subsequent studies have confirmed the systematic differences in VOT and indicated VOT as the primary acoustic cue for Korean stops (e.g., C.-W. Kim 1965; Cho 1996; Cho, Jun & Ladefoged, 2002; Silva 2002, 2006).   Figure 1 shows the average VOT values of the three laryngeal gestures of Korean stops as reported by previous studies. All of these values are from Seoul standard Korean speakers, and all the target consonants are placed in word-initial position.

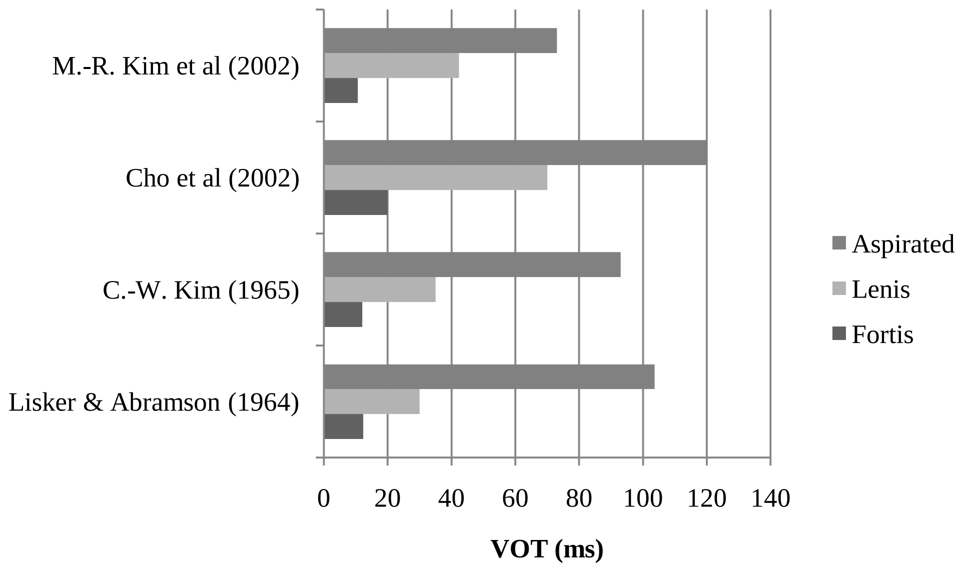


Figure 1. Average values of VOTs reported in previous studies (Adapted from Lisker and Abramson, 1964; C.-W Kim, 1965; Cho *et al*, 2002; M.-R. Kim *et al*, 2002)

The acoustic measure of VOT in Korean obstruents has been investigated from various points of view. Silva (2006) examined age variation in VOT for Korean stops. His earlier review paper (2002) revealed that some acoustic characteristics in stop categories have shown some changes over the past 40 years, and suggested increasing overlapped values of VOT duration between aspirated and lenis stops for the younger generation. Accordingly, his recent study (2006) confirmed age variation as a key factor for varied VOTs. More specifically, the subjects who were born before 1965 showed well-separated VOT values for Korean stop categories, with mean VOT in fortis stops ranging from 3 to 18 ms, mean VOT in lenis stops ranging from 36 to 90 ms, and mean VOT in aspirated stops ranging from 51 to 117ms. However, the subjects who were born after 1965 revealed a neutralized value of VOT for lenis and aspirated stops, while the mean VOT in fortis and lenis stops is nearly equal to that for the older generation group. That is, the mean VOT in aspirated stops for the younger generation is significantly lower than that for the older generation: 69.7 ms and 94.0 ms for the younger and the older generation respectively. Silva (2006) suggested that *f0* plays a primary role in distinguishing lenis stops from aspirated stops for the young generation, and Seoul standard Korean may be developing a tonal system. This age variation in VOT is confirmed by a recent study. Kang and Guion (2008) examined the acoustic cue for Korean stops in two different age groups, a younger group (average age=25.8) and an older group (average age=46.7), and compared clear speech to conversational and citation-form speech conditions. Their study reported that the VOT of Korean stops is in the order of fortis, lenis, and aspirated, which is in line with previous studies. In addition, the VOT in Korean stops is enhanced in clear speech for both age groups. However, Kang and Guion (2008) suggested some age variation, reporting that younger speakers showed overlapped VOT values between aspirated and lenis stops in the conversational condition, but the older speakers did not. Also, although the younger group revealed an enhanced VOT in the clear speech condition, the VOT difference between aspirated and lenis stops in the clear speech condition was only 10ms for the younger group. In contrast, the VOT difference between aspirated and lenis stops in the clear speech condition was 31ms for the older group. Based on these results, the researchers suggested that the older speakers are more likely to use VOT to differentiate the Korean stop contrasts. These overlapping VOT patterns have been explored considering not only age variation but also dialectal variation. Choi (2002) investigated the acoustic cues for Korean stops in Seoul standard Korean and Chonnam Korean, spoken in the southern part of Korea. In her study, all the speakers in both dialectal groups were in their late twenties. She reported that mean VOT is shortest for fortis, intermediate for lenis, and longest for aspirated stops in two dialects, which is in accordance with other studies, but suggested some overlap between lenis and aspirated stops for Seoul Korean speakers. Specifically, Chonnam dialect speakers show relatively well-separated interquartile boxes. On the other hand, the interquartile ranges for lenis and aspirated stops of Seoul Korean speakers show substantial overlap, while the range for fortis stops is more separated from the other two categories. With this result, Choi (2002) suggested that VOT is more of a cue to Chonnam dialect Korean speakers, and Seoul dialect speakers are more likely to use *f0* as an acoustic cue. From these acoustic studies on Korean stops, several things are noteworthy. First, the overlap in VOT, particularly in lenis and aspirated stops, indicates that VOT alone cannot be a sufficient acoustic cue for the three-way distinction of Korean stops, suggesting *f0* as another primary acoustic cue. Second, this overlapping pattern seems to be related to age and dialect. Third, regardless of this overlap, previous research generally agrees with the patterning of VOT variation: shortest for fortis, intermediate for lenis, and longest for aspirated stops.

1.2.1.2. *Fundamental frequency (f0)*

Despite the systematic differences in VOT values of Korean stops, the overlapping ranges question the validity of VOT as a single acoustic cue. Accordingly, some researchers turned their attention to the voice quality of the vowel after the stop release. C.-W. Kim (1965) argues that the voicing features (voiced/ voiceless, aspirated/unaspirated) to differentiate stop categories are inadequate by claiming the autonomy of the tensity feature in stop classification. He reports that the average VOT is in the order of fortis, lenis and aspirated, which is in line with other studies. However, he also noted that the values overlap in fortis and lenis or lenis and aspirated stops, and reported the slow rate of vocal fold vibration at the onset of the following vowel after the lenis stop release compared to fortis and aspirated stops. More specifically, C.-W. Kim (1965) measured the distance between the two onset of glottal pulses in three categories of Korean stops (i.e., *f0*=1/T - the duration of one full cycle), and reported that a cycle in lenis stops took 5.75 ms, while the cycle was 5.15ms in the fortis stop, and 5.3ms in the aspirated stop on the average. Consequently, he suggests the “tension” of the vocal folds as a feature to distinguish lenis stops from the other two stop categories, and both the tensity and voicing feature are autonomous to classify stops, particularly in languages with more than two stop categories.

A similar finding by Han and Weitzman (1970) supports the conclusion by C.-W. Kim (1965) through acoustic and perception studies. Han and Weitzman (1970) indicate that along with the VOT feature in stop segments, fundamental frequency and intensity characteristics are the primary cues for the three categories of Korean stops. In the acoustic measurements, Han and Weitzman (1970) reported that the fundamental frequency after the lenis stops is relatively lower than after fortis or aspirated stops. Also, the comparison of *f0* in the following vowel between fortis and aspirated stops reveals slightly higher *f0* values after aspirated stops than after lenis stops, although it shows considerable overlap in individual values. Accordingly, Han and Weitzman (1970) suggest the quality of the voice onset in terms of fundamental frequency and intensity characteristics as the acoustic cues for Korean stops along with VOT (see the next section for more discussion on intensity characteristics). Han and Weitzman (1970) further discussed that the differences in the timing of voice onset (VOT) cues distinguish aspirated stops from fortis and lenis stops, and the fundamental frequency serves to distinguish lenis stops from fortis and aspirated stops. Several subsequent studies agree with these results reported by C.-W. Kim (1965) and Han & Weitzman (1970). Figure 2 shows the average values of fundamental frequency (*f0*) of the three laryngeal gestures of Korean stops as reported by previous studies. All of the values are from Seoul standard Korean speakers, and mean *f0* in Figure 2 shows *f0* value measured at the onset of the following vowel. The values from Han & Weitzman (1970) and M.-R.Kim *et al*.(2002) are measured from female speakers and the values from C.-W.Kim (1965) and Cho *et al*.(2002) are measured from male speakers.

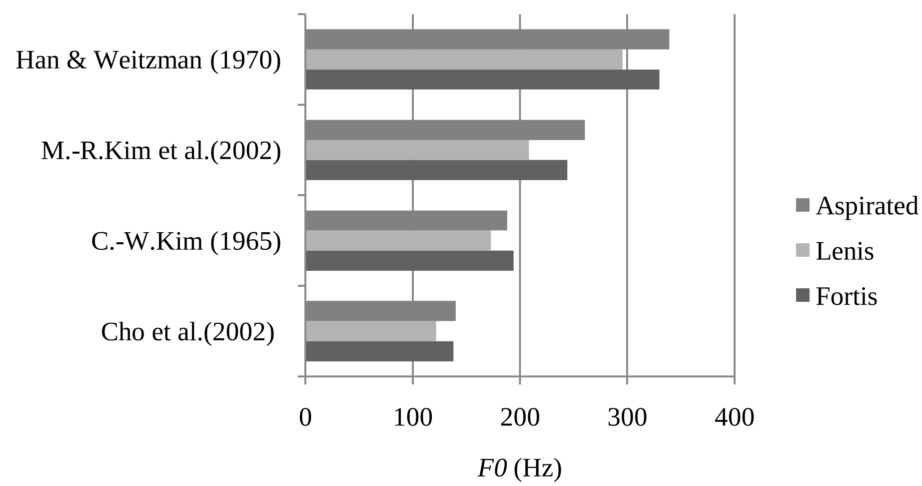


Figure 2. Mean *f0* (Hz) values at vowel onset reported in previous studies (Adapted from C.-W Kim, 1965; Han & Weitzman, 1970; Cho *et al*. 2002; M.-R. Kim *et al*. 2002)

In Figure 2, we can identify that *f0* after the lenis stops is always lower than the other two laryngeal categories, while the comparison between fortis and aspirated stops is ambiguous. A recent study by Cho *et al*. (2002) also confirmed that this pattern is persistent even in the middle of the following vowel, although the difference is not significant as in vowel onset. These acoustic studies, which consistently reported a lower *f0* at vowel onset after lenis stops, are supported by a recent perception study. M.-R. Kim and Beddor (2002) tested how well the vowel portion can signal the three stop categories. In their study, the subjects were given cross-spliced stimuli whose consonant portion and the vowel portion were crossed by the three laryngeal gestures. For example, the listeners heard the fortis stop consonant with a lenis vowel portion, or the lenis stop consonant with an aspirated vowel portion. In this stop identification experiment with cross-spliced stimuli, the accuracy rate for perceiving lenis stops with a fortis or aspirated vowel portion was low: 4% for lenis stops with the fortis vowel, 6% for lenis stops with the aspirated vowel. Also, listeners incorrectly identified the fortis or aspirated stop as the lenis stop, when the fortis or aspirated stop consonants were paired with the lenis vowel portion: 92% lenis responses to fortis stops with a lenis vowel, 81% lenis responses to aspirated stops with a lenis vowel. Based on these results, the researchers suggested that listeners were dependent on the vowel portion for perceiving lenis stops. This perception study indicates that *f0* distinguishes the lenis stop from the other stop categories.

Choi (2002) investigated the *f0* of Korean stops considering dialect variation. In her study, the *f0* pattern shows the difference between two dialects, namely Seoul standard Korean and Chonnam dialect Korean, which differ in their intonational systems. Choi (2002) reports that *f0* at vowel onset after the lenis stop is always lower than after the other stop categories in both dialects, but there is an overlap pattern among fortis and aspirated stops in Chonnam dialect, which has a salient phrase-initial rising intonational contour. On the other hand, Seoul speakers show well-separated *f0* values for the three laryngeal gestures. From these results, Choi (2002) concludes that the role of *f0* for classifying the laryngeal gesture is differed by the intonation systems.

Several things are noted from these previous acoustic studies on *f0*. Firstly, *f0* of the following vowel for each laryngeal gesture shows differences: the lowest for lenis stops, and relatively high for fortis and aspirated stops. However, the differences of *f0* between the following vowels after fortis and aspirated stops is non-significant, although *f0* after the aspirated stop shows slightly higher values than after the fortis stops. This is clearly marked in the dialect like Chonnam, which has phrase-initial rising intonational contour.

1.2.1.3. *Phonation Types*

The manner of vocal fold vibration, which is collectively referred as phonation type, has also been explored to distinguish the three-way distinction of Korean stops. The different types of phonation are determined by various factors like the position of the vocal folds, the shape and area of the glottal opening, or the rate of the airflow (Reetz and Jongman 2008, p94). Accordingly, we can postulate the glottal state or the rate of the airflow by determining the phonation types. Languages such as Mazatec and Mpi employ two types of nonmodal phonation (i.e., breathy and creaky) as separate phonemes that contrast with modal voicing (Blankenship 2002). The nonmodal voicing also results from the influence of preceding consonants. Therefore, previous acoustic studies on Korean stops have investigated the onset of vowels after the stop consonant to determine the phonation type, namely modal, breathy, and creaky voice. The acoustic correlate of breathy voice is a large amplitude difference between the first harmonic (*H1*) and the second harmonic (*H2*), or a steep spectral slope. On the other hand, the acoustic correlate of creaky voice is a small or negative amplitude difference between the first and second harmonic, or shallow slope. Han and Weitzman (1970) noted the difference in the quality of the voice onset among the three types of stops (e.g., *f0*, intensity build-up) and suggested the different intensity build-up at vowel onset as an acoustic cue, particularly for differentiating the fortis stop from the lenis one. They observed differences in intensity build-up at the onset of voicing after each stop, reporting that the harmonic partials are weak after lenis stops, strong after fortis stops, and intermediate after aspirated stops. Based on these results, Han and Weitzman (1970) proposed that voice quality following lenis stops is breathier than following fortis stops. The researchers further discussed that more time is required to build up the intensity at vowel onset after lenis stops than after the other two stop categories. Therefore, Han and Weitzman (1970) suggested that “lenis and fortis stops differ primarily in terms of a gradual versus a relatively rapid intensity build-up after stop release” (Han & Weitzman 1970, p.127)

A recent study by Cho, Jun, and Ladefoged (2002), where acoustic and aerodynamic characteristics of Korean obstruents were investigated in two dialects, agrees with Han and Weitzman (1970). Cho *et al*. (2002) noted that the voice quality of a following vowel changes systematically as a function of the three-way laryngeal gesture in Korean stops. Their study measured the amplitude differences between the first harmonic and the second harmonic at the onset of a following vowel after the each stop (*H1-H2*), and reported the significant main effect of three laryngeal gestures. The *post hoc* comparison indicates the greatest *H1-H2* for lenis stops, intermediate for aspirated stops, and smallest for fortis stops. Based on this result, they suggest that the voice quality of the vowel after lenis stops is more breathy than the other two stop categories. On the other hand, the voice quality of the vowel after fortis stops, with a negative value of *H1-H2*, is closer to creaky voice. Moreover, Cho *et al*. (2002) argued that the difference in intensity at vowel onset is maintained even in the middle of the vowel, although the difference is not larger than that at vowel onset.

Kang and Guion (2008) also examined this intensity feature. However, their findings are inconsistent with the findings of Cho *et al*. (2002). Kang and Guion (2008) measured *H1-H2* in the following vowel and compared different speech conditions (i.e. clear speech condition, citation-form speech, and conversational speech condition) and age variation (younger speakers, mean=25.8 years and older speakers, mean=46.7). They reported that *H1-H2* varies from small to large in the order of fortis, lenis and aspirated and revealed an enhancement of the *H1-H2* distinction in the clear speech condition, particularly for fortis stops. Hence, they argued that in the clear speech condition, the voice quality of the following vowel after fortis stops is creakier than in other speech conditions for both age groups. However, regardless of speech condition and age variation, the *H1-H2* at vowel onset after aspirated stops always shows larger differences than the *H1-H2* at the vowel onset after lenis stops, which is the opposite result from Cho *et al*. (2002). Figure 3 shows the comparison of *H1-H2* at vowel onset reported by Cho *et al*. (2002) and Kang and Guion (2008). The data from Kang and Guion (2008) shows the results from the old group (mean=46.7) in clear speech condition.

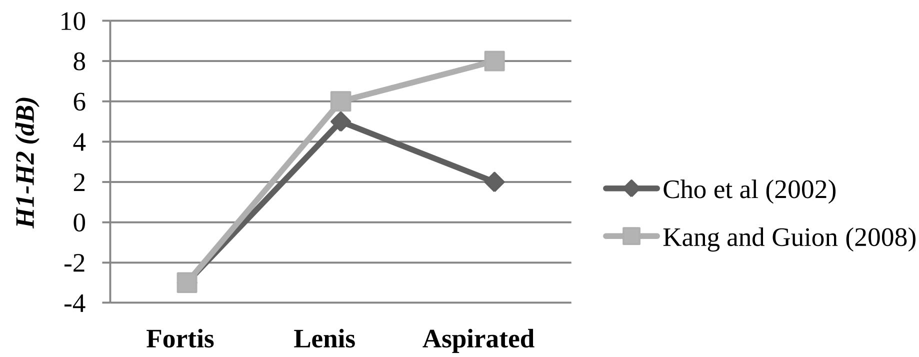


Figure 3. Comparison of the *H1-H2* (dB) at vowel onset reported by Cho *et al.* (2002) and Kang and Guion (2008) (Adapted from Cho *et al.*, 2002 and Kang and Guion, 2008)

Ahn (1999) also indicated the same *H1-H2* pattern as Kang and Guion's (2008) report. Ahn (1999) investigated phonation types of vowels following Korean voiceless stops by measuring the normalized difference in intensity between the first and second harmonics from six of Seoul Korean speakers (mean age = 36.5). Ahn (1999) mentioned that the traditional measure of *H1-H2* is not reliable due to a boost effect of the first formant in the very initial part after stop release, which can affect the first and second harmonics. Ahn, therefore, used a new measure called *H1*-H2** (Subtracting 'predicted values of *H1-H2* from 'observed values' of *H1-H2:* Obs(*H1-H2*) – Exp(*H1-H2*)) suggested by Stevens and Hanson (1995). In Ahn's (1999) study, his statistical analysis reported that the *H1*-H2** value is significantly lower for the fortis stop than the other categories, while the difference between the aspirated stop and the lenis stop is not significant. Based on these results, Ahn (1999) suggested the creaky voice for the vowel after the fortis stop, and the breathy voice for the aspirated and the lenis stop, and further discussed that the phonological features [±Stiff Vocal Folds] / [±Slack Vocal Folds] (Halle & Stevens, 1971) is required to represent the Korean stops which are also distinguished by different phonation types (See section 3.2. for more discussion).

1.2.1.4. *Physiological and Aerodynamic Characteristics*

A number of researchers have also investigated Korean stops in a three-way distinction to clarify the physiological properties as well as acoustic properties. The cineradiographic study by C.-W. Kim (1970) examined the correlation between aspiration and glottal opening during the Korean stop production. Kim (1970) reported that the glottal opening is largest for aspirated stops, intermediate for lenis stops, and narrowest for fortis stops at all places of articulation. Based on this evidence, he suggests a direct correlation between the degree of the glottal opening at the time of release and the degree of aspiration. In other words, Kim (1970) argued that the duration of aspiration seems to be equal to the time it takes for the open glottis to close for the vibration of the following vowel (Kim 1970, p.31). Figure 4 is a picture of the glottis: Kim (1970) measured the glottal opening shown as a horizontal line in Figure 4. This cineradiographic study by Kim (1970) was also confirmed by a recent MRI study by H. Kim, Honda and Maeda (2005). In this stroboscopic-cine magnetic resonance imaging (MRI) study for the three-way distinction in Korean stops, the researchers investigated the movements of the tongue and the larynx as well as the state of glottal opening to observe multiple speech movements during the production of Korean stops in alveolar position. From the transverse MRI images of glottal width and opening, H. Kim *et al.* (2005) supported the results of C.-W. Kim. (1970), indicating that glottal opening and glottal width vary from small to large in the order of fortis, lenis and aspirated stops. In addition, the researchers provided information on linguopalatal contact and tongue movement from midsagittal MRI images. H. Kim *et al*. (2005) reported apico-dental contact for the lenis stop /t/, apico-laminal contact for the aspirated stop /t^h/, and more extensive apico-laminal contact for the fortis stop /t’/. As for the tongue movement, the researchers reported that “maximum height of the blade position varies from low to high in the order of lenis, aspirated, and fortis stops” (H. Kim *et al*. 2005, p.9). Based on these results, H. Kim *et al*. (2005) suggested “the operation of a “tongue-pull” mechanism during the production of the Korean three-way phonation contrast: tongue movement affects the vertical larynx movement such that the higher the tongue moves up, the higher the larynx rises”. (H. Kim *et al*. 2005, p.15), and the concomitant tongue and larynx movement, and glottal opening are involved in producing the Korean three-way distinction in stops.

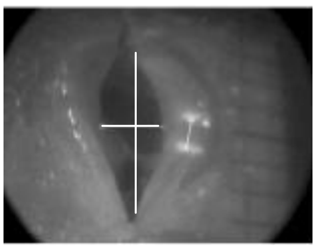


Figure 4. A picture of the glottis: the horizontal line indicates glottal opening, and the vertical line indicates glottal width (picture adopted from Popolo & Titze 2008)

Hirose *et al.*(1974) have also investigated the glottal state in the production of Korean stops by examining the actions of the intrinsic laryngeal muscles with electromyography (EMG). Hirose *et al*. (1974) indicates the different laryngeal muscle activity for the three different stop categories in Korean. In the study by Hirose *et al*. (1974), the electrodes were inserted into the interarytenoid (INT), the vocalis (VOC), and the lateral cricoarytenoid (LCA) muscles. Hirose *et al*. (1974) reported that the aspirated stop is characterized by suppression of all the adductor muscles of the larynx after the release of the stop closure and a steep increase in activity after the suppression. Moreover, the researchers indicated that the patterns of VOC and LCA activity mostly characterized fortis stops, suggesting a marked increase in VOC activity before fortis stop release, and they consequently argued that this resulted in the increased tension of the vocal folds and constriction of the glottis during or after the fortis stop closure. Based on these results, Hirose *et al*. (1974) agree with the notion that fortis stops are classified as “laryngealization” or “glottalization”. In contrasts, VOC activity before the release of lenis stops did not show a transient increase. In addition, unlike the aspirated stop, the suppression of the adductor muscles was not significant in lenis stops. Therefore, based on these results, Hirose *et al*. (1974) suggested that a simple dimension of adduction-abduction of the vocal folds is not sufficient to classify the Korean stops and proposed to consider another dimension as shown in VOC activity.

Aerodynamic studies have also documented the distinctive Korean stops through measuring air pressure and airflow and given us information on the subglottal and supraglottal systems. Dart (1987) measured intraoral air pressure (Po) and airflow (Uo) of Korean fortis and lenis bilabial stops in word-initial position. Dart (1987) reported that despite individual variation, lenis stops showed greater airflow, but less air pressure. In contrast, fortis stops were reported as having less airflow, but greater air pressure. Dart (1987) tested the hypotheses that the difference in airflow is caused by differences in VOT, and the difference in air pressure comes from the tension of the vocal folds or subglottal state by means of computer modeling. Glottal area function, vocal tract wall tension, respiratory muscle force, and supraglottal cavity volume were simulated following the reported values of glottal opening, VOT values or vocal tract wall tension in previous studies for Korean fortis and lenis stops. Based on the observed values and aerodynamic modeling, Dart (1987) suggested that the unbalanced pattern of Uo and Po for fortis stops is because of the adducted vocal folds before release and suggested more tensed vocal folds and heightened subglottal pressure for fortis stops . Cho *et al*. (2002) have also examined the aerodynamic properties of Korean stops in two dialects, namely Seoul standard Korean and Cheju dialect Korean, an endangered Korean language. Unlike Dart's study in 1987, this study included all three stop categories and measured intraoral air pressure (Po) and intraoral airflow (Uo) of Korean bilabial stops. Cho *et al*. (2002) reported that the maximum oral pressure during the stop closure is smaller for the lenis stop than for the fortis and aspirated stops, while the maximum air pressure rate for fortis and aspirated stops is comparable. For the intraoral airflow, the fortis stops show less airflow rate than the lenis stops, which is in line with Dart (1987). Figure 5 shows the pattern of airflow and air pressure reported by Cho *et al*. (2002). The figure indicates only Seoul speakers.

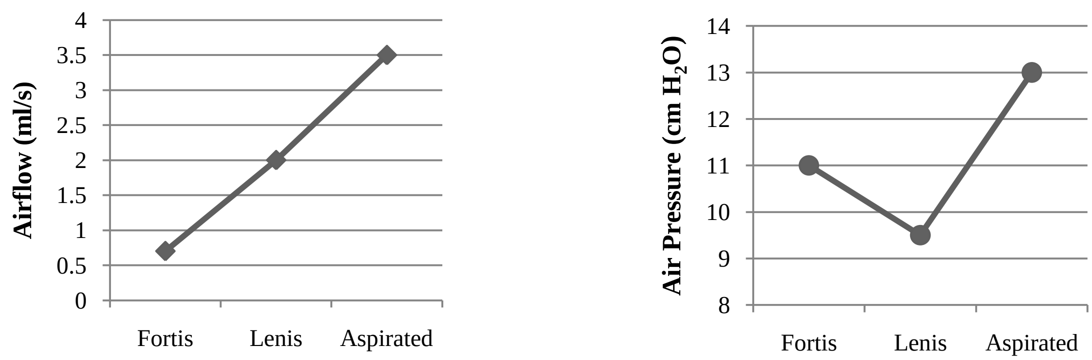


Figure 5. Oral airflow (Uo) and air pressure (Po) from Seoul speakers reported by Cho *et al.* (2002)

As shown in Figure 5, the air pressure and airflow rate in fortis stops show the unbalanced pattern between airflow and air pressure. Based on these results and Dart's aerodynamic model, Cho *et al*. (2002) suggested that "an increase in subglottal pressure due to an increase in respiratory effort is the cause of the higher oral pressure in fortis stops" (p. 210). In contrast, the researchers proposed that the constricted vocal tract wall and smaller glottal area might cause the decrease in velocity of airflow in fortis stops, which accounts for the small airflow rate for fortis stops. In addition, the glottal impedance with constricted vocal folds might lower the oral pressure in fortis stops as compared to aspirated stops. In contrast, Cho *et al*. (2002) posit that the large glottal area at the stop release might cause the greater oral airflow and pressure in aspirated stops.

1.2.2. Dialectal Variation

The atypical Korean stop contrasts have also been explored considering dialectal variation. As introduced in previous sections, Choi (2002) investigated cross-dialectal variation in the use of the acoustic cues of VOT and *f0*. In her study, the three-way distinction of Korean stops in Seoul standard Korean and Chonnam dialect Korean, which differ in their intonational systems, was investigated. Based on the result of two distinctions of *f0* in Chonnam dialect, Choi (2002) concluded that Chonnam dialect speakers are more likely to use VOT as a primary acoustic cue rather than *f0*, and suggested that the phrase-initial pitch in Chonnam dialect might minimize the use of the acoustic cue of *f0* from preceding consonants. Cho *et al*.(2002) have also examined the acoustic and aerodynamic characteristics of Korean stop contrasts between Seoul dialect Korean and Cheju dialect Korean. One potential dialectal difference in Cho *et al*.(2002)'s study was in VOT: VOT for Seoul Korean speakers is in general longer than that for Cheju speakers. Particularly, the dialect difference was clear in lenis stops: the mean VOT for the lenis stop in Seoul dialect Korean was 72ms, and in Cheju dialect Korean was 47ms. For this shorter VOT for Cheju dialect Korean, Cho *et al.(*2002) reasoned that Korean stops might possibly be undergoing a diachronic change (Silva 2006), but that Cheju people who are isolated from mainland Korea might not participate in the diachronic change. Figure 6 shows a map of the Korean Peninsula and the regions of which dialects were introduced in previous studies, namely Seoul, Cheju, and Chonnam dialect; it also shows South Kyungsang region, whose dialect will be considered in the current study.

Figure 6. Korean Peninsula and the dialectal regions

1.2.2.1. *Tone in Kyungsang Korean*

The Kyungsang dialect is spoken in the southeastern part of the Korean peninsula. Contrary to the Seoul dialect which has lost the lexical *f0* contrasts, the Kyungsang dialects (North Kyungsang dialect, South Kyungsang dialect) preserve their lexically distinctive tonal property (Ramsey 1975; Park 2004; Kenstowicz and Park 2006). The Kyungsang dialects have three tonal contrasts in disyllabic words as shown in example (1) a.

(1) a. kácì (HL) 'kind'
ká:cí (HH) 'branch'
kàcí (LH) 'eggplant'

In monosyllabic words, a tonal contrast between high and rising tones is preserved in the South Kyungsang Korean (near Pusan city). In North Kyungsang (near Taegu city), these words are distinguished by vowel length but not tone, as shown in the example (1) b.

b. mál 'horse'
mǎl 'speech' (Pusan - South Kyungsang)
má:l 'speech' (Taegu - North Kyungsang) (Kenstowicz and Park 2006, p3)

Kenstowicz and Park (2006) have investigated the three-way laryngeal contrasts of stops in Kyungsang Korean. As introduced in previous research on Korean stops, *f0*, the vowel property after the stop, primarily cues the Korean obstruents along with VOT. Accordingly, Kenstowicz and Park (2006) examined how the *f0* property in Korean obstruents is deployed, and how *f0* is used to distinguish tonal contrasts as well as the laryngeal contrasts in Kyungsang dialects, in which *f0* is used for lexical tonal contrasts. Hence, the researchers have compared the acoustic characteristics of Korean stops in tonal Kyungsang dialects and non-tonal Seoul dialect, mainly focusing on the *f0* property. In the study by Kenstowicz and Park (2006), the first comparison was between the underlying voiced lenis stops and voiced nasals and underlying voiceless fortis and aspirated stops. One of the main findings by Kenstowicz and Park (2006) is that *f0* after the underlying voiceless consonants such as fortis and aspirated stops is relatively high, compared to that of the underlying voiced consonants such as lenis and nasal consonants in the Kyungsang dialects. More specifically, they reported that the onset *f0* value after the lenis and nasal consonants (underlying voiced consonants) is about 210 Hz (from female speakers), and the onset *f0* value after the fortis and aspirated stops (underlying voiceless consonants) is about 240 Hz. Moreover, Kenstowicz and Park (2006) argued that the effect of voicing on the *f0* values shows up in the middle of the following vowel as well as at vowel onset. Also, the researchers compared the High vs. Low tonal contrasts at vowel onset and midpoint in the initial syllable to see how well the two tonal contrasts were separated. Kenstowicz and Park (2006) reported that the onset *f0* of a high tone vowel after the fortis and aspirated stop and the onset *f0* of a low tone vowel after the lenis stop are clearly separated from each other, while the onset *f0* of a low tone vowel after the fortis and aspirated stop and the onset *f0* of a high tone vowel after the lenis stop are considerably overlapped. However, there was no overlap in the middle of the vowel between High and Low tonal distinctions. Based on these results, the researchers posited the spreading of the Halle and Stevens (1971) feature [± stiff vocal folds] to the middle of the vowel in the Kyungsang dialects, and suggested that the spreading effect of [± stiff vocal folds] overlays the High vs. Low [± upper] tonal contrast and the *f0* scaling differences between the Kyungsang dialects and Seoul dialect.

1.3. Goal of the Current Study and Hypotheses

While a great number of studies have investigated the unusual three-way distinction of Korean stops, only a few studies have focused on the effect of the lexical pitch accent contrasts. In addition, although the recent study by Kenstowicz and Park (2006) investigated the effect of the pitch accent of Korean stops in Kyungsang dialects, the researchers focused on the tonal effects on the underlying [±stiff vf] voicing features, mainly concerning *f0* with little attention on other acoustic properties such as VOT. Accordingly, the present study will consider how the tonal contrasts in Kyungsang dialect Korean boost or restrict the three laryngeal contrasts, which surface differently in word-initial position, and how differently *f0* distinguishes the three stop categories in the two dialects with different tonal systems: non-tonal Seoul dialect and tonal South Kyungsang dialect Korean. The present study has some additional goals and investigates the following hypotheses:

(1) The present study aims to make generalizations for the acoustic and aerodynamic characteristics of Korean stops based on a representative sample as well as to replicate previous findings.

(2) The acoustic and aerodynamic properties on Korean stops will be considered with dialectal variation between Seoul and South Kyungsang dialect using the same stimuli. The comparison between Seoul and Kyungsang dialect Korean in Kenstowicz and Park's (2006) study is across two different studies. Kenstowicz and Park (2006) compared their findings with those of Cho *et al*. (2002). That is, the comparison was with different stimuli and different speech context: word stimuli in isolation for Cho *et al*. (2002) and stimuli in sentential frames for Kenstowicz and Park (2006). Therefore, the current study intends to obtain reliable data by eliminating variables which can possibly come from different stimuli or speech conditions.

(3) The lexical tonal contrast feature in South Kyungsang dialect Korean will be considered and the following research questions will be addressed.

a. Does Kyungsang indeed have pitch accent contrasts?

b. If so, how are the acoustic and aerodynamic properties of the three laryngeal contrasts deployed in Kyungsang?

c. Are the acoustic cues for Korean stops in the South Kyungsang dialect different from those of the Seoul dialect?

d. If the acoustic cues are different, how can the phonological features be represented in the two dialects?

With the assumption of a lexical pitch accent in Kyungsang dialect Korean, the following hypotheses will be tested.

(4) The *f0* of three laryngeal gestures will pattern differently in the two dialects due to their different tonal systems.

(5) The *f0* properties in the Korean stop will be ambiguous in South Kyungsang dialect, particularly between *f0* for the L tone fortis stop and the H tone lenis stop, and this ambiguous distinction may become strong at the midpoint of the following vowel because of the increased effect of tone in Kyungsang dialect. In other words, *f0* may be unreliable to distinguish the three Korean stops in South Kyungsang dialect, and this will be clear at the midpoint of the vowel.

(6) The *f0* variation of the three stop categories will be more distinct at the onset of the following vowel than at the vowel midpoint. Conversely, the *f0* distinction by three laryngeal gestures will be even less clear at the midpoint of the following vowel in South Kyungsang dialect.

Chapter 2 Acoustic and Aerodynamic Studies of Seoul and South Kyungsang Dialect Korean Stops

2.1. Methodology

2.1.1. Participants

Sixteen native speakers of Korean participated in both acoustic and aerodynamic studies. The data were collected from Seoul and South Kyungsang dialectal groups. Each group had eight male speakers. The age in the Seoul dialectal group ranged from 21 to 32 years old, and the mean age was 27.6 years old. All of the Seoul speakers were born in Seoul, Korea and had lived in the U.S. less than 2 years. The age in the South Kyungsang dialect group ranged from 24 to 48 years old, and the mean age was 34.9 years old. All of the South Kyungsang speakers had lived in South Kyungsang area near Pusan with parents who were speakers of the same dialect and educated in South Kyungsang until they entered the University in other regions or moved to the United States. Seven of the South Kyungsang speakers had lived in the U.S. less than five years, and one of the South Kyungsang speakers had lived in the U.S. more than five years. They were all graduate or undergraduate students at the University of Kansas. None of the speakers in either dialect reported any speech or hearing disorders, and all of the speakers were literate in Korean.

2.1.2. Data Acquisition Procedure

For the acoustic study, all speakers were recorded in the Anechoic Chamber at the University of Kansas, using a cardioid microphone (Electrovoice-RE 20) and a digital recorder (Marantz PMD 671). Each speaker in both dialectal groups produced the disyllabic target words in isolation written in standard Korean orthography. The words or phrases triggering the context were written next to the target words to help speakers produce the word more naturally and distinguish the homonym. For example, the target word for “eggplant”, which is *kaci* in Korean, was written with the context of “I eat____”; a target word for “branch”, which is also *kaci* in Korean, was written with the context of “Look at the bird on the ____”. Each of the subjects received instructions and practiced before the actual recording. The stimuli were recorded at a sampling rate of 22050 Hz and analyzed using the software package *Praat* (Boersma and Weenink, 2005).

The aerodynamic study included the same speakers who participated in the acoustic recording. Each speaker was recorded at the University of Kansas Phonetics and Psycholinguistics Laboratory (KUPPL) right after the acoustic study recording. For the aerodynamic data, only bilabial stops were recorded, and the stops in alveolar and velar position were not recorded. Oral airflow and pressure were recorded using the Macquirer X16 system (Scicon Company). To capture the oral airflow, speakers held a face mask against the lower part of the face, below the nose, and they also held a tube (internal diameter 2 mm and 6 cm length) between their lips to record the oral air pressure. The air pressure transducer and flow mask were calibrated with CAL 110/220 (Scion), prior to collecting data from the speakers. The flow and pressure signals were sampled at a rate of 2 kHz and analyzed with Macquirer (Scicon).

2.1.3. Stimuli

For the acoustic study, all nine stops of Korean were recorded in both dialects. Since the present study focuses on the acoustic cues of a three-way laryngeal distinction by tonal contrasts in two dialects, which have different tonal systems, all the stimuli were categorized according to tonal dialect Korean (South Kyungsang) rather than non-tonal dialect Korean (Seoul). Therefore, for the measurement and analyses, it is assumed that the same stimuli in both dialect groups have the same tonal condition. For example, stimulus /tali/ ‘leg’, which is LH tonal contrast in South Kyungsang dialect, is also treated as LH for non-tonal Seoul dialect Korean.

Disyllabic words were drawn from each of the two contrasting HH and LH tonal patterns with systematically varied initial consonants. If there was no disyllabic word with the appropriate tonal contrasts, monosyllabic words, which were followed by the nominative case marker /-i/ with HH and LH tonal contrasts, were used. Most of the stimuli contained the vowel /a/ in the first syllable, and target consonants were placed in the initial position. The words in the list were randomized with fillers, and each subject in both dialectal groups read the list twice for a total of 36 tokens per subject. Most of the stimuli were adopted from Kenstowicz and Park's study (2006). The word list that was used for the present study is shown in Table 2.

		HH		LH	
fortis	p'	p'ang-i	"bread"	p'alɯm	"being fast"
lenis	p	pal-i	"foot"	pantal	"a half-moon"
aspirated	p^h	p^han-i	"broad"	p^hacu	name of city
fortis	t'	t'al-i	"daughter"	t'alɯm	"following"
lenis	t	tal-i	"moon"	tali	"leg"
aspirated	t^h	t^həl-i	"hair"	t^hal-i	"mask"
fortis	k'	k'aki	"to peel"	k'apul	"naughtiness"
lenis	k	kaci	"branch"	kaci	"eggplant"
aspirated	k^h	k^hal-i	"knife"	k^hoil	"coil"

Table 2. Stimuli recorded for the acoustic study

The stimuli used in the aerodynamic study consisted of those with the bilabial stops used in the acoustic study. Subjects in both dialectal groups read the bilabial subset of Korean stops twice for aerodynamic recording.

2.1.4. Measurements

Voice onset time (VOT), fundamental frequency (*f0*) and the amplitude difference between the first harmonic and the second harmonic (*H1-H2*) were measured using *Praat*. VOT was measured from the point of the stop release to the onset of the following vowel as seen in both waveform and spectrograms. *f0* was measured at the onset and the midpoint of the following vowel. *f0* was determined using waveforms (F=1/T) and also the first harmonic values from an FFT (fast Fourier transformation) spectrum with a 25ms window were used as secondary checks. *H1-H2* which is the amplitude difference (dB) between the first harmonic (H1) and second harmonic (H2) was measured at the vowel onset, using FFT spectra with a 25ms window.

Intraoral airflow (Uo) and air pressure (Po) were measured for the aerodynamic study using the Macquirer X16 system (Scicon). Measurements were made of the maximum oral airflow after the release of stop closure, and the peak oral air pressure during the stop closure.

2.1.5. Data Analysis

Measurements were averaged over the two repetitions for each speaker. All the data were evaluated based on repeated measures General Linear Model (GLM) Analyses of Variance (ANOVAs). In most of the cases, the within-subject factor was Laryngeal Gesture with three level (Fortis, Lenis, Aspirated), and the between-subject factor was Dialect (Seoul, South Kyungsang). Moreover, Place of Articulation was considered as within-subject factors (Bilabial, Alveolar, Velar) for VOT, and Vowel Position (onset vs. midpoint) was also considered for *f0*.

In order to verify the lexical pitch contrasts in South Kyungsang dialect, the *f0* differences between HH and LH in both Seoul and South Kyungsang dialects were compared by Laryngeal Gestures at both vowel onset and midpoint and Dialect was considered as between-subject factor.

The acoustic measures of VOT, *H1-H2*, *f0*, intraoral airflow (Uo), and air pressure (Po) were all entered as dependent variables. In addition, to identify how the acoustic properties of three laryngeal gestures are affected by tonal contrasts, all the acoustic measures by laryngeal gestures were also considered by HH and LH tonal contrasts. In order to further explore the data within a factor, Bonferroni post hoc comparison were conducted ($\alpha = 0.05$) between Fortis-Lenis, Fortis-Aspirated, and Lenis-Aspirated stops. The SPSS statistical software package (version 17.0, SPSS Inc., 1999) was used to conduct repeated measures ANOVAs and paired sample t-tests.

2.2. Results of Acoustic Study

2.2.1. *f0* differences between HH and LH in Seoul and South Kyungsang Dialect Korean

One of the main foci in the present study is to investigate the effect of tone on other acoustic properties such as VOT or *H1-H2* in Korean voiceless stops through comparing the South Kyungsang dialect, which is known as tonal dialect Korean with the non-tonal Seoul dialect. Therefore, it was necessary to verify the tonal distinction in South Kyungsang dialect before analyzing the other acoustic characteristics such as VOT or *H1-H2*. To verify the lexical pitch accent contrasts in South Kyungsang dialect, the *f0* differences in the following vowel between HH and LH were analyzed in both Seoul standard Korean and South Kyungsang dialect Korean by Laryngeal Gesture. Table 3 and Figure 7 indicate the average *f0* difference between HH and LH in both dialects, and the values also indicate the *f0* differences at the onset and midpoint of the following vowel.

		Fortis		Lenis		Aspirated	
Seoul	V.Onset	3.50	(3.65)	-1.13	(1.78)	0.58	(6.80)
	V.Midpoint	4.02	(4.44)	-0.95	(1.88)	1.43	(5.43)
Kyungsang	V.Onset	11.93	(7.32)	11.33	(6.09)	16.02	(6.97)
	V.Midpoint	12.85	(6.45)	16.50	(5.61)	18.04	(6.57)

Table 3. Average values of *f0* differences (Hz) between HH and LH in Seoul and South Kyungsang dialect Korean (standard deviation in parentheses) by Laryngeal Gestures at onset and midpoint of the following vowel

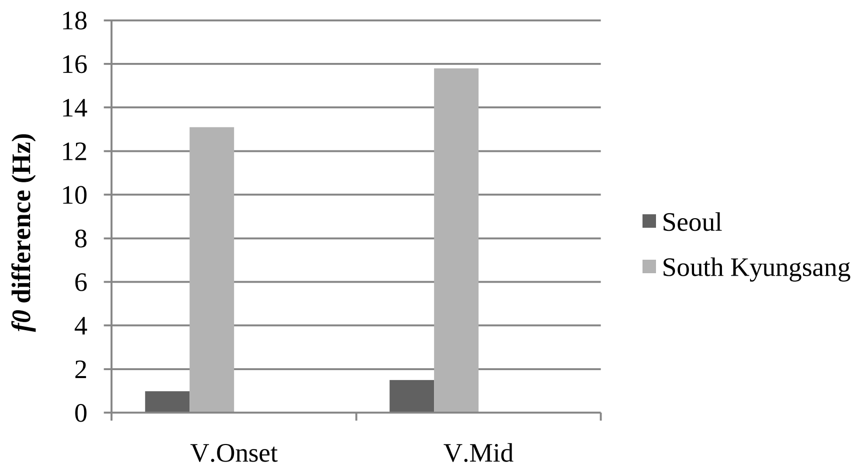


Figure 7. Average *f0* differences (Hz) between HH and LH in Seoul and South Kyungsang dialect Korean at onset and midpoint of the following vowel. Data are pooled across Laryngeal Gesture.

The *f0* differences between HH and LH tonal contrasts measured at vowel onset and midpoint were 0.98Hz (V. onset) and 1.5Hz (V.mid) for Seoul dialect; 13.09Hz (V. onset) and 15.80Hz (V.mid) for South Kyungsang dialect. Repeated measures ANOVA (Vowel Position (onset vs. midpoint) by Dialect) showed that there was a significant effect of Dialect (F (1,14) = 35.147, $p < 0.01$) and a significant effect of Vowel Position (F (1, 14) = 5.482, $p = 0.035$). This result indicates that South Kyungsang dialect Korean indeed has toanl contrasts between High and Low tones, while the Seoul dialect does not, and this lexical pitch contrast is more distinctive at vowel midpoint than vowel onset. After the verification of tonal contrasts in South Kyungsang, all the satatistical analyses for South Kyungsang dialect has considered the Tonal Contrasts as a factor.

2.2.2. VOT

For the Seoul dialect group, the mean duration of VOT by Laryngeal Gesture is 17.27 ms for the fortis stop, 65.15 ms for the lenis stop, and 80.16 ms for the aspirated stop. A repeated measures analysis of variance (ANOVA) (Laryngeal Gesture by Place of Articulation) showed a significant main effect of

Laryngeal Gesture (F (2, 6) = 46.648, $p < 0.01$). Bonferroni post hoc comparison showed that the VOT of each Laryngeal Gesture is significantly different from each other. The comparisons showed that VOT is shortest for the fortis stop, intermediate for the lenis stop, and longest for the aspirated stop in Seoul dialect ($p < 0.05$ for each comparison).

Statistics showed a significant main effect of Place of Articulation (F (2, 6) = 49.541, $p < 0.01$). Bonferroni post hoc comparison showed that the VOT of velar stops (60.44 ms) is significantly longer than that of bilabial (50.22 ms) or alveolar stops (51.92 ms), while the comparison between bilabial and alveolar stops was not significant ($p = 0.79$). There were no significant interactions between Laryngeal Gesture and Place of Articulation in the Seoul dialect.

For the South Kyungsang dialect, the mean duration of VOT by Laryngeal Gesture is 18.17 ms for the fortis stop, 38.14 ms for the lenis stop, and 104.38 ms for the aspirated stop. Repeated measures ANOVAs (Laryngeal Gesture by Place of Articulation by Tonal Contrasts) showed a significant main effect of Laryngeal Gesture (F (2, 6) = 157.009, $p < 0.01$). Bonferroni post hoc comparison showed that VOT is shortest for the fortis stop, intermediate for the lenis stop, and longest for the aspirated stop in South Kyungsang dialect ($p < 0.01$ for each comparison).

The results of ANOVA also showed a significant main effect of Place of Articulation (F (2, 6) = 69.79, $p < 0.01$). Bonferroni post hoc comparison indicated that the VOT duration of velar stops (64.23 ms) was significantly longer than that of bilabial (47.19 ms) or alveolar stops (49.26 ms) ($p < 0.01$), while the comparison between bilabial and alveolar stops was non-significant ($p = 1.00$).

Regarding the tonal effect on VOT, ANOVA showed that there is no main effect of Tonal Contrasts in the South Kyungsang dialect. There was no significant interaction between Laryngeal Gesture and Place of Articulation or between Laryngeal Gesture and Tonal Contrasts in South Kyungsang dialect. A summary of the results is shown in Table 4 and Figure 8.

	Fortis		Lenis		Aspirated	
Seoul	17.27	(3.17)	65.15	(18.21)	80.16	(15.90)
South Kyungsang	18.17	(4.79)	38.14	(5.16)	104.38	(17.74)
Mean	17.72	(3.95)	51.64	(19.02)	92.27	(20.53)

Table 4. Average values of VOT duration (ms) in Seoul and South Kyungsang dialect groups as a function of Laryngeal Gesture (standard deviation in parentheses)

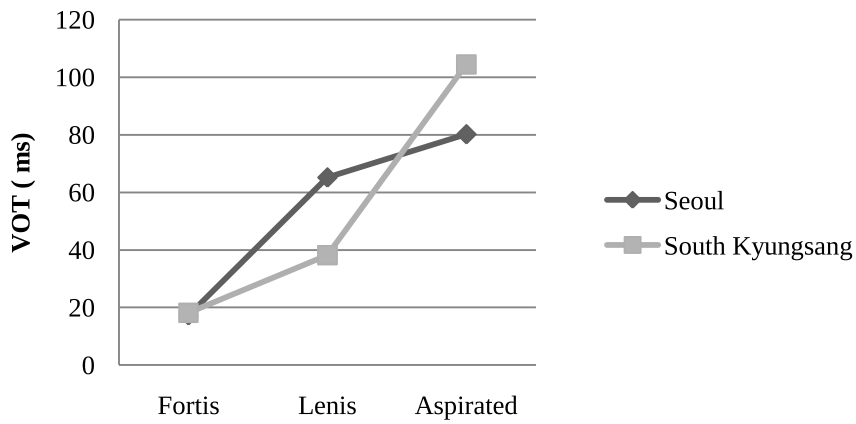


Figure 8. Average duration of VOT (ms) in Seoul and South Kyungsang dialect groups depending on Laryngeal Gesture

A three-way repeated measures ANOVA (Laryngeal Gesture by Tonal Contrasts by Dialect) showed a significant main effect of Laryngeal Gesture (F (2, 13) =131.038, $p < 0.01$), and a significant interaction of Laryngeal Gesture by Dialect (F (2, 13) = 22.69, $p < 0.01$), but neither a main effect of Dialect nor a Tonal Contrasts by Dialect interaction was found. The VOT variation does not show a paralell pattern between the two dialects: the VOT for the lenis stop is significantly longer in Seoul dialect than in South Kyungsang dialect, while the VOT for the aspirated stop is longer in South Kyungsang dialect than in Seoul dialect.

Repeated measures ANOVA (Place of Articulation by Tonal Contrasts by Dialect) showed a significant main effect of Place of Articulation (F (2, 13) = 131.053, $p < 0.01$), but no main effect of Tonal Contrasts or Dialect. In addition, either Place of Articulation by Tone or Place of Articulation by Dialect interaction was not found. Table 5 and Figure 9 indicate the average VOT duration in both dialects depending on the place of articulation.

	Bilabial		Alveolar		Velar	
Seoul	50.22	(10.17)	51.92	(11.76)	60.44	(10.17)
South Kyungsang	47.19	(7.92)	49.26	(6.69)	64.23	(7.22)
Mean	48.70	(8.94)	50.59	(9.35)	62.33	(8.74)

Table 5. Average values of VOT duration (ms) in Seoul and South Kyungsang dialect groups as a function of place of articulation (standard deviation in parentheses)

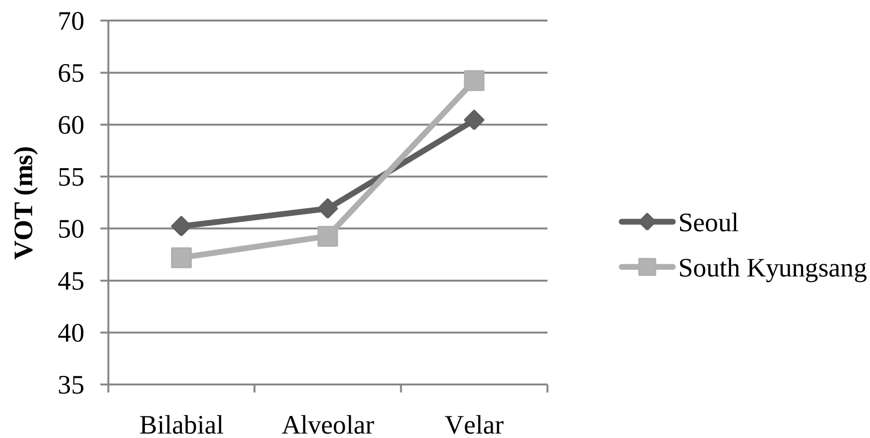


Figure 9. Average duration of VOT (ms) in Seoul and South Kyungsang dialect groups depending on Place of Articulartion

2.2.3. *H1-H2*

For the Seoul dialect group, the *H1-H2* measure showed that the vowel after the fortis stop release had a smaller value of *H1-H2* than those after the lenis and aspirated stop.   At the onset of following vowels, the mean value of *H1-H2* by Laryngeal Gesture is – 0.61dB for the fortis stop, 0.60 dB for the lenis stop, and 4.88 dB for the aspirated stop. Repeated measures ANOVA (Laryngeal Gesture) showed the significant main effect of Laryngeal Gesture (F (2, 6) = 11.198, $p < 0.01$). Bonferroni post hoc comparison showed that the *H1-H2* values by Laryngeal Gesture differ significantly from each other at

$p < 0.05$, but the comparison between the fortis and lenis stop was not significantly different from each other. The comparisons showed that the amplitude difference between the first and the second harmonic in the following vowel is comparable for the fortis stop and the lenis stop, and greatest for the aspirated stop in Seoul dialect.

For the South Kyungsang dialect group, the amplitude differences between the first and the second harmonic at vowel onset showed that the vowel after the fortis stop had a negative *H1-H2* value, which is the smallest value among three stop categories. At the onset of following vowels, the mean value of *H1-H2* by Laryngeal Gesture (across Tonal Contrasts) is -3.52 dB for the fortis stop, 0.87 dB for the lenis stop, and 2.27 dB for the aspirated stop in the South Kyungsang dialect. The results of ANOVA indicated a significant main effect of Laryngeal Gesture (F (2, 6) = 23.059, $p < 0.01$). Bonferroni post hoc comparison showed that *H1-H2* values at vowel onset after the fortis stop were significantly different from *H1-H2* after the lenis and aspirated stop, while the comparison between the lenis stop and the aspirated stop was non-significant ($p = 0.47$). Regarding the tonal effect on *H1-H2*, results of ANOVA showed that there is a main effect of Tonal Contrasts (F (1, 7) = 21.739, $p = 0.002$) in the South Kyungsang Korean but no interaction between Laryngeal Gesture and Tonal Contrasts. A summary of the results is shown in Table 6 and Figure 10.

		Fortis		Lenis		Aspirated	
Seoul		-0.61	(3.02)	0.60	(3.54)	4.88	(3.79)
South Kyungsang	HH	-2.72	(3.11)	1.43	(4.37)	4.06	(4.03)
	LH	-4.33	(3.42)	0.32	(5.74)	0.47	(4.19)
Mean		-2.07	(3.78)	0.74	(4.16)	3.57	(4.94)

Table 6. Average values of *H1-H2* (dB) in Seoul and South Kyungsang dialect groups for three laryngeal gestures (standard deviation in parentheses)

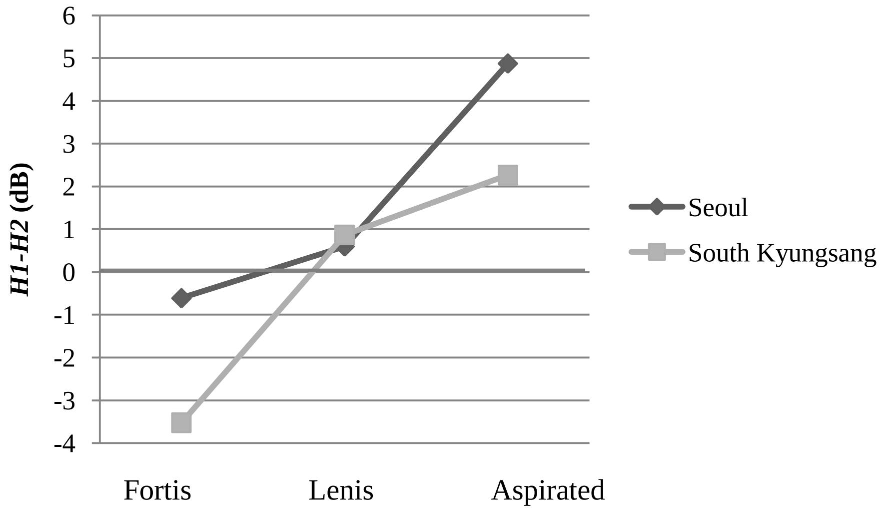


Figure 10. Average value of *H1-H2* (dB) at vowel onset in Seoul and South Kyungsang dialects as a function of Laryngeal Gesture. Data were pooled across tonal contrasts.

Repeated measures ANOVAs (Laryngeal Gesture by Tonal Conatrasts by Dialect) showed a significant main effect of Laryngeal Gesture (F (2, 13) = 31.452, $p < 0.01$) and a main effect of Tonal Contrasts on *H1-H2* (F (1, 14) = 41.09, $p < 0.01$). In addition, there were significant interactions between Laryngeal Gesture and Tonal Contrasts (F (2, 13) = 8.589, $p = 0.004$). However, there was no main effect of Diaelct. In addition, either an interaction effect of Laryngeal Gesture by Dialect or interaction of Tonal Contrasts by Dialect was not found. The *H1-H2* comparison across Dialect showed that *H1-H2* is smallest for the fortis stop, intermediate for the lenis stop, and greatest for the aspirated stop.

Regarding the significant interaction between Laryngeal Gesture and Tonal Contrasts, the unpararell patterns mostly came from the aspirated stop; the vowel after the aspirated stop in High tone condition shows greater *H1-H2* values than that in Low tone condition as indicated in Figure 11.

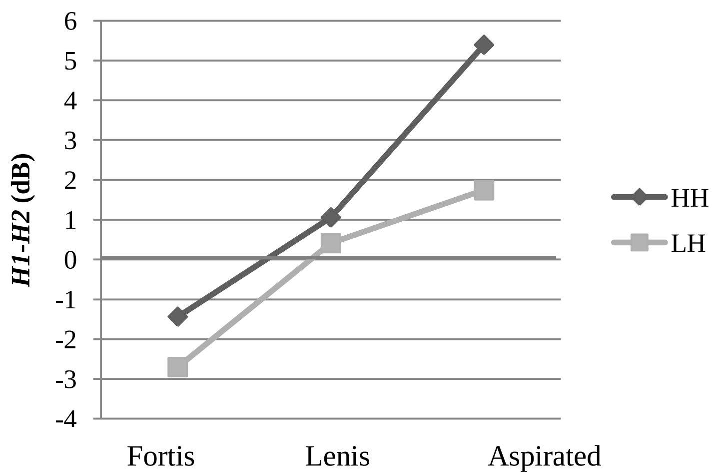


Figure 11. Average value of *H1-H2* (dB) at vowel onset in HH vs. LH tonal contrasts as a function of Laryngeal Gesture. Data were pooled across dialects.

Overall, the vowel after the fortis stop in South Kyungsang dialect shows significantly lower *H1-H2* values than that in Seoul dialect and the vowel after the aspirated stop in Seoul dialect shows significatly greater *H1-H2* values than that in Kyungsang dialect as indicated in Figure 10.

2.2.4. *f0*

In the Seoul dialect, the average *f0* after the lenis stop was always significantly lower than *f0* after the fortis or the aspirated stop, which is true for both vowel positions (onset vs. midpoint). Across vowel positions and tonal contrasts, the mean *f0* after the lenis stop was 116.82 Hz, and 141.97 Hz and 157.05 Hz after the fortis stop and after the aspirated stop, respectively. A repeated measure ANOVA (Laryngeal Gesture by Vowel Position (onset v. midpoint)) was conducted.
Statistical results showed that *f0* was significantly influenced by Laryngeal Gesture (F (2, 6) = 41.941, $p < 0.01$). However, there was no significant effect of Vowel Position (F (1, 7) = 1.222, $p = 0.306$). Bonferroni post hoc comparison showed that the *f0* values by Laryngeal Gesture differ significantly from each other at $p < 0.01$ in the Seoul dialect. Bonferroni post hoc comparison indicated that *f0* for the lenis stop was lowest, intermediate for the fortis stop, and highest for the aspirated stop. Table 7 and Figure 12 show the average value of *f0* in the Seoul dialect. The average value of *f0* at the onset and midpoint of the following vowel are shown separately.

	Vowel Position	**Fortis**		**Lenis**		**Aspirated**	
Seoul	Onset	140.31	(11.58)	116.65	(8.58)	157.40	(15.84)
Seoul	Midpoint	143.64	(12.45)	117.00	(8.54)	156.72	(16.64)
Mean		141.97	(11.82)	116.82	(8.48)	157.05	(16.12)

Table 7. Average values of *f0* (Hz) by Laryngeal Gesture by Vowel Position in Seoul dialect (standard deviation in parentheses)

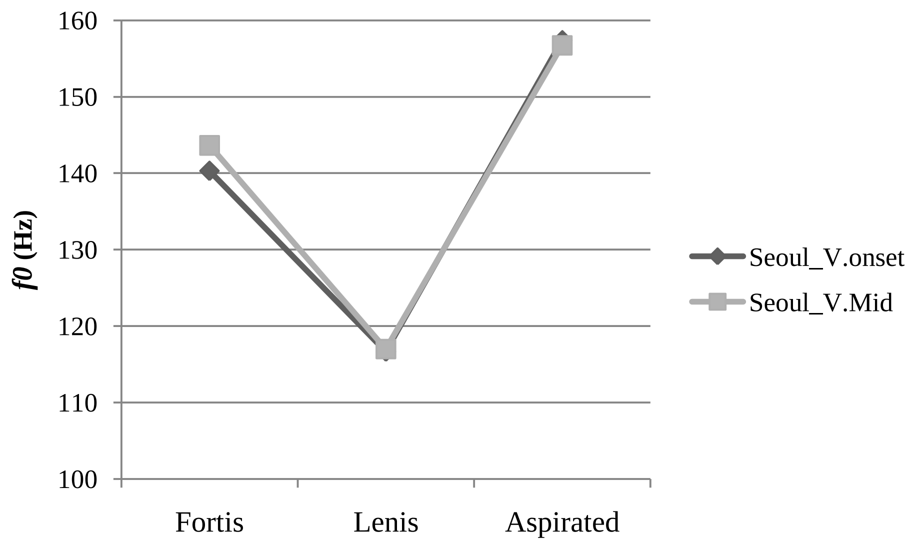


Figure 12. Average values of *f0* (Hz) in the following vowel for Laryngeal Gesture in Seoul dialect. Data shows the average values in different vowel position (onset vs. midpoint).

For the South Kyungsang dialect, the average *f0* was always greater after the aspirated stop than after the fortis or the lenis stop, and this is true for the two tonal contrasts. In addition, the absolute values of the *f0* are always higher in HH tonal contrasts in both vowel positions. Across vowel position and tonal contrasts, the mean *f0* after the lenis stop was 117.61Hz, and 130.10 Hz and 146.12 Hz after the fortis stop and after the aspirated stop, respectively. A repeated measure ANOVA (Laryngeal Gesture by Tonal Contrast (High vs. Low) by Vowel Position (onset v. midpoint)) was conducted.

Statistical results indicated that *f0* was significantly influenced by Laryngeal Gesture (F (2, 6) = 147.32, $p < 0.01$), and also by Tonal Contrast (F (1, 7) = 58.65, $p < 0.01$), but not by Vowel Position (F (1, 7) = 0.018, $p = 0.898$) . Since different tonal contrasts (HH vs. LH) have an influence on *f0* in South Kyungsang dialect Korean, the following-up comparisons were conducted separately for the two tonal contrasts at vowel onset position. First, in the HH tonal condition at vowel onset, Bonferroni post hoc comparison showed that the *f0* values by Laryngeal Gesture differ significantly from each other in South Kyungsang dialect at $p < 0.05$, except for the *f0* comparison between the fortis and lenis stop at $p = 0.10$. The second set of comparisons was made in LH tonal condition at vowel onset, and it reported that the *f0* is significantly different among three laryngeal gestures at $p < 0.05$. Bonferroni post hoc comparison indicated that *f0* for the aspirated stop is greater than the other two categories in both High and Low tonal conditions, but the comparison between the fortis and lenis stop was comparable in HH tonal contrasts. Table 8 and Figure 13 show the average value of *f0* in South Kyungsang dialect Korean by HH vs. LH tonal contrasts. The average values of *f0* at the onset and midpoint of the following vowel are shown separately.

	Vowel Position	**Fortis**		**Lenis**		**Aspirated**	
S.Kyungsang(HH)	Onset	135.56	(26.92)	122.19	(18.22)	155.96	(19.69)
S.Kyungsang (LH)		123.63	(24.92)	110.85	(15.43)	139.94	(18.29)
S.Kyungsang(HH)	Midpoint	137.04	(24.07)	126.96	(19.58)	153.31	(22.46)
S.Kyungsang(LH)		124.19	(19.20)	110.46	(15.29)	135.27	(18.59)
Total Mean		130.10	(23.39)	117.61	(16.87)	146.12	(19.49)

Table 8. Average values of *f0* (Hz) by Laryngeal Gesture by Tonal Contrast by Vowel Position in South Kyungsang dialect (standard deviation in parentheses)

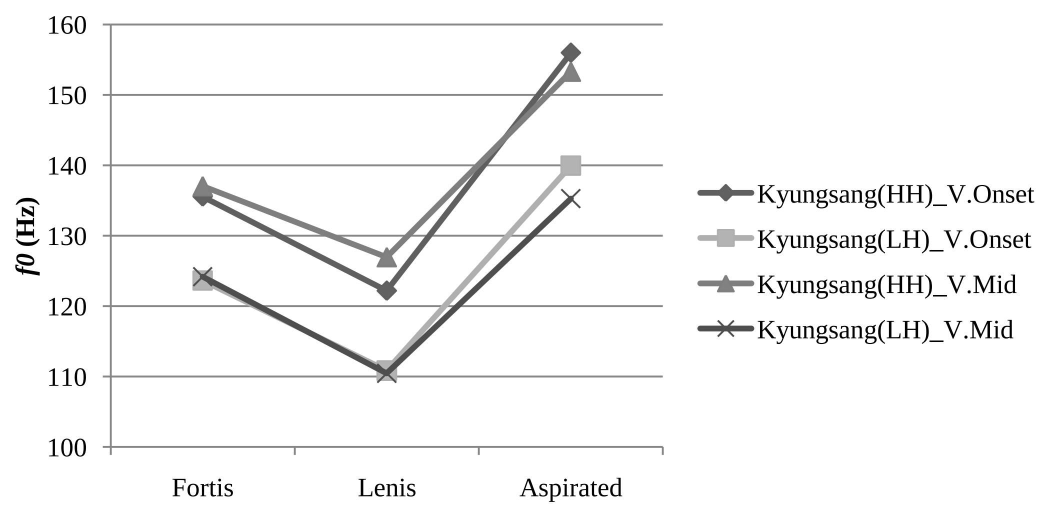
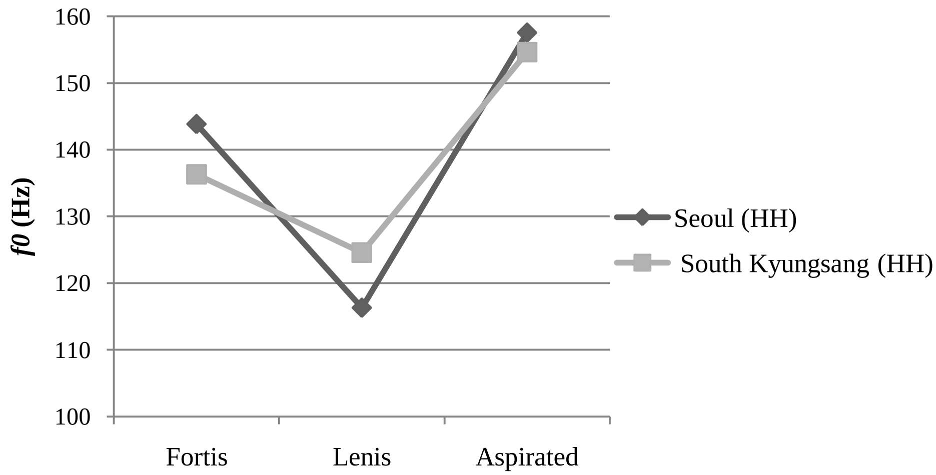


Figure 13. Average values of *f0* (Hz) in the following vowel for Laryngeal Gesture in South Kyungsang dialect. Data shows the average values in different vowel positions (onset vs. midpoint) and tonal distinction (HH vs. LH).

Since the statistical results indicated a main effect of tonal contrasts for South Kyungsang dialect, the comparisons between the two dialects were made in two tonal conditions, and data were pooled across vowel position. Table 9 and Figure 14 show the comparison between the two dialects.

Dialect	**Tone**	**Fortis**	**Mean**	**Lenis**	**Mean**	**Aspirated**	**Mean**
Seoul	HH	143.85	141.97	116.30	116.82	157.56	157.06
Seoul	LH	140.09		117.34		156.55	
S. Kyungsang	HH	136.30	130.10	124.57	117.61	154.64	146.12
S. Kyungsang	LH	123.91		110.56		137.60	
Total Mean		136.04		117.22		151.59	

Table 9. Average values of *f0* (Hz) by Laryngeal Gesture by Tonal Contrast in Seoul and South Kyungsang dialects across Vowel Position.



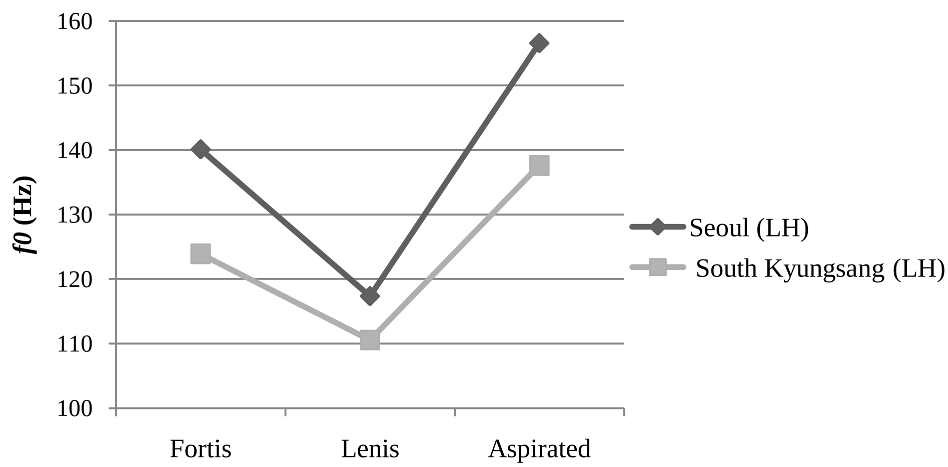


Figure 14. Average value of *f0* in Seoul and South Kyungsang dialect groups by Laryngeal Gesture in HH(upper) and LH(lower) tonal condition. Data were pooled across vowel positions (Hz)

A repeated measure ANOVA (Laryngeal Gesture by Tonal Contrast by Dialect) showed a main effect of Laryngeal Gesture (F (2, 13) = 71.106, $p < 0.01$), a main effect of Tonal Contrast (F (1, 14) = 36.061, $p < 0.01$) on *f0*, but no main effect of Dialect. In addition, there is a significant interaction between Dialect and Laryngeal Gesture (F (2, 13) = 4.223, $p = 0.039$), as well as an interaction between Tonal Contrast and Dialect (F (1, 14) = 35.147, $p < 0.01$) (see Figure 15). In both HH and LH conditions,the Seoul dialect showed the larger *f0* difference among three layngeal gestures than that in the

South Kyungsang dialect. For the interaction between Tonal Contrast and Dialect, while the *f0* values in the South Kyungsang dialect show distinctive tonal pattern, the *f0* values in the Seoul dialect do not.

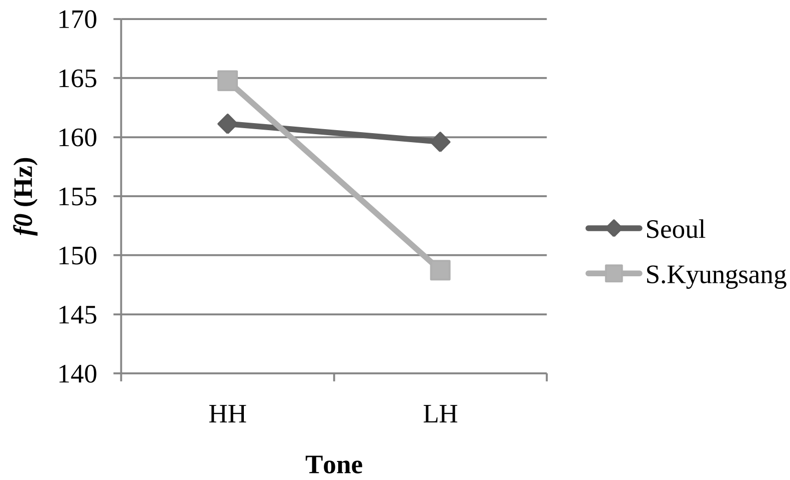


Figure 15. Interaction between Tonal Contrast and Dialect

2.3. Results of Aerodynamic Study

2.3.1. Intraoral Airflow (Uo)

For the Seoul dialect speakers, the oral airflow was significantly influenced by Laryngeal Gesture (F (2, 6) = 57.896, $p < 0.01$). Table 10 and Figure 16 show the summary of the results on the airflow rate regarding the comparison of two dialects across the tonal contrasts. Bonferroni post hoc comparison showed that the airflow rates were significantly different among the three laryngeal gestures at $p < 0.01$. The maximum intraoral airflow rate is lowest for the fortis stop, intermediate for the lenis stop, and greatest for the aspirated stop in Seoul dialect group.

In the South Kyungsang dialect group, the oral airflow was significantly influenced by Laryngeal Gesture (F (2, 6) = 23.606, $p < 0.01$), but there was no effect of Tonal Contrasts. Bonferroni post hoc comparison showed that the airflow rates were significantly different among the three laryngeal gestures at $p < 0.01$ except for the comparison between the fortis and lenis stop ($p = 0.13$). The maximum intraoral airflow rate is comparable for the fortis and the lenis stop, and greatest for the aspirated stop in the South Kyungsang dialect.

	Fortis		Lenis		Aspirated	
Seoul	1.11	(0.46)	2.18	(0.64)	2.87	(0.50)
South Kyungsang	0.65	(0.27)	1.02	(0.57)	1.96	(0.74)
Mean	0.84	(0.43)	1.60	(0.84)	2.42	(0.77)

Table 10. Average of maximum intraoral airflow (l/sec) in Seoul and South Kyungsang dialect groups by three laryngeal gestures (standard deviation in parentheses). Data were pooled across Tonal Contrast.

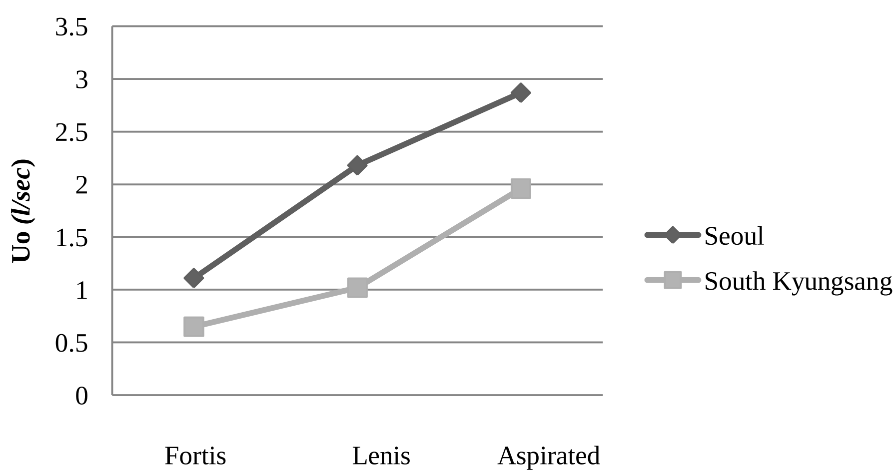


Figure 16. Comparison of the maximum intraoral airflow rates (l/sec) in Seoul and South Kyungsang dialect groups by three laryngeal gestures. Data were pooled across Tonal Contrast.

A repeated measure ANOVA (Laryngeal Gesture by Dialect) showed a significant main effect of Laryngeal Gesture (F (2, 13) = 68.473, $p < 0.01$) on the intraoral airflow (Uo). There was also a main effect of Dialect (F (1,14) = 9.856, $p = 0.007$). In addition, there was a significant interaction of Laryngeal Gesture by Dialect (F (2, 13) = 5.77, $p = 0.016$), indicating the greater difference between the dialects for the lenis stop as compared to other stop categories . Bonferroni post hoc comparison showed that the airflow rates for the three Laryngeal Gestures differ significantly among the three laryngeal gestures at $p < 0.01$across dialects. Statistical results indicated that the intraoral airflow (Uo) is lowest for the fortis stop, intermediate for the lenis stop, and greatest for the aspirated stop across dialects.

2.3.2. Intraoral Air Pressure (Po)

For the Seoul dialect speakers, the oral air pressure was significantly influenced by Laryngeal Gesture (F (2, 6) = 82.756, $p < 0.01$). Bonferroni post hoc comparison showed that the air pressure was significantly different between the fortis and the lenis stop at $p < 0.01$. However, the comparison between the lenis and aspirated stop was not statistically significant at $p = 0.20$, and the comparison between the fortis and aspirated stop was non-significant at $p = 1.0$. Statistical results indicated that the maximum intraoral air pressure is lowest for the lenis stop but comparable values for the fortis and aspirated stops in Seoul dialect group.

Since one of the Kyungsang speakers had difficulty producing the stimuli holding a tube, data from only seven of the South Kyungsang speakers were included in statistical analysis for intraoral air pressure. In the South Kyungsang dialect group, there was neither main effect of Laryngeal Gesture (F (2, 5) = 2.318, $p = 0.194$) nor a main effect of Tonal Contrast (F (1, 6) = 0.344, $p = 0.579$). Table 11 and Figure 17 show the summary of the results on the air pressure regarding the comparison of two dialects across the tonal contrasts.

	Fortis		Lenis		Aspirated	
Seoul	8.54	(1.67)	6.89	(1.30)	8.42	(2.27)
South Kyungsang	9.85	(2.39)	8.40	(1.71)	8.45	(2.73)
Mean	9.15	(2.11)	7.60	(1.67)	8.43	(2.45)

Table 11. Average of maximum intraoral air pressure (cm H_2O) and Standard Deviation in Seoul and South Kyungsang dialect groups by three laryngeal gestures (standard deviation in parentheses). Data were pooled across Tonal Contrast.

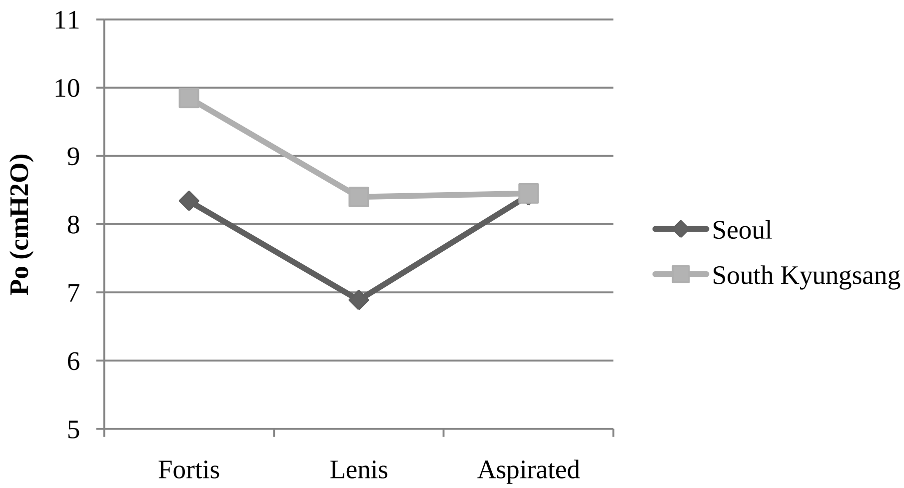


Figure 17. Comparison of the maximum intraoral air pressure rates (cm H_2O) in Seoul and South Kyungsang dialect groups by three laryngeal gestures. Data were pooled across Tonal Contrast.

A repeated measure ANOVA (Laryngeal Gesture by Dialect) showed that a main effect of Laryngeal Gesature (F (2, 12) = 14.32, $p < 0.001$), but neither a main effect of Dialect nor an interaction between Laryngeal Gesture and Dialect. Bonferroni post hoc comparison showed that the air pressure rates for the three Laryngeal Gestures differ significantly only between the fortis and lenis at $p < 0.01$ across dialects and the other comparison was not statistically significant. Statistical results indicated that the intraoral air pressure (Po) is lowest for the lenis stop and comparable for the fortis and the aspirated stop.

2.4. Summary of Results

The main findings of the current study will be briefly summarized in this section. In general, the present study not only replicated the previous findings, but also reported several new findings regarding the dialectal variation. As for the tonal verification in South Kyungsang dialect, the *f0* differences between HH and LH in South Kyungsang Korean were greater than those of Seoul standard Korean, and hence the tonal differences in South Kyungsang dialect Korean have an influence on the *f0* as an acoustic cue for Korean obstruents. Statistical reports revealed a significant effect of Dialect on the acoustic properties: the significant effect of Dialect is on *f0* differences between HH and LH, and on the intraoral airflow (Uo). In addition, there were significant interactions between the two Dialects by Laryngeal Gesture for VOT, *f0*, and the intraoral airflow (Uo). More specifically, the *f0* differences between HH and LH tonal contrasts measured at the following vowel onset and midpoint in the two dialects were greater in the South Kyungsang dialect. The differences were more distinctive at the midpoint of the following vowel. Consequently, this result supports the existence of a lexical pitch accent in South Kyungsang Korean. VOT is significantly different from each other among three laryngeal gestures and the pattern of VOT variation was the same in the two dialects: VOT is shortest for the fortis, intermediate for the lenis, and greatest for the aspirated stop in both dialects. However, statistical analysis showed that Seoul dialect speakers had a longer VOT in the lenis stop than Kyungsang speakers; but South Kyungsang speakers had a longer VOT in the aspirated stop than Seoul speakers.

The amplitude differences between the first and the second harmonic (*H1-H2*) also showed a similar pattern in the two dialects. However, following-up comparison reported a non-significant difference between the fortis and lenis stop in Seoul dialect, and the comparison between the lenis and aspirated stop in South Kyungsang Korean was not significantly different from each other.

As for the fundamental frequency property in the three-way distinction of Korean stops, statistical analysis reported that there was a significant main effect of Laryngeal Gesture for both dialects. However, the main effect of Tonal Contrast was only in the South Kyungsang dialect. *f0* is significantly different among the three-way distinction of stops, with *f0* being highest for the aspirated stop, intermediate for the fortis stop, and lowest for the lenis stop only in the Seoul dialect. At vowel onset position, *f0* in the Kyungsang dialect showed overlap patterns between the fortis and lenis stop in HH tonal condition.

In the aerodynamic study, ANOVAs indicated a significant effect of Dialect and Laryngeal Gesture on intraoral airflow (Uo). Post hoc comparison reports that the airflow rate is lowest for the fortis, intermediate for the lenis, and greatest for the aspirated stops only in the Seoul dialect, but overlap between the fortis and lenis stop in the South Kyungsang dialect. Oral airflow rates tend to be greater in Seoul Korean in all three stop categories, and particularly Seoul speakers had greater airflow in the lenis stop than South Kyungsang speakers. Regarding the intraoral air pressure (Po), the air pressure rates pattern differently in the two dialects; the intraoral air pressure (Po) is lower in the lenis stop than in the fortis or aspirated stops in the Seoul dialect, but the air pressure rate in the South Kyungsang dialect is not significant among three laryngeal gestures. A more specific discussion of these findings will be provided in the next chapter.

CHAPTER 3 DISCUSSION AND CONCLUSION

3.1. Discussion

The purpose of this study was to compare the acoustic cues to the three-way Korean stop distinction in two dialects which differ in their tonal system. The results reported in the present study indicate that although the two dialects share the lexical items and have the three-way laryngeal distinction, the different tonal systems between the dialects have an influence on the phonological contrasts. In this section, the present study will further discuss the main findings from the acoustic and aerodynamic studies.

First, this study verified the High and Low tonal contrast in South Kyungsang dialect. The comparison of *f0* differences between the HH and LH tones in the same stop category were compared in both dialects indicates the boosted tonal distinction at the midpoint of the following vowel as well as the basic H vs. L tonal contrast in the South Kyungsang dialect. These results are consistent with Kenstowicz and Park's (2006) observation in some sense. Kenstowicz and Park (2006) investigated the effect of initial obstruent voicing on the following vowel by measuring the *f0* values at both vowel onset and midpoint in Kyungsang dialects. They concluded that the effect of voicing on *f0* is significant not only at vowel onset but also at the midpoint of the vowel, though the difference is smaller at the vowel midpoint. However, in the comparison of the H vs. L tonal contrast itself, the researchers reported a greater tonal contrast regardless of the voicing of the preceding consonant at vowel midpoint, while average *f0* values of vowels following H tone voiced and L tone voiceless obstruents overlapped. Therefore, the comparison of the *f0* differences between the H and L tone in two Korean dialects in the current study supports that South Kyungsang Korean indeed preserves the lexical pitch accent contrast, and that the tonal contrast becomes clearer at the middle of the vowel.

Second, this result leads us to test the research questions about the *f0* deployment in the Seoul and South Kyungsang Korean; that is, how the *f0* variation (Lenis < Fortis < Aspirated) in Seoul Korean would be different from *f0* in South Kyungsang dialect depending on H and L tone, and how the *f0* variation in South Kyungsang dialect differs as a function of the vowel position in two different tonal contrasts, compared to *f0* in Seoul Korean. Since the vowel properties (e.g., *f0*, *H1-H2*) have been proposed as primary acoustic cues for Korean stops (e.g., Han and Weitzman, 1970; Kim, 1970; Cho, 1996; Cho *et al*. 2002), if the tonal contrasts overlay the laryngeal distinction in South Kyungsang dialect, we might expect secondary acoustic cues other than *f0* in the South Kyungsang Korean.
The current study shows a statistically significant main effect of laryngeal gesture on *f0* in both the Seoul and South Kyungsang dialectal groups in HH and LH tonal contrasts. For the Seoul dialect, the *f0* patterns are in accordance with previous reports: lowest for the lenis, intermediate for the fortis and greatest for the aspirated stop, and this is true for both vowel positions, suggesting that the laryngeal specification of the consonant continues well into the following vowel in non-tonal Seoul Korean. Consequently, the current study supports the recent findings by Cho *et al*. (2002) and Kang and Guion (2008) which reported *f0* values from low to high in the order of the lenis, fortis and the aspirated stop in the Seoul Korean.

In the South Kyungsang dialect, two aspects, laryngeal gestures and the effect of tone on *f0* are noteworthy. As mentioned in section 2.2.4., the statistical results indicate significant main effects of laryngeal gestures and tonal contrasts on *f0* in South Kyungsang dialect. However, the follow-up comparisons reported that *f0* is not significantly different between the fortis and lenis stop for HH tonal condition at vowel onset. These statistical results also lead us to assume the overlapped *f0* values in the comparison across two tonal conditions. Accordingly, to test hypothesis (5): The *f0* properties in the Korean stop will be ambiguous in the Kyungsang dialect, particularly between *f0* for the L tone fortis stop and the H tone lenis stop, a comparison was made across tonal contrasts to see how well *f0* alone can distinguish the three laryngeal gestures in different tonal conditions. Since previous studies have proposed the *f0* values as a primary acoustic cue to distinguish the lenis stop from the other two stop categories (e.g., C.-W. Kim 1965; Han and Weitzman 1970; Cho 1996; Cho *et al*. 2002), the current study compares the H tone lenis stop to the L tone fortis or to L tone aspirated stop, expecting ambiguous differences between two categories . Figure 18 shows the *f0* distribution depending on the three laryngeal gestures and two tonal conditions in the Seoul and South Kyungsang dialects.

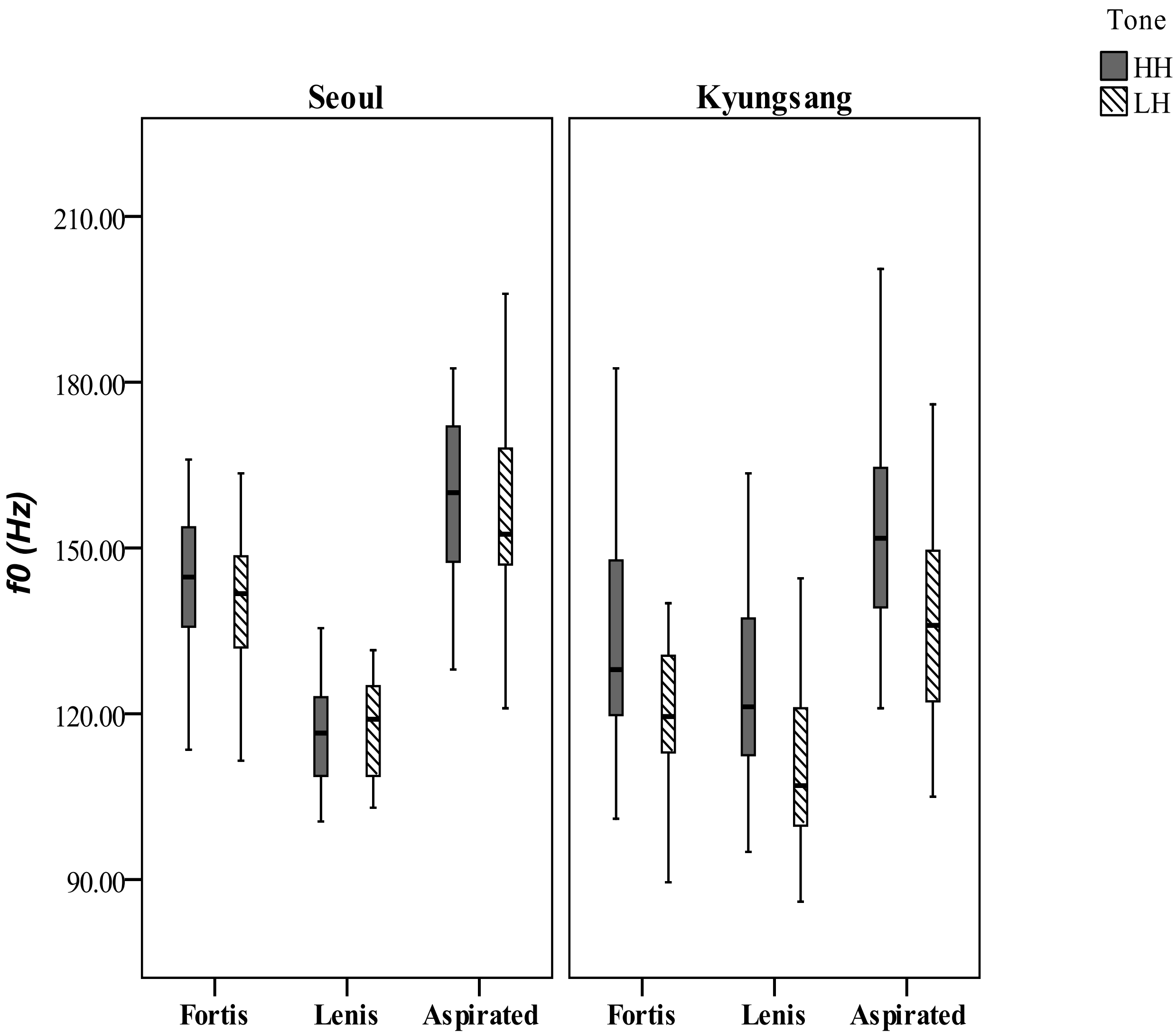


Figure 18. *f0* distribution (Hz) for Seoul and South Kyungsang dialect in the two tonal contrasts. Data were pooled across Vowel Position.

In Figure 18, we can identify that the *f0* distribution in Kyungsang dialect shows significantly overlapped interquartile ranges among all three laryngeal gestures across tonal conditions. Comparatively, the *f0* distribution in the Seoul dialect shows more spread interquartile ranges for the fortis and lenis stop, patterning the *f0* values in the order of 'Lenis < Fortis < Aspirated' in all tonal conditions.

To obtain statistically meaningful results, the current study conducted a paired sample t-test for the H tone lenis and the L tone fortis and aspirated stops and for the H tone fortis and L tone aspirated stops in the South Kyungsang data. Statistical results showed that *f0* for the L tone fortis and the H tone lenis stops and *f0* for the H tone fortis and the L tone aspirated stop are non-significantly different at $p = 1.00$ and at $p = 1.00$ respectively, while the comparison between the H tone lenis and L tone aspirated stop was significant ($p = 0.003$). These statistical reports suggest that unlike Seoul dialect, in which *f0* is significantly different among three laryngeal gestures, *f0* is not a sufficient acoustic cue for South Kyungsang dialect speakers to distinguish three Korean stop contrasts. As an attempt to provide more concrete evidence about how much each dialectal group relies on *f0* as a single predictor, the current study conducts the discriminant analysis. This further statistical analysis lets us know that only with *f0* property how well three laryngeal gestures can be classified. It reports that for the Seoul dialect, *f0* can be a single predictor with 77% classification accuracy rate, but for the South Kyungsang, it is only 54%. This confirms that *f0* is a better predictor for categorizing the three laryngeal gestures for the non-tonal Seoul dialect speakers than for the tonal Kyungsang speakers. Consequently, in support of hypotheses (4) and (5), the use of High and Low tonal contrasts of South Kyungsang speakers causes the dissimilar patterns of *f0* in the two dialects and the *f0* use for tonal distinctions makes *f0* an unreliable acoustic cue for three Korean obstruents.

As an attempt to test hypothesis (6): The *f0* variation of the three stop categories will be more distinct at the onset of the following vowel than at the vowel midpoint. Conversely, the *f0* distinction by three laryngeal gestures will be less clear at the midpoint of the following vowel in the South Kyungsang dialect; the current study examined the *f0* variation at two vowel positions for the South Kyungsang dialect. Previous studies (e.g., Cho *et al*.2002; Kenstowicz and Park 2006) have reported that the *f0* effect by laryngeal gestures is significant at the vowel midpoint as well as at vowel onset, which suggests that the consonant effect continues to deep inside the syllable (Kenstowicz and Park 2006, p.8). However, these previous studies have reported slightly higher values of *f0* at vowel onset compared to vowel midpoint, though the effect of *f0* is significant at both vowel positions. Therefore, the current study might expect that the overlap *f0* at vowel onset (*cf*. between the fortis and lenis stop) would continue to the midpoint of the following vowel and the overlap would even worse at the midpoint of vowel in South Kyungsang dialect due to slightly lower *f0* differences. Figure 19 shows the averaged *f0* values in two tonal conditions at two vowel positions.

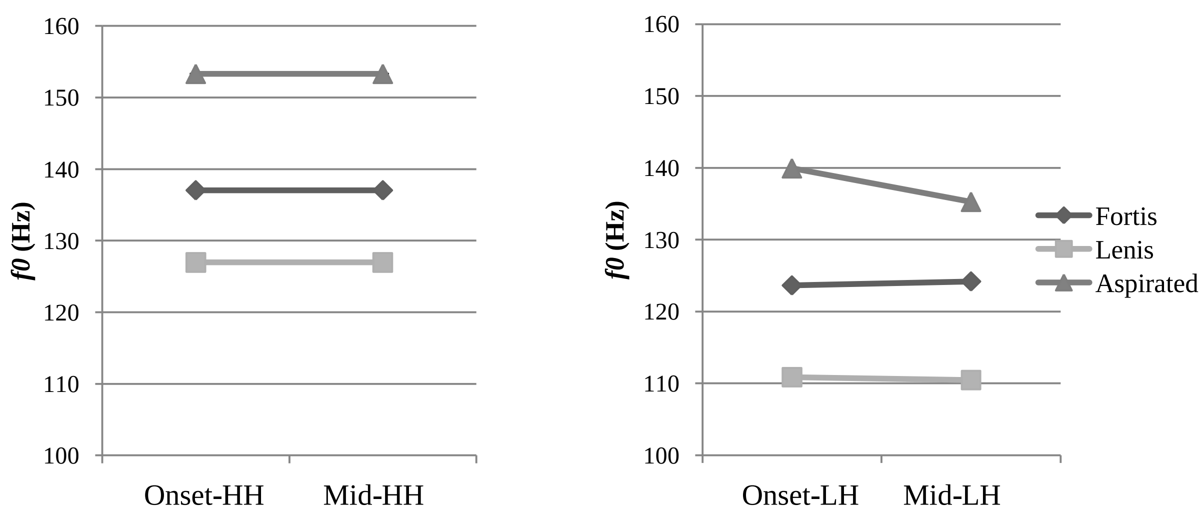


Figure 19. Average *f0* values by vowel positions and laryngeal gestures in HH and LH tonal conditions in South Kyungsang dialect

To test hypothesis (6), Bonferroni post hoc comparison is conducted at vowel midpoint. It reports that the *f0* values by Laryngeal Gesture differ significantly from each other at $p < 0.05$ in the HH tonal condition at vowel midpoint. The comparisons made in LH tonal condition at vowel midpoint report that the *f0* values of the three Laryngeal Gestures are significantly different from each other ($p < 0.05$). Unlike at the vowel onset position, the result shows distinctive *f0* variation at vowel midpoint in HH tonal condition. In LH condition, there was no overlap in both vowel onset and midpoint. Based on these reports, we can further discuss that although the *f0* distinction in South Kyungsang dialect is not clear at vowel onset, the non-clear distinction of *f0* does not become worse at vowel midpoint.

Third, to investigate the consonant durational property, the present study measured the VOT duration in Seoul and South Kyungsang Korean. Moreover, since *f0* turns out to be an unreliable acoustic cue for South Kyungsang speakers, the current study expects that the durational property might be a primary cue to distinguish three laryngeal gestures for Kyungsang dialect. The experimental results showed that VOT is shortest for the fortis, intermediate for the lenis and longest for the aspirated stop in both dialects. However, as Figure 21 shows, we can see that VOT distribution patterns differently for the two dialects, although statistical results reported main effect of Laryngeal Gesture in the two dialects.

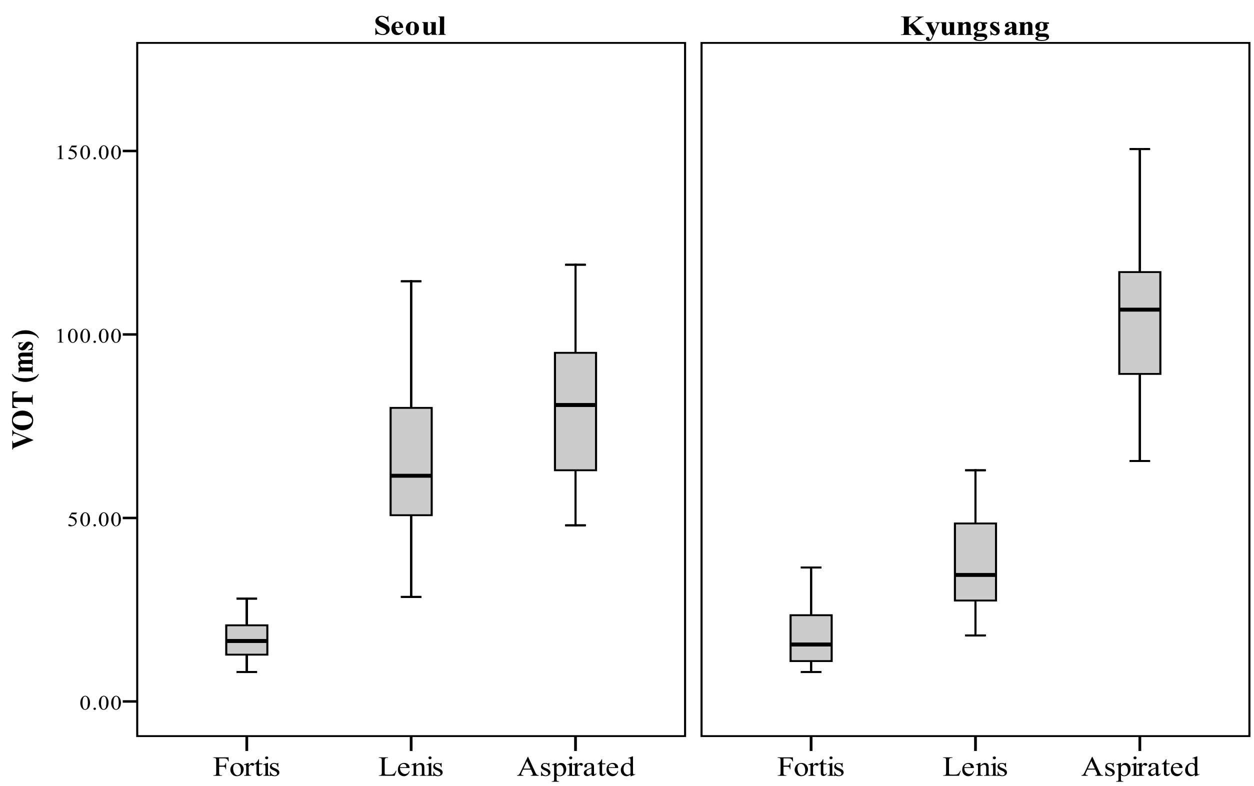


Figure 20. VOT distribution for Seoul and South Kyungsang Korean

In Figure 21, we can identify that the interquartile ranges are significantly overlapped between the lenis and aspirated stop for Seoul dialect, while the VOT distribution for South Kyungsang dialect is well separated. By conducting discriminant analysis, the current study tries to figure out how much each dialectal group relies on VOT as a single predictor. It reports that for the Seoul dialect, VOT can be a single predictor only with 71.5% classification accuracy rate, but for the South Kyungsang, it is 83%. This suggests that compared to Seoul speakers, VOT is a stronger predictor for categorizing three laryngeal gestures for South Kyungsang dialect speakers who do not primarily rely on *f0* to distinguish three stops.

The interesting assertion on VOT had been made by Silva (2006). Silva (2006) has proposed that VOT differences between the lenis and aspirated stop have decreased over the past 50 years, and suggested age variation as an explanation for the VOT pattern in Seoul Korean. The results in the current study support Silva's (2006) argument on the historical transition, confirming that the younger Seoul speakers are more likely to minimize the VOT differences between the lenis and aspirated stop. This notion becomes clearer as compared with the Cho *et al.* (2002) study. Table 12 shows the previously reported VOT duration including Cho *et al*.'s (2002) measurement for Seoul and Cheju speakers and the duration measured in the current study.

		Fortis	Lenis	Aspirated
Cho *et al*. 2002	Seoul	20	70	120
	Cheju	20	45	105
Kenstowicz *et al*. 2006	Kyungsang	22	50	81
Current Study	Seoul	17	65	80
	Kyungsang	18	38	104

Table 12. Comparison of VOT duration (ms) reported by Cho *et al*. 2002, Kenstowicz and Park, 2006 and the current study.

While the VOT values for the fortis and lenis stop for the Seoul dialect in the present study are comparable to the values in Cho *et al*.'s (2002) study, the average value for the aspirated stop is smaller than that in Cho *et al*.'s (2002) study. The notion that older speakers are more likely to maintain a clear distinction between the lenis and aspirated stop can be evaluated by comparing the VOT values and speakers' age between Cho *et al*.'s (2002) study and the current study: Seoul speakers in Cho *et al*. (2002) were in their late 50s and early 60s while the mean age of Seoul speakers in the present study is 27.6 years old. In addition, Kenstowicz and Park (2006) explained that their smaller values for the aspirated stop compared to those in Cho *et al*.'s (2002) study might be due to differences in context in the two studies. The stimuli in Cho *et al*. (2002) were words in isolation while Kenstowicz and Park (2006) used words in sentential frames. However, the explanation by Kenstowicz and Park (2006) needs to be complemented with the age variation: the Kyungsang speakers in Kenstowicz and Park (2006) were in their mid twenties and mid forties.

Along with the age variation, it is noteworthy to consider the dialectal variation; particularly for the VOT distribution pattern and the great difference in the lenis stop in the two dialects. As mentioned earlier, the present study reports well-separated VOT ranges for the South Kyungsang speakers, compared to VOT ranges for the Seoul speakers. In addition, the discriminant analysis revealed that VOT is a better cue for Kyungsang speakers (classification accuracy: 83%) than for Seoul (classification accuracy: 72%). In other words, the VOT difference is more reliable acoustic cue for the South Kyungsang speakers than *f0*, particularly to distinguish the lenis stop from the aspirated stop; the VOT difference between the aspirated stop and the lenis stop is 66.24 ms for South Kyungsang Korean, and 15.01ms for Seoul Korean respectively. The experimental results suggest that VOT duration signals the three laryngeal gestures well, and these well-separated VOT ranges can complement the overlap in *f0* range for the Kyungsang speakers. In other words, Kyungsang speakers primarily use VOT to distinguish three laryngeal gestures. Choi (2002) has also proposed a complementary way to mark three stop categories between two dialects which differ in their intonation systems, namely Seoul and Chonnam Korean; Chonnam dialects have a consistent and salient phrase-initial rising intonational contour while Seoul dialect does not, but typically realized phrase-finally (Choi 2002, p5). Choi (2002) reasoned that the different intonation systems caused different ways of using VOT and *f0* as acoustic cues in two dialects (see section 1.2. for more discussion). Another dialect difference is the VOT duration of the lenis stop. The present comparison between dialects reported 27.01 ms longer values for Seoul dialect, which is also true for the Seoul and

Cheju dialect in Cho *et al*.'s (2002) study (25ms longer for Seoul dialect). Cho *et al.* (2002) have commented that the shorter duration of VOT for the Cheju dialect is due to the conservatism of the Cheju people. In other words, the conservatism might prevent Cheju people who are isolated from mainland Korea from going through the diachronic change of a longer VOT for the lenis stop. Nevertheless, it seems difficult to explain why there is a difference in VOT for the lenis stop between Seoul and South Kyungsang dialects in the current study. Since the procedure in this study was exactly the same for both dialectal groups, the regional difference may be a possible explanation, that is, it is simply because the Kyungsang dialectal region may be more conservative for the historical transition than Seoul region where the diachronic change is active.

Fourth, this study investigated the phonation type for Korean stops by measuring the amplitude differences between the first harmonic (*H1*) and the second harmonic (*H2*) in the following vowel. The result revealed that *H1-H2* in the following vowel is always greater in the aspirated stop than in the fortis stop, while the comparison between the fortis and the lenis stop in Seoul dialect or the comparison between the lenis and the aspirated stop in the South Kyungsang dialect are not significant. This indicates that the vowel following the aspirated stop is breathier than the vowel following any other stop categories. In contrast, the vowel after the fortis stop has creakier voice than the others (Han and Weitzman, 1970; Blankenship, 2002; Cho *et al.*, 2002; Kang and Guion, 2008). For the acoustic results of *H1-H2*, several aspects are noteworthy; the effect of tone on *H1-H2* in the two dialects, the individual variation and the inconsistent findings across studies on *H1-H2*. Statistical reports revealed a significant effect of tone on *H1-H2* in South Kyungsang dialect and Seoul dialect (see Figure11 in section 2.2.3).

As shown in Figure 11 (p. 33), the pattern of *H1-H2* is different depending on the tonal condition. Specifically, *H1–H2* in the HH tonal condition consistently shows larger *H1–H2* values than *H1–H2* in LH condition, and the *H1–H2* differences between the lenis and the aspirated stops are not distinctive in the LH tonal condition. This unclear distinction is statistically confirmed: paired sample t-test reported that *H1-H2* is not significantly different between the lenis and aspirated stop in LH condition in the two dialects (p = 1.0) and in HH condition Seoul dialect group did not show significant difference between the fortis and the lenis stop (p = 1.0).

To see how well the phonation types can distinguish the Korean stop for each speaker and to what extent the speakers are dependent on the phonation type as an acoustic cue, the present study considers speaker differences. Figure 22 shows the *H1-H2* difference for each speaker. Since both Seoul and Kyungsang dialects revealed significant effect of tonal contrasts, the *H1-H2* difference is shown by laryngeal gestures and the tonal conditions. In Figure 22, we can see the inconsistent *H1-H2* values across speakers in both dialects. As regarding Seoul speakers, we can identify that only three of the Seoul speakers (e.g. SK 5,6) show the average *H1-H2* pattern (Fortis < Lenis < Aspirated) with clear distinction, and *H1-H2* for the rest of the speakers patterns dissimilarly. In general, Seoul speakers have large *H1-H2* values for the vowel after the aspirated stop. As for the South Kyungsang speakers, we can also see the inconsistent pattern of *H1-H2* for each speaker, and this is more obvious in the LH tonal condition.

Cho *et al.* (2002) discussed that despite the individual variation in *H1-H2*, which was possibly caused by speakers' paralinguistic differences, the *H1-H2* for the lenis stop always shows larger values than the others; based on this, the researchers have suggested that speakers linguistically control the voice quality to make a distinction at least between the fortis and the lenis stop. (*cf*. Cho *et al*. (2002) reported the *H1-H2* pattern of 'Fortis < Aspirated < Lenis'). Although the speaker variability in the current study makes it difficult to generalize the *H1-H2* property as a primary acoustic cue for the three-way distinction of Korean stops, most of the Seoul speakers seem to use the breathiness of the aspirated stop as a secondary acoustic cue to differentiate the aspirated stop from the other stop categories. However, considering dialectal variation, this argument seems true only for some of South Kyungsang speakers because the breathiness of the aspirated stop is not clear compared to that of the lenis stop especially in LH tonal condition.

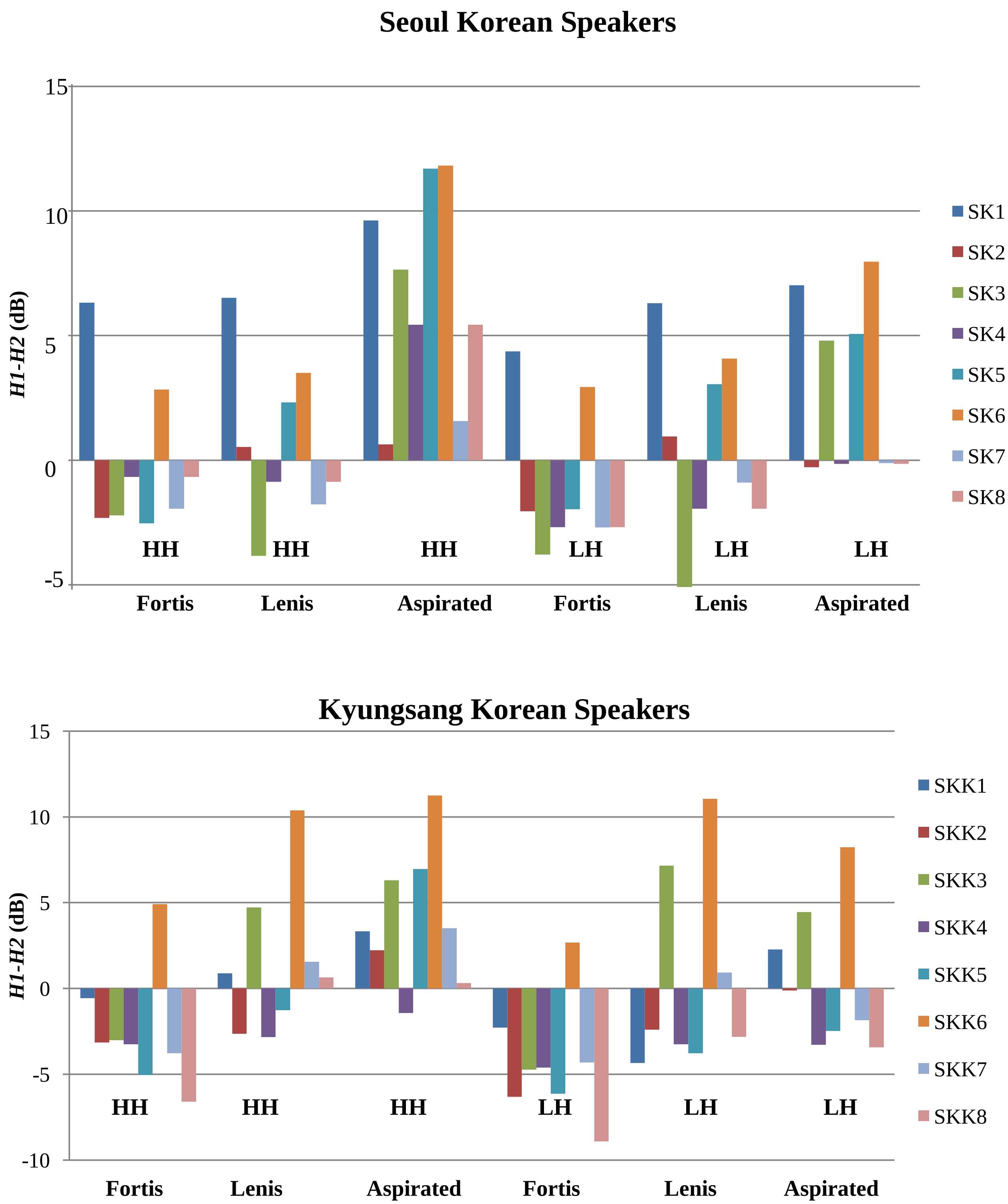


Figure 21. Difference between the first harmonic and the second harmonic (*H1-H2*) at vowel onset for each Seoul (SK) and South Kyungsang Korean speaker (SKK). Figure shows the *H1-H2* values by laryngeal gestures and tonal condition.

The inconsistent *H1-H2* findings across several studies also require discussion. Table 13 shows the *H1-H2* patterns documented in previous studies.

Study	Dialect	*H1-H2* Pattern
Cho *et al*. 2002	Seoul	Fortis < Aspirated < Lenis
	Cheju	Fortis < Aspirated < Lenis
Kenstowicz *et al*. 2006	Kyungsang	Fortis < Aspirated < Lenis
Ahn. 1999	Seoul	Fortis < Lenis ≤ Aspirated
Kang and Guion. 2008	Seoul	Fortis < Lenis < Aspirated
Current Study	Seoul	Fortis ≤ Lenis < Aspirated
	Kyungsang	Fortis < Lenis ≤ Aspirated

Table 13. Comparison of *H1-H2* patterns in previous acoustic studies

Several acoustic studies have examined the difference in the voice quality of the vowel after the Korean stop. Nevertheless, we can see the inconsistent pattern of *H1-H2* among these studies. Especially, the difference concerns the *H1-H2* values for the lenis and the aspirated stop, while *H1-H2* after the fortis stop has smallest value in all studies. Cho *et al*. (2002) commented that the different pattern from Ahn's study (1999) could be possibly caused by the difference in speakers' age or procedural differences. However, the influence of age is questionable, since Kang and Guion (2008) reported the same pattern of *H1-H2* in both younger and older groups. Procedural differences may cause these different patterns among studies, or Korean speakers may be dependent on *H1-H2* only to distinguish the fortis stop from others, and rely on other acoustic cues (e.g., VOT, *f0*) to differentiate the lenis from the aspirated stop. The current study conducts discriminant analysis to obtain statistical evidence; it reports that *H1-H2* solely classifies the three distinctions of Korean stops with 47.2% of classification accuracy for Seoul dialect and with 52.1% for South Kyungsang dialect.

To sum up, while *H1-H2* can determine the voice quality at vowel onset as a function of the preceding Korean stop to some extent, the speaker variability, and the inconsistent pattern of *H1-H2* among studies lead us to conclude that both Seoul and Kyungsang do not use the harmonic components primarily to distinguish the Korean stops.

To understand the articulation, in particular the subglottal and supraglottal components during Korean stop production, this study examined aerodynamic properties by measuring the intraoral airflow (Uo) and the intraoral air pressure (Po). Dart (1987) indicated that the flow differences during the production of Korean stops are due to the differences in glottal aperture, and the pressure differences in Korean stops can be caused by differences in subglottal pressure (Ps), vocal tract wall tension, subglottal cavity volume and stop closure duration. The present study revealed the unbalanced patterns between the intraoral air pressure (Po) and airflow (Uo) as a function of the preceding consonant types, which is consistent with previous studies (Dart 1987; Cho *et al*. 2002): the pattern for the airflow is in the order of 'Fortis < Lenis < Aspirated' and the pattern for the air pressure is in the order of 'Lenis ≤ Aspirated = Fortis' in Seoul dialect. Dart (1987) and Cho *et al.* (2002) suggested that the greater air pressure for the fortis stop than for the lenis stop comes from the greater subglottal pressure for the fortis stop, but the great glottal impedance (smaller glottal area), which can also account for the lowest airflow for the fortis stop, might lower the air pressure compared to that of the aspirated stop. In the current study, we identified that the air pressure (Po) comparison between the fortis and aspirated stop was comparable. Based on this, we might assume that regardless of the great glottal impedance for the fortis stop, the great subglottal pressure (Ps), which is even greater than for the aspirated stop, seems to cause the intraoral air pressure (Po) as great as the aspirated stop.

Regarding the effect of dialect on the airflow in the current study, it is interesting to compare this airflow pattern with the VOT pattern in the two dialects. In the current study, the difference in VOT was greatest in the lenis stop between the two dialects, indicating that the VOT for the lenis stop in South Kyungsang dialect (average duration: 38 ms) was significantly lower than that of Seoul dialect (average duration: 65 ms). This potential dialect effect on VOT corresponds to the airflow pattern, which also revealed the greatest airflow differences for the lenis stop between two dialects. Through the aerodynamic model, Dart (1987) suggested that the airflow could be postulated by the glottal area (p.142, 143). Accordingly, the VOT differences, which are caused by the differences in the glottal aperture at stop release, might correspond to the airflow differences (Kagaya 1974). Therefore, with the tendency of the shorter VOT and the lower airflow for the lenis stop in South Kyungsang dialect, we might assume a smaller glottis or more glottal impedance during the lenis stop production for the Kyungsang speakers, compared to Seoul speakers.

For the Seoul dialect speakers, the present results showed a higher oral pressure during the aspirated and the fortis stop than the lenis stop, which might be ultimately caused by the greater subglottal pressure (Ps) due to an increase in the respiratory muscular force (Dart 1987; Cho *et al*. 2002). For the South Kyungsang speakers, however, the intraoral air pressure was not statistically significant among three laryngeal gestures. This suggests several things: in terms of the air pressure (Po), the Korean three obstruents are not distinguished and we might have two possible discussions on this. The first possible assumption is that the subglottal pressure (Ps), the main source of oral air pressure, is not simply distinctive for Kyungsang speakers. The other possible assumption is the ambiguous vocal tract wall tension. As Dart (1987) mentioned, the stiffening of the vocal tract wall might cause the pressure increase (p.143). Therefore, we can assume that if the vocal tract wall tension or the stiffness of the vocal tract, which can be accounted by *f0*, is ambiguous, the oral air pressure might be indistinctive. As seen in section 2.2.4., the *f0* distinction is not significant among three laryngeal gestures in the South Kyungsang dialect. Consequently, although the subglottal air pressure (Ps) in the South Kyungsang dialect is originally distinctive among three laryngeal gestures, the ambiguous stiffness of the vocal tract, presumably caused by the tonal distinction, causes the unclear oral air pressure rate.

Tables 14 and 15 summarize the main findings of the present acoustic and aerodynamic study in the two dialects and show postulated articulatory states based on previous research and the main findings of the current study (C.-W Kim, 1965; Kagaya, 1974; Blankenship, 2002; Childers and Lee, 1991; Kim *et al*., 2005). Based on these findings, the possible phonological representations which can arrange these various phonetic dimensions in the two dialects will be presented in the next section.

	Acoustic outcome	Aerodynamic outcome	Postulated articulatory state
Fortis	Short VOT	Small rate of airflow (Uo)	Small glottal opening (most constricted vocal folds)
	Intermediate *f0*	Great oral pressure (Po)	Vocal folds tensed
			Great subglottal pressure (Ps)
	Small *H1-H2*		Creaky voice : Smaller ratio of open phase to complete cycle (open 25-45% of cycle) (Childers and Lee, 1991)
Lenis	Intermediate VOT; but overlapped interquartile range boxes between the lenis and aspirated	Intermediate rate of airflow	Larger glottal opening than the fortis stop, but similar to that of the aspirated stop
	Lowest *f0*		Vocal folds less tense
		Lowest oral pressure	Smallest subglottal pressure (Ps)
	Intermediate *H1-H2*;but overlap with the fortis		Closer to modal voicing: Intermediate ratio of open phase to complete cycle (open 65-70% of cycle) (Childers and Lee, 1991)
Aspirated	Long VOT	High rate of airflow	The same or larger glottal opening than the lenis stop (least constricted vocal folds)
	Great *f0*		Vocal folds more tensed than the fortis stop
		High oral pressure, but overlap with the fortis stop	Great subglottal pressure (Ps)
	Great *H1-H2*		Breathy voice: Larger ratio of open phase to complete cycle (open 80-100% of cycle) (Childers and Lee, 1991)

Table14. Summary of main acoustic and aerodynamic features in Seoul dialect. Articulatory state is postulated based on previous research and the main findings of the current study.

	Acoustic outcome	Aerodynamic outcome	Postulated articulatory state
Fortis	Short VOT	Small rate of airflow (Uo)	Small glottal opening (constricted vocal folds)
	High *f0*, but overlap with the High tone lenis and Low tone aspirated stop	Non-distinctive oral air pressure	Vocal folds tense, particularly in the High tone condition, but the tenseness would be similar to the high tone lenis stop
			Great subglottal pressure (Ps)
	Small or negative *H1-H2*		Creaky voice : Smaller ratio of open phase to complete cycle (open 25-45% of cycle) (Childers and Lee, 1991)
Lenis	Intermediate VOT	Intermediate rate of airflow (Uo), but overlap with the fortis stop	Larger glottal opening than the fortis stop (less constricted vocal folds than the fortis stop)
	Low *f0* in Low tone condition, but overlapped *f0* in High tone condition with the Low tone fortis stop	Non-distinctive oral air pressure	Vocal folds less tense, especially in the Low tone condition
			Less subglottal pressure (Ps) than the fortis stop
	Intermediate *H1-H2*; but overlap with the aspirated		Closer to modal voicing: Intermediate ratio of open phase to complete cycle (open 65-70% of cycle) (Childers and Lee, 1991)
Aspirated	Long VOT	High rate of airflow (Uo)	Largest glottal opening
	Great *f0*in High tone condition; but overlapping between Low tone aspirated and high tone fortis	Non-distinctive oral air pressure	Vocal folds tense
			Less subglottal pressure (Ps) than the fortis stop
	Great *H1-H2*		Breathy voice: Larger ratio of open phase to complete cycle (open 80-100% of cycle) (Childers and Lee, 1991)

Table 15. Summary of main acoustic and aerodynamic features in South Kyungsang dialect. Articulatory state is postulated based on previous research and the main findings of the current study.

3.2. Phonological Representation of Korean stops

The phonetic findings of the current study lead us to the following questions: how can phonological features represent the distinctive Korean stops and how can the differences in the phonetic realization in the two dialects be specified by phonological features. In this section, the possible phonological representation of Korean obstruents in the two dialects is suggested based on the previous approach and the phonetic findings in this study.

Halle & Stevens (1971) investigated the featural specification of voicing, aspiration, and glottalization and suggested the phonological system of Korean stops based on the acoustic findings by C-W, Kim (1965, 1970) (see section 1.2.1.1. and 1.2.1.2. for more discussion) as in Table 16.

	Phonological features	**Fortis**	**Lenis**	**Aspirated**
Glottal Width	Spread Glottis	–	+	+
	Constricted Glottis	–	–	–
Tension of Vocal Folds	Stiff Vocal Folds	+	–	+
	Slack Vocal Folds	–	–	–

Table 16. Laryngeal features of Korean stops by Halle & Stevens (1971) based on Kim's (1965, 1970) acoustic findings

Halle & Stevens (1971) proposed the binary features of [±Spread Glottis] and [±Constricted Glottis] to specify obstruents. Moreover, they indicated that the features of [±Stiff Vocal Folds] and [±Slack Vocal Folds] are appropriate to assign the voiceless stops. The researchers mentioned that the Korean fortis stop for which the glottis is neither constricted nor spread was specified as [–Spread Glottis, –Constricted Glottis]. In addition, based on the acoustic finding by Kim (1965) that *f0* after the fortis or aspirated stop tends to increase, the feature of [+Stiff, –Slack Vocal Folds] is suggested. As for the lenis and the aspirated stop, Halle & Stevens (1971) mentioned that not only fully aspirated stops (e.g. Hindi stops) but also the moderately aspirated Korean stop (*cf.* the lenis stop) is specified as

[+Spread Glottis, – Constricted Glottis]. In addition, unlike the aspirated or the fortis stop which is specified as [+Stiff, – Slack Vocal Folds] because of its higher *f0* tendency at vowel onset, Halle & Stevens (1971) suggested [–Stiff, – Slack Vocal Folds] for the lenis stop, but the [–Stiff, + Slack Vocal Folds] feature only in intervocalic position for the lenis stop.

Cho *et al*. (2002) discussed that three-way contrast stops in other languages can be successfully specified in terms of the categories [voiced], [voiceless unaspirated] and [aspirated] with the VOT values as a phonetic realization. However, Cho *et al*. (2002) also noted that this categorization is not applicable to the Korean stop, which has a three-way contrast in the voiceless region. First, Cho *et al*. (2002) argue that when Korean stops are categorized only in terms of VOT, the four categories [voiced], [voiceless unaspirated], [voiceless slightly aspirated] and [voiceless heavily aspirated] are inevitable, but this is redundant based on Keating's proposal that no language needs more than three voicing categories. Second, this categorization overlooks the vowel correlates such as *f0*, and different phonation types (*H1-H2*). Cho *et al.* (2002) mentioned Halle & Stevens' (1971) featural specification of Korean stops [±Spread Glottis] and [±Constricted Glottis] reflecting that the glottal width varies across stop categories, and also mentioned the laryngeal features [±Stiff Vocal Folds] and [±Slack Vocal Folds] might be used to characterize the tension of the vocal folds and other phonetic correlates related to the stops and the following vowel. However, Cho *et al.* (2002) pointed out that a binary feature system, which categorizes the phonological features by the presence or absence of the features, cannot be applied to describe lenis stop voicing in word-medial position or neural position of the vocal folds. In other words, specifying the lenis stop either as [–Spread Glottis] or as [+Spread Glottis] cannot reflect the intermediate vocal folds and 'intervocalic lenis stop voicing phenomenon'. Hence, Cho *et al*. (2002) discussed that the privative feature system, which uses only two laryngeal features [Spread glottis] / [Constricted glottis] under the framework of underspecification theory (Lombardi 1991, 1995), is more preferable to the binary feature system to specify the Korean stop categories. Cho *et al.* (2002) further argued that this reflects that the lenis stop is associated with a neutral position of the vocal folds and the context-dependent laryngeal variation of the lenis stop. Cho *et al*.'s suggestion (2002) is provided in (1) in the next page:

(1) Fortis stop [constricted glottis]

Aspirated stop [spread glottis]

Lenis stop unspecified

Redundancy rules

[Constricted glottis] → [stiff vocal folds]

[Spread glottis] → [stiff vocal folds] (Cho *et al*. 2002, p.224)

In contrast to this phonological representation in Cho *et al*.'s study (2002), Ahn (1999) argued that Korean stops primarily need [Stiff Vocal Folds] / [Slack Vocal Folds] features, maintaining [Spread Glottis] / [Constricted Glottis] features proposed by Halle and Stevens (1971). He suggested that [Stiff Vocal Folds] / [Slack Vocal Folds] features can represent the distinctive phonation type as well as the fundamental frequency property in Korean stops. However, Ahn (1999) pointed out that Halle and Stevens' (1971) suggestion that the lenis stop is specified as [+Spread glottis] / [–Slack Vocal Folds] and the fortis stop as [– Constricted Glottis] is phonetically wrong. Ahn (1999) indicated that the phonological representation of the lenis stop as [+ Spread Glottis] should be re-investigated because of the fluctuating glottal size across speakers and the voicing phenomenon of the lenis stop in intervocalic position. Ahn (1999) further discussed that the feature of [Slack Vocal Folds] for the lenis stop is able to account for the [voice] feature of preceding sonorant, and the use of all four features is required to represent Korean stops, being able to explain some low-level phonological processes such as 'post-stop tensification' and 'obstruent nasalization' in Korean. Ahn's suggestion (1999) is provided in (2) below:

(2) Fortis stop [Stiff Vocal Folds] [Constricted Glottis]

Aspirated stop [Stiff Vocal Folds] [Spread Glottis]

Lenis [Slack Vocal Folds] (Ahn 1999)

Now, we can turn our attention to the phonetic findings in the current study. This study first considers the phonological representation in the Seoul dialect. As revealed in the acoustic study, the acoustic properties of *f0* and VOT showed significant difference among three laryngeal gestures in the Seoul dialect. In addition, the further analysis showed that *f0* as a single predictor classifies three distinctions with 77% accuracy, and VOT alone classifies Korean stops with 72% accuracy. This indicates that Seoul speakers use not only VOT but also *f0* to distinguish three laryngeal gestures. Moreover, comparing the classification accuracy indicates that *f0* is stronger predictor than VOT for Seoul speakers. This leads us to question the validity of [Spread Glottis] / [Constricted Glottis] as a primary phonological feature, and [Stiff Vocal Folds] / [Slack Vocal Folds] as a redundant specification of the Korean stop. The acoustic findings in the current study suggest that this typical phonological view should be re-examined, at least for the younger speakers of Seoul dialect, and the [Stiff Vocal Folds] / [Slack Vocal Folds] might be regarded as a primary role to distinguish the lenis vs. aspirated stop instead of [Spread Glottis] / [Constricted Glottis]. Therefore, closely following Ahn (1999), the use of all four features [Stiff Vocal Folds] / [Slack Vocal Folds] and [Spread Glottis] / [Constricted Glottis] are preferable to use only two features [Spread Glottis] / [Constricted Glottis] as in Table 17:

	Feature Specification	
Aspirated	[Stiff Vocal Folds]	[Spread Glottis]
Fortis	[Stiff Vocal Folds]	[Constricted Glottis]
Lenis	[Slack Vocal Folds]	

Table 17. Possible Phonological features of Korean stops in Seoul dialect

Our next discussion will be on the phonological representation for the South Kyungsang dialect. In the acoustic and the aerodynamic study, we have noted that the acoustic cues (VOT, *f0*) are marked differently in the two dialects, which differ in their tonal systems, and this suggests that the same phonological system is not applicable to both dialects. One of the main findings is the different distribution of *f0* and VOT between the two dialects. *f0* in the South Kyungsang dialect showed significant overlap among three laryngeal gestures, while *f0* in Seoul did not; discriminant analysis also supported the unreliability of *f0* as an acoustic cue to South Kyungsang speakers (classification accuracy: 54%). However, unlike the *f0* distribution, South Kyungsang dialect speakers showed well-separated VOT ranges (classification accuracy: 84%), while Seoul dialect speakers had overlap in the lenis and aspirated stop in the interquartile ranges. This suggested that South Kyungsang speakers primarily use VOT for three contrastive stops and the phonological feature of [Spread Glottis] / [Constricted Glottis] should be the primary feature. In addition, since South Kyungsang dialect has the lexical pitch accent, the *f0* space of the phonological dimension might be different from that of Seoul dialect.

For the phonological representation in the South Kyungsang dialect, the current study adopts Lombardi's (1991, 1995) notion that Korean stops could be differentiated by the privative laryngeal features, primarily using [Spread Glottis] / [Constricted Glottis] features. The lenis stop with phonetic realization of the intermediate VOT (neutral vocal fold position) might not be assigned by any of [Spread Glottis] / [Constricted Glottis] features. Under this account, the possible features will be as in Table 18:

			Feature Specification	**Redundancy Features**
Aspirated	HH	[Upper]	[Spread Glottis]	[Stiff Vocal Folds]
	LH	[Lower]		
Fortis	HH	[Upper]	[Constricted Glottis]	[Stiff Vocal Folds]
	LH	[Lower]		
Lenis	HH	[Upper]	Unspecified	[Slack Vocal Folds]
	LH	[Lower]		

Table 18. Possible Phonological features of Korean stops in South Kyungsang Korean

Along with tone specification [Upper] / [Lower], the underspecification and redundancy rules capture the phonetic findings in the current study. First, the tonal contrast High vs. Low can be expressed by [Upper] / [Low] distinction. Second, the underspecification rule with the features of [Spread Glottis] / [Constricted Glottis] captures the VOT and the airflow differences; [Spread Glottis] for long VOT duration, high intraoral airflow (Uo), [Constricted Glottis] for the short VOT duration, low intraoral airflow (Uo), and the lenis stop, which was unspecified, for neutral vocal folds position and the intermediate intraoral airflow (Uo). Under this account, the feature of [Stiff Vocal Folds] can be predicted from either of [Spread Glottis] or [Constricted Glottis] for the aspirated and the fortis stop respectively in the redundancy rule. In addition, the phonetic realization of *H1-H2*, the indicator of phonation type, can be accounted for by [Spread Glottis] / [Constricted Glottis]; [Spread Glottis] for the breathy voice with the acoustic outcome of large *H1-H2,* and [Constricted Glottis] for the creaky voice with the acoustic outcome of small or negative *H1-H2.* In other words, the current study can make the 4-way distinction in terms of tonal contrasts and the *f0* differences in South Kyungsang Korean stops; i) upper – stiff vocal folds, ii) lower – stiff vocal folds, iii) upper – slack vocal folds, iv) lower – slack vocal folds. Therefore, the acoustic findings for the stop in tonal South Kyungsang dialect can be represented with the combination of specification of tonal contrasts and *f0,* and [Spread Glottis] / [Constricted Glottis].

3.3. Conclusion

This study investigates the acoustic and aerodynamic properties of well-known three-way distinction of Korean voiceless stops in two dialects, non-tonal Seoul dialect Korean and tonal South Kyungsang dialect Korean. Previous study by Kenstowicz and Park (2006) examined the characteristics of the three Korean laryngeal gestures in Kyungsang dialects; however, the comparison between Seoul (standard Korean) and Kyungsang dialects was made across Cho *et al*.'s (2002) study. Therefore, using same experimental procedure enables the current study to truly compare the property of Korean stops in the two dialects.

In this study, we have identified several acoustic and aerodynamic factors that determine the three-way distinction of Korean stops in Seoul and South Kyungsang dialects. First, the two dialects use acoustic cues differently to distinguish the three-way stop contrasts; Seoul speakers are more likely to use *f0* as a primary acoustic cue, while South Kyungsang speakers primarily use VOT, which leads us to the different phonological representations for the two dialects. Second, Seoul speakers' tendency to use *f0* as a main acoustic cue instead of VOT seems to be related to the diachronic transition. Third, South Kyungsang dialect speakers indeed make the tonal distinction between High vs. Low, and as identified by significant overlapping *f0* distribution among stops, particularly in the Low tone fortis and the High tone lenis stop, the tonal contrasts in South Kyungsang dialect make the *f0* an unreliable acoustic cue for the Korean obstruents. Since Kyungsang speakers are already using *f0* cue to distinguish tonal contrasts, the use of *f0* to distinguish three laryngeal gestures seems to be diminished, of which notion is similar to the relationship between lexical tones and stress in Mandarin Chinese (Duanmu 2000) . Finally, the results of the aerodynamic study not only replicated previous findings, but also made it possible to postulate the differences in articulation between the two dialects along with the acoustic findings. The current study investigated the unusual three-way distinction of Korean stops, and provided some new data about the stop by considering dialectal variation.

At least, two things need to be explored in future studies; first, there is a need for more specific phonological representations which can specify the detailed phonetic properties for Korean stops in various dialects of Korean. Although the current study represents possible phonological features in two dialects, it is not specific enough to indicate the dialectal variation in intraoral air pressure (Po) caused by subglottal air pressure (Ps), and the tonal variation in *H1-H2* in both dialects. Second, perception experiments could confirm the acoustic findings in the current study. In the present acoustic study, we identified the tonal contrasts in Kyungsang dialect, and they are closely linked to *f0* as an acoustic cue for the three laryngeal gestures. Therefore, it would be worthwhile to verify this *f0* property (e.g. tonal contrasts, *f0* for the three obstruents) in Kyungsang dialects by conducting perception experiments. In addition, it would be meaningful to investigate the notion of the diachronic change on VOT through perception studies with listeners from different age groups.

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