

Acoustic Cues for the Korean Stop Contrast - Dialectal Variation

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Abstract

In this study, cross-dialectal variation in the use of the acoustic cues of VOT and F0 to mark the laryngeal contrast in Korean stops is examined with Chonnam Korean and Seoul Korean. Prior experimental results (Han & Weitzman, 1970; Hardcastle, 1973; Jun, 1993 & 1998; Kim, C., 1965) show that pitch values in the vowel onset following the target stop consonants play a supplementary role to VOT in designating the three contrastive laryngeal categories. F0 contours are determined in part by the intonational system of a language, which raises the question of how the intonational system interacts with phonological contrasts. Intonational difference might be linked to dissimilar patterns in using the complementary acoustic cues of VOT and F0. This hypothesis is tested with 6 Korean speakers, three Seoul Korean and three Chonnam Korean speakers. The results show that Chonnam Korean involves more 3-way VOT and a 2-way distinction in F0 distribution in comparison to Seoul Korean that shows more 3-way F0 distribution and a 2-way VOT distinction. The two acoustic cues are complementary in that one cue is rather faithful in marking 3-way contrast, while the other cue marks the contrast less distinctively. It also seems that these variations are not completely arbitrary, but linked to the phonological characteristics in dialects. Chonnam Korean, in which the initial tonal realization in the accentual phrase is expected to be more salient, tends to minimize the F0 perturbation effect from the preceding consonants by taking more overlaps in F0 distribution. And a 3-way distribution of VOT in Chonnam Korean, as compensation, can be also understood as a durational sensitivity. Without these characteristics, Seoul Korean shows relatively more overlapping distribution in VOT and more 3-way separation in F0 distribution.

1 Introduction

Phonological contrasts involving the laryngeal features of stop consonants are marked through the interaction of diverse acoustic features (Lisker & Abramson, 1964). Contrasts among oral stops involving voicing (e.g., French), aspiration (e.g., Mandarin), or both (e.g., Hindi) are manifest by the presence or absence of phonation during stop closure and variation in the onset of voicing following stop release (Borden et al., 1994). Many factors may interact to affect the acoustic realization of a phonological contrast in laryngeal features, and prosodic factors are a primary source of variation in many languages. Language varieties that have the same phonological contrast but differ in their prosodic systems might be expected to differ in the realization of the acoustic cues that signal the contrast. This paper explores such differences in the acoustic realization of a 3-way laryngeal contrast in two dialects of Korean that differ in their prosodic systems.

Korean stops exhibit a 3-way laryngeal contrast among oral stop consonants: plain (/tal/, 'moon/month'), tense (/t'al/, 'daughter'), and aspirated (/t^hal/, 'mask')¹. All three categories of stops are voiceless and pulmonic egressive, and differ in a number of acoustic features. VOT and the F0 value at the following vowel onset distinguish at least partially

¹ I follow Han's terms for the three kinds of stops in Korean (Han, 1998). Kim, C. (1997) uses occlusive, tense, and aspirate, whereas Kim, W. (1983) divides them into lenis, fortis, and aspirated. On the other hand, Silva (1991) uses the terms of lax, reinforced, and aspirated.

among the three stop categories. Aspirated stops exhibit the highest VOT and F0 values, while tense stops show the lowest VOT values and a relatively higher F0 onset than the plain series. The laryngeal contrast is also evident in differences in wide-band spectrograms of the initial portion of the periodic signal following release of the three kinds of stops. After tense stops, the voice source is relatively undamped, while damping occurs after aspirated stops, and to the greatest degree, after plain stops (Han & Weitzman, 1970). In the temporal dimension, plain stops show a shorter closure duration than tense or aspirated stops.

Among these various acoustic markers of the Korean laryngeal contrast, VOT has been cited as primary. The success of VOT in distinguishing the three categories is not complete, though. Lisker and Abramson (1964) observe that the three divisions in VOT values in Korean are not perfectly separated from one another. Several subsequent studies confirm the finding of overlapping VOT ranges in Korean, and together they shed doubt on the status of VOT as the primary acoustic correlate of the laryngeal contrast (Han & Weitzman, 1970; Hardcastle, 1973; Kim, C., 1965). Results of VOT analysis are not consistent across these studies, as illustrated by comparing Lisker and Abramson’s findings with those of Han and Weitzman, as represented in Figures 1 and 2 below.

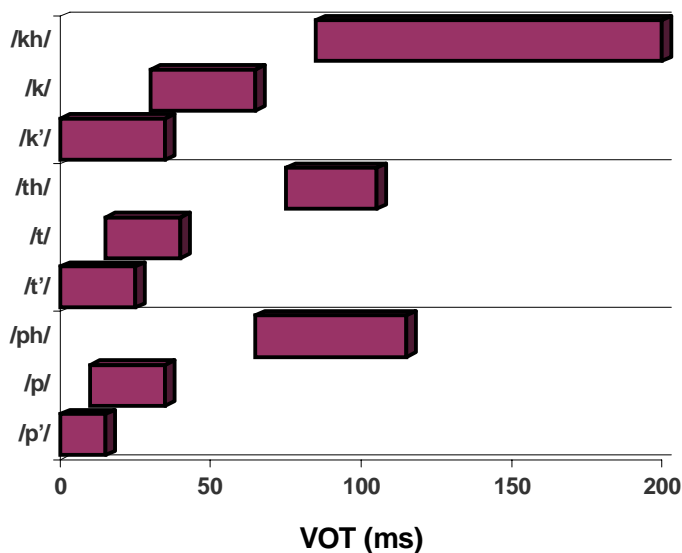


Figure 1. *Lisker and Abramson’s VOT of Korean stops in initial position (Adapted from Lisker & Abramson, 1964).*

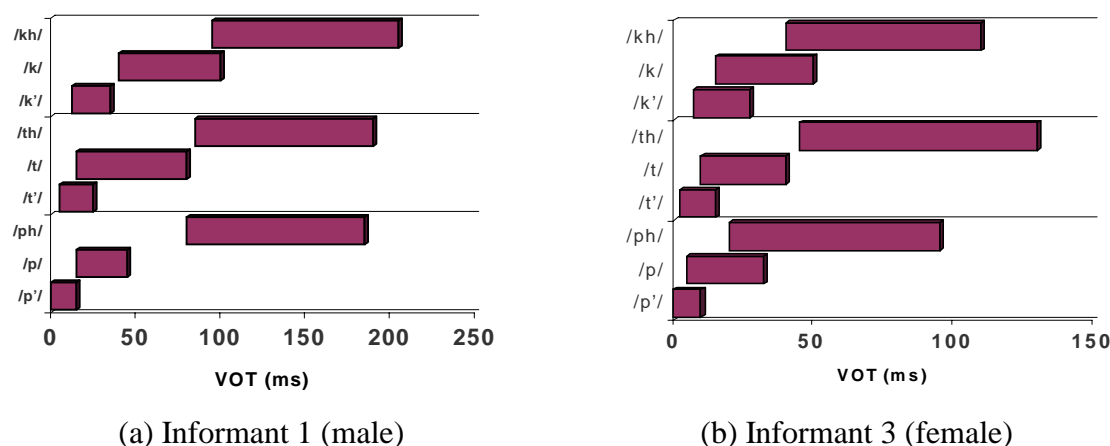


Figure 2. *Han and Weitzman's* VOT of Korean stops in initial position (Adapted from Han & Weitzman, 1970).

Figure 1 relates the finding from Lisker & Abramson that VOT ranges of plain and tense stops overlap. Figure 2 shows a similar finding from Han & Weitzman (1970). Additionally, Figure 2 displays overlap between the plain and aspirated stops. The tense stop never overlaps with the aspirated stop in VOT in either study. These findings suggest that VOT alone cannot be a sufficient cue for the different laryngeal gestures in the word-initial position.

Overlap in the values of an acoustic cue that marks a phonological contrast might cause confusion for the listener if the cue is the only acoustic feature to mark the contrast. In the case of the laryngeal contrast in Korean, phonation and aspiration gestures also play a role in establishing the phonological contrast. Tense stops have been analyzed as involving a gesture of glottal constriction (marked by [+constricted glottis]), while the aspirated stops involve glottal abduction (marked by [+spread glottis]). Glottal adjustment can be linked to variation in the onset of phonation following the stop release, influencing the F0 value at the onset of the following vowel (Kingston & Diehl, 1994). Evidence for the distinct glottal gestures of the Korean oral stops has been reported by Kim (1965), who observed a slower rate of vocal fold vibration at the beginning of the vowel following the plain stops. This finding is consistent with the general characterizations provided by Hardcastle (1973) and Hombert (1978) that associate aspirated or tense obstruents with a raised F0 of the following vowel onset. Han and Weitzman (1970) also report multiple differences in the onset of voicing after stop release dependent on the laryngeal characteristics of the stop. Among these, F0 is argued to serve as an additional cue to VOT in marking the laryngeal contrast. In general, F0 after plain stops is reported to be lower than the other stop categories (Hardcastle, 1973; Han & Weitzman, 1970; Kim, C., 1965). This general pattern is confirmed further in the subsequent study by Cho (1996), and by my pilot study, where I also observed consistently lower F0 values after tense stops than aspirated stops with the lowest F0 values after plain stops.

Supporting evidence for the role of F0 as a supplementary cue in marking laryngeal contrasts among oral stops is provided by Whalen et al. (1993), who demonstrate that the F0 value at stop release influences perception of the laryngeal feature of the stop even when the primary VOT cue is not ambiguous. Though Whalen et al.'s study concerns the phonological voice contrast, which is not involved in the Korean system, the findings are still significant for Korean because the 3-way Korean contrast is similarly manifest in F0 differences

following stop release². Cho (1996) and Kim (2000) also report experimental results which show that F0 perturbation after stop release cues the identification of the laryngeal stop category in Korean.

1.1 Dialectal variation in acoustic characteristics

If VOT and F0 together signal the laryngeal category of stops in Korean, the question arises how these two features interact. The findings of Cho and Ladefoged (1999) show that languages with an analogous laryngeal contrast may nonetheless vary in the manifestation of that contrast through the acoustic feature of VOT. In other words, the phonetic realization of the laryngeal contrast is not predictable from the phonological system of contrast alone. Similar variation may also be expected in the case of distinct varieties of a single language. Moreover, variation in the expression of a single cue to a contrast, such as VOT, raises the possibility about correlated patterns of variation in other cues to the same contrast.

In this paper, I investigate the question of whether distinct varieties of Korean exhibit variation in the way the VOT and F0 cues signal the laryngeal contrasts, and in the interaction between the two acoustic features. This investigation is motivated in part by the observation that among the varieties of Korean for which phonological descriptions exist, there are significant differences in prosodic systems that could in principle lead to different patterns of realization of the laryngeal contrast for stop consonants. In particular, prosodic features that are expressed in patterns of duration and F0 are predicted to have a possible interaction with the use of VOT and F0 to cue the laryngeal contrast. I report here on differences in the acoustic realization of the 3-way laryngeal contrast in word-initial position in two dialects of Korean that differ in prosodic features expressed through pitch and duration patterns. I show that the variation in the acoustic realization of the laryngeal contrast through VOT and F0 cues can be related to the differences in the prosodic systems of the two dialects.

A recent study by Cho et al. (2001) provides additional confirmation of dialectal variation in Korean for the cues that mark the laryngeal contrast. That study compared the acoustic features of the Seoul and Cheju dialects, examining VOT, burst energy, F0 and energy values (dB) for the first and second harmonics and for the peak harmonic of the second formant, and aerodynamic characteristics of oral pressure and flow. Of interest here, Cho et al. report different patterns for VOT and F0 cues: the Cheju dialect exhibits more overlap in VOT ranges for the three types of consonants than does the Seoul dialect, with a compensatory 3-way division in F0 values in Cheju. On the other hand, the Seoul dialect exhibited less overlap in VOT values and only a 2-way distinction in F0 values (plain vs. aspirated and tense). Cho et al. do not elaborate on the possible basis for this dialectal difference, and therefore it is hard to determine if the discrepant patterns of VOT and F0 derive from or are related to any other divergent properties of the two dialects.

² Kingston & Diehl (1994) maintain that the similar effects on F0 following stop release between Korean and English support a parallel phonological analysis involving the feature [voice]. Specifically, they argue that the contrast between unaspirated and aspirated Korean stops should be analyzed in terms of the features [+voice] and [-voice], respectively. In support of this argument Kingston & Diehl observe that the Korean unaspirated stops are realized with phonetic voicing in intervocalic position, just as English [+voice] stops are. Under this view, the acoustic property of F0 depression marks the phonological category [+voice] in Korean as it does in English, German, Swedish, and Danish. However, this interpretation of voicing on the basis of F0 depression is made more complicated in light of a more complete picture of the F0 cue to the laryngeal category in Korean. As reported below, for at least some speakers F0 values are distinct for each of the three contrastive laryngeal stop categories in Korean.

1.2 Chonnam Korean vs. Seoul Korean

The Korean dialects compared in the present study are the Seoul and Chonnam dialects, whose prosodic features have been analyzed and described by Jun (1993, 1998). The dialects differ in their intonational systems and in the contrastive status of vowel length. The Chonnam dialect has a phonemic vowel length contrast and a consistent, salient phrase-initial rising intonational contour. The Seoul dialect has no vowel length contrast and a consistent, salient rising intonational contour typically realized phrase-finally. Based on the observed phonological differences between these dialects, there are two hypotheses for this study. First, in Chonnam Korean, the salient phrase-initial pitch contour may restrict the role of F0 in cueing the laryngeal contrast in initial position. Second, the presence of a phonological contrast in vowel length may render Chonnam speakers more sensitive to the differences in the durational properties of vowels in the context of different preceding consonants, supporting a greater role for VOT in signaling the laryngeal contrast. In comparison, Seoul Korean is hypothesized to allow a greater role for F0 as a cue to the laryngeal contrast in phrase-initial position, since there is no interference with a demarcative intonational pattern in that position. On the other hand, Seoul is predicted to have a lesser role for VOT in marking the laryngeal contrast, since the phonological system does not exploit duration for a contrastive feature and thus listeners may not be as well-attuned to durational features associated with vowels. The experiment described in the following section examines the VOT and F0 features of each laryngeal type of consonant in Chonnam and Seoul dialects, and examines the role each feature plays in distinguishing among the laryngeal categories.

2 Methods

2.1 Subjects

Subjects were 6 Koreans, three Seoul Korean speakers and three Chonnam Korean speakers. The subjects were born in the given dialectal area under the parents who are speakers of the same dialect and had stayed in the dialectal region until they moved to the United States. In each dialectal group, two of the subjects were male and one was female. They were similar both in their age, all being in their late twenties, and in the period of time they had been in the States, all less than 2 years. They were all graduate students and reported no speaking impairment. None of them had had any phonetic training and knowledge for this kind of experiments.

2.2 Stimuli

The stimuli consisted of nonsense words with a CVCV sequence, in which the initial C was the one of the target consonants, /p, t, k, p', t', k', p^h, t^h, k^h/. The medial C was /p/. The vowel /a/ was used for V position because it is one of the edge vowels and does not involve phonological phenomenon as Umlaut for /i/ in Korean. To reduce variation from the vowel context, an identical vowel was used for all stimuli. Disyllabic words were chosen because they sound like more natural and common words in Korean. Within the set, the words were different only in the target C as in (1).

(1)	Velar:	/kaba/ ³	/k'aba/	/k ^h aba/
	Alveolar:	/taba/	/t'aba/	/t ^h aba/
	Labial:	/paba/	/p'aba/	/p ^h aba/

All the target words were embedded in the frame sentence, /nanun _____ heyo/⁴ 'I say _____'.

2.3 Procedure

Each subject repeated the nine stimuli 10 times for a total of 90 stimuli per subject. Before the recording procedure, done in a sound-attenuated booth in the phonetics laboratory in University of Illinois at Urbana-Champaign, there was a short instruction session in Korean. For familiarization for each word, subjects rehearsed the word list before recording. Target words were provided visually in a random order, and each repetition was done with a small pause between each word. All repetitions were recorded with a Tascam DAT recorder.

2.4 Measurements

The recorded words were transferred to a PC and analyzed with the Praat program (Boersma & Weenink). VOTs were measured from the stop release to the onset of the second formant in the following vowel⁵. Fundamental frequency value was taken from the onset at the phonation phase after the stop release with the pitch analysis of Praat program, using autocorrelation function. The onset value was taken as the mean of five initial values, which were measured every 0.01 second from the beginning of the second formant.

3 Results

3.1 Results of ANOVA analyses

The results are analyzed for each speaker individually. Because of possible differences caused by gender, male and female subjects were compared within the own gender group.⁶

The results of an ANOVA analysis for each individual showed that the factor of laryngeal contrast had a significant effect for all the subjects ($F(2,88) = 460.891$, $p < .0001$ for Chonnam Male 1; $F(2, 88) = 493.793$, $p < .0001$ for Chonnam Male 2; $F(2,88) = 228.799$, $p < .0001$ for Seoul Male 1; $F(2,88) = 547.726$, $p < .0001$ for Seoul Male 2). Tukey and Scheffe post hoc comparison showed that the three laryngeal categories are significantly distinctive from one another for the two Chonnam male speakers and for Seoul male speaker 1, with the highest value for the aspirated, intermediate for the plain, and the lowest value for the tense. Seoul male speaker 2 did not show a clear separation between plain and aspirated stops.

³ Korean voiceless plain stops become voiced without aspiration in intervocalic position, and the phonetic aspects were followed to describe the intervocalic stop.

⁴ The phonetic terms for vowels follow Lee's notation in the *Handbook of the International Phonetic Association* (1999).

⁵ This is the same measurement technique used in Cho et al. (2001). For the intervocalic plain stops, some of which showed voicing during their closure, the stop release was clearly detected, and VOTs were measured from that point.

⁶ Smith (1978), Swartz (1992), and Ryalls et al. (1997) discuss the gender effect on VOT.

Another significant effect was shown by the place-of-articulation for all the subjects ($F(2,88)=96.948, p<.0001$ for Chonnam Male 1; $F(2, 88) = 6.206, p = .003$ for Chonnam Male 2; $F(2,88) = 15.227, p < .0001$ for Seoul Male 1; $F(2,88) = 23.771, p < .0001$ for Seoul Male 2). All speakers showed significantly higher VOT values for velar stops than the other stops.

The results of the analysis of variance does not clearly show a dialectal difference. The second Seoul male speaker shows different patterns in VOT from the other three speakers. On the other hand, examination of the distribution of VOT values shown in Figure 3 reveals a distinctive pattern for the two dialects. In Seoul Korean, the VOT range for plain stops overlaps substantially with the range for the aspirated stops. The values for the three stop categories in the Chonnam dialect are more separated in their ranges.

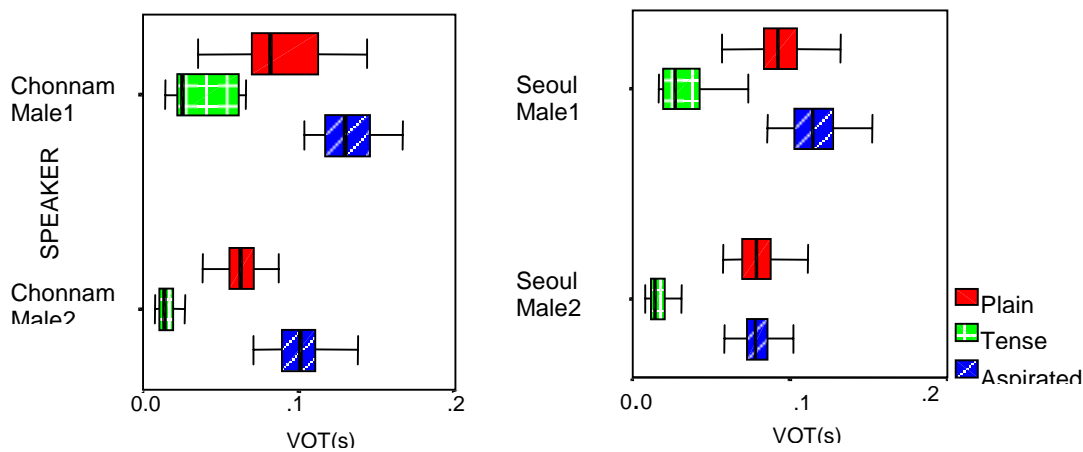


Figure 3. VOT distribution for Chonnam Korean and Seoul Korean.

Figure 3 reveals overlapping VOT values of the three laryngeal categories for all four male speakers. The two dialects are, however, different in the distribution of the interquartile ranges marked with shaded boxes. The three interquartile boxes in the Chonnam dialect are well-separated. Comparatively, the interquartile ranges for plain and aspirated stops in Seoul Korean show a substantial overlap, while the ranges for tense stops are more separated from the other two categories. In other words, compared with Seoul Korean, Chonnam Korean shows more of a 3-way distinction in the range of laryngeal categories of stops, whereas Seoul Korean shows only a 2-way distinction among the three categories.

One-way ANOVA was done for all the subjects separately. The results show a significant effect from the laryngeal contrast for all the speakers ($F(2,88) = 135.332, p < .0001$ for Chonnam Male 1; $F(2, 88) = 540.468, p = .003$ for Chonnam Male 2; $F(2,88) = 105.384, p < .0001$ for Seoul Male 1; $F(2,88) = 294.758, p < .0001$ for Seoul Male 2), while there is no effect from place of articulation. The results of a Tukey and Scheffe post hoc comparison indicate that the F0 values for two Seoul male speakers and Chonnam male speaker 2 have 3 divisions with the highest F0 value after aspirated stops, the intermediate F0 values after tense stops, and the lowest one after plain stops. In contrast, the homogeneous subsets for Chonnam male speaker 1 were divided into two parts. For this speaker, tense stops and aspirated stops were not clearly separated. The distribution from the box plots reveals a dialectal difference, specifically, in the overlap between tense and aspirated categories, though there is also a fair amount of individual variation.

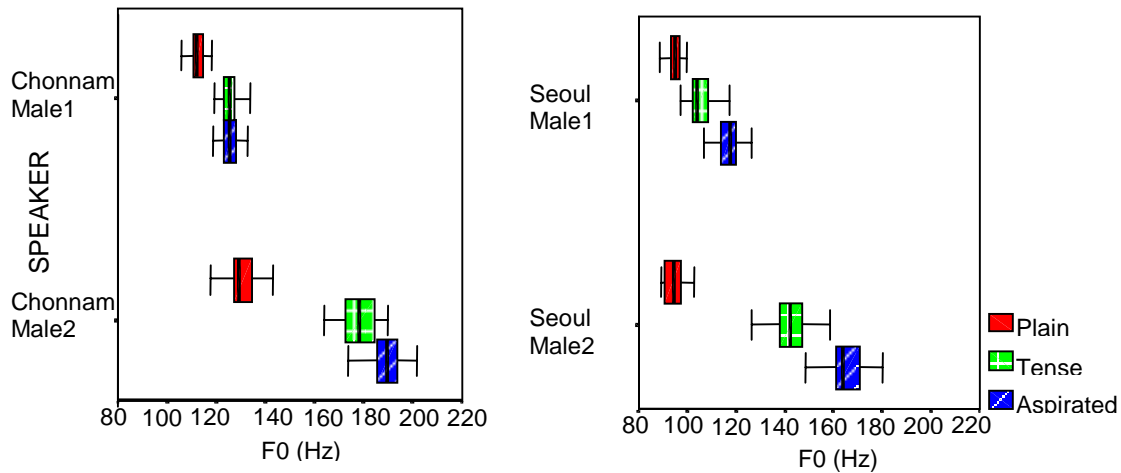


Figure 4. F0 distribution for Chonnam Korean and Seoul Korean.

The Chonnam speakers exhibit a 2-way distinction in F0, with plain stops separated from tense and aspirated stops which overlap. Comparatively, the Seoul Korean speakers show a more evenly spread 3-way distribution of F0 values for the three laryngeal categories.

Since VOT patterns can differ for male and female speech, the female speakers' data are presented separately here. The results of the ANOVA analysis for each individual did not show any difference between the two female speakers. Both female speakers showed a significant effect of laryngeal contrast in F0 and VOT. It is interesting that both female speakers did not show any significant effect from place of articulation in F0 and VOT, though all the male speakers had higher VOT values for velar stops. Tukey and Scheffe post hoc comparison show that there are two homogeneous subsets of values – one for tense stops and the other for plain and aspirated stops – in VOT whereas the distinction for F0 is 3-way for both females. The results are consistent for the two female subjects. But the results of a 2-way ANOVA ([laryngeal contrast] by [speaker]) analysis showed that the interaction between two factors was significant for VOT ($F=93.531$, $P<.0001$) and for F0 ($F=6.842$, $P=.001$). This interaction indicates differences in the distribution of VOT and F0 for the two female speakers.

3.2 Overlapping pattern in the core distribution

For a more precise comparison of the overlapping patterns in the distribution, the percentage of overlap was calculated. The percentage of overlap was considered within the core distribution, because the presence of outliers in a few extreme examples distorts the range. The ranges of the interquartile distribution were taken as the core distribution, which was calculated by putting the mean of the 95% confidence interval as a center value. The entire range of the core distribution had an equal value to that of the interquartile range. In other words, the upper bound of the core distribution was calculated by adding half the value of interquartile range to the mean of the 95% confidence interval, while the lower bound was determined by deducting half the value of interquartile range from the mean of 95% confidence interval. To confirm the normality of distribution, the Kolmogorov-Smirnov test showed that none of the actual distributions were significantly different from the hypothesized normal distribution at the level of 0.01. With the core distribution, the overlapping percentage was calculated in the following way. First, the number of all tokens within the core distribution range was counted for each category, and then, the number of tokens within the overlapping range, which was established between tense stops and aspirated stops for F0 and between plain stops and aspirated stops for VOT for all the speakers, was also counted. The

percentage was, therefore, the number of tokens within the overlapping range over the number of tokens within the core distribution multiplied by 100. Now, the dialectal tendency is clear with following bar charts.

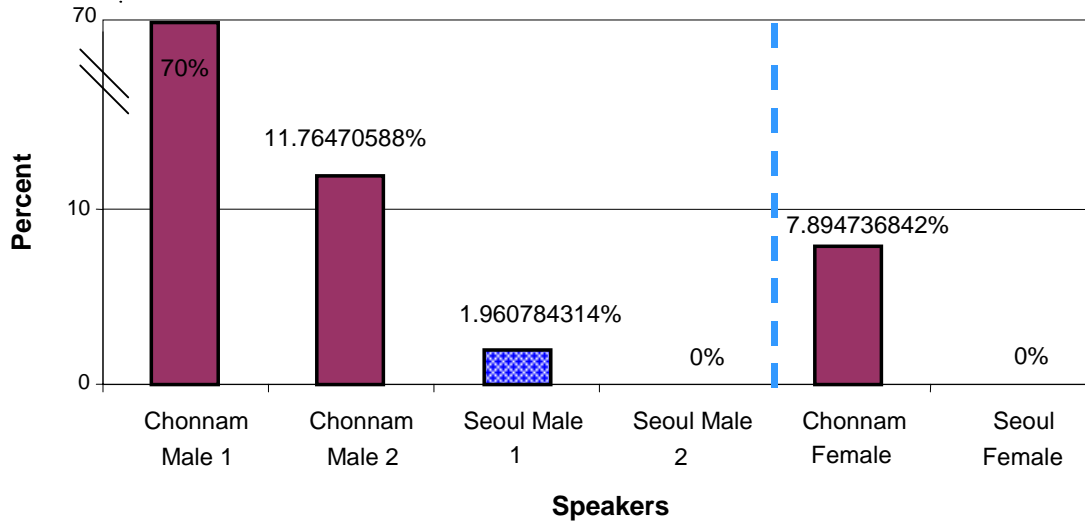


Figure 5. Percentage of overlap in F0 distribution.

In Figure 5, the three bars fully filled with plain color are for Chonnam Korean speakers, and the patterned one is for Seoul Korean speaker. The bar chart shows that there is a noticeable percentage of overlap for all the Chonnam speakers, while only one Seoul male speaker involves minor overlap for F0 values. There is no overlap for the two Seoul Korean speakers. This pattern goes in a reverse way in the following bar chart for VOT values.

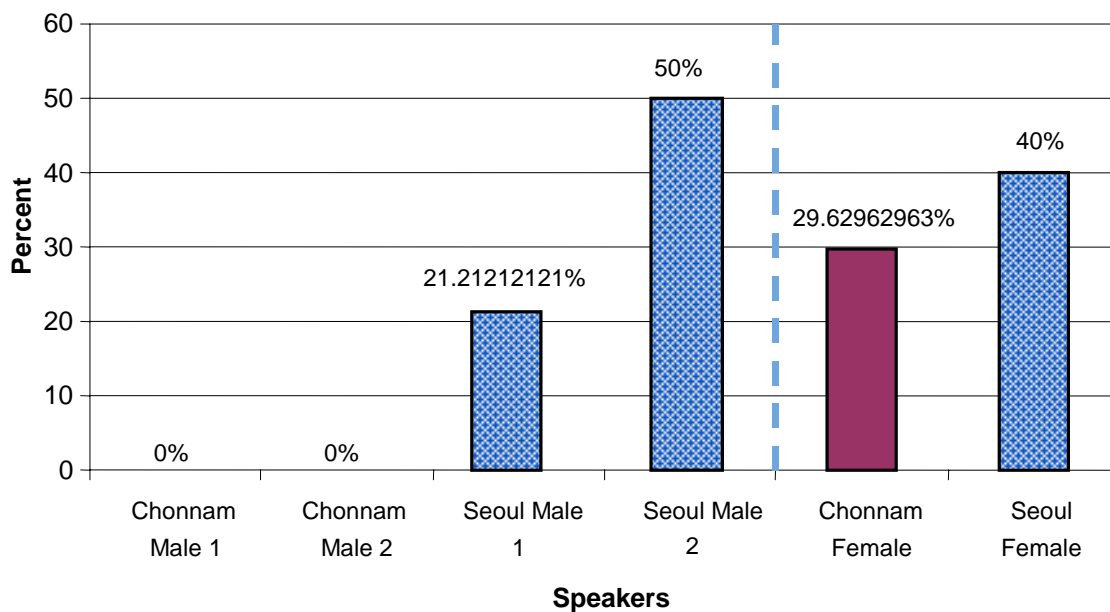


Figure 6. Percentage of overlap in VOT distribution.

Figure 6 shows three bars for substantial percent of overlap in VOT for the Seoul Korean speakers. In contrast, the two Chonnam male speakers do not show any overlap among three laryngeal categories. The Chonnam female speaker still shows the overlapping pattern to some degree but less than the Seoul female speaker's percentage of overlaps. It can be considered as a gender difference in VOT distribution, in that the female speakers show more overlap than the male speakers. Actually, the same pattern that shows more overlap in VOT values can be detected from the floating bars in Figure 2, which is adapted from Han & Weitzman (1970). More research is needed for the topic of gender variation.

It is, however, noteworthy that the acoustic characteristics of VOT and F0 in the two dialects are complementary, in that Seoul Korean exhibits more overlapping VOT ranges for the three laryngeal categories of stops, which is compensated for by the 3-way distinction in F0. In contrast, Chonnam Korean exhibits 3 separate VOT ranges that mark the three stop categories, and, conversely, there is more overlap in F0 distribution. This complementary patterning in the two acoustic cues is similar to the result reported by Cho et al. (2001) for the Cheju and Seoul dialects.

4 Discussion

The experimental results reported here show that the same phonological contrast is marked differently in two dialects that differ also in their intonation systems and sensitivity to vowel weight. In Seoul and Chonnam Korean, the acoustic cues of VOT and F0 pattern in a variable but complementary way to mark three stop categories. In summary, there is clear overlap in VOT for all the subjects, and the F0 values show a 3-way distinction for many speakers. As for dialectal tendencies, Seoul Korean shows a 3-way distinction in F0 with more overlapping distribution in VOT values, while Chonnam Korean shows less overlapping VOT distribution for the three stop categories and more overlapping in F0 distribution. The results support the initial hypotheses that the roles of VOT and F0 in signaling the laryngeal contrast will differ according to the interaction with the intonation system and the system of phonological weight contrast.

The patterns of dialectal variation are consistent, but the differences are not categorical. One reason may be the position of the stimuli. They are placed in AP-initial position in both dialects, which conditions some degree of paradigmatic strengthening in Korean (Cho & Jun, 2000; Cho & Keating, 1999; Jun, 1993). The strengthening from the same prosodic boundary may work very similarly in both dialects. The salience of the Chonnam phrase-initial intonation pattern may not observe F0 cues from the consonant, if those cues are strengthened independently in domain-initial position.

It is also noteworthy that individual variation within each dialect is also great. Without mentioning the different ranges of F0 and VOT values, the patterns of overlap or the spread of each category vary to a great degree speaker by speaker. Particularly, the Chonnam female speaker and the first Seoul male speaker are distinguished from the other speakers who display either overlap or no-overlap patterns in F0 and VOT distribution. For these four speakers, a single acoustic cue without overlap can function in a reliable way to demarcate the 3-way laryngeal contrast in stops. On the other hand, the Chonnam female and the first Seoul male speakers show overlap in both cues. None of the acoustic features can be solely reliable to the laryngeal contrast for the two speakers. However, a closer examination reveals that the two speakers are different from each other. The percentage of overlap in the Seoul male speaker is minor for both cues, whereas the Chonnam female speaker shows a great degree of

overlap in two cues but a wider range of distribution. Thus, both cues for the first Seoul male speaker are marking the contrast independently, though they are not good enough with overlap and a small separation. On the contrary, the Chonnam female speaker's acoustic cues are dependent on each other marking the 3-way contrast through their interaction. It is very interesting that the 2-dimensional acoustic space defined by F0 and VOT shows a better separation for the Chonnam female speaker, as is illustrated with Figure 7.

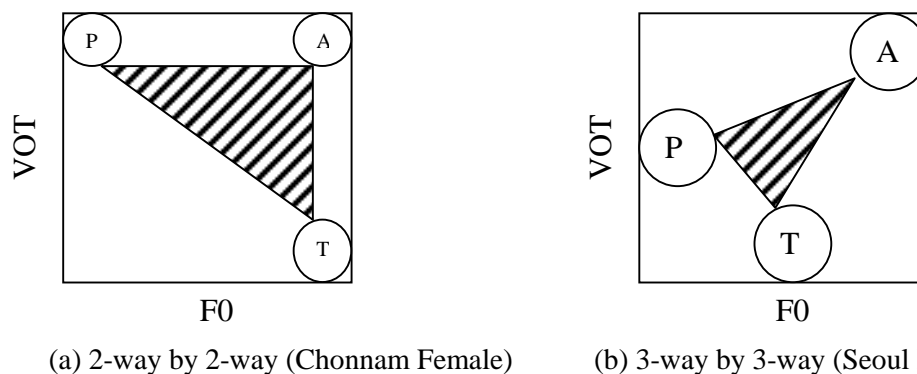


Figure 7. Simplified representation for 2 dimensional acoustic space with F0 and VOT for consonantal laryngeal contrast in stops. (A: aspirated stops, P: plain stops, T: tense stops)

In Figure 7, the three circles indicate the acoustic values marked with VOT and F0 together, and the slashed triangles inside can be considered as the space between the acoustic representations for the three laryngeal types. Instead of marking a wider range of values for the Chonnam female speaker, the greater separation between the values is depicted with smaller circles in (a). The space of the triangle in (a) is bigger than that in (b), and the distance between plain stops and tense stops in (b) is very small relative to the other separation. The results in Figure 7 also imply that paradigmatic strengthening⁷ in acoustic aspects needs to consider the interaction of multiple acoustic cues. That is, in one dimension of VOT or F0, the 2-way separation in (a) may not maximize phonetic distinction of all the three laryngeal categories. But the 2-dimensional space with VOT and F0 in (a) displays a better separation of the three categories than in (b) which seems to enhance the paradigmatic contrast in one-dimensional space of VOT or F0 more than (a).

Perceptual space may be different from acoustic space. If discrepancy in the acoustic patterns corresponds to perceptual patterns, dialectal variation in perception for various acoustic cues is also expected. In future studies, the perceptual patterns for stop identification needs to be tested with speakers from diverse language groups that differs in the acoustic cues that express an analogous phonological contrast.

⁷ I understand paradigmatic strengthening as an enhancement of the phonemic distinction of contrastive segments. For example, paradigmatic strengthening marks two contrastive values in a 2-way contrast with a greater separation between the values. In the same way, a 3-way contrast will be marked better with a greater separation among the three contrastive segments under paradigmatic strengthening. Hsu and Jun (1998) show an example of paradigmatic strengthening of VOT in a 3-way contrast

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