On the Lenis Stop Consonants in Korean*

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This paper explores the acoustic cues for differentiating the lenis stop consonants from the other two stop categories in Korean-i.e., the tense and aspirated stop consonants. For this goal, I employ the H1*-H2* measure to investigate post-release phonation modes of vowels following the three different stop consonants in question. In addition, I investigate the relationships among H1*-H2*, VOT, and F0 measures. The phonetic findings under the study are: (1) three manner classes are clearly distinguished in the H1*-H2* vs. VOT plot where the H1*-H2 values are obtained at the initial portion of vowels; (2) the F_0 values for the post-lenis vowels are significantly lower than those of the other two classes throughout the first half of the vowels. Based on these phonetic findings, I argue for the need to incorporate the two features [stiff vocal folds] and [slack vocal folds] into the phonological treatments of Korean stops, while maintaining the two features [constricted glottis] and [spread glottis]. For the phonological representation of the lenis stops, I suggest that the lenis stop category should be assigned the [slack vocal folds] only.

1. Aims and Motivations of the Study

This paper aims to investigate acoustic cues for differentiating the lenis stop consonants from the other two stop series in Korean-i.e., the tense and aspirated stop consonants. The major acoustic measure employed in this study is the measurement of H1*-H2*, a corrected amplitude difference between the first and second harmonics that will be discussed in greater detail below. Specifically, I will investigate the phonation modes of the vowels following the three phonemically different stop consonants in Korean,

* I sincerely express my deep gratitude to the two anonymous reviewers for their insightful comments and suggestions. Of course, I am the only person that is fully responsible for any kind of mistakes found in this paper.

the tense stops, the lenis stops, and the aspirated stops. This study focuses on the acoustic differences of the vowels following the consonants in question, specifically in /_a/ sequences. This analysis will allow us insight into the laryngeal settings made in the post-release circumstances without the use of fiberoptic measures of glottal width. The different articulatory gestures characterizing the three stop series in Korean have been described in previous studies (Kagaya 1974, among others) as follows: constricted glottis for tense stops, spread glottis for aspirated stops, and/or moderate glottis for lenis stops. In addition, this study also investigates the relationship between H1*-H2* and VOT measures as well as F_0 measures. Particularly, the extent to which the different laryngeal settings are directly mapped to the durational difference in the Voice Onset Time (=VOT, henceforth) is still unknown. Finally, based on acoustic findings, this paper suggests more plausible phonological representations for the three different stop classes in Korean.

According to the previous literature (Lisker and Abramson 1964; Kim C-W 1965, among others), the VOT, the highly effective phonetic cue for differentiating stop categories with different laryngeal settings in a variety of languages, proved not to be the sole distinguishing characteristic between lenis and tense stops in Korean. Specifically, VOT was significantly longer in aspirated stops. Although VOT values of the lenis stops are, on the average, longer than those of the tense stops, these two categories showed overlapping values. If this is the case, we would rather, as a next available acoustic cues, move our research focus from stop sounds themselves to the differences in laryngeal settings manifested in the vowels that follow the stops in question. This is why I launched this research.

2. The Obs(H1-H2) Measure

One way of determining a phonation type is by numeric measurements of the observed amplitude difference in decibels between the first and second harmonics (=Obs(H1-H2), henceforth). As clearly specified in Johnson (1997 : 127-130), the value of H1-H2 plays an important role as an index of the relative breathiness or creakiness of phonation. The general assumption is that the value of Obs(H1-H2) is much larger during breathy voice than during creaky voice. The difference in Obs(H1-H2) is mainly due to the difference in the shape of the glottal waveform. Specifically, the amplitude of the first harmonic in the breathy phonation is more dominant over the others. The creaky phonation does not show a difference in amplitude between the first few harmonics.

On the assumption that the spectral characteristics of the glottal waveform are directly reflected in the acoustic characteristics of a vowel, the value of Obs(H1-H2) can be used as an indication of determining the phonation type of that vowel. In this respect, the vowel in question should be a low vowel like [a], where the first formant (=F1, henceforth), which is highest among the vowels, does not boost either the first or second harmonics appreciably.

3. The H1*-H2* Measure

However, the method of Obs(H1-H2) is not entirely reliable if it is measured at the voicing onset of a vowel in a /CV/ context, where C is a stop sound. This is because the first and second harmonics undergo a 'boost effect' due to the first formant during the transitional segment in the initial part of a vowel that follows a stop. This F1 transition would affect the amplitude levels of the first few harmonics at the voicing onset position. Thus, the Obs(H1-H2) measure is not entirely dependable, since the main concern of this study is to observe the difference in phonation type at the voicing onset of the vowel following a stop. At this time point the laryngeal influence of the preceding stop is supposedly most salient.

To correct this F1 amplitude perturbation effect at the voicing onset, Stevens and Hanson (1995) suggested a new method of H1*-H2*, a corrected amplitude difference between the first and second harmonics. The value of H1*-H2* is obtained by subtracting the expected value of H1-H2 (=Exp(H1-H2), henceforth) from the value of Obs(H1-H2), as shown in the formula (1) below.

(1) H1* - H2* = Obs(H1-H2) - Exp(H1-H2)

According to the acoustic theory of speech production (Fant, 1960), we can predict an expected value of Exp(H1-H2) if we know F0 and the first few formant frequencies (Fant 1960 : 49-60, 1972). This prediction is based on the assumption that the glottal wave is characteristic of modal phonation. Hence, the spectral tilt of the glottal source is fixed at -12 dB/*octave*. Since H1*-H2* compares observed and expected differences, it provides an indication of how the source spectrum deviates from the reference. In this respect, the value of H1*-H2* naturally represents a corrected amplitude difference between the first and second harmonics. For example, a zero value of H1*-H2* indicates that the sound wave observed at that particular time point has a glottal spectrum of modal phonation; specifically, the spectral tilt of the waveform falls off at a rate of -12 dB/*octave*.

The H1*-H2* value is free from the variations of the F-patterns. Conversely, a value of Exp (H1-H2) varies depending on the F-pattern, so that the value naturally reflects the F1 amplitude perturbation effect. Because H1*-H2* is a value obtained by subtracting Exp(H1-H2) from Obs(H1-H2), this measure reflects the characteristics of pure glottal phonation, which is computed relative to modal phonation.

4. Experimental Method

A total of 6 male subjects participated in the recording. None reported any medical problems influencing their language ability. The average age of the subjects was 36.5. They all speak standard Korean (Seoul dialect).

Speech samples were of CV structure with C being a stop consonant varying in place and manner and V being a fixed vowel [a]. Some of these items turned out to be real words, others nonsense words. For the data, the words in (2) were used, embedded in the carrier sentence in (3):

(2) a. tense series: /p'a/, /t'a/, /k'a/
b. lenis series: /pa/, /ta/, /ka/
c. aspirated series: /pha/, /tha/, /kha/

(3) Carrier sentence
sentence: /ikəsi____ita/ [igəʃi____ida]
gloss: this + thing + nominative marker _____ + be(declarative form)
meaning: This is _______.

The subjects were required to repeat each of the items in (2) in succession until 5 clear tokens of each sample were obtained. Eventually, a total of 45 tokens was obtained from each subject (i.e., 3 manner categories* 3 places* 5 repetitions = 45 tokens). Subjects were recorded in a soundproofed room in the phonetics laboratory of the University of Texas at Austin. They were asked to speak the samples at normal speed and as naturally as possible in front of the microphone (Electro-Voice® 671A, Dynamic Cardioid, Electro-Voice, Inc.). The microphone was connected to a Power Mac computer (7100/80) via a stereo mixing console (Realisitc®, Model No. 32-1200B). The recording for each subject took approximately 30 to 45 minutes.

Since it was important to keep the amplitude level of each token constant, a method of on-line digitization was adopted. The digitization was made at a sampling rate of 22,050 Hz with the aid of 'Sound Scope 1.43f (Macintosh software program from GW Instruments, Inc.)'. Those signals clipped either at the top or bottom were discarded. The amplitude level of each token was easily maintained within the range of +/- 10 volts. In addition, when the subject found the pronunciation of the token unnatural, that token was also discarded. Some subjects produced the speech sample more than five times in a row until five clear signals were obtained. The digitized tokens were analyzed using Sound Scope to obtain the following raw data in (4).

(4) a. VOT
  b. Amplitude levels of harmonic 1 and 2
  c. F_0
  d. Frequency values of formant 1 through formant 4

The VOT value was obtained by measuring the durational length from the instant of the release of an articulator to the beginning of the first complete glottal pulse of the following vowel. To obtain the values of the various measures in (4 b, c, d), a digital signal program of 'Fast Fourier Transform Routine' (=FFT, henceforth) included in Sound Scope was used with the following parameters in (5):

(5) a.	FFT points:	1024
b.	Bandwidth of Filter:	59Hz (25ms window)
c.	6 dB pre-emphasis:	Off

The phonation mode (via H1*-H2*) and F_0 pattern at voicing onset position were most highly affected by the laryngeal settings of the preceding stop. To trace the extent to which they were maintained into a vowel, the values in (4 b,c,d) were obtained along a target vowel at the following five different time points as in (6) below:

(6) a. 13ms away from the voicing onset of the vowel
(+13ms time point, henceforth)
b. 1/8 of the vowel (1/8 time point, henceforth)
c. 1/4 of the vowel (1/4 time point, henceforth)
d. 3/8 of the vowel (3/8 time point, henceforth)
e. 1/2 of the vowel (1/2 time point, henceforth)

The reason for measuring at +13ms point and not right on the first glottal pulse of a vowel (i.e., zero time point of a vowel) was that since the relevant FFT points centered around the marker on the waveform in this particular software program, and since the window frame is fixed at 25ms, the +13ms point (i.e., around half of 25 ms window) could be the minimum distance used to identify a phonation mode of a pure vowel at its earliest position measurable. If the marker of that program was on the voicing onset position, it would include a mixture of the sound of aspiration and the vowel. Determining the remaining time points (i.e., 1/8, 1/4, 3/8, and 1/2 time points) was somewhat arbitrary and relational, and was mainly decided in reference to the whole length of a vowel. These obtained raw data were then processed using 'Excel' (Microsoft Office 2000) in order to calculate the theoretical values of Exp(H1-H2), and H1*-H2*.

5. Statistical Treatment

For the statistical analyses, the present study used two different methods; repeated measures ANOVA and regression analysis. The former was conducted to test the significance of means of H1*-H2*, F0, and VOT on three manner classes of stops across all subjects. The latter was performed to measure relationship between VOT and H1*-H2*values. This method was adopted to determine the strength of the association between the two dependent variables as expressed in terms of R^2 values (the square of a correlation coefficient multiplied by 100). The repeated measures ANOVA design employed in this study has the following parameters in (7).

(7) a. 3 within-subject variables: manner (3 levels) * place (3 levels) * time (5 levels)
b. between-subject variable: none
c. dependent variables:

3 (at +13ms time point): VOT, H1*-H2*, F_0
2 (at all other time points): H1*-H2*, F_0

6. Working Hypotheses

According to the fiberscopic studies (Kim C-W 1965, Kagaya 1974), the three Korean stop categories can be distinguished in terms of the glottal width during the stop closure; it is smallest for the tense stops, intermediate for the lenis stops, and largest for the aspirated stops. On the assumption that these distinct physiological characteristics are proportionally reflected in the H1*-H2* values at the +13ms time point, we can suggest the following working hypotheses as shown in (8):

(8) a. The H1*-H2* value should be larger in the aspirated class than in the lenis class.
b. The H1*-H2* value should be larger in the aspirated class than in the tense class.
c. The H1*-H2* value should be larger in the lenis class than in the tense class.

Following Ladefoged and Maddieson's (1996) hypothesis that the wider the glottis at release, the longer the VOT, and on the assumption that glottal width is proportionally reflected in the H1*-H2* value, we suggest a working hypothesis in (9) below with regard to the interrelationship between H1*-H2* and VOT measure:

(9) The larger the H1*-H2* value, the longer the VOT duration.

7. Results and Discussions

7.1. Results for the H1*-H2* Measure

Table 1 represents the numerical mean values of the Obs(H1-H2), Exp(H1-H2), and H1*-H2* measures for the three stop categories obtained at the +13ms time point.

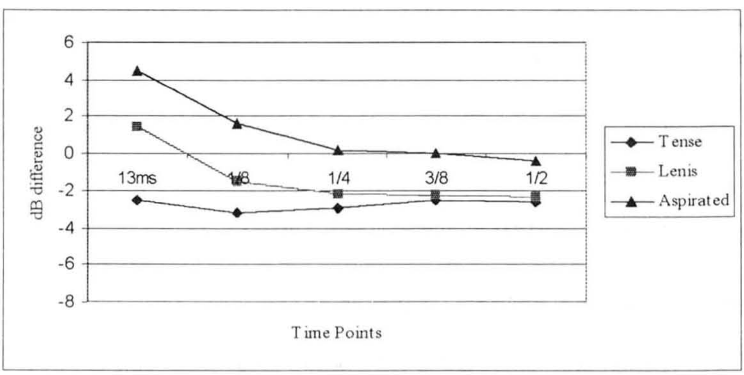
Table 1. Mean values of the Obs(H1-H2), Exp(H1-H2), and H1*-H2* measures at the +13ms time point.

Manner Classes	Obs(H1-H2)	Exp(H1-H2)	H1*-H2*
Tense	-1.55	0.95	-2.50
Lenis	3.06	1.61	1.45
Aspirated	6.13	1.69	4.44

The F1 amplitude perturbation effects are reflected in the Exp(H1-H2) values. The post-lenis and post-aspirated vowels show somewhat higher values in this measure than the post-tense vowels. This is mainly because of the long duration of aspiration during which formant transition occurs simultaneously, as is usual for stops with long VOT's. Due to their short VOT, on the other hand, the post-tense vowels show Exp(H1-H2) values smaller than those of the other two classes. As for this class, the F1 transition is salient in the initial portion of the vowel, causing an amplitude perturbation effect on the first and second harmonics.

Temporal patterns of average H1*-H2* values are presented in figure 1 below. The figure shows that the average H1*-H2* values tend to decrease as a function of time for the post-lenis and post-aspirated vowels, while the corresponding post-tense values stay relatively flat.

Figure 1. The line graphs based on the average H1*-H2* values at the five time points.



The graphic trends introduced in figures 1 should be evaluated statistically. Table 2 shows the results of the statistical analyses of the repeated measures ANOVA.

Table 2. Source table: analysis of variance with repeated measures for the H1*-H2* measure at the five time points.

Time point	Sum of Squares	Degree of Freedom	Mean of Squares	F-statistic	p-value
+13	2175.51	2	1087.76	15.84	<.01*
1/8	1066.23	2	533.18	7.50	<.05*
1/4	459.65	2	229.82	2.57	.125
3/8	342.52	2	171.26	2.57	.126
1/2	269.47	2	134.73	2.85	.105

First of all, for an alpha level of .05, the results in table 2 show a strong main effect for the factor 'Manner' at the +13ms and 1/8 time points, indicating a statistically significant difference in mean numbers between at least two manner classes. Statistically, the differences in this measure disappear among the three classes at and after the 1/4 time point. As a next step, a pairwise Bonferroni test on estimated marginal means was performed as a post-hoc test to determine which means truly differ at the first two time points. The results of the pairwise comparisons are presented in table 3:

Table 3. The pair-wise comparisons (the Bonferroni test with adjusted alpha level = 0.05) of the estimated mean values of the three Korean manner classes at the +13ms and 1/8 time points.

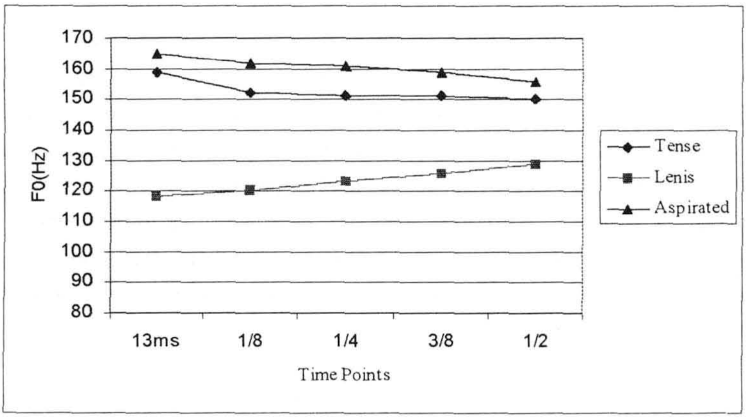
Time points	Classes Compared	p-value (α = .05)
+13ms	Tense vs. Lenis	<.05*
	Tense vs. Aspirated	<.01*
	Lenis vs. Aspirated	.365
1/8	Tense vs. Lenis	.462
	Tense vs. Aspirated	<.05*
	Lenis vs. Aspirated	.356

At the +13ms time point, the estimated mean value of the post-aspirated data is significantly higher than the mean values of the other two classes, while the difference in estimated means between post-lenis and post-aspirated classes is found to be non-significant. Consequently, the working hypothesis in (8a) is rejected. In a statistical sense, the lenis and aspirated classes are just variations of sampling distributions.

7.2. Results for the F_0 Measure

The course of F_0 during the vowel is diagrammed in figure 2:

Figure 2. Average F_0 values of the three manner classes plotted as a function of the five time points.



In terms of average values, F_0 is high for the post-aspirated, intermediate for the post-tense, and low for the post-lenis conditions. These results are consistently maintained along the time scale. The univariate analysis with repeated measures is given in table 4 showing the Manner factor effect. The associated Bonferroni tests are provided in table 5.

Table 4. Analysis of variance with repeated measures for the F_0 measure at the five time points. Degrees of freedom are 2 at all time points.

Time points	+13ms	1/8	1/4	3/8	1/2
F-value	49.02	56.36	51.82	43.15	44.61
p-value	<.001*	<.001*	<.001*	<.001*	<.001*

Table 5. The pair-wise comparisons (the Bonferroni test with an alpha level .05) of the estimated F_0 mean values obtained at the five time points.

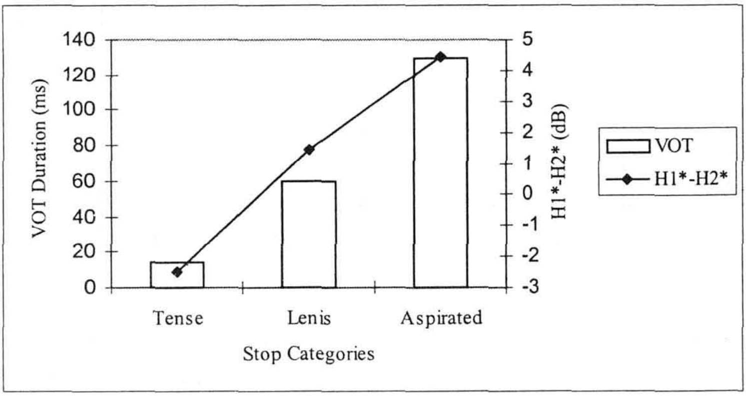
	p-value (α = .05)				
	+13ms	1/8	1/4	3/8	1/2
Tense vs. Lenis	<.01*	<.01*	<.01*	<.01*	<.001*
Tense vs. Aspirated	.633	.277	.191	.255	.304
Lenis vs. Aspirated	<.001*	<.001*	<.01*	<.01*	<.01*

According to the statistical results, for an alpha level of 0.05 there is no significant difference in mean values between post-aspirated and post-tense classes along all the 5 time points. On the other hand, the lenis F0 values are significantly lower than those of the other two classes at all time points. In the H1*-H2* patterns, differences between post-tense and the other two classes seem to statistically merge at and after the 1/4 time point. However, the F_0 patterns can be said to behave differently in that the significant low F_0's of the post-lenis vowels are maintained at all five time points. Therefore, it is possible that the laryngeal mechanism underlying glottal width is different from the one controlling F_0. A plausible explanation for the F_0 patterns of the Korean stops is as follows. For the lenis class, it seems that the laryngeal muscle activities resulting in a low F_0 are maintained throughout the vowels. For example, the post-suppression degree of Vocalis muscle (=VOC, henceforth) reactivation is slight and slow for the lenis class, which produces a low F_0. In contrast, the quick and heightened post-suppression VOC activities appear to make F_0 high in the vowels following tense and aspirated stops (Hirose et al., 1981). The Cricothyroid muscle (as well as the VOC muscle) has been assumed to facilitate a high F_0 for post-tense segments (Hirose et al. 1983). Regarding the aspirated class, it is highly possible that the aerodynamic mechanism helps increase F_0 on the adjacent vowels (Ladefoged 1973).

7.3. Correlation between H1*-H2* and VOT Measures

Figure 3 helps make the relationship between the two measures somewhat clearer:

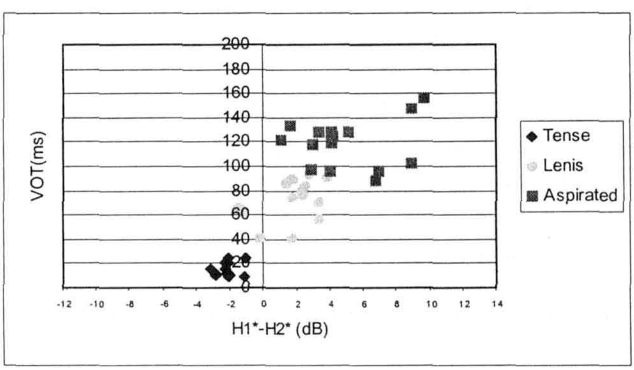
Figure 3. A combination chart where the average H1*-H2* and VOT values are plotted on the primary and secondary y-axes, and the three manner classes are plotted on the x-axis.



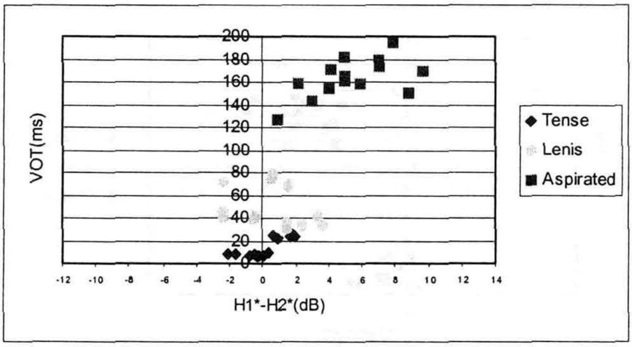
In figure 3, the correlation between VOT and H1*-H2* appears to be positive, showing that our hypothesis in (9) is roughly supported. The low score on variable H1*-H2* has a correspondingly low score on variable VOT, while a high score on H1*-H2* has a correspondingly high score on VOT. For the lenis observations, however, the main trend is obeyed aside from a slight discrepancy between the two variables. To explore the reason for this pattern, H1*-H2* vs. VOT scattergrams were prepared for each subject, as shown in figure 4 below.

Figure 4. Individual variations in the relationship between H1*-H2* and VOT measures across the three manner classes

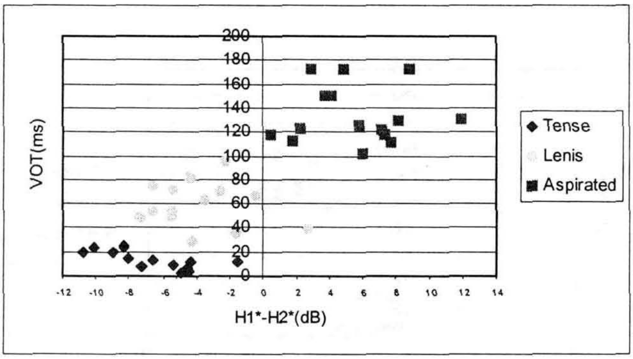
A. Subject 1



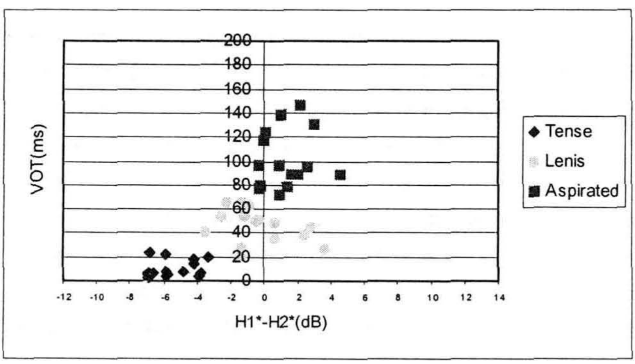
B. Subject 2



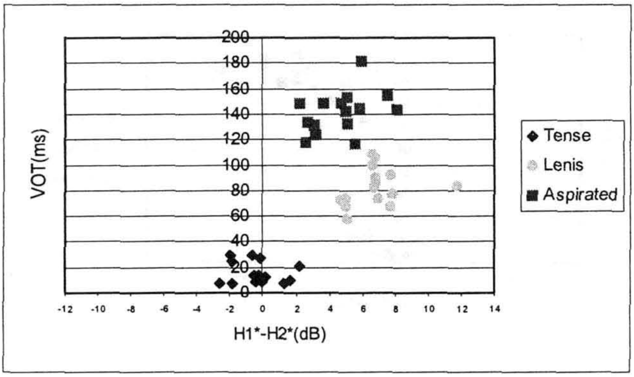
C. Subject 3



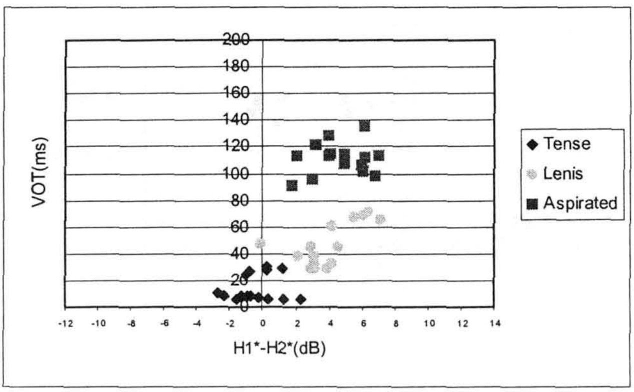
D. Subject 4



E. Subject 5



F. Subject 6



From the examination of these figures, two things merit attention. First, in this two-dimensional scattergram (H1*-H2* vs. VOT), three manner classes are clearly distinguished regardless of the subject, though each dimension is subject to some degree of overlap. For example, the H1*-H2* values clearly overlap between tense and lenis classes and sometimes between lenis and aspirated classes for all subjects. On the other hand, some subjects show an overlap in VOT between tense and lenis classes or between lenis and aspirated classes. Since it is assumed that the H1*-H2* value indirectly corresponds to the glottal width, and that the VOT value corresponds to the lag of the adductor muscle reactivation after suppression, it is reasonable to expect each manner class to occupy its own space in this scattergram. This is mainly because of the slow and weak laryngeal adduction activities conducted by the lenis class, relative to their corresponding glottal width.

A second interesting observation is that these lenis patterns appear to be subject-dependent. For subject 5, for example, the data seem to have no relation to the data of the tense and aspirated classes. For subject 1, on the other hand, the lenis data seem to be neatly arranged in relation to the tense and aspirated data, all of which show a consistent patterning. Given that these are just subjective impressions, however, it is necessary to evaluate them statistically, using R^2 values. These R^2 values were calculated in terms of regression analyses on the variously combined data for each subject. Table 6 shows the final outcomes.

Table 6. The R^2 values of the variously combined groups. These values are obtained from the data in a H1*-H2* vs. VOT scattergram.

	R^2 Scores (%)			
	Tense & Lenis & Aspirated	Tense & Aspirated	Lenis & Aspirated	Tense & Lenis
Subject 1	68	73	39	70
Subject 2	65	76	57	03
Subject 3	65	75	54	09
Subject 4	53	79	10	43
Subject 5	41	75	12	79
Subject 6	51	74	13	65
Mean	57.17	75.33	30.83	44.83
Standard Deviation	10.55	2.07	21.89	32.39
Max/Min Values	68/41	79/73	57/10	79/03

Table 6 shows two interesting patterns. Surprisingly enough, as indicated in column 3 when the tense and aspirated classes are considered together, the percentage of variance that the two variables have in common is 75.33%. It is even more surprising that, as indicated by a standard deviation of 2.07, this score is consistently high across all subjects. It is true that, as one of the two anonymous reviewers pointed out, the R^2 values tend to be significantly rising if calculated on the combined data of two disconnected classes (ex. the tense and aspirated classes here). But, this tendency does not necessarily guarantee the low score of standard deviation such as the score of 2.07 above. Look at the other standard deviation scores in table 8, all of which are larger than 10. To sum up, the afore-mentioned findings strongly imply that the Korean tense and aspirated stops are determined primarily in terms of the degree of glottal width at release. The corresponding VOT duration can be predicted in terms of a speaker-specific formula-i.e., each subject has his own pattern of laryngeal activities implying proportionality between glottal width and VOT duration. This hypothesis is also supported by the observations of post-suppression VOC reactivations, where strength is almost the same for both classes (i.e., almost the same F0's on neighboring vowels), and the time response is quick for both stops.

8. Phonological Representations of the Korean Stop Sounds

According to the model developed by Halle and Stevens (1971), there are two phonetic dimensions used for classifying stop sounds: (i) glottal space, i.e., the amount of space between the vocal folds and (ii) the degree of tension in the vocal folds. The former is represented by a combination of two binary features [+/- spread glottis] and [+/- constricted glottis], while the latter by [+/- stiff vocal folds] and [+/- slack vocal folds]. According to Stevens (1980), in stiff mode, the vocal folds are probably accompanied by a decrease in the vibrating mass, which has the following two consequences: (i) the F0 increases for vowels; (ii) it is more difficult for the vocal folds to vibrate since more sub-glottal pressure is needed to maintain vibration. In slack mode, on the other hand, the vocal folds are probably accompanied by an increase in the vibrating mass, which results in the following two consequences: (i) the F0 decreases for vowels; (ii) it is easier to maintain vocal fold vibration with a small drop in pressure across the glottis.

This two-dimensional model might be regarded as an appropriate system for the phonological representations of the three manner classes of Korean stop sounds. Specifically, the phonetic findings discussed so far naturally lead us to establish the phonological representations for the three stop categories of Korean as described below in (10). As for the features, however, I use the privative distinctive features of [constricted glottis], [spread glottis], [stiff vocal folds], and [slack vocal folds] (closely following Lombardi, 1991). This study did not find any phonetic motivation for postulating negative values, as with the model of Halle and Stevens, in the phonological description of the Korean stops.

(10) a. tense stops: [stiff vocal folds] + [constricted glottis]
b. aspirated stops: [stiff vocal folds] + [spread glottis]
c. lenis stops: [slack vocal folds]

The fact that the tense stops are characterized by the smallest glottal opening at release (creaky phonation) was confirmed by the results of the H1*-H2* measure in this study, where the average value is significantly lower at the +13ms time point than that of the post-lenis class or the post-aspirated class. Also, the fact that post-aspirated vowels show the largest glottis at release (breathy phonation) is strongly implied by the H1*-H2* measure under study. Related to the correlation between H1*-H2* and VOT, the consistently high R2 scores across subjects on the joint data of tense and aspirated classes show that these two classes can be systematically distinguished only in terms of one dimension; that is, the degree of glottal width at release. The VOT duration is a by-product that is naturally determined in proportion to the degree of glottal width, even though its determining strategy is subject-dependent. Also recall that these two classes show high F_0 values which are not significantly different along the five time points.

As for the lenis stop category, the main aim of its laryngeal activity seems to lie in keeping F_0 low on the neighboring vowel. Without an intentional maneuver of controlling laryngeal actions set for this purpose, it is not easy to explain why the significantly low F_0 is maintained along the vowel at all five time points since the differences in H1*-H2* values among the three classes disappear from the 1/4 time point onward. Now consider the statistical result that the H1*-H2* values of the lenis and aspirated stops did not show any significant difference at the +13ms time point. On the basis of this result alone, the lenis stops should have been assigned the same [spread] feature as the aspirated stops in (10b). However, there are three reasons to argue that the representation in (10c) is on the right track. First, as seen in Figure 4 above, the glottis size of the lenis stops showed subject-dependent fluctuations to a large extent relative to the glottal width of the aspirated stops. According to Kim, M-R's (1994) study, some male speakers of the Pusan dialect did not show any sign of aspiration, which indicates that their glottis was not wide enough to permit a puff of air before the beginning of the vocal fold vibration of the following vowel. Consider that the English voiced stops show similar voicing fluctuations in word-initial position-i.e., fully voiced, partially voiced, or unvoiced-- even though they are usually unvoiced (cf. Ladefoged and Maddieson 1996). In a similar vein, Korean lenis stops in word-initial position can be realized with a variety of glottis sizes, even though the glottis is usually open and spread. Second, the lenis class in word-initial position shows some phonetic characteristics closely approaching those expected for voicing as specified below: (i) its closure duration is consistently and significantly shorter than that of the tense stops (cf. Hirose et. al., 1981); (ii) its production, compared to the tense or aspirated stop, involves lower air pressure in the cavity behind the point of articulation, a slower rate of pressure build-up, and a moderate rate of airflow after release (cf. Shimizu 1996). Thirdly, the lenis stops are easily voiced when they are flanked by two sonorants (ex. /i+tal/ --> [idal] 'this + moon'). Neither tense nor aspirated stops are passively voiced in the same environment (ex. /i+t'al/ --> [it'al] *[idal] 'this + daughter'; /i+t^{h}al/ --> [it^{h}al] *[idal] 'this + mask'). With a representation that lacks the [spread] feature in (10c), we can easily show why the lenis stops readily receive the voicing feature of a preceding sonorant. Note that passively voiced lenis stops are not identical with voiced aspirated stops (i.e., [b(, d(, g(]) as observed in Hindi, which have both [spread] and [slack] as features. In sum, the aforementioned discussion provides justification for the phonological representation in (10c) as appropriate for the Korean lenis stops. If the lenis stops are represented with the combined features of [slack, spread], it would be much more difficult to describe the three phenomena mentioned above in a phonetically natural manner.

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