Korean lenis, fortis, and aspirated stops: Effect of place of articulation on acoustic realization

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Abstract

Unlike most of the world's languages, Korean distinguishes three types of voiceless stops, namely lenis, fortis, and aspirated stops. All occur at three places of articulation. In previous work, acoustic measurements are mostly collapsed over the three places of articulation. This study therefore provides acoustic measurements of Korean lenis, fortis, and aspirated stops at all three places of articulation separately. Clear differences are found among the acoustic characteristics of the stops at the different places of articulation.

Index Terms: speech production, stop consonants, phonetics

1. Introduction

Korean stops are special; they have been described as atypical [1], unusual, and unique [2]. Unlike most of the world's languages [3], Korean distinguishes three types of stops, lenis, fortis, and aspirated, that are all voiceless word-initially. All types of stops occur at bilabial, denti-alveolar, and velar places of articulation. Table I shows the nine Korean stops.

	Bilabial	Denti-alveolar	Velar
Lenis	/p/	/t/	/k/
Fortis	/p*/	/t*/	/k*/
Aspirated	/p^h/	/t^h/	/k^h/

Table I. *Korean stop obstruents.*

Lenis stops are commonly described as lenis or lax, breathy, and unaspirated or slightly aspirated, fortis stops as fortis or tense, unaspirated, and laryngealized, and aspirated stops as strongly aspirated [e.g., 1, 2, 4, 5]. Lenis stops are voiced in intervocalic position [6]. In syllable-final position, the fortis, lenis, and aspirated stop contrast is neutralized; all three stop categories are then produced as voiceless unreleased [4].

Whereas the acoustic characteristics of the stops are well studied, measurements are often presented collapsed over the three places of articulation. It is likely, however, that the stops differ in their exact phonetic make-up depending on place of articulation. Therefore, this study provides acoustic measurements of Korean lenis, fortis, and aspirated stops at all three places of articulation separately.

2. Method

2.1. Materials

Target sounds were the nine stops /p/, /p*/, /p^h/, /t/, /t*/, /t^h/, /k/, /k*/, /k^h/. Each target sound occurred in initial position, in three phonetic contexts, followed by the vowel /i/, /u/, or /ɛ/. There were thus 27 (9*3) CV items. Each item was recorded 20 times, yielding a total of 540 stimuli.

The materials were recorded by a 23 year old female native speaker of Korean, who had been born and raised in Seoul. She read the items, presented in Korean orthography, one by one, separated by a pause, in a clear citation style.

The recording was made in a sound proof booth with a Sennheiser microphone and stored directly onto a computer at a sample rate of 41.5 kHz. Stimuli were excised from the recording using the speech editor Praat.

2.2. Acoustic measurements

Five acoustic measurements were done on each stimulus. VOT, the amplitude difference between the first and second harmonic (H1-H2), fundamental frequency (F0), Relative Burst Energy, and vowel duration were determined.

VOT was measured from the beginning of the release burst to the onset of the first full glottal pulse in the vowel. Note that this method is similar to that of [7], but differs from that of [2], who measured VOT from stop release to the voice onset of the second formant, thus including breathy voicing in the VOT. Here, breathy voicing was not included in the VOT, but in the duration of the following vowel, which was therefore also analyzed. (Note that, in contrast to [7], there were no negative VOTs in the present materials.)

H1-H2: Energy values (dB) for the first (H1) and the second (H2) harmonics were measured at the onset of the vowel. A Gaussian window was centered around the first full glottal pulse in the waveform and a narrow-band FFT spectrum of 25 ms was calculated. For each stimulus, H2 was subtracted from H1 to obtain a measure of voice quality, with larger values indicating more breathy voicing and smaller values more creaky voicing. Measures were taken at vowel onset rather than vowel midpoint, as in [7], because the differences among the stop categories have been shown to be larger at vowel onset than midpoint [2].

F0 was taken at the midpoint of the vowel by measuring the first harmonic from a narrow-band FFT spectrum, using a Gaussian window of 25 ms. The pitch track was used as a supplementary check, but the former measure was always decisive; differences between the two measurements were found to be negligible. F0 was also measured at vowel onset, but as noted by [7], for fortis stops, F0 could often not be measured reliably there, due to the irregular glottal pulses associated with creaky voicing. Therefore, those measurements were not further analyzed.

Relative Burst Energy: Acoustic energy (Pa^2) was measured from a 10 ms window at the release burst and at the temporal midpoint of the vowel. Following [2], the Relative Burst Energy was calculated as the percentage of the energy at the burst relative to the energy at the vowel midpoint.

Vowel Length: The duration of the vowel following the stop was measured from the first full glottal pulse to the end of periodicity in the waveform. As breathy voicing was included in the Vowel Length, vowels were expected to be longer after lenis stops than after the other two stops.

3. Results and Discussion

Figures 1-5 show the means of the acoustic measurements for each phoneme separately. Analyses of Variance (ANOVAs) were done with acoustic measures as dependent variable, and with Category (i.e., lenis, fortis, aspirated) and Context (i.e., following vowel) as independent variables. For each acoustic measure and for each place of articulation, a separate ANOVA was done. All analyses showed a significant main effect of Context and a significant interaction between Category and Context (all with $p < .01$) that are not further discussed here. Main effects of Category are reported in Table II.

Bilabials	
VOT	F (2, 357) = 491.1, $p < .001$
H1-H2	F (2, 357) = 249.7, $p < .001$
F0	F (2, 357) = 69.2, $p < .001$
Relative Burst Energy	F (2, 357) = 1.7, $p > .1$
Vowel Length	F (2, 357) = 30.5, $p < .001$
Denti-alveolars	
VOT	F (2, 347) = 285.7, $p < .001$
H1-H2	F (2, 347) = 159.4, $p < .001$
F0	F (2, 347) = 3.4, $p < .05$
Relative Burst Energy	F (2, 347) = 23.8, $p < .001$
Vowel Length	F (2, 347) = 8.0, $p < .001$
Velars	
VOT	F (2, 347) = 1071.2, $p < .001$
H1-H2	F (2, 347) = 61.9, $p < .001$
F0	F (2, 347) = 81.3, $p < .001$
Relative Burst Energy	F (2, 347) = 28.3, $p < .001$
Vowel Length	F (2, 347) = 18.0, $p < .001$

Table II. *Main effects of Category (lenis, fortis, aspirated) for the five acoustic measures.*

Bonferroni posthoc tests for Category further revealed the following patterns (with $p < .01$, unless stated otherwise).

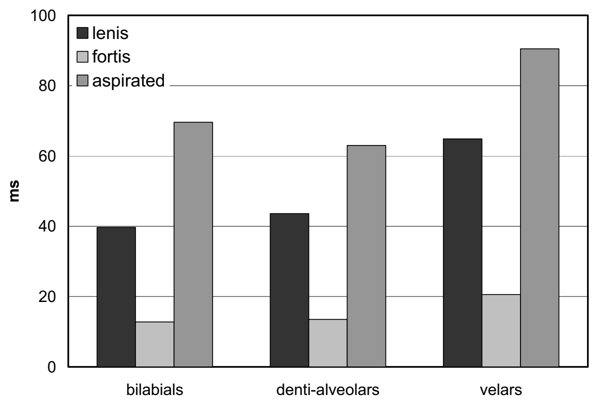

Figure 1: *Voice Onset Time.*

VOTs were longest for aspirated stops, intermediate for lenis stops, and shortest for fortis stops, with significant differences among all three Categories, at all places of articulation, in line with previous studies [e.g., 2, 7, 8, 9, 10].

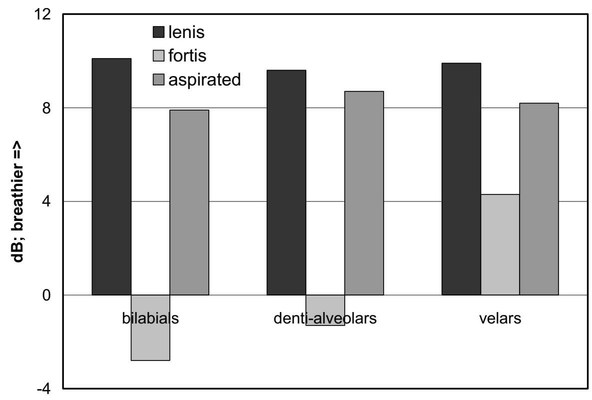

Figure 2: *H1-H2.*

H1-H2 was largest for lenis, intermediate for aspirated, and smallest for fortis stops. The difference between lenis and aspirated denti-alveolars, however, did not reach significance. The results are fully in line with [2], and for the lenis and fortis stops also with [7]. The results for the aspirated stops differ from [11] and [7], who found that H1-H2 was larger for aspirated than for lenis stops.

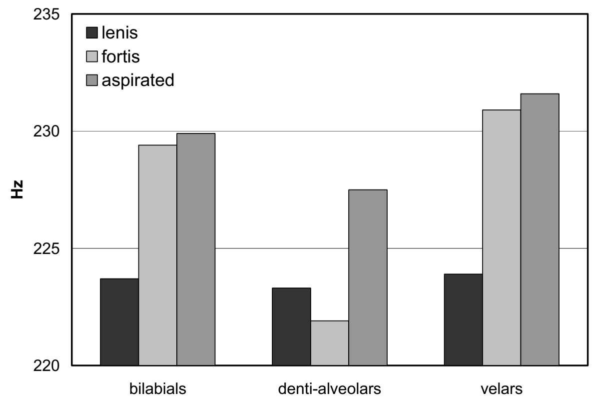

Figure 3: *F0.*

For bilabials and velars, F0 was lower for lenis stops than for the other two stop categories, in line with previous studies [2, 7, 9, 12], and there were no significant differences between the fortis and aspirated stops, in contrast with [7] but in line with [2]. For the denti-alveolar stops, on the other hand, lenis stops did not significantly differ from the other two. There, on the other hand, F0 was higher for aspirated than fortis stops (with p < .05), in line with [7], and there were no other significant differences.

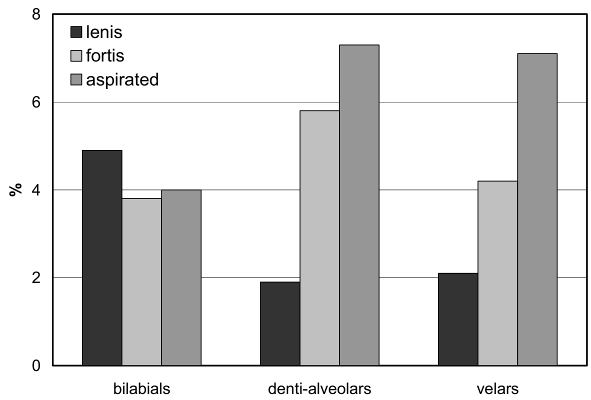

Figure 4: *Relative Burst Energy.*

The results for Relative Burst Energy were more variable. Relative Burst Energy did not significantly differ among the bilabial stops. For the velars, it was largest for aspirated stops, intermediate for fortis stops, and smallest for lenis stops, with significant differences among all three categories. For the denti-alveolar stops, the pattern was similar but now there was no significant difference between aspirated and fortis stops. The results are partially similar to those by [2], but there are also some interesting differences. [2] found that Relative Burst Energy was generally greater for aspirated stops than for lenis and fortis stops. This pattern was not replicated here for the bilabials. [2] also found a non-significant tendency of Relative Burst Energy being larger for lenis than for fortis stops. Although this tendency varied strongly between speakers, it is interesting to note that in the present data, the results showed a reverse pattern, with larger values for the fortis than for the lenis stops for the velars (and, non-significantly, for the denti-alveolars). Differences between the present results and those of [2] might be partially due to the strong variation among speakers [2], and partially to the separate versus joint analysis of the three places of articulation.

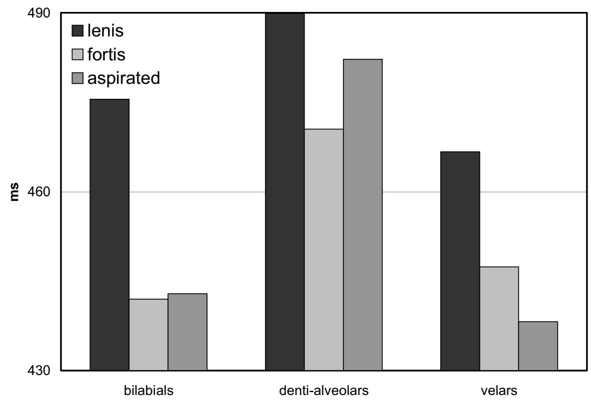

Figure 5: *Vowel Length.*

Vowel Length was larger after lenis stops than after the other two stops for bilabials and velars, as expected. For denti-alveolar stops, Vowel Length was smaller after fortis stops than after the other two stops, and there were no other significant differences.

All acoustic measures thus varied significantly with the lenis, fortis, and aspirated stop categories at almost all places of articulation (with the one exception of Relative Burst Energy for the bilabial stops). Result patterns for some acoustic measures differed for the three places of articulation.

To further assess the relative strength of the acoustic properties, multiple regression analyses (Method Stepwise) were done for each contrast at each place of articulation separately, with the five acoustic measures as predictors and Category as independent variable. The multiple regression analyses thus indicate which of the acoustic measures distinguish best between the two phonemes of each contrast, taking into account that the acoustic measures are often correlated with one another. If an acoustic measure is not included in the final regression model, that does not imply that the measure does not differ for the two phonemes, but only that other cues differentiate them better.

Table III shows which predictors were included in the final regression models, in order of their relative importance in those models (with a larger Beta value, either positive or negative, indicating greater importance). The informativeness of the five perceptual cues across all contrasts, judging from the number of models they were included in and their ranking in those models, ranged from VOT to H1-H2, F0, Relative Burst Energy, and Vowel Length. However, results differed widely both for contrast type and for place of articulation.

VOT was the best predictor for all types of contrasts and all places of articulation, with the single exception that it was the second best predictor for the bilabial lenis-fortis contrast. H1-H2 was the second best predictor for all fortis-aspirated contrasts and for the denti-alveolar lenis-fortis contrasts, and the best predictor for the bilabial lenis-fortis contrasts. F0 was the second or third predictor for all aspirated-lenis contrasts, and for the bilabial lenis-fortis contrast. Relative Burst Energy was the second or third predictor for all denti-alveolar contrast types, and for the velar aspirated-lenis contrast. Vowel Length was the fourth and second predictor, respectively, for the denti-alveolar fortis-aspirated contrast and for the velar lenis-fortis contrast.

All acoustic measures were included in the regression models for at least two types of contrasts and at least two places of articulation, showing that all five measures distinguished between the Categories of multiple types of contrasts and at multiple places of articulation, in line with the expectations. The role of the acoustic cues differed, however, for the three types of contrasts and, importantly, also for the three places of articulation.

4. Conclusions

In previous studies on Korean lenis, fortis, and aspirated stop consonants, acoustic measurements have often been collapsed over bilabial, denti-alveolar, and velar place of articulation. In the present study, separate analyses of the stop contrasts at the three places of articulation showed that the acoustic characteristics of the stops and the relative importance of the acoustic measures for distinguishing between the stops differed substantially depending on place of articulation.

5. Acknowledgments

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6. References

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Contrast	**Predictors**	**Beta**	***p*** **<**	**F test**	**Adjusted R^2**
Bilabials					
Lenis – Fortis	H1-H2 VOT F0	+.589 +.411 -.116	.001 .001 .01	F (3, 119) = 182.4, p < .001	.821
Fortis – Aspirated	VOT H1-H2	-.748 -.267	.001 .001	F (2, 117) = 390.8, p < .001	.870
Aspirated – Lenis	VOT F0	+.518 +.418	.001 .001	F (2, 119) = 74.6, p < .001	.553
Denti-alveolars					
Lenis – Fortis	VOT H1-H2 Relative Burst Energy	+.515 +.273 -.138	.001 .001 .05	F (3, 113) = 49.6, p < .001	.563
Fortis – Aspirated	VOT H1-H2 Relative Burst Energy Vowel Length	-.773 -.240 -.138 -.118	.001 .001 .001 .01	F (4, 113) = 140.8, p < .001	.832
Aspirated – Lenis	VOT Relative Burst Energy F0	+.419 +.366 +.158	.001 .001 .05	F (3, 119) = 20.9, p < .001	.334
Velars					
Lenis – Fortis	VOT Vowel Length	+.858 +.171	.001 .001	F (2, 113) = 203.9, p < .001	.782
Fortis – Aspirated	VOT H1-H2	-.982	.001 .05	F (2, 113) = 685.7, p < .001	.924
Aspirated – Lenis	VOT F0 Relative Burst Energy	+.596 +.408 +.141	.001 .001 .05	F (3, 119) = 69.5, p < .001	.633

Table III. *Multiple regression models for lenis-fortis, fortis-aspirated, and aspirated-lenis contrasts. (Beta: + or – sign indicates positive or negative correlation with the first phoneme.)*