Closure Duration and Pitch as Phonetic Cues to Korean Stop Identity in AP Medial Position: Production Test*

Hyunsook Kang · **Laura Dilley*****

ABSTRACT

The present study investigated some phonetic attributes which distinguish two Korean stop types -aspirated and lax- in a prosodic position which has previously received little attention, namely medial in an accentual phrase. The intonational pattern across syllables which are initial in an accentual phrase (Jun, 1993) is said to depend on the type of stop (aspirated or lax), while that of syllables which are medial in an accentual phrase are not. In Experiment 1, nine native Korean speakers read sentences with a controlled prosodic pattern in which aspirated or lax stops occurred in accentual phrase-medial position. Acoustic analysis revealed significant differences between aspirated and lax stops in closure duration, voice-onset time, and fundamental frequency (F0) values for post-stop vowels. The results indicate that a wider range of acoustic cues distinguish aspirated and lax Korean stops than previously demonstrated. Phonetic and phonological models of consonant-tone interactions for Korean will need to be revised to account for these results.

Keywords: Korean aspirated and lax consonants, intonational pattern, medial in an accentual phrase

1. Introduction

Among the world's languages, Korean is notable for distinguishing not only three places of stop articulation but also three manners of articulation, termed lax, aspirated, and tense (or fortis), giving rise to nine voiceless stops (<Table 1>) (Lisker & Abramson, 1964; Kim, 1965, 1970; Han & Weitzman, 1970). Understanding the phonetic cues that distinguish Korean stops is complicated by the fact that prosodic structure has been shown to affect stop consonant realization (Jun, 1993, 1995; Han, 2000; Cho & Keating, 2001). For example, <Tables 2 and 3> present stop contrasts in word-initial and word-medial position. The present research addresses

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** Hanyang University

*** Bowling Green State University

some gaps in knowledge concerning the realization of two Korean stop types -aspirated and lax- and how they vary with prosodic structure in continuous, spoken Korean utterances.

Table 1. Stops in Korean

	Bilabial	Dental	Velar
Lax	p	t	k
Tense	P	T	K
Aspirated	p^h	t^h	k^h

Table 2. Example lexical items with stops in word-initial position

	Bilabial	Dental	Velar
Lax	pul 'fire'	tam 'fence'	kaŋ 'river'
Tense	Pul 'horn'	Tam 'sweat'	Kori 'tail'
Aspirated	p^hul 'grass'	t^ham 'greed'	k^hal 'knife'

Table 3. Example lexical items with stops in word-medial position

	Bilabial	Dental	Velar
Lax	apəci 'father'	kita 'to crawl'	aki 'baby'
Tense	oPa 'brother'	kwiTurami 'cricket'	aKita 'be precious'
Aspirated	ap^{h}ɨta 'be sick'	Kat^{h}uri 'hen pheasant'	sok^{h}uri 'bamboo basket'

Three phonetic variables have previously been demonstrated to distinguish Korean stops in some prosodic positions. First, voice-onset time (VOT) is generally longer for aspirated stops compared to lax stops, and longer for lax stops compared to tense stops (cf. Lisker & Abramson, 1964; Kim, 1965, 1970; Han & Weitzman, 1970). However, VOT ranges for different manners of articulation often overlap (Lisker & Abramson, 1964; Kim, 1965, 1970; Silva, 1992, in press; Park, 2002).

A second factor which has been shown to be important in distinguishing Korean stops is F0. The F0 levels of vowels following aspirated and tense stops are higher than those of vowels following lax stops (Han & Weitzman, 1970; Hardcastle, 1973; Jun, 1993; Ahn, 1999). Moreover, Korean listeners can use these F0 differences to distinguish stop contrasts (Han & Weitzman, 1970 etc.). While voiceless consonants in general raise the F0 of vowels in post-consonantal position (Lehiste & Peterson, 1961; Liberman, 1963; Ladefoged, 1964; Hombert, 1978), a number of researchers have confirmed that for Korean, differences in F0 observed among different stop types across the post-stop vowel cannot be explained solely by segmental effects in the vicinity of the stop release (Jun, 1993; Ahn, 1999). This suggests that F0 across post-stop vowels is determined in large part by prosodic structure, a point to which we return shortly.

Third, closure duration differences have been reported in several studies in productions of aspirated, tense, and lax stops. Lax stops have the shortest closure duration, while tense stops have the longest closure duration (more than twice that of lax stops word-medially) (Silva, 1992; Han, 1996). Moreover, aspirated stops have a closure duration which is intermediate between that of tense and lax stops. In addition, closure duration is used in perceptually distinguishing among stop types. In particular, shortening word-medial intervocalic closure durations for tense stops leads them to be perceived as lax, while lengthening word-medial intervocalic closure durations of lax stops leads them to generally be perceived as tense (Han, 1996; Kang & Kang, 2006).

Recent work has shown that the phonetic attributes of Korean stops can vary depending on their positions within prosodic constituents (Jun, 1993, 1995; Cho & Keating, 2001). Prosodic structure in Korean is generally held to consist of multiple embedded levels (Jun, 1993; Pierrehumbert, 1980; Beckman & Pierrehumbert, 1986). From the largest to the smallest constituent, these are the intonational phrase (IP), an accentual phrase (AP), or a prosodic word (PW). Building on this characterization of Korean prosody, recent work has shown that voice-onset time (VOT) differs depending on whether stops are positioned at the onset of an intonational phrase (IP), an accentual phrase (AP), or a prosodic word (PW) (Jun, 1993, 1995; Han, 2000; Cho & Keating, 2001). Moreover, for some prosodic contexts, F0 differences are stronger perceptual cues to stop contrasts than VOT differences (Kim, Beddor & Horrocks, 2002).

In spite of that, relatively little is known about variation in Korean stop consonants in some prosodic positions, particularly medial in an AP. In the present research, we investigated how two phonetic attributes of Korean stops, F0 and closure duration, vary in production in AP-medial position. There were two primary aims of this work. The first was to test some assumptions of phonological theory regarding how F0 varies with prosodic structure across two stop consonant types. The second was to present a fuller picture of how phonetic attributes of Korean stops vary with prosodic structure. In the following, we present background on how F0 has been claimed to interact with stop consonant identity across prosodic positions. We then discuss how the present work investigated additional phonetic cues to stop consonant identity and how they are affected by prosodic structure.

The tonal properties, and hence the F0 characteristics, of stop-initial syllables in Korean are held to depend on their position within the AP, which is generally assumed to be the basic unit of Korean intonational structure. According to Jun (1993), an AP is defined by a sequence of four tones, $[T_1H_2..L_{n-1}H_n]$. The first tone, T_1, coincides with the first syllable in the AP. Like a number of other languages of the world, Korean shows an interaction between the type of consonant and the tone across the syllable (Bradshaw, 1999). In particular, if the initial word in an AP begins with a tense or aspirated consonant the first syllable in this AP will have a high tone. On the other hand, if the initial word begins with a lax stop or other segment, the first syllable in the AP will have a low tone. In contrast, the F0 in positions other than AP-initial position is assumed not to be affected by the type of stop consonant. For example, the second tone, which is a High tone, is assumed to be assigned to the second syllable in the phrase and hence to be realized with an F0 maximum whose absolute value should be unaffected by the type of stop consonant. The third tone, Low, is assigned to the penultimate syllable in the phrase; this syllable is expected to realize an F0 minimum. Next, the fourth tone, which is High, is assigned to the final syllable in the phrase. Finally, any medial syllables occurring between the High tone on the second syllable and the Low tone on the penultimate syllable are predicted to show phonetic interpolation between the High and the Low.

The first aim of the present research was therefore to test the claim that the F0 in positions other than AP-initial position are not affected by the type of stop consonant. Perhaps surprisingly, previous work demonstrating that the F0 levels of vowels vary systematically with different Korean stop onset types has exclusively examined such effects only for stop consonants in AP-initial position. Given recent findings that position of stops within prosodic structure affects other phonetic variables, such as VOT (Jun, 1993, 1995; Han, 2000; Cho & Keating, 2001), it is informative to examine whether differences in F0 may indeed exist, perhaps in diminished form, in other positions in Korean prosodic structure. If speakers produce and listeners perceive F0 differences among contrastive stops in non-initial position in AP's, it would suggest the need to revise the phonological description of Korean prosodic structure and its interaction with consonants.

A second aim of the present research was to investigate how an additional phonetic variable, namely closure duration, varies in AP-medial position. While previous research has established a role for closure duration in distinguishing among some stop types, gaps remain in knowledge of the effects of this variable on stop perception and how this may covary in production with prosodic structure.

To address these issues, Experiment 1 investigated the consistency with which speakers use closure duration and F0 differences to signal the distinction in production between aspirated and lax stops in AP-medial position. If talkers produce F0 and closure duration differences consistently in distinguishing between Korean stops, it will highlight the need for revisions.

2. Experiment

2.1 Methods

Subjects. Nine native speakers of Seoul Korean (two males, seven females) participated in the production study. Four of these talkers were graduate students at the Ohio State University who had been in America less than 4 years at the time of recording. The remaining five speakers were students at Hanyang University in Korea. All participants were naïve to the purposes of the study.

Materials. Our goal was to examine the characteristics of aspirated vs. lax stop consonants within particular prosodic positions in order to evaluate some claims of prosodic theory. Therefore, two sets of sentences were constructed which differed in (1) length, in order to elicit different numbers of prosodic units (AP's) produced by talkers, as well as (2) position of the stop consonant within an AP. Text A consisted of similar short sentences of six syllables: *ike Vtaneyo* or *ike Vt^{h}aneyo,* where *V* was *a, e, i, o,* or *u.* The translation was *This is an "at(^{h})a" at(^{h})aneyo* is an AP consisting of a nonsense word *at(^{h})a*-followed by a suffix *-neyo.* It was expected that talkers would naturally produce the final four of six syllables as a single AP, where the initial three syllables of this AP began with an LHL tonal sequence.[1] Moreover, Text B consisted of similar, long sentences with embedded stop-initial nonce words *tanari* or *t^{h}anari,* which participants were told corresponded to types of animals. Substituting *tanari,* the sentence was *əje CəŋV tanari-ka YəŋV tanari, KyəŋV tanari-ril towassəyo,* where V corresponded to *a, e, i, o,* or *u. CəŋV, YəŋV,* and *KyəŋV* corresponded to proper names. The sentence is translated as e.g. "It was the tanari named *CəŋV* which helped the tanari named *YəŋV* and the tanari named *KyəŋV* yesterday."[2] These sentences consisted of both five-syllable [*YəŋV* tanari] and six-syllable phrases [*CəŋV* tanari-ka, *KyəŋV* tanari-ril], which will be referred to here as "t(^{h})anari-phrases." These embedded t(^{h})anari-phrases were constructed in order to investigate phonological claims regarding the characteristics associated with "interpolation" of the F0 contour across aspirated vs. lax stops between a phonological H tone and the phonological L tone. The H tone occurred on each *-V* and the L tone occurred on *na-* if the phrase was 5 syllables long or on *ri-* if the phrase was 6 syllables long.

The type of vowel preceding the target stop consonant was varied in both sets of sentences for two reasons. First, we wished to reduce or eliminate possible effects of the intrinsic F0 of the preceding vowel on stop identification by providing multiple vowel contexts. Second, varying the vowel context across sentences served as a distractor manipulation intended to increase the likelihood that talkers would not focus on the tonal pattern in producing sentences.

Procedure. Talkers were recorded in a quiet environment at Ohio State University or at Hanyang University in Korea. At Ohio State University the utterances were recorded in a

1) The exact tonal composition of the last syllable depended on the semantic interpretation of the sentence. In particular, talkers produced these sentences in one of the following ways. First, if the talker produced the utterance as a declarative, either L or HL tone pattern was produced. Second, if the talker interpreted an utterance as question, then a H tonal pattern was produced.

2) Literally, the sentence was "Yesterday Cəŋ*V* t(^{h})anari-subject marker *YəŋV* t(^{h})anari, *KyəŋV* t(^{h})anari-object marker helped".

sound-attenuated booth using a Shure SM10A head-mounted microphone connected to a Symetrix 302 preamplifier. At Hanyang University the same utterances were recorded in a quiet office at Hanyang University in Korea using a Sennheiser 835S microphone. In either case, the speech was digitized on a PC running Praat software (Boersma & Weenink, 2002) using a 22.05 kHz sampling rate. For Text A materials, talkers were simply asked to read the sentences; no instruction was given regarding the meaning of the sentence or the tonal pattern to be produced. For Text B materials, the intended meaning of the sentence was explained to subjects, both in order to clarify the meaning given the presence of nonsense words in the utterance, as well as to facilitate production of the desired tonal pattern. In addition, some subjects were asked to pronounce an example sentence with similar syntactic structure, which was *"əje aki taramCwi-ka əmma taramCwi, aPa taramCwi-ril towassəyo"* ("It was baby squirrel that helped mommy squirrel and daddy squirrel yesterday"). Subjects were given no direct coaching regarding the type of tonal pattern to be produced. However, the sentence was spoken by one of the authors (H. Kang) with an *undesired* tonal pattern, one in which the last four syllables of each six-syllable phrase were pronounced with an [LHLH] pattern for *tanari-ril* or a [HHLH] pattern for *t^hanari-ril,* which clearly makes the second part of the phrase its own AP structure. Subjects were instructed to avoid this pattern, and the intended meaning of each sentence was re-emphasized. One phonetically sophisticated subject who was a linguistics graduate student was told "to pronounce AP's as AP's" with the meaning indicated above, but was given no further instruction about the nature of the tonal pattern; this subject, like the others, was naïve to the purposes of the experiment. Most subjects did not show any difficulty in producing the appropriate sentences with the desired pattern.

Talkers read each sentence five times, with the exception of two talkers (JL and EK), who read sentences three times. For all talkers, the first three renditions of each sentence served as the basis for the analysis. In total, 310 sentences (5 vowel contexts * 2 consonant types * 3 repetitions * 9 speakers) were analyzed for long and short sentence types, respectively.

Analysis. Subjects' productions were examined for the target intonational structures. In particular, we determined whether for Text B sentences subjects produced exactly one AP across each separate *t(^{h})anari*-phrase.[3] Of nine talkers, three failed to produce the desired AP structure, precluding an examination of stop consonants in AP-phrase-medial position. Of these three talkers, one was re-recorded after explaining the intended semantic content of the

3) In particular, it was necessary for subjects to produce a single AP across every t(h)anari-phrase in the sequence: *CəŋV tanari-ka, YəŋV tanari, and KyəŋV tanari-ril.* Phrases were judged to be produced with an undesired tonal pattern if either the first two syllables or the last two syllables of the phrase failed to show an F0 minimum followed by an F0 maximum. Across the seven talkers, an average of 4% of *t(^{h})anari*-phrases were discarded for failing to meet these criteria (range: 0-11%).

sentence to the talker.[4] The last two speakers' tokens were discarded.

For both Text A and Text B sentences, the onsets and offsets of vowels and consonants in each target word were identified and marked using a spectrogram display in Praat software. Based on these spectral landmarks, closure durations, VOTs, and F0 values were automatically extracted; F0 values were then hand-corrected for pitch-halving due to non-modal voicing. F0 measurement points for Text A sentences included the following. First, Text A materials were produced with a pattern which began in phonological terms with LH... across *Vta-* or *Vt^{h}a-*. Thus the F0 minimum in the initial *V* in *Vtaneyo* or *Vt^{h}aneyo* was taken as an indication of the L; measurements were not taken in the vicinity of the extreme right edge of the vowel, so as to avoid segment-related F0 obtrusions (Lehiste, 1970). Moreover, the F0 value 60 msec from the stop release was taken as an indication of the H, so as to further avoid segmental effects (Hombert, 1978). In addition, to determine the direction of the F0 contour following the phonological H, we measured the F0 value at the midpoint of *-ne* in each word. Finally, to determine how much the F0 was locally raised at the release of the aspirated or lax stop, the duration of the first pitch period for *ta-* or *t^{h}a-* was measured. The pitch period selected was the first one which visually showed the shape characteristics and periodicity of the modal pattern which had been established after startup of voicing.

Next, Text B sentences were produced with an LH across each instance of *CəŋV*, *YəŋV*, or *KyəŋV*, followed by a falling F0 pattern across *tanari* or *t^{h}anari*. For these sentences, F0 estimates were taken at various points in this speech as an estimate of (1) the F0 values associated with the phonological L and H, as well as (2) the F0 values associated with the falling F0 contour across *tanari* vs. *t^{h}anari*. First, we measured the minimum F0 value of *CəŋV*, *YəŋV*, or *KyəŋV* as an indication of the L tone in each case. Moreover, the maximum F0 in the second syllable of *CəŋV*, *YəŋV*, and *KyəŋV* where V was *a, e, i, o* or *u*, was measured, which was taken as an indication of the H tone; measurements were not taken at the extreme right edge of the vowel so as to avoid segmental F0 effects. Next, an estimate of the F0 associated with *ta-* or *t^{h}a-* was taken at a point 60 ms after the stop release, again to avoid segmental effects (Hombert, 1978).[5] Moreover, the F0 at the midpoint of the vowel of the syllable *-na* in *tanari* or *t^{h}anari* was measured as an indication of the overall F0 trajectory between phrasal H and L tones. Finally, the duration of the first pitch period for *ta-* or *t^{h}a-* was measured in order to estimate how much

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4) To aid the subject in producing the desired intonation pattern, the subject was told that the *t(^{h})anari* that helped other *t(^{h})anaris* was CəŋV (the *tanari's* name), where *CəŋV* was emphasized. Likewise, it was emphasized that the names of *tanaris* that were helped were *YəŋV* and *KyəŋV*, not any other *tanaris*.

5) Due to speaking rate differences affecting vowel durations, a minority of F0 estimates of *ta-* and *t^{h}a-* taken 60 ms after the burst release corresponded to points just after the vowel offset, near the onset of the following /n/. The average number of such cases across talkers was 15% (by talker: KAY, 2%, EK, 3%; LJH, 8%, KJK 10%, HJL 15%, JL 23%, JWH 43%.)

the F0 was locally raised at the stop release due to segmental effects. From these values, several derivative measures were calculated, including differences and ratios of F0 values.

Given that relations among F0 values, rather than absolute values, are most likely to convey the communicative value of pitch, we also calculated relative F0 values. Given conflicts in the literature regarding how relative F0 should be calculated (see e.g., Pierrehumbert & Beckman, 1988; Nolan, 2003; Dilley, 2005), two different methods were used: (1) a linear difference measure in Hz between F0 values, and (2) a ratio of F0 values. We were interested in which metric resulted in greater consistency across talkers, where the more consistent measure is more likely to be the relational cue actually used in communication. To address consistency across talkers, we therefore calculated the normalized standard deviation (NSD), equal to the standard deviation divided by the absolute value of the mean; this metric gives the relative scatter in data with respect to the mean.

2.2 Results

Closure duration. For Text A materials, the average closure durations for lax and aspirated stops were 48 ms (n = 105) and 110 ms (n = 105), respectively ($p < .0001$, $t = -19.22$, df = 6). For Text B materials, the average closure durations for lax vs. aspirated stops were 38 ms (n = 299) and 66 ms (n = 308), respectively ($p < .0001$, $t = -10.75$, df = 6).

VOT. For Text A materials, the average VOT values for lax vs. aspirated stops were 14 ms (n = 105) and 38 ms (n = 105), respectively (p < .004, t = -4.58, df = 6). For Text B materials, the average VOT's across talkers for lax and aspirated stops was 16 ms (n = 298) and 39 ms (n = 308), respectively ($p < .0001$, $t = -7.65$, df = 6).

Fundamental frequency. Figure 1 shows average F0 values for absolute F0 values taken at different measurement points for Text A materials for sentences containing lax vs. aspirated alveolar stops: (1) the F0 minimum for the L tone associated with the initial *V* in *Vtaneyo* or *Vt^{h}aneyo*(L); (2) the F0 of the initial pitch period after the burst release (burst): (3) the F0 during the H-toned syllable, *ta-* or *t^{h}a-* (H *ta-/t^{h}a-*), and (4) the F0 at the midpoint of *ne-* (*ne-*). The F0 values at the burst and H *ta/t^{h}a-* measurement points were significantly different from one another for sentences containing lax vs. aspirated stops, but no other points (burst: $p < .05$, t = -3.034, df = 6; H: p < .01, t = -4.220, df = 6; L: p = .33, t = 1.067, NS; *ne-*: $p = .92$, t = -0.105, NS). Figure 2 shows average F0 values for several measurement points for Text B materials for sentences containing lax vs. aspirated alveolar stops: (1) the F0 minimum for the L tone associated with *Cəŋ, Yəŋ*, or Kyəŋ (L); (2) the maximum F0 during V for the phonological H tone (H); (3) the F0 of the initial pitch period after the burst release (burst); (4) the F0 during the syllable containing the lax or aspirated consonant 60 msec after the burst release (ta-/t^{h}a-), and (5) the F0 at the midpoint of na- (na-). The F0 values at the burst, in the syllable containing the stop (ta- or t^{h}a-), and during na- were significantly different from one another for sentences containing lax vs. aspirated stops, but no other points (L: $p = .06$, $t = 2.312$, NS; H: $p = .10$, $t = -1.954$, NS; burst: $p < .005$, $t = -4.501$, $df = 6$; ta-/tʰa-: $p < .005$, $t = -5.331$, $df = 6$; na-: $p < .005$, $t = -5.589$, $df = 6$).

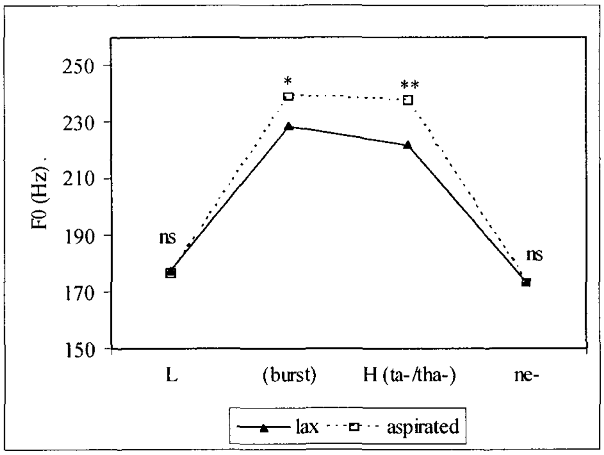

Figure 1. Average F0 values at four measurement points for seven talkers for Text A sentences containing lax vs. aspirated alveolar stops. These measurements were taken during the syllable with a phonological low tone (L), at the first pitch period after the alveolar stop release (burst), during the syllable with a phonological high tone (H), and during the following post-high syllable (*-ne*).

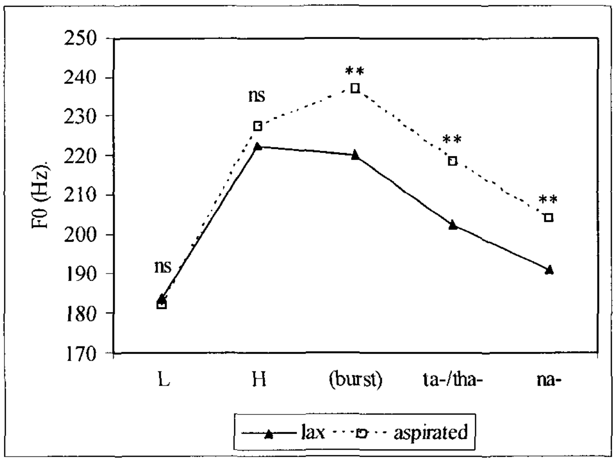

Figure 2. Average F0 values at five measurement points for seven talkers for Text B sentences containing lax vs. aspirated alveolar stops. These measurements were taken during the syllable with a phonological low tone (L), during the syllable with a phonological high tone (H), at the first pitch period after the alveolar stop release (burst), during the vowel following the alveolar stop (ta-/tʰa-), and during the following syllable (na-).

To further investigate which F0 cues might be relevant to stop identification, we examined two types of relational F0 values among the measurement points described above. <Tables 4 and 5> give relational F0 data for Text A and Text B sentences, respectively.

Table 4. Mean differences and ratios of F0 values at different measurement points in Text A sentences, for utterances containing lax vs. aspirated consonants. L and H indicate the F0 values associated with the first and second syllables of the phrase *Vtaneyo* or *Vt^h^aneyo*. Normalized standard deviations are given in parentheses. See text for further explanation.

	(a)	(b)	(c)		(d)	(e)	(f)
Difference	lax	aspirated	Significant?	Ratio	lax	aspirated	Significant?
H-L	44.2 (.27)	61.0 (.19)	$p < .01$ $t = -4.58$	H/L	1.25 (.06), *	1.34 (.05), *	$p < .01$ $t = -4.96$

Table 5. Mean differences and ratios of F0 values at different measurement points in Text B sentences, for utterances containing lax vs. aspirated consonants. L, H and stop indicate F0 values associated with the first, second, and third syllables in phrases like *CəŋV tanari-ka* or *t^h^anari-ka*. Normalized standard deviations are given in parentheses. See text for further explanation.

	(a)	(b)	(c)		(d)	(e)	(f)
Difference	lax	aspirated	Significant?	Ratio	lax	aspirated	Significant?
H-L	38.9 (.34)	45.4 (.29)	$p < .05$ $t = -2.87$	H/L	1.21 (.07),**	1.25 (.08),**	$p < .05$ $t = -3.06$
stop - H	-20.1 (.40)	-9.1 (1.94)	$p < .005$ $t = -5.71$	stop/H	0.91 (.03),*	0.96 (.04),ns	$p < .001$ $t = -6.91$
stop - L	18.7 (.36)	36.3 (.63)	$p < .005$ $t = -6.46$	stop/L	1.10 (.07),**	1.20 (.07),**	$p < .001$ $t = -8.63$

Columns (a) and (b) in these tables give mean F0 differences in Hz across talkers, while columns (d) and (e) give mean ratios of F0 values. In addition, columns (c) and (f) show significance in data comparing lax vs. aspirated stops for the corresponding F0 differences and ratios, respectively; the fact that all relational measures are statistically different suggests that these measures convey reliable relational differences between aspirated vs. lax stops. Moreover, the normalized standard deviation (NSD) is listed in parentheses below each mean relational value (difference or ratio). NSD's for which the mean ratio (e.g., H/L) was significantly less variable than the corresponding mean difference (e.g., H-L) in a two-tailed test are marked with "*" ($p < .01$) or "**" ($p < .001$), respectively. The fact that F0 ratios uniformly showed more consistency than F0 differences suggests the usefulness of this measure in expressing relations among F0 values; based on this result, we plotted a histogram of the relative proportion of F0 ratios for aspirated vs. lax stops (<Figure 3>).

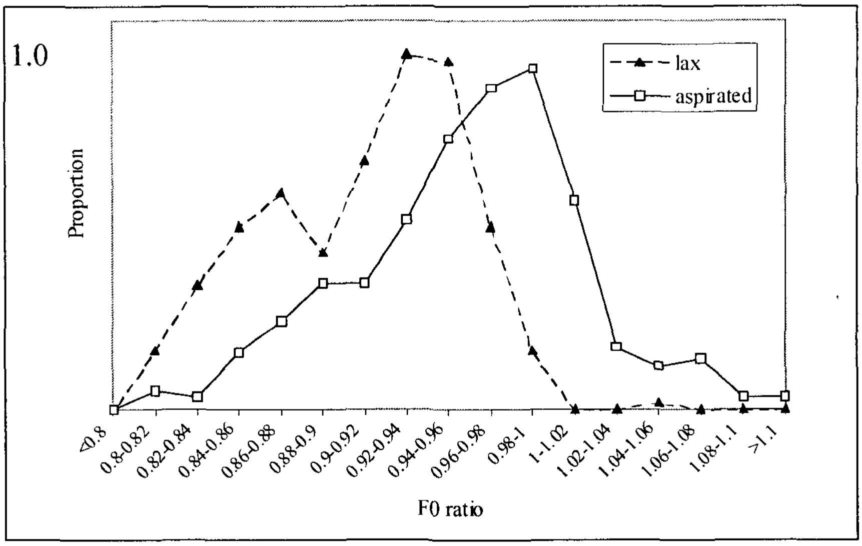

Figure 3. Histogram showing the relative proportion of ratios of F0 measurements on *ta-* or *t^ha-* vs. on the H-toned *V* of *CəŋV/ YəŋV/ KyəŋV* for aspirated vs. lax stops.

3. Conclusion

This production study reveals several noteworthy results. One finding was that aspirated stops showed longer closure durations and VOT's compared to lax stops, as expected. Another finding concerned three sorts of F0 differences that are not predicted under existing phonological accounts of Korean phonetics and phonology. First, analysis of Text A materials revealed that syllables that were assigned a phrasal H tone had a higher F0 if they began with an aspirated stop than if they began with a lax stop. Second, analysis of Text B materials revealed that the F0 levels of stop-initial syllables occurring between syllables assigned phrasal H and L tones were affected by whether the stops were aspirated or lax. Third, a histogram revealed partial separation of lax vs. aspirated stops when ratios of F0 measurement points were plotted, suggesting that F0 might be productively used as a phonetic cue in distinguishing these stops. Finally, the fact that relations among F0 values show more consistency across talkers when expressed as a ratio than as a simple frequency difference in Hz is consistent with the view that the relevant phonetic F0 cue to linguistic and semantic distinctions is a ratio of frequencies (Dilley, 2005). These three sorts of differences obtained even though measurement points occurred later than onset F0's associated with segmental perturbations

(Silverman, 1986; Whalen, Abramson, Lisker, & Mody, 1990), suggesting that these differences in the F0's of aspirated and lax stops arose from the intonational component of Korean prosodic structure. These facts cannot be accounted for by current Korean prosodic theories.

In summary, the present study demonstrated that speakers use pitch to differentiate between aspirated and lax stops in AP-medial position. These results are not predicted under current intonational phonological theories. These findings have implications for the understanding of morphological processes in Korean.

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▲ Hyunsook Kang
Division of English Language and Culture
Hanyang University
Sa-1 dong, Sangnok-gu, Ansansi, Kyunggi-do, Korea, 426-791
Tel: +82-31-400-5348
E-mail: hskang@hanyang.ac.kr

▲ Laura Dilley
Department of Psychology
Bowling Green State University
Bowling Green, OH 43403
Tel: +1-419-372-4307
E-mail: dilley@bgsu.edu