Ongoing sound change in the stop system of Korean: A three- to two-way categorization*

Mi-Ryoung Kim
(Korea Soongsil Cyber University)

Kim, Mi-Ryoung. 2014. Ongoing sound change in the stop system of Korean. *Studies in Phonetics, Phonology and Morphology* 20.1. 51-82. Korean stops undergo a sound change, characterized by the merger of voice onset time (VOT) in the consonantal portion but the maximized differences of fundamental frequency (f0) in the vocalic portion. This study replicated VOT and f0 and further examined vowel duration, *H1-H2*, and intensity (dB) to see how they play a role in the sound change of the Korean stop system. By controlling socio-phonetic factors such as age, gender, dialect, L2 English exposure period, and speech rate, individual differences in sound change were also investigated. Speech data were collected by thirteen speakers of purely native Seoul Korean (7 female and 6 male speakers). The results showed that, similar to VOT and f0, other acoustic parameters also underwent some changes in that each acoustic parameter showed a two-way distinction of *H1-H2*, intensity, and vowel duration, instead of an early three-way categorization. In particular, the consonantal differences between lax and aspirated stops are being neutralized in terms of VOT and intensity while their vocalic differences are being increased in terms of f0 and *H1-H2*. There was a correlation between tone and breathiness among female speakers: lax consonants correlated with low tone contain some breathiness. Individual differences in sound change were noticeable. The present findings imply that, since acoustic properties including f0 differences are fully predictable from consonant types, we can say that sound change is still in progress in contemporary Seoul Korean **(Korea Soongsil Cyber University)**.

Keywords: Korean stops, sound change, VOT, f0, *H1-H2*, vowel duration, intensity, tonogenesis, Seoul Korean

1. Introduction

Sound change may include any processes that affect pronunciation (i.e., phonetic change) or sound system structures (i.e., phonological change). Sound change can consist of the replacement of one speech sound by another, the complete loss of the affected sound, or even the introduction of a new sound in a place where there was previously none. Ohala (1993: 238) states, “only sound changes are most likely to arise from language universal factors,

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i.e., physiological and psychological factors common to all human speakers at any time." In the current study, the term 'sound change' will be used to refer to these common frequently encountered sound changes.

One representative example in sound change is the development of tone. The emergence of tone in a previously non-tonal language based on earlier consonantal contrasts is often called 'tonogenesis,' a term first introduced by Matisoff (1973). The process of tonogenesis is summarized in the following three steps (Matisoff 1973, Hombert et al. 1979). First, there are consonantly-induced f0 perturbations on vowels as the seeds of the sound change (Stage I). For example, voiceless consonants give rise to high f0 whereas voiced counterparts give rise to low f0. Second, the f0 perturbations become a perceptual cue to the identification of the initial consonant (Stage II). Third, if other cues to the contrast between initial consonants are lost, the contrast may be maintained solely by differences in f0 or tonal (Stage III). A well-known example of tonogenesis is found in Lhasa Tibetan, as given in (1) (from Kim and Duanmu 2004: 69).

(1) Historical Tibetan	Lhasa Tibetan	
ko	ko H	'he'
go	ko LH	'hear'

The example (1) shows that a historically voiceless onset gave rise to a syllable with a high tone, and a historically voiced onset gave rise to a syllable with a low tone. The voicing distinctions on consonants in prevocalic position are lost and thus tones lexically become contrastive. In recent studies, a similar process of tonogenesis has been discussed for Korean (M.-R. Kim 2000, 2008, 2012a, 2012b, 2013a, 2013b, Duanmu 2000, Kim and Duanmu 1998, 2004, Kingston 2011, Silva 2006, Wright 2008).

1.1 Background on VOT and f0 (or tone[1]) for Korean stops

Korean has three kinds of stops, often described as aspirated /p^h t^h k^h/, tense or fortis /p* t* k*/ (or /p' t' k'/), and lax or lenis /p t k/ (or /b d g/) (e.g., 달 /tal/ 'moon', 딸 /t*al/ 'daughter', 탈 /t^hal/ 'mask')[2]. In the current study, I

[1] Following a common approach in generative phonology (Pierrehumbert 1980), I represent both tone and intonation with the same phonological features H (high) and L (low). In addition, I use the terms "tone" to refer to all pitch patterns whether they are used to distinguish word meaning (as in Chinese) or not (as in English), as described in Kim and Duanmu (2004: 61).

[2] Traditionally, Korean stops are considered to be unique because they are all voiceless. Arguing against this, a different proposal has been made by M.-R. Kim (2000, 2012a, 2012b) and Kim and Duanmu (2004). Kim and Duanmu (2004) states, "While languages with two kinds of voiceless are common, such as Hindi, Thai, and Chinese, Korean is the only language that reportedly has three (p. 59)." Hence, Korean has regular stops, voiceless aspirated /p^h t^h k^h/ for aspirated stops, voiceless unaspirated /p t k/ for tense stops, and voiced /b d g/ for lax stops. Along with the regular stop system hypothesis, the development of tone

use the terms, "tense," "lax," and "aspirated" for readers' convenience. Recent studies show that Korean stops are undergoing a sound change, characterized by the merger of voice onset time (VOT) in the consonantal portion but the maximized differences of fundamental frequency (f0) in the vocalic portion as discussed below.

Since Lisker and Abramson (1964), VOT is considered to be the primary cue to distinguish voiced from voiceless stops in the world's languages (Keating 1984, Kingston and Diehl 1994). However, VOT is not enough to contrast the three Korean voiceless stops because of the overlapping VOT values. In early studies, on average, VOTs are shortest for tense stops, longer for lax, and longest for aspirated (Lisker and Abramson 1964, C.-W. Kim 1965, Han and Weitzman 1970, Hardcastle 1973, Kagaya 1974). At the same time, despite systematic mean differences, VOT values for individual tokens of lax and tense stops, and to a lesser extent lax and aspirated stops, overlap (C.-W. Kim 1965, Han and Weitzman 1970, M.-R. Cho Kim 1994). In recent studies, among Seoul Korean speakers, VOT values between tense and lax stops are not overlapped whereas those between lax and aspirated stops are largely overlapped (M. Kim 2004, Silva 2006, M.-R. Kim 2008, Wright 2008, Oh 2011). Compared with early findings, the VOT overlap has been diachronically shifted from the lax-tense to the lax-aspirated pair over time. The overlap is due to the fact that VOTs for the lax stop are increased while those for the aspirated stop are decreased. In the current study, when VOTs show a three-way VOT categorization well (i.e., tense<lax<aspirated) as in early findings, the pattern is considered "a conservative VOT pattern that is not undergoing a sound change." When VOTs show a two-way categorization with the overlap between aspirated and lax stops (i.e., tense<lax=aspirated), the pattern is considered "an innovative VOT pattern that undergoes a sound change" (Labov 1990, Silva 2006).

Since M.-R. Kim (2000) and Kim et al. (2002), f0 has been considered to be the important cue to distinguish lax from aspirated stops in Korean. In early studies, on average, f0 at vowel onset is lowest for vowels following lax stops, higher following tense stops, and highest following aspirated stops, although the f0 ranges reported for the tense and aspirated categories substantially overlap (Han and Weitzman 1970, Kagaya 1974, M.-R. Cho Kim 1994, M.-R. Kim 2000). In recent studies, f0 values for aspirated and tense stops are remarkably higher than those for lax counterparts. M.-R. Kim (2000) examines not only f0 at vowel onset but also f0 at the midpoint and offset of the rime to capture the f0 contour of the syllable. She suggests that the f0 contours following onset stops form two tonal patterns, high (H) and Low (L) where the H tone is correlated with aspirated/tense onsets and the L tone is correlated with lax and other onsets (see Jun 1996 for an intonation

in contemporary Korean is explained as voiceless- H and voiced- L.

property of tone). The f0 differences following onset stops are considered as tonal (i.e., onset-tone interaction), in which Korean is undergoing tonogenesis (Kim and Duanmu 1998, 2004, M.-R. Kim 2000, 2012a, Wright 2008). Perception studies provide additional evidence for the role of tone in contrasting lax and aspirated stops. Kim et al. (2002) show that, in word pairs like 달 /tal/ 'moon' and 탈 /t^hal/ 'mask'), the vocalic portions carry more contrast than consonantal portion. Their findings suggest that f0 differences play more important role in contrasting the two stops than consonantal VOT differences.

With respect to VOT and f0, the role of each acoustic parameter in Korean differs from other languages. For example, in English and many other languages, VOT is a primary cue and f0 is a secondary cue in contrasting voiced and voiceless stops (Keating 1984, Kingston and Diehl 1994). In contrast, in Korean, f0 becomes a primary cue to distinguish lax from aspirated stops because of the VOT merger or neutralization of a consonantal opposition. If Korean is the case of tonogenesis and has already undergone Stage I and II, one question arises: Does it in the process of Stage III? If other cues to the contrast between initial consonants are lost, the contrast may be maintained solely by differences in f0 or tonal. If then, we may expect that, similar to VOT, other acoustic cues may be neutralized toward the loss of a consonantal opposition. In the current study, other acoustic parameters such as *H1-H2*, vowel duration, and intensity contours in accounting for the sound change of the Korean stop system are investigated. In addition, VOT and f0 are also replicated with a quantitative and reliable methodology.

1.2 The role of socio-phonetic factors on VOT in sound change

For the sound change of the Korean stop system, the role of socio-phonetic factors such as age, gender, dialect, and L2 proficiency has been reported and has exclusively focused on VOT (Choi 2002, Silva 2006, Kang and Guion 2008, Wright 2008, M.-R. Kim 2011, Oh 2011). Labov (1990) hypothesizes that, if socio-phonetic factors are working well, young female speakers are leaders in sound change. His hypothesis is well attested in the following studies. First, young speakers tend to produce VOTs between lax and aspirated stops with more overlap (Silva 2006, Kang and Guion 2008, Wright 2008). Second, Seoul speakers tend to produce more overlapping distribution than other dialectal speakers (Choi 2002, M.-R. Kim 2013a). Third, female speakers tend to produce more VOT merger than male speakers (Oh 2011). Fourth, advance L2 learners tend to have more merger than less advanced learners (M.-R. Kim 2011). Some different patterns are reported in M.-R. Kim for the factor 'age,' Cho et al. (2002) for the factor 'dialect,' M.-R. Kim (2013a) for the factor 'gender,' and M.-R. Kim (2014) for the factor 'L2 proficiency.' In addition, there are remarkable interspeaker variations on VOT within each factor (M.-R. Kim 2008, 2011, 2013a). Since the role of socio-phonetics on VOT is not the main concern of the current study, I skip to discuss here further.

The current study replicates VOT and examines more acoustic parameters because previous results have a number of limitations to generalize the VOT merger in sound change. First, there is a serious speaker-bias problem. If someone wants to examine the sound change of native Seoul speakers, she must employ participants who have never been exposed to an English speaking country. Without taking it consideration, the results are hard to exclude the influence of L2 on L1 speech production (Grosjean 1989, Flege 1995, 2002, Fowler et al. 2008, Chang 2012). Since most of the speech data in previous findings are collected from participants who have already stayed abroad, their findings are not reliable. Second, the size of the study is too small to generalize. If someone wants to generalize certain effects, she must employ at least more than six speakers in a speech production study. Third, since previous findings on sound change have mainly focused on group-normative effects, that is, effects that are representative of the population as a whole, it is not clear whether there are individual differences in sound change. Fourth, it is not clear whether, in addition to VOT and f0, other acoustic correlates also undergo some changes. In the current study, the aforementioned problems in previous studies are reduced with a systematically designed quantitative study by controlling factors. The present study is designed to answer the following research questions:

1. Does the sound change hold for across individual Seoul Korean speakers with all socio-phonetic factors controlled?
2. Similar to VOT or f0, do other acoustic parameters such as *H1-H2*, vowel duration, and intensity play a role in sound change?

2. Methods

In methodology, factors such as age, gender, dialect, and L2 proficiency as well as speech rate are all controlled to minimize speakers' bias.

2.1 Participants[3]

All speech data were collected in Seoul, Korea. Participants were recruited only when they met the following criteria:

-ones who have never lived in an English speaking country (→ the factor

[3] Participants' language backgrounds were strictly controlled in the current study. Since speech data in previous studies (e.g., Silva 2006, Kang and Guion 2008) were collected abroad, some influences of L2 English on L1might not be excluded. Even for a short period time during the stay abroad, some speakers are very good at speaking English because of their preparation even before the departure. Recently, Chang (2012) reports that rapid effects of second-language learning on first-language speech production are possible for novice L2 speakers even for a week or so.

"L2 exposure period and proficiency" controlled)
-ones who self-rate themselves as 1 out of 7 (→ the factor L2 proficiency" controlled)
-ones who are in their twenties and thirties (→ the factor "age" controlled)
-ones who were born and have grown up in Seoul (→ the factor "dialect' controlled)

Thirteen college students, six males and seven females, participated in this study. Their mean age was 25 years, 4 months and the individuals ranged from 20 years, 7 months to 32 years, 11 months. Since they were born and have grown up in Seoul, all participants were purely native Seoul Korean speakers and spoke the standard dialect of Seoul Korean (i.e., 서울토박이). All participants were novice L2 learners of L2 English. They had never visited or lived in an English speaking country. While interviewing, they could not answer simple questions and hardly made a couple of sentences in comfort.

2.2 Speech materials and procedure

Eighteen monosyllabic words were balanced for the three stop phonation types (lax, aspirated, and tense) and for the three places of articulation (labial, alveolar, and velar) followed by a vowel /a/ context. The target words consisted of two syllable types: CVC and CV. In CVC, the final coda was /t/ (a neutralized unreleased stop) for the aspirated and the lax stop but /k/ for the tense stop because there was no minimal triplet ending with /t/ across the three phonation types. Most of the speech materials are real words, as presented in Table 1.

Table 1. Speech materials[4]

	Bilabilal	Alveolar	Velar
Aspirated	/p^{h}ɑt/ 'red bean'	/t^{h}at/ 'blame'	/k^{h}at/ 'stop'
	/p^{h}a/ 'to dig'	/t^{h}a/ 'to get in'	/k^{h}a/ 'car'
Lax	/pat/ 'field'	/tat/ 'anchor'	/kat/ 'cap'
	/pa/ 'to see'	/ta/ 'all'	/ka/ 'to go'
Tense	/p*ak/ 'head'	/t*ak/ 'precisely'	/k*ak/ 'croak'
	/p*a/ 'to grind'	/t*a/ 'to pick'	/k*a/ 'to peel'

Note: /k^{h}at/ 'stop' and /k^{h}a/ are borrowing words and /p*ak/ 'head' is a slang.

Recordings were made in a sound-attenuated room or in a quiet office

4 The phonemic status of the three Korean stops is somewhat controversial: Avery and Idsardi (2001) for the geminate hypothesis and Kim and Duanmu (2004) for the regular stop hypothesis.

directly into a Samsung SENS NT900X4C-A78 laptop computer. The recordings were digitized at a sampling rate of 22,050 Hz. In order to minimize the effect of boundary tones in isolation, the target words were recorded in the frame sentence [igə _____ *hasɛjo*] "Say this _____." They were presented in *Hangul (*the writing system of Korean) four times in random order. In order to minimize the effect of speech rate, the stimuli were automatically popped up at a 3-second interval per each sentence using a PowerPoint slide show (one sentence per slide). This makes speech rate control by using the frame sentence and limiting the speakers' production time of sentences to a fixed 3s. A short familiarization for the target words was given ahead of recording. A total of 936 tokens (18 words x 4 repetitions x 13 speakers) were obtained for analysis. All utterances were recorded and analyzed using Praat 5.3.47, a speech analysis program (Boersma and Weenink 2013).

2.3 Acoustic measurements

In order to investigate the progress of the sound change of the Korean stop system, acoustic properties such as duration (i.e., VOT and vowel duration), intensity, f0, and voice quality (*H1-H2*) were taken into consideration. Using a Praat script, acoustic measurements were semi-automatically taken for all acoustic parameters but voice quality. *H1-H2* values alone were taken by hand at vowel onset and midpoint due to the fact that automated values were not reliable[5]. Each acoustic property met the measurement criteria as follows:

Voice onset time (VOT). VOT duration (ms) was measured from the release burst to the onset of periodicity in the waveform (Lisker and Abramson 1964, Kim et al. 2002). The onset of voicing (= vowel onset) was defined as the first and periodic pulse of a vocalic waveform that show features typical of a vowel. The onset of the voicing energy in the second formant shown in a time-locked spectrogram was used to help determine voicing onset in conjunction with the waveform.

Vowel duration. Vowel duration (ms) was measured from onset of the periodic waveform to offset of the periodic waveform for vowel or vowel-final syllables.

Intensity[6]: In order to see whether there are any differences between lax and aspirated stops in loudness in the whole syllable, intensity values (dB) were taken at approximately 20% interval each of six measurement points for both consonantal and vowel portions, respectively (i.e., 6 measurement

[5] Similar to other measurements, *H1-H2* values were also semi-automatically obtained in the earlier manuscript. One anonymous reviewer raised an issue about the reliability of *H1-H2* values. Thanks to his insightful comments, all *H1-H2* values were able to be corrected.

[6] Borden et al. (1994) describes, "intensity or sound pressure, like frequency, is a physical property of the acoustic signal that can be measured by an instrument called a sound level meter. The loudness of a signal is directly related to its intensity. As intensity is increased, the sound is judged by listeners to be louder. Loudness is the subjective, psychological sensation of judged intensity (p. 39)."

points each for a consonant and vowel).

Fundamental Frequency (f0): In order to obtain f0 contours in the vowels, f0 values (Hz) were taken at approximately 20% interval each of six measurement points from the onset and offset of a vowel.

H1-H2. Differences in energy values (dB) for the first (*H1*) and second (*H2*) harmonics were taken at the onset and midpoint of a vowel. The difference in amplitude between H1 and H2 has been frequently used to distinguish between breathy and modal voicing. According to Stevens (1999: 86), a greater or positive *H1-H2* indicates breathiness of the vowel and a smaller or negative *H1-H2* indicates "pressed" (or creaky) voicing quality.

Acoustic measurement values were statistically tested using repeated measures analysis of variance (RM ANOVA) in the uni- and multivariate context of a general linear model (SPSS/PASW 2012, R 2012). A multivariate RM ANOVA includes both "between" subjects effects (i.e., gender and individuals: 13 speakers) and "within" subject effects (i.e., three phonation types and three places). Acoustic correlates such as VOT, vowel duration, f0, *H1-H2*, and intensity and their measurement points were dependent variables. Their main and interaction effects were statistically analyzed at a 0.05 significance level.

Post hoc Tukey HSD multiple tests were also run to answer the questions: (i) for any acoustic parameter, whether any differences in pairs among the stop phonation types in the pool data were significant and (ii) for any acoustic parameter, whether any differences in pairs among the stop phonation types in the individual data were significant. For statistical analysis, I focus on discussing those that involve the effects of most central interest to the present paper: acoustic differences among stop phonation types in the consonantal and vocalic portion.

3. Results and Discussion

3.1 Voice Onset Time (VOT)

For the pool data, results of univariate repeated measures (RM) ANOVA showed a main effect of phonation type on VOT ($F(2, 933) = 1188.657$, $p < 0.001$) in that mean VOT values are significantly longest (83ms) for the aspirated, longer (71ms) for the lax stop, and shortest (15ms) for the tense stop. *Post hoc* Tukey HSD multiple comparisons revealed that differences in any pairs among the three phonation types were statistically significant ($p < 0.0001$) (i.e., a three-way categorization). However, the VOT ranges between aspirated and lax onsets are largely overlapped, as seen in Figure 1.

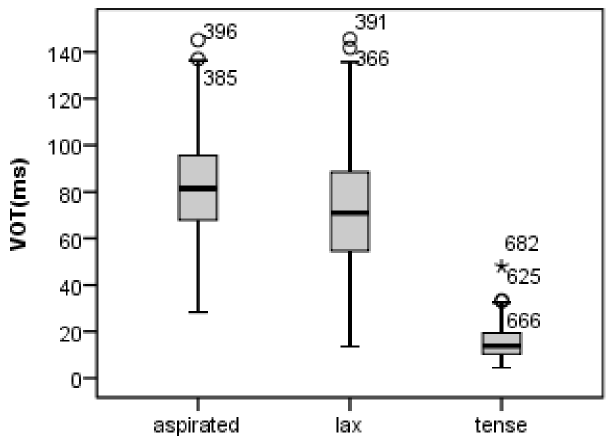


Figure 1. Mean VOT values (ms) and range (± 1 SD) aggregated from 13 Seoul Korean speakers according to aspirated, lax, and tense targets in initial position (a total of 936 tokens)

The pooled results on VOT are analogous to recent findings in that VOT differences between lax and aspirated stops are decreased toward the merger of the two stops (Kang and Guion 2008, M.-R. Kim 2006, 2013b, Silva 2006). There was a main effect of place of articulation on VOT ($F(2, 933) = 11.500$, $p < 0.001$) in that mean VOTs are shortest for labials, longer for alveolars, and longest for velars, similar to previous findings (Han and Weitzman 1970), as presented in Table 2. *Post hoc* Tukey HSD multiple comparisons revealed that differences in the labial-velar and alveolar-velar pairs were statistically ($p < 0.05$) but differences in the labial-alveolar pairs were not. As a result, there were two statistical groupings among the places of articulation (i.e., labial = alveolar < velar). Table 2 shows that the effect of phonation type on VOT holds well for across the three places of articulation.

Table 2. Mean values for VOT in ms. Duration ranges are given in parentheses (n=13).

	Labial	Alveolar	Velar	***Mean***
Aspirated	77(28~132)	80(20~145)	92(44~137)	*83(28~145)*
Lax	66(17~136)	70(14~121)	79(33~146)	*71(14~146)*
Tense	11(5~19)	13(5~48)	21(13~33)	*15(5~48)*
Mean	*51(5~136)*	*54(5~145)*	*64(13~146)*	

The effect of phonation type on VOT held well across the places of articulation in that, for each place of articulation, mean VOT values are longest for the aspirated, longer for the lax stop, and shortest for the tense stop. There was no interaction between phonation type and place of articulation ($p > 0.5$), as seen in Figure 2(a).

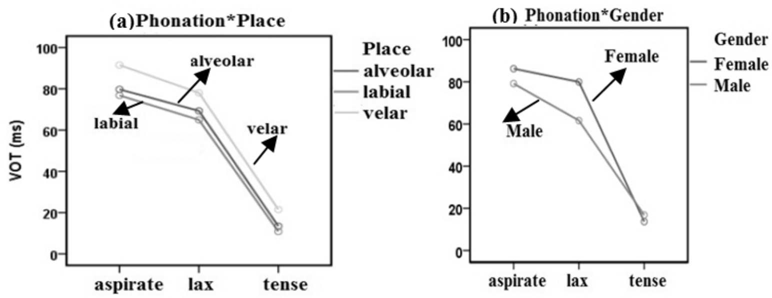


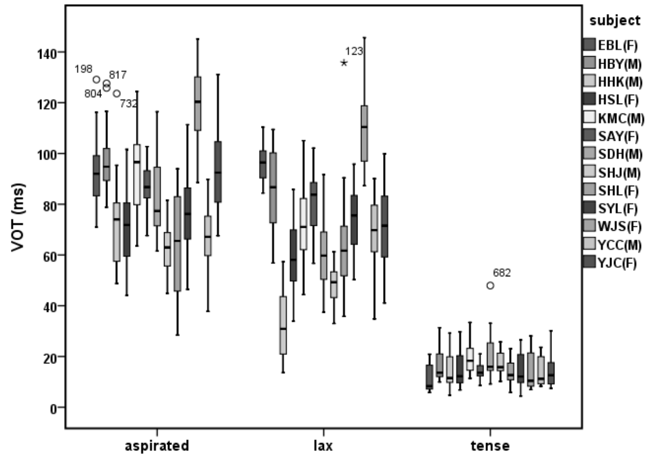
Figure 2. Mean VOT values (ms) by (a) Phonation*Place and (b) Phonation*Gender according to aspirated, lax, and tense targets in initial position

There was a main effect of gender on VOT ($F(1, 930) = 40.634$, $p < 0.001$) and an interaction between phonation type and gender ($F(2, 930) = 28.429$, $p < 0.001$) in that VOT differences between the aspirated and lax stop are getting smaller for female speakers than male speakers, as seen Figure 2(b). With respect to the VOT merger, female speakers show more merger than male speakers: six out of seven female speakers vs. one out of six male speakers. The effect of gender on VOT is analogous to the findings of Choi (2002) and Oh (2011). *Post hoc* Tukey HSD multiple comparisons revealed that, for female speakers, there were statically two subsets (tense < lax = aspirated) whereas, for male speakers, there were three subsets (tense < lax < aspirated). There was neither interaction between gender and place nor any 3-way interaction among phonation type, gender, and place of articulation ($p > 0.5$).

Next, consider how phonation types are individually different. Results of RM ANOVA showed a main effect of subject on VOT ($F(12, 897) = 163.731$, $p < 0.001$) and a significant interaction between phonation and subject ($F(24, 897) = 23.692$, $p < 0.001$) in that individual speakers produce the three phonation types differently. The results are summarized in Figure 3(a) and 3(b) where individual speakers show huge interspeaker variations on VOT, especially for the merger pattern and duration between lax and aspirated stops.

As seen in Figure 3(a), VOT durations for the tense stop are quite stable among speakers whereas those for the lax and aspirated stop are not. Note that, for the production of both lax and aspirated stop, speaker WJS relatively produces long VOTs whereas speaker HHK produces relatively short VOTs. It is interesting to observe huge differences between speaker WJS and HSL because they share a similar language background in terms of generation, gender, dialect, and no L2 exposure. Despite the fact that speakers' socio-phonetic factors were all controlled, they still showed different variation on VOT duration. Similarly, interspeaker variations on VOT can also be observed among male speakers.

(a) Individual



(b) Individuals*Phonation

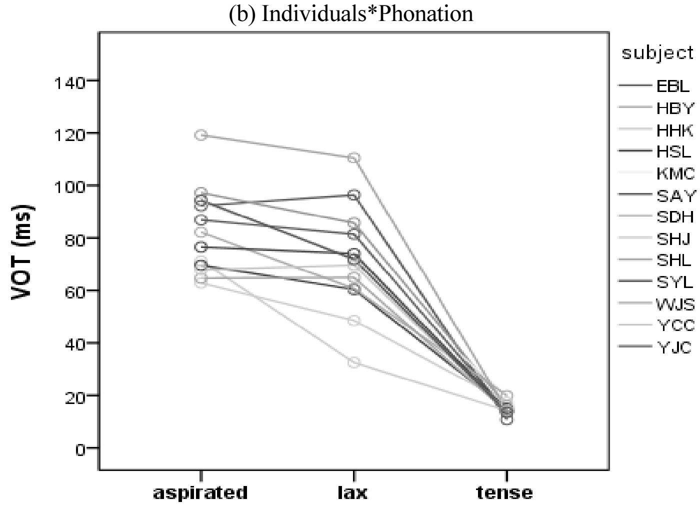


Figure 3. Mean VOT values (ms) by (a) the individual data (top) and (b) individuals*phonation type (bottom) according to aspirated, lax, and tense targets

Compare the mean VOT values and ranges of speaker HHK with those of speaker YCC, as presented in Table 3. Similar to female speakers, they have similar background. In Table 3, for the aspirated stop, although their mean VOTs are very similar, their ranges are very different. Speaker HHK produces much longer VOTs than speaker YCC. For the lax stop, speaker YCC produces twice longer VOTs than speaker HHK. As a result, speaker YCC show a VOT merger between the aspirated and lax stop whereas speaker HHK does not.

Table 3. Mean (*M*: italicized) VOTs, range, and standard deviations (SD) of Korean stops for the two male speakers

Speaker	Phonation	*M*	Range	SD
HHK	Aspirated	*72*	49~124	17
	Lax	*32*	14~57	12
	Tense	*14*	5~29	6.3
YCC	Aspirated	*67*	38~90	12
	Lax	*69*	35~90	13
	Tense	*14*	7~30	5

As seen in Figure 3(b), some speakers tend to show a three-way VOT categorization (tense<lax<aspirated) whereas others tend to show a two-way VOT categorization (tense<lax=aspirated) due to the merger of aspirated and lax stops. Table 4 summarizes the statistical grouping among the three phonation types and the VOT merger between aspirated and lax stops.

Table 4. Mean VOTs and their statistical merger between the lax and aspirated stop. Duration ranges are given in parentheses.

Initials	VOT_{asp}	VOT_{lax}	$VOT_{asp\text{-}lax}$	$Merger_{asp=lax}$
SF1(YJC)	94(68~131)	72(41~100)	23	NO
SF2(WJS)	119(89~145)	111(87~146)	9	YES
SF3(SAY)	87(69~103)	81(57~102)	0.4	YES
SF4(HSL)	70(44~102)	60(34~86)	9	YES
SF5(EBL)	92(71~129)	96(84~110)	-4.1	YES
SF6(SHL)	65(28~94)	65(36~136)	-0.2	YES
SF7(SYL)	77(46~111)	74(50~96)	3	YES
SM1(SHJ)	63(45~82)	49(33~61)	14	NO
SM2(HHK)	71(49~124)	33(14~57)	39	NO
SM3(SDH)	82(62~116)	61(37~92)	22	NO
SM4(KMC)	94(64~124)	73(44~105)	21	NO
SM5(HBY)	97(79~128)	86(57~109)	12	NO
SM6(YCC)	68(38~90)	70(35~90)	-1.8	YES
Mean	***83(28~145)***	***71(14~146)***		

(SF=Seoul Female and SM=Seoul Male)

In Table 4, almost all female speakers but SF1 undergo a VOT merger between lax and aspirated stop whereas almost all male speakers but SM6 do not. For the effect of gender on VOT, the present results are analogous to Oh (2011) where female speakers tend to show more VOT merger than males.

There are remarkable interspeaker variations on VOT. Compared to some previous results (Han and Weitzman 1970, M.-R. Cho Kim 1994), the ranges of VOT for aspirated and lax stops are relatively large from 14 ms to 146 ms across speakers. Even within the same gender, some speakers relatively produce shorter VOTs than others. Some speakers carry the merger while others do not.

Among the three stops in Korean, the lax stop is the most prominent one that undergoes a sound change because its VOT duration has largely increased over time. Compared to early findings, mean VOTs for lax stops are getting twice longer than Lisker and Abramson's (1964) (M_{lax}=30ms (10~65ms)). This shift is still fluctuated from speaker to speaker. The aspirated stop is another one in that the VOT duration is getting shorter, compared to Lisker and Abramson's (1964) (M_{asp}=103ms (65~200ms)). The current results indicate that consonantal durations (i.e., VOT) for the lax and aspirated stops are in the process of changing diachronically as well as synchronically. The two stops truly undergo a sound change toward the merger (or loss) of a consonantal opposition (i.e., VOT).

3.2 Fundamental Frequency (f0)

Figure 4 gives the overall mean f0 contours according to the three phonation types. Similar to early findings (Han and Weitzman 1970), at vowel onset, f0 is lowest for the lax stop, higher for the tense stop, and highest for the aspirated stop. However, in the pool data, f0 differences between the aspirated and tense stop are getting much smaller and disappear after 40% measurement point. As a result, f0 contours dynamically fall into the two tonal groups: aspirated and tense consonants are correlated with a H tone whereas lax counterparts are correlated with a L(H) tone. Since the effect of phonation type on f0 contour is beyond the intrinsic perturbation, it is called "onset-tone interaction" (M.-R. Kim 2000).

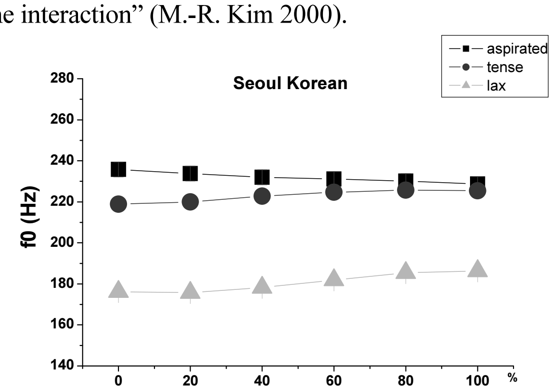


Figure 4. Mean f0 values (Hz) at 20% intervals from the onset of the vowel (0 ms) to the offset (100 ms) of the vowel. Data are averaged across 13 Seoul Korean speakers (6 males and 7 females) according to aspirated, lax, and tense targets.

Results of multivariate RM ANOVAs showed that there was a significant effect of phonation type on f0 at all six measurement points ($p < 0.001$) due to the rising effect of aspirated and tense onsets, compared to lax onsets. The results are summarized in Figure 4. *Post hoc* Tukey HSD multiple comparisons revealed that f0 differences in the lax-aspirated pairs were statistically significant at all six measurement points ($p < 0.001$). In contrast, f0 differences in the tense-aspirated pairs were significant at vowel onset and 20% measurement point, but not statistically significant after 40% measurement point ($p = 0.05$). The statistical outcomes in the aspirated-tense merger support the two tonal subsets among the three phonation types: L tonal group for lax but H tonal group for aspirated and tense.

As expected, there was an effect of gender on f0 in that female speakers produced higher f0 than male speakers at all six measurement points ($p < 0.001$). Regardless of gender differences, the effect of phonation type on f0 contour in the pool data held well for both male and female speakers, similarly due to the rising effect of aspirated and tense onsets, compared to lax onsets, as seen in Figure 5. There was also an interaction between phonation type and gender at all six measurement points ($p < 0.0001$). Gender differences on f0 contours can be observed on whether the f0 merger between the aspirated and tense stop occurred. *Post hoc* Tukey HSD multiple comparisons revealed that, for female speakers, differences in any pairs between the tense and aspirated stop were not statistically significant after 80% measurement point whereas, for male speakers, those were not statistically significant after 40% measurement point ($p > 0.05$). In other words, the f0 merger between the two stops occurs immediately after vowel onset for male speakers but not for female speakers. This is due to the fact that the pitch range for female speakers is wider and higher than male speakers.

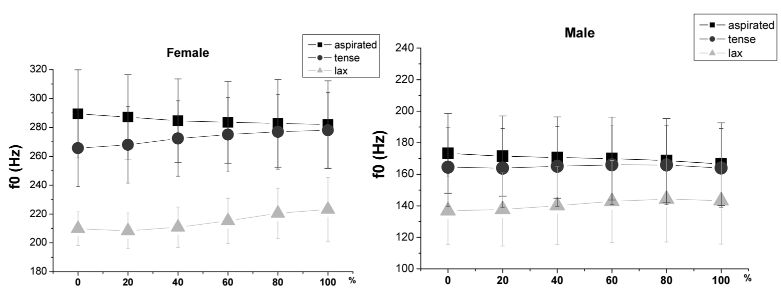


Figure 5. Mean f0 contours according to three stops averaged by female (left) and male (right) speakers

The effect of phonation type on f0 contour in the pool data held well for across individual speakers in that, at all six measurement points, f0 values following the aspirated/tense stop were statistically higher than that following the lax counterpart. *Post hoc* Tukey HSD multiple comparisons revealed that, for all individual speakers, f0 differences between the lax and aspirated stop were statistically significant at all six measurement points ($p < 0.0001$) whereas those between the aspirated and tense stop were not. There were interspeaker variations depending on how large f0 differences between the aspirated and lax stops were and where the f0 merger between the tense and aspirated stop occurred. The results are summarized in Table 5 (see Appendix A2 for mean f0 values of the three phonation type at 60% measurement point).

In Table 5, the mean f0 differences between the aspirated and lax stops for female speakers are twice larger than those for male speakers throughout three measurement points. Compared with other speakers, f0 differences between the aspirated and lax stops are much smaller (8 Hz) for speaker SM2(HHK) after 60% of the vowel. This may be due to the fact that, unlike other speakers who carry the flat tone, speaker HHK produced target words with a phrase-final H boundary tone. For almost all speakers, the large f0 differences between aspirated and lax stops at vowel onset (0%) persist till vowel offset (100%). However, unlike the f0 differences between the aspirated and lax stops, those between the aspirated and tense stops are being merged for all speakers except for SF1 and SM6. In contrast, for speaker SM1, SM2, and SM5, the merger occurs from 0% (i.e., vowel onset).

Table 5. Individuals' f0 differences (Hz) between aspirated and lax or tense stops at vowel onset, 60%, and vowel offset and the place of the statistical f0 merger between aspirated and tense stops

	$f0_{asp\text{-}lax}$			$f0_{asp\text{-}ten}$			*Merger* $_{asp\text{-}=ten}$
Initials	*Vonset*	*60%*	*Voffset*	*Vonset*	*60%*	*Voffset*	
SF1(YJC)	75	58	46	30	16	10	No
SF2(WJS)	103	95	87	27	7	2	80%
SF3(SAY)	61	64	55	15	9	8	80%
SF4(HSL)	85	68	49	12	1	-2	40%
SF5(EBL)	122	96	86	38	15	9	100%
SF6(SHL)	59	51	49	19	5	4	60%
SF7(SYL)	51	45	39	26	6	-3	80%
Mean (F)	*80*	*68*	*59*	*24*	*9*	*4*	
SM1(SHJ)	28	22	18	2	3	1	0%
SM2(HHK)	22	8	5	1	-2	-3	0%
SM3(SDH)	21	14	13	8	2	2	40%
SM4(KMC)	47	37	32	17	8	4	100%
SM5(HBY)	50	37	28	6	5	5	0%
SM6(YCC)	50	45	45	19	8	6	No
Mean(M)	36	27	23	9	4	3	

With respect to f0 contours according to the three phonation types, most of the individual speakers except for two (SF1 and SM6) carried the two statistically-supported tonal groupings: L for lax onsets versus H for aspirate/tense onsets. This suggests that, along with the merger of a consonantal duration (i.e., VOT), the tonal differences are truly in the process of developing in contemporary Seoul Korean. The current findings are analogous to M.-R. Kim's (2000) and recent findings (i.e., tonogenesis from M.-R. Kim, 2000, 2012b, Silva 2006, Kim and Duanmu 2004). Considering the VOT merger in the consonantal portion but the f0 maximization in the vocalic portion, in order to distinguish the word 달 /tal/ 'moon' and 탈 /t^hal/ 'mask', we can expect that the tonal differences in the vocalic portions play more important role than the VOT differences in the consonantal portion, as suggested by Kim et al. (2002).

3.3 *H1-H2* (Difference between the first and second harmonics)

For the pool data, multivariate RM ANOVAs showed that there was a main effect of Phonation type on *H1-H2* at vowel onset (F(2, 933) = 472.356, $p <$ 0.0001) and midpoint (F(2, 933) = 34.311, $p < 0.0001$) in that overall mean *H1-H2* values were significantly smaller (i.e., negative) for the tense stop, compared with those for the aspirated and lax stop.

At vowel onset, *H1-H2* is greater (positive) for aspirated and stops than for tense stops. At vowel midpoint, however, it is greater (positive) for lax stops than for aspirated and tense stops. The results are summarized in Figure 6 where mean *H1-H2* contours at vowel onset and midpoint are illustrated. Note that, at midpoint, the lax stop has some breathy quality whereas the other two stops do not.

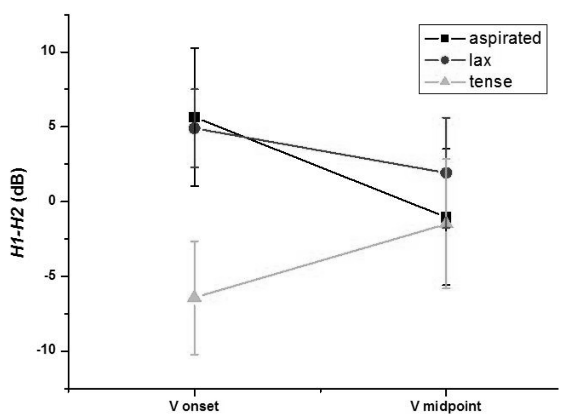


Figure 6. Mean *H1-H2* values (Hz) at the onset and midpoint of the vowel. Data are averaged from 13 Seoul Korean speakers (6 males and 7 females) according to aspirated, lax, and tense targets.

Post hoc Tukey HSD comparisons showed that stops differed significantly from each other at $p < 0.001$, depending on the measurement point. At vowel onset, differences in the lax-tense and aspirated-tense pairs were significant ($p < 0.01$) whereas those in the aspirated-lax pairs were not ($p > 0.05$). However, at vowel midpoint, differences in the lax-tense and lax-aspirated pairs were significant ($p < 0.01$) whereas those in the aspirated-tense pairs were not ($p > 0.05$), as can be seen in Figure 6. As pointed out by one anonymous reviewer, *H1-H2* has some positive values due to the glottal opening of aspirated and lax stop to which both have large VOT. According to the reviewer's account, the differences are expected to disappear in the middle of a vowel because the voice quality becomes to be normal. Note that, even at vowel midpoint, speakers still carry some breathiness for the lax stop unlike the other two stops.

The present findings at vowel onset differ from earlier findings of Ahn (1999) and Cho et al. (2002) in two aspects: Firstly, there was a statistically significant *H1-H2* merger between lax and aspirated stops at vowel onset. Cho et al. (2002: 208) states "all four Seoul speakers make a clear three-way distinction among stops, showing a pattern of tense < aspirated < lax in *H1-H2*." Ahn (1999) also reports that *H1-H2* is greatest (positive) for aspirated stops, intermediate for lax stops, and smallest (negative) for tense stops. In the current study, there were statistically not three categorizations on *H1-H2* but only two: tense < aspirated =lax at onset but tense = aspirated < lax at midpoint. Secondly, unlike Cho et al.'s finding, the voice quality of the vowel after the lax stop at vowel onset maintained till midpoint. However, these aspects remarkably differ in gender, as shown in Figure 7.

At vowel onset, there was a main effect of gender on *H1-H2* ($F(1, 930) = 135.726$, $p < 0.001$) and an interaction between phonation and gender on *H1-H2* ($F(2, 930) = 76.319$, $p < 0.001$) on *H1-H2* in that the lax stop was produced in a different way. The results are summarized in Figure 7. For female speakers, *H1-H2* is greater (positive) values for lax and aspirated stops than tense counterparts. Note that, for female speakers, the breathy voice for the lax stops persists till the midpoint of a vowel. In contrast, for male speakers, *H1-H2* is greatest (positive) for aspirated stops, intermediate (almost zero) for lax stops, and smallest (negative) for tense stops. *Post hoc* Tukey HSD multiple comparisons revealed that there were three subsets (tense < lax < aspirated) for both female and male speakers.

At vowel midpoint, there was a main effect of gender on *H1-H2* ($F(1, 930) = 16.597$, $p < 0.001$) and an interaction between phonation and gender on *H1-H2* ($F(2, 930) = 7.684$, $p < 0.01$) on *H1-H2.* As can be seen in Figure 7, for female speakers, there were statically two subsets (tense = aspirated < lax) whereas, for male speakers, there was only one group (tense = lax = aspirated). There was neither interaction between gender and place nor any 3-way interaction among phonation type, gender, and place of articulation ($p > 0.5$). According to Stevens' definition on breathiness (1999: 86), the present results show that, for lax stops, female speakers carry some breathy voicing whereas male speakers do not.

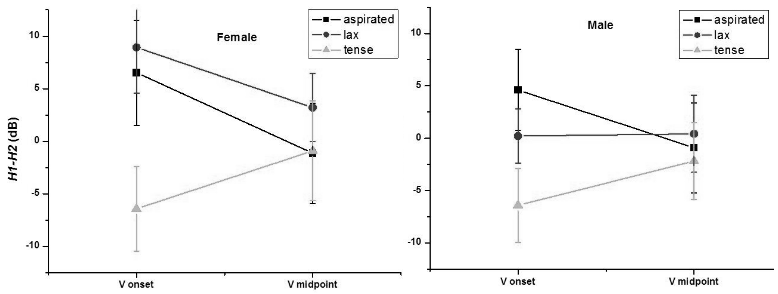


Figure 7. Mean *H1-H2* contours according to three stops averaged by female (left) and male (right) speakers

There are also remarkable interspeaker variations on *H1-H2*. The individual results are summarized in Table 6. At vowel onset, some speakers have a three-way categorization at vowel onset whereas other speakers have a one or two-way categorization. The same thing happens at vowel midpoint. The *H1-H2* results suggest that the values are not stable among speakers. The behavior of *H1-H2* is similar to that of VOT and f0. One can speculate that *H1-H2* is another important acoustic parameter in sound change in that, similar to the VOT merger, most of the female speakers carry some breathy quality for the lax stop but not among male speakers. The *H1-H2* merger between aspirated and lax stops has occurred, different from previous findings (Ahn 1999, Cho et al. 2002).

How can we account for the fact that the lax stop carries some breathiness into the middle of a vowel? M.-R, Kim (2000) and Kim and Duanmu (2004) observed that Korean lax consonants that correlated with low tone contain some breathiness, a mixture of voicing and tone. We may speculate that, in Seoul Korean, there is also a correlation between breathiness and tone, as found in other Asian languages. Nguyen and Edmondson (1997) show that Vietnamese uses voice quality in its tonal system: low tones are correlated with breathiness. Voice quality is ultimately related with consonantal voicing: voiceless-clear and voice-breathy. Since there is a correlation between breathiness and tone in Seoul Korean, *H1-H2* is another important property that actively participates in sound change. As a result, in addition to VOT and f0, *H1-H2* can be also another important acoustic parameter that undergoes some changes.

Table 6. Statistical *H1-H2* groupings among aspirated, tense, and lax stops and its merger at vowel onset and midpoint (Mean values are in parentheses)

Initials	V onset	V midpoint
SF1(YJC)	tense (-11) < asp (0.9) < lax (5.8)	tense (-4.8) =asp (-4.3) < lax(4)
SF2(WJS)	tense (0.3) < asp (3.6) = lax (3.7)	tense (-2.5) <asp (3.4) = lax(5.6)
SF3(SAY)	tense (-3.2) = asp (0.1) = lax (0.9)	tense (-4.8) <asp (1.8) = lax(0.9)
SF4(HSL)	tense (-1.0) < asp (11) = lax (9.4)	tense (-3.3) <asp (8.1) = lax(11)
SF5(EBL)	tense (-2.0) < asp (5.9) = lax (2.8)	tense (-8.3) <asp (8.7) = lax(8.7)
SF6(SHL)	tense (-2.3) < asp (2.4) = lax (2.0)	tense (-6.1) < asp (2.1) = lax (0.6)
SF7(SYL)	tense (-1.7) = asp (1.0) = lax (2.3)	tense (-2.6) = asp (1.0) ≤ lax (2.6)
SM1(SHJ)	tense (-4.6) =asp (-1.6) ≤ lax (1.1)	tense (-4.0) =asp(-2.5) ≤ lax (-0.2)
SM2(HHK)	tense (-5.5)< asp (-0.3) = lax (0.7)	tense (-6.8)< asp (-1.0) = lax (0.9)
SM3(SDH)	tense (-1.8)= asp (-0.3) = lax (0.6)	tense (-3.3)= asp (-0.8)≤ lax (-0.1)
SM4(KMC)	tense (-1.7)= asp (-0.1) = lax (0.9)	tense (-2.5)= asp (0.2)≤ lax (0.9)
SM5(HBY)	tense (-9.5) < lax (1.1) < asp (6.2)	tense (-3.4) = asp (-2.3) < lax (1.6)
SM6(YCC)	tense (0.1)= asp (2.2) = lax (3.2)	tense (-2.2)= lax (-1.3) = asp (-0.8)

(‘<’ refers to a statistically different group, ‘≤’ refers to a statistically different or similar group, and ‘=’ refers to the same statistical group)

3.4 Intensity (dB)

Kim et al. (2002: 79) states, “Korean initial stops also differ in several intensity characteristics, and lax stops emerge as the least intense in terms of release bursts (C.-W. Kim 1965), aspiration (C.-W. Kim 1965, Kagaya 1974), and formant structure at the onset of the following vowel (Han and Weitzman 1970, Hardcastle 1973).” Cho et al. (2002) show that at vowel onset the aspirated stop has significantly greater burst energy than the other two stops whereas there is no difference between the tense and the lax stops.

Based on previous findings, it is expected that lax stops have the least intensity. Surprisingly enough, the present results are not analogous to previous findings in that aspirated and lax stops are merged in intensity almost throughout the whole syllable, as seen in Figure 8.

For the consonantal portion, results of multivariate RM ANOVAs show that there was a main effect of phonation type on intensity (dB) at any measurement point ($p < 0.001$) due to the raising effect of a tense category, compared to aspirated and lax categories as shown in Figure 8(a). *Post hoc* Tukey HSD multiple comparisons revealed that differences in the tense-aspirated or tense-lax pairs were statistically significant ($p < 0.001$). However, those between the lax and aspirated stop were not significant at any measurement point ($p > 0.01$). In other words, there were two statistical groupings (aspirated = lax < tense) on intensity in consonants.

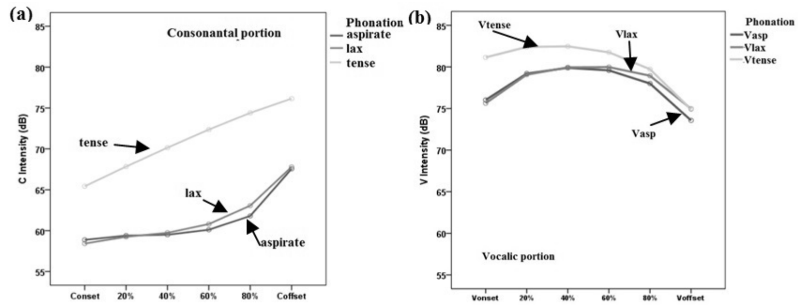


Figure 8. The pooled data: mean intensity values (dB) at 20% intervals from the release of a stop to the onset of the vowel for the consonantal portion (left) and from the onset of the vowel to the offset for the vocalic portion (right). Data are averaged from 13 Seoul Korean speakers (6 males and 7 females) according to aspirated, lax, and tense targets.

The intensity contours of the three stops in the vocalic portion are similar to those of the consonantal portion, as seen in Figure 8(b). Multivariate RM ANOVAs showed that there was a significant effect of phonation type ($p < 0.001$) on intensity (dB) at all six measurement points due to the raising effect of a tense category, compared to aspirated and lax categories. *Post hoc* Tukey HSD comparisons revealed that the differences in the lax-aspirated pairs were not significant at any measurement points except for 80% and vowel offset. The intensity differences in the lax-tense pairs were significant at all measurement points except for 80% and vowel offset. As a result, there were statistically two subsets (aspirated = lax < tense) from the onset of a vowel till 60% into a vowel and two subsets (aspirated < lax = tense) at 80% into a vowel and the offset of a vowel.

For both consonantal and vocalic portions, there was no main effect of gender and no interaction between phonation and gender on intensity ($p > 0.5$). There were some interspeaker variations on intensity for both portions (see Appendix A2 for some individual data). Since they were not linguistically important, I skip to discuss them here.

Unlike previous findings (C.-W. Kim 1965, Cho et al. 2002), the results show that there were no significant differences on intensity between the lax and aspirated syllables. Although the aspirated stop in the word 탈 /t^hal/ 'mask' can be heard much louder and stronger than the lax stop in the word 달 /tal/ 'moon', their physical loudness in intensity are in fact similar to each other toward the consonantal merger. The results suggest that lax and aspirated stops are truly undergoing a merger in terms of not only VOT and *H1-H2* at vowel onset but also intensity throughout the syllables. In addition to VOT, f0, *H1-H2,* Intensity can be also an important acoustic parameter that undergoes some changes.

3.5 Vowel duration

Results of univariate RM ANOVA showed that there was a weak effect of phonation type on vowel duration (ms) ($F(2, 933) = 28.665$, $p = 0.034$) in that vowels after the aspirated categories were produced slightly shorter than those following the lax and tense categories, as shown in Figure 9. Note that differences in vowel duration among the three stops were very small (mean 10-20ms), as presented in Table 7 (see Appendix A1 for individual data). *Post hoc* Tukey HSD multiple comparisons revealed that differences in the tense-aspirated or lax-aspirated pairs were statistically significant ($p < 0.0001$). However, those between the lax and tense pairs were not significant ($p > 0.05$). Thus, there were two statistical groupings (aspirated < lax = tense) on vowel duration.

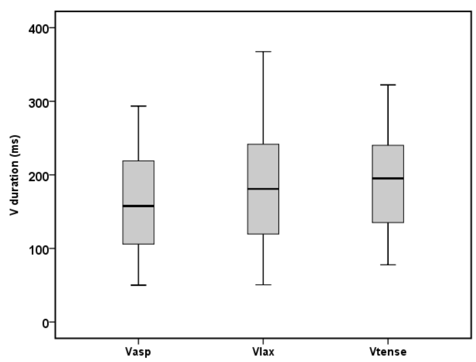


Figure 9. Mean vowel duration (ms) according to aspirated, lax, and tense targets. Data are averaged from 13 Seoul Korean speakers (6 males and 7 females).

Table 7. Mean (*M*: italicized) vowel durations, range, and standard deviations (SD) following Korean stops (n=13).

Phonation	*M*	Range	SD
$V_{aspirated}$	164	50~293	65
V_{lax}	184	51~368	74
V_{tense}	192	78~322	62

There was also a main effect of gender on vowel duration ($F(2, 930) = 96.792$, $p = 0.010$) in that female speakers have more merger in the tense-lax pairs than male speakers. There was no effect of place of articulation and no interaction effect between phonation type and gender as well as place ($p > 0.05$). However, there was a weak effect of subject on vowel duration ($F(12, 897) = 13.061$, $p < 0.001$) in that vowel durations were slightly different among individual speakers. Most of the speakers have two subsets (aspirated

< lax = tense) whereas others have three subsets (aspirated < lax < tense). There was no interaction between phonation type and subject ($p > 0.05$).

Early studies report that, on average, vowel duration following the stop type is relatively longest for the tense, longer for the lax stop, and shortest for the aspirated stop (aspirated < lax < tense) (Cho 1996, Kim et al. 2002) (see Appendix A1 for individual data). The current results are different from early findings in that differences in vowel duration for the lax-tense pairs were merged. The results of vowel duration suggest that similar to other acoustic parameters, vowel duration, in particular for the lax stop, play a role in sound change.

4. Summary and Discussion

In methodology, the current study is differently designed from previous studies (Silva 2006, Kang and Guion 2008) in the following three aspects. First, more acoustic parameters (VOT, f0, *H1-H2*, intensity, and vowel duration) are examined in accounting for the sound change of the Korean stop system. Second, speakers' biases are minimized to see individual differences in sound change by controlling socio-phonetic factors such as age, dialect, gender, and L2 proficiency (i.e., no exposure in an English speaking country) as well as speech rate. Third, more measurement points are analyzed. The current findings are different from previous ones in that stops are not systematically differentiated by each acoustic parameter. Instead of a three-way categorization, a two-way categorization is robust because of one of the mergers, lax-aspirated, aspirate-tense, or lax-tense. For each acoustic property, the findings of the current study are summarized as follows:

VOT: As VOT values between aspirated and lax stops are partially or completely overlapped (or merged), VOT contributes a two-way categorization (tense < lax = aspirated) instead of a three-way distinction (tense < lax < aspirated). There are gender and interspeaker variations: female speakers show more merger than male speakers. Compared to early findings (Lisker and Abramson 1964, Han and Weitzman 1970), lax stops are produced with longer VOT, and aspirated stop are produced with reduced VOT, similar to recent findings (Silva 2006, Oh 2011 and M.-R. Kim 2008, 2013b). Despite the fact that socio-phonetic factors such as age, gender, dialect, L2 proficiency, and speech rate were controlled in the current study, VOT values were noticeably different from speaker to speaker. This suggests that there are individual differences in sound change. The overall VOT results indicate that lax and aspirated stops are truly undergoing a sound change. VOT does not play any role in distinguishing lax from aspirated stops anymore, as discussed in Kim et al. (2002) and among others.

F0: f0 for the lax stops is remarkably lower than for the tense and aspirated stop in the whole syllable, as found in M.-R. Kim (2000). In contrast to the VOT merger, the f0 differences between lax and aspirated stops are maximized or increased. Instead, the f0 merger between aspirated and tense stops occurs. With the aspirated-tense merger, f0 contributes a two-way categorization (lax < tense = aspirated) instead of a three-way distinction (lax < tense < aspirated). The f0 groupings are statistically polarized into two different tones: L tone following lax stops but H tone following aspirated/tense stops, similar to M.-R. Kim's (2000). As expected, there are gender variations on f0 in that female speakers have much larger f0 gap between lax and aspirated/tense stops than male speakers. There are interspeaker variations on f0 in that some speakers show a three-way categorization instead of two for the whole syllable. Compared to VOT, f0 can replace VOT as a primary acoustic cue to distinguish lax from aspirated categories, as discussed in M.-R. Kim's (2000), Kim et al. (2002), and Silva (2006).

H1-H2: At vowel onset, *H1-H2* is greater (positive) for the aspirated and lax stop than for the tense counterpart (negative). With the lax-aspirated merger, *H1-H2* statistically contributes a two-way categorization (tense < lax = aspirated), different from a three-way distinction in early studies in that *H1-H2* is greatest (positive) for aspirated stops, intermediate (positive) for lax stops, and smallest (negative) for tense stops (i.e., tense < lax < aspirated) (Ahn 1999, Cho et al. 2002).

At vowel midpoint, *H1-H2* is greater (positive) for the lax stop than for the aspirated and tense stop (negative). With the aspirated-tense merger, *H1-H2* statistically contributes a two-way categorization (tense = aspirated < lax). The vowel following the lax stop maintains its breathy quality into the middle of a vowel. The lax-breathy quality is obtained from most of the female speakers but from male speakers, indicating that there are gender variations on *H1-H2*. *H1-H2* is another acoustic parameter that is related to sound change for Korean stops.

Vowel duration: Vowel duration is slightly shorter for the aspirated stop than for the lax and tense stops. With the lax-tense merger, vowel duration contributes a two-way statistical categorization (tense = lax < aspirated), different from a three-way categorization (tense < lax < aspirated) in Cho (1996) and M.-R. Kim (2000). Different from VOT, f0, and *H1-H2*, there are little gender and interspeaker variations on vowel duration.

Intensity: Intensity values are greater for the tense stop than for the lax and aspirated stops, whereas there is no significance difference between the latter two. With the lax-aspirated merger, intensity contributes a two-way (lax = aspirated < tense) instead of a three-way distinction (lax < aspirated < tense or lax < tense < aspirated) in early studies (Han and Weitzman 1970, M.-R. Cho Kim 1994, Cho 1996). Very importantly, the *intensity* contours between lax and aspirated syllables are fully merged for a whole syllable, indicating that there are no physical differences between the two stops in loudness. Similar to vowel duration, there are little gender and interspeaker variations on intensity. Along with the intensity merger between lax and aspirated stops, it is clear that their consonantal contrasts are in the process of neutralization. Hence, intensity can be added as another important acoustic property that is correlated with the sound change of the Korean stops.

As discussed above, all five acoustic parameters investigated in the currently study play a role in the process of a sound change in the Korean stop system. With respect to statistical categorization and sound change, the results of acoustic properties are summarized in Table 8, compared with early findings (M.-R. Kim 2000: 189, Cho et al. 2002).

Table 8. Summary of acoustic parameters in sound change

Parameters	Early (3-way)	Current (2-way)	Sound change
VOT (ms)	tense<lax<asp	tense<lax=asp	asp-lax merger
Intensity (dB)	lax<asp<tense	lax=asp<tense	asp-lax merger
f0 (Hz)	lax<tense<asp	lax<tense=asp	tonal polarization asp-tense merger
V duration (ms)	asp<lax<tense	asp<lax=tense	lax-tense merger
Intensity (dB)	lax<asp<tense	lax=asp<tense	asp-lax merger
***H1-H2* (dB)**	tense<lax<asp	tense<lax=asp	asp-tense merger lax-breathy (female)

(Note: VOT and intensity in the upper row are related with consonantal characteristics and f0, Vowel duration, intensity, and *H1-H2* in the low row are related with vocalic characteristics)

The phonetic results of the present study imply that all five acoustic parameters are undergoing some changes from an early three-way to a two-way categorization. The overall results suggest that, unlike the tense stop, the lax and aspirated stop are truly undergoing a sound change toward the loss of a consonantal opposition. In other words, for most of the native Seoul speakers, tonal differences arise whereas consonantal differences are disappearing. That is to say, Korean undergoes tonogenesis in that the tonal differences (i.e., lax-L vs. aspirated/tense-H) have appeared to compensate for the loss of a consonantal opposition (i.e., VOT and intensity merger).

The current findings support Labov's (1990) hypothesis that young female speakers can be the main propagators. As reported in recent findings (Silva 2006, Oh 2011, M.-R. Kim 2011), the role of young female speakers in the sound change of Korean stops is well supported in the current study. With respect to sound change, female speakers tend to show more VOT merger, larger f0 polarization, and more breathy quality for the lax stop into the middle of a following vowel than male speakers. Hence, we can say that female speakers are more active propagators in sound change, compared to male speakers. In addition, individual differences in sound change even within the same gender suggest that some speakers play an active role as 'innovative' propagators in sound change, while others do not.

With respect to the sound change of Korean stops, acoustic parameters tend to be correlated with each other. F0 maximization tends to cooccur VOT merger and vice versa. Breathiness tends to cooccur low tone and vice versa. If a speaker carries tonal differences, she also has a robust VOT merger as well as breathy voice (e.g., most of the females but SF1). If a speaker does not have tonal differences with a three-way categorization, she also does not carry a VOT merger with a three-way categorization (e.g., SF1), either. For all five acoustic parameters, some speakers show a two-way categorization whereas others show a three-way categorization. Further discussion is necessary to account for the relationship between the loss of a consonantal opposition and the emergence of tone in phonology (see M.-R. Kim 2000: 52-54 for a theory of enhancement to which some features or acoustic properties cooccur or enhance other features in both production and perception). I skip to discuss here in detail since it is not the main concern of the current study.

If a particular language is undergoing tonogenesis as sound change, it is common to have the loss of a consonantal opposition as well as the development of tone. As discussed in introduction, the process of tonogenesis involves the following steps: an intrinsic perturbation of initial consonants on f0 (1^{st} step), f0 polarization due to consonantal differences in production and perception (2^{nd} step), and the loss of a consonantal opposition (3^{rd} step). Since tonal differences are fully predictable from consonantal types, tones are not lexically contrastive in Seoul Korean, yet. Thus, Korean is still undergoing a sound change.

With respect to the sound change of the Korean stop system, a number of questions still remain unanswered. Firstly, what initiates the sound change of the Korean stops (i.e., actuation problem)? The question is directly related to the actuation problem, that is, what causes the inception of language change. This problem of language change is first articulated by Weinreich (1953) and is still largely unanswered to this day. It is one of the great mysteries of linguistics. Since Weinreich's classic 1953 book *Languages in Contact,* research over the past half-century has started with a recognition of the importance of language contact for explanations of many linguistic changes. The relationship between language contact and sound change has been speculated by M.-R. Kim (2011). She reports that there are some effects of L2 English on L1 sound change in that advanced L2 learners show more VOT merger in L1 Korean than novice learners. Since her results are based on a couple of speakers for each proficiency level, further quantitative research is necessary to generalize that language contact might be the one that causes the inception of sound change.

Secondly, how is it propagated by whom (i.e., propagation problem)? Previous studies on sound change have mainly focused on group-normative effects, that is, effects that are representative of the population as a whole. In the current study, we have focused on the role of individuals in the actuation of sound change. Recent work has drawn on interspeaker variation as a solution to the actuation puzzle. Understanding the sources of the individual linguistic differences is seen as crucial for understanding sound change propagation, particularly for the purpose of identifying the characteristics of the linguistic innovators and early adopters of change. As found in the current and previous studies, young female speakers can be the early adopters of change, compared to male speakers.

Thirdly, how can we account for the ongoing sound change in contemporary Seoul Korean? A couple of speculations are possible. As discussed above, one can speculate that the process of a sound change can be interpreted as tonogenesis where the onset differences are being lost and tonal differences arise to compensate for the loss of a consonantal opposition. However, although the Korean case belongs to tonogenesis, a couple of issues still remain unsolved (see M.-R. Kim 2012a, 2012b). For example, is it Korean-specific tonogenesis or standard tonogenesis? (see M.-R. Kim 2012a for detailed discussion). This question comes from the traditional hypothesis that there is no voicing contrast in Korean. In standard tonogenesis, certain tonal distinctions developed out of former (subsequently neutralized) voiced vs. voiceless contrasts on prevocalic consonants: a higher tone developing after what had been the voiceless consonant and a lower tone after the voiced (Hombert et al. 1979). Unlike many other languages, the Korean case is quite a mystery on how a lower tone is developing voiceless lax onsets in Korean. Kiparsky (1995: 640) states, "The existence of an important class of exceptionless sound changes grounded in natural articulatory processes is not in doubt, of course. It is the claim that it is the *only* kind of sound change that is under question." According to the sound change in general, it is hard to claim that Korean is the only language that undergoes a sound change in its unique way. The other can speculate a phonologization account of tone. Kirby (2013: 228) describes, "phonologization - the process by which intrinsic phonetic variation gives rise to extrinsic phonological encoding - is often invoked to explain the acquisition and transmission of sound patterns". This account implies that tonal differences in Seoul Korean will become phonemic (Silva 2006 and among others).

Regardless of some phonological arguments on the development of tone in Seoul Korean, the current study shows that Korean stops, especially the lax and aspirated ones, undergo a sound change in terms of all five acoustic parameters such as VOT, f0, *H1-H2*, intensity, and vowel duration. Synchronic and diachronic evidence on individual differences in sound change supports that the sound change of the Korean stop system is still in progress.

5. Conclusion

The current study examined five acoustic parameters to see how they play a role in accounting for the sound change of the Korean stop system. Among the five parameters, the results of VOT and f0 replicate previous findings, while others such as *H1-H2*, intensity, and vowel duration contribute new data to the literature about Korean stops. In addition to the VOT merger and the f0 polarization (or phonologization), there is an intensity merger throughout the lax and aspirated syllables. Each acoustic parameter contributes a two-way categorization instead of three. That is, the opposition of lax and aspirated consonants is being lost, while f0 differences in the vocalic portions are solely prominent. The current findings indicate that Korean stops, especially the lax and aspirated stop, are truly undergoing a sound change in that tonal differences arise to distinguish lax from aspirated syllables. For the words, 달 /tal/ 'moon' and 탈 /tʰal/ 'mask', the loss of a consonantal opposition has already occurred, while f0 (i.e., tonal) differences in the vocalic portions are maximally polarized into a L tone for 달 but a H tone for 탈 (i.e., 달 [tʰal] 'moon' with L vs. 탈 /tʰal/ 'mask' with H). The sound change in Seoul Korean is analogous to tonogenesis where tonal differences arise to compensate for the loss of a consonantal opposition. Since tonal differences are fully predictable form initial consonant types, however, we can say that the sound change of the Koreans stop system is still in progress. An issue still remains unsolved: since it's different from a standard tonogenesis hypothesis (i.e., voiceless-H vs. voiced-L), further study is necessary on how we can account for the process of tonal development in contemporary Seoul Korean.

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Mi-Ryoung Kim
Department of Practical English
Korea Soongsil Cyber University
#307 Jongno Biz-well, 23 Samil-daero 30 gil
Jongno-gu, Seoul, 110-340, Korea
e-mail: kmrg@mail.kcu.ac

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Appendix A1. Mean VOT, V duration, and *H1-H2* at onset and midpoint

		VOT			Vduration			*H1-H2*	
Stop	Sub.	*M*	min.	max.	*M*	min.	max.	onset	mid
Asp.	SF1	94	68	131	137	76	209	0.9	-4.3
	SF2	119	89	145	199	115	283	3.6	3.4
	SF3	87	68	103	191	107	282	0.1	1.8
	SF4	70	44	102	182	92	279	11	8.1
	SF5	92	71	129	144	60	226	5.9	8.7
	SF6	65	28	94	191	87	293	2.4	2.1
	SF7	77	46	111	190	116	278	1.0	1.0
	SM1	63	45	82	171	89	265	-1.6	-2.5
	SM2	71	49	124	194	142	255	-0.3	-1.0
	SM3	82	62	116	132	63	231	-0.3	-0.8
	SM4	94	64	124	140	53	265	-0.1	0.2
	SM5	97	79	128	144	75	229	6.2	-2.3
	SM6	68	38	90	118	50	193	2.2	-0.8
	M	**83**	**28**	**145**	**164**	**50**	**293**	**2.6**	**1.7**
Lax	SF1	72	41	100	167	86	266	5.8	4
	SF2	111	87	146	233	145	322	3.7	5.6
	SF3	81	57	102	204	117	325	0.9	0.9
	SF4	60	34	86	226	90	368	9.4	11
	SF5	96	84	110	161	79	273	2.8	8.7
	SF6	65	36	136	205	112	308	2.0	0.6
	SF7	74	50	96	211	126	331	2.3	2.6
	SM1	49	33	61	198	106	304	1.1	-0.2
	SM2	33	14	57	202	156	258	-0.7	0.9
	SM3	61	37	92	154	67	263	0.6	-0.1
	SM4	73	44	105	151	60	305	0.9	0.9
	SM5	86	57	109	159	76	233	1.1	1.6
	SM6	70	35	90	123	51	200	3.2	-1.3
	M	**71**	**14**	**146**	**184**	**51**	**368**	**2.4**	**2.1**
Ten.	SF1	14	7	30	175	124	239	-11	-4.8
	SF2	14	7	28	245	169	322	0.3	-2.5
	SF3	14	9	21	198	118	306	-3.2	-4.8
	SF4	15	7	30	210	99	314	-1.0	-3.3
	SF5	11	6	21	174	93	288	-2.0	-8.3
	SF6	14	6	23	213	126	306	-2.3	-6.1
	SF7	14	4	27	218	130	314	-1.7	-2.6
	SM1	17	10	26	203	118	320	-4.6	-4.0
	SM2	14	5	29	217	174	250	-5.5	-6.8
	SM3	20	9	48	158	94	244	-1.8	-3.3
	SM4	20	11	33	162	94	228	-1.7	-2.5
	SM5	16	10	31	171	101	242	-9.5	-3.4
	SM6	14	8	24	150	78	245	0.1	-2.2
	M	**15**	**4**	**48**	**192**	**78**	**322**	**-2.2**	**-4.7**

Appendix A2. Mean f0, Cintensity, and Vintensity values at 60% into a vowel

		f0			Cintensity			Vintensity		
Stop	Sub.	*M*	min.	max.	*M*	min.	max.	*M*	min.	max.
Asp.	SF1	278	250	310	57	54	61	79	75	84
	SF2	292	277	306	63	60	65	79	77	82
	SF3	283	269	295	54	49	57	74	72	81
	SF4	293	276	321	68	64	73	83	79	87
	SF5	334	310	361	70	66	72	86	81	89
	SF6	259	236	278	55	51	60	74	70	78
	SF7	246	233	263	59	55	62	79	73	83
	SM1	130	115	152	57	53	62	81	77	88
	SM2	180	163	189	57	54	60	80	77	84
	SM3	160	136	180	55	51	60	79	75	89
	SM4	169	151	196	63	60	66	81	73	87
	SM5	211	186	241	66	62	69	85	82	88
	SM6	169	159	183	58	55	62	74	71	81
	M	**231**	**115**	**361**	**60**	**49**	**73**	**80**	**70**	**89**
Lax	SF1	220	214	227	59	56	65	80	77	83
	SF2	197	188	211	65	62	66	81	79	84
	SF3	218	211	227	52	49	56	75	71	77
	SF4	225	204	243	69	64	74	82	80	84
	SF5	238	209	259	71	69	74	86	79	89
	SF6	208	195	226	56	50	68	73	67	77
	SF7	201	181	217	58	55	62	80	76	83
	SM1	108	98	130	59	55	65	81	77	88
	SM2	173	158	180	60	52	72	81	75	85
	SM3	146	134	162	57	49	65	80	74	83
	SM4	132	123	141	62	59	69	81	75	87
	SM5	175	150	203	64	59	68	86	84	88
	SM6	124	118	133	58	55	61	73	70	76
	M	**182**	**98**	**259**	**61**	**49**	**74**	**80**	**67**	**89**
Ten.	SF1	262	232	291	72	64	78	82	78	86
	SF2	285	271	300	73	65	77	81	77	83
	SF3	274	264	281	65	62	69	78	76	80
	SF4	292	272	311	76	71	81	82	78	85
	SF5	319	302	335	82	74	86	88	85	89
	SF6	254	236	270	67	59	75	75	69	81
	SF7	241	229	253	72	64	79	81	75	85
	SM1	127	113	142	70	61	78	82	79	88
	SM2	182	172	189	73	65	79	83	80	85
	SM3	158	141	169	71	60	77	83	79	87
	SM4	162	153	175	73	65	78	84	82	88
	SM5	206	187	231	77	69	81	87	84	90
	SM6	161	149	170	71	61	76	77	73	81
	M	**225**	**113**	**335**	**72**	**59**	**86**	**82**	**69**	**90**