Title: Development of pitch contrast and Seoul Korean intonation: A corpus study

Sunghye Cho[a]*, Yong-cheol Lee[b], and Mark Liberman[a]

* Corresponding author: csunghye@sas.upenn.edu, Tel: 215-898-6046
[a] Department of Linguistics, University of Pennsylvania, Philadelphia, PA 19104, USA
[b] Department of English Language and Literature, Cheongju University, Cheongju, 306-764, South Korea

Abstract
This paper is an apparent-time study of a tonogenetic sound change and its effect on the intonational tonal pattern in Seoul Korean. The data were drawn from a speech corpus published by the National Institute of the Korean Language. The study examined 59 sentence-initial Accentual Phrases (AP) read by 118 speakers (born between 1932 and 1984) in the corpus. We measured mean pitch values of syllables in the target APs to investigate how the AP-initial pitch contrast and intonational patterns varied by age and gender. The results confirm previous findings that the AP-initial pitch difference between High-pitch inducing and Low-pitch inducing contexts increases in younger speakers, and pitch distinction in the AP-initial syllable extends further into later syllables of the same AP. The novel finding is that the size of APs and the intonational Low tone on the penultimate syllable affect the realization of the AP tonal pattern. The results also show that the enhancement of pitch distinction in non-initial syllables is greater for younger than older speakers, and also greater for females than males. In the discussion, we compare Seoul Korean to other languages that previously underwent tonogenesis. [189 words]

Keywords
Accentual Phrase, Intonation, Seoul Korean, Sound change, Tonogenesis, Age, Gender

Development of pitch contrast and Seoul Korean intonation: A corpus study

1. Introduction

Tonogenesis refers to a process where previously toneless languages develop a tonal contrast and previously tonal languages multiply their tonal inventories by a tone split (Hombert 1978, Hyman 1978, Kingston 2011, Kirby 2014, Matisoff 1973, Maran 1973, Thurgood 2002, among others). Several steps are involved in tonogenesis. The first step is that consonantal features, such as a voicing contrast or a laryngeal contrast, give rise to a pitch contrast. At this stage, the pitch contrast coexists with the segmental contrast as a secondary cue. Next, the pitch contrast is exaggerated to the extent that it can no longer be attributed to phonetic perturbation of consonants. In the final stage, the pitch contrast develops as a tonal contrast when the consonantal contrast that coexisted with the pitch contrast is lost.

The following table shows an example of Vietnamese tonogenesis, first proposed by Haudricourt in 1954 (cited from Kingston 2011; also see Diffloth 1989, Matisoff 1973, Thurgood 2002). In the initial stage, post-vocalic consonants gave rise to a three-way contrast of pitch contours. A final stop consonant developed a rising tone, and a final fricative induced a falling tone. A level tone developed from either open syllables or syllables with a nasal coda consonant. In a later stage, these three tones split into two different pitch heights depending on onset consonants. Syllables with a voiced onset developed a low tone, and those with a voiceless initial induced a high tone, resulting in a six-way tonal contrast (2 pitch heights x 3 contours).[1]

Table 1. Vietnamese tonogenesis (borrowed from Kingston 2011). "T" stands for any following stops, and the Vietnamese tone names are in parentheses.

		Following consonants		
		CV, CVN	CVT	CVs, CVh
Preceding consonants	voiceless	*pa > pa high level (ngang)	*pak > pak high rising (sac)	pas > pa high falling (hoi)
	voiced	*ba > pa low level (huyen)	bak > pak low rising (nang)	bas > pa low falling (nga)

Previous studies show that Seoul Korean is also undergoing a tonogenetic sound change (Kang 2014, Kim 2000, Oh 2011, Silva 2006, Wright 2007). Korean has a unique three-way contrast among voiceless stop consonants: aspirated /p^h, t^h, k^h/, tense /p', t', k'/, and lenis /p, t, k/. The three stop categories differ from one another in many acoustic features, such as Voice Onset Time (VOT), fundamental frequency, and the amplitude difference between the first harmonic and the second one (Cho et al. 2002, Han and Weitzman 1970, Kang 2014, Lisker and Abramson 1964, Oh 2011, Silva 2006, Wright 2007, among others).

The most frequently studied features of the Korean stops are VOT and pitch. Previous studies demonstrate that older speakers produce the aspirated category with the longest VOT and the tense one with the shortest VOT (Cho et al. 2002, Kang 2014, Han and Weitzman 1970, Lisker

[1] Thurgood (2002, 2007) states that the origin of the development of tonal contrasts in Vietnamese is the laryngeal gestures accompanied with voice qualities, not consonants by themselves. He suggests that rising and level tones developed from differences in voice quality, where a rising tone was induced by a creaky voice and a level tone developed from a modal voice. See Thurgood (2002, 2007) for more information.

and Abramson 1964). However, the VOT difference between aspirated and lenis is merging for younger speakers, resulting in a two-way VOT contrast: aspirated & lenis (long VOT) vs. tense (short VOT) (Choi 2002, Kang and Guion 2008, Kang 2014, Kim 2000, Kim 2004, Kong et al. 2011, Lee and Jongman 2012, Oh 2011, Silva 2006, Wright 2007). It is also found that younger speakers of Seoul Korean are likely to use a pitch difference in distinguishing the stop categories, where both vowels following aspirated and tense stops are produced with a higher pitch than those following lenis stop onsets (Jun 1996, Kang 2014, Kim 2004, Kong et al. 2011, Lee and Jongman 2012, Oh 2011, Silva 2006, Wright 2007). This trade-off between the VOT contrast and the pitch contrast is in line with the process of tonogenesis, where the consonantal feature is replaced with a pitch contrast. Kang (2014) suggests that Seoul Korean is in the stage where the VOT distinction is weakening while the pitch contrast is further being enhanced.

Many aspects of this tonogenetic change have previously been studied. Previous research find that the VOT value of aspirated decreases and overlaps with that of lenis for younger speakers, but not for older speakers (Jin 2008, Kang 2014, Kang and Guion 2008, Silva 2006, Wright 2007). Also, previous studies show that there is a gender effect on VOT realization in that young female speakers produce aspirated stops with a shorter VOT than young male speakers do, resulting in a more overlapping VOT range between aspirated and lenis for females (Oh 2011, Kang 2014). The observed gender pattern is in line with the finding in the literature of sociolinguistics that female speakers lead a change below the level of (speakers') consciousness (Eckert 1989, Eckert and McConnell-Ginet 2003, Labov 1990, Labov 2001, among others), meaning that females are the leaders of this tonogenetic change, which many native speakers of Seoul Korean are not consciously aware of.

As for pitch, Kang (2014) finds that the pitch difference between lenis and aspirated is larger for younger speakers than older ones and also larger for females than males, suggesting than the tonogenetic sound change is the most advanced for younger females. By weighting the two acoustic cues, VOT and f0, she shows that female speakers use f0 to distinguish aspirated from lenis regardless of their age, whereas male speakers use both cues with a tendency that younger males rely more on f0 than VOT. A similar gender effect is also found in perception. For example, Kong et al. (2011) demonstrate that females more rely on a pitch cue in identifying lenis and aspirated stops than males.

There are a few studies that investigate fricatives and affricates (Cho et al. 2002, Kang 2014, Kim 2004), because Korean also has a three-way contrast in affricates (aspirated /ts^h/, tense /ts'/, lenis /ts/) and a two-way contrast in coronal fricatives (tense /s'/ and plain /s/). Jun (1993) finds that a phrase-initial /s/ also triggers a high pitch, although Cho et al. (2002) show that the f0 of syllables with the /s/ onset is lower than those with a tense /s'/. Kang (2014) finds that the pitch value of syllables starting with the non-coronal fricative /h/ is similar to that of aspirated-stop-initial syllables.[2] As for affricates, Kim (2004) and Perkins and Lee (2010) suggest that vowels following aspirated and tense affricates are also produced with a higher pitch than those following the lenis affricate. The results of the previous studies suggest that the tonogenetic sound change is a structural one affecting all aspirated and tense categories.

What remains to be seen is how this tonogenetic sound change affects the intonational melody of Seoul Korean. The model of Seoul Korean intonation proposed by Jun (1993, 1996, 2006, 2007, 2011) is provided in Figure 1. Seoul Korean has three prosodic units: Intonational Phrase (IP), Intermediate Phrase (ip), and Accentual Phrase (AP). An IP is the largest unit,

---

[2] For our study, we categorize /s, h/ as aspirated fricatives for the same reason with Kang (2014). See the result section.

marked by an utterance-final boundary tone, and an ip is the domain of pitch resetting within an utterance. One or two content words with optional grammatical markers form the smallest prosodic unit (AP) in Seoul Korean. Jun's theory incorporates the observation that phrase-initial syllables show a substantial pitch difference depending on its onset category. The basic melody of an AP is TH-LH, where T stands for either H (High) or L (Low). The first two syllables of an AP are assigned with the first two tones (**TH**-LH), respectively, and the final two syllables are assigned with the second LH melody (TH-**LH**). When an AP is longer than 4 syllables, intermediate syllables receive their pitch values via interpolation from the first H (T**H**) to the penultimate L (**L**H), and when an AP is shorter than 4 syllables, AP-medial tones (T**H-L**H) are optionally undershot, resulting in various pitch patterns from L-LH, LH-H, L-H, H-LH, to H-H.

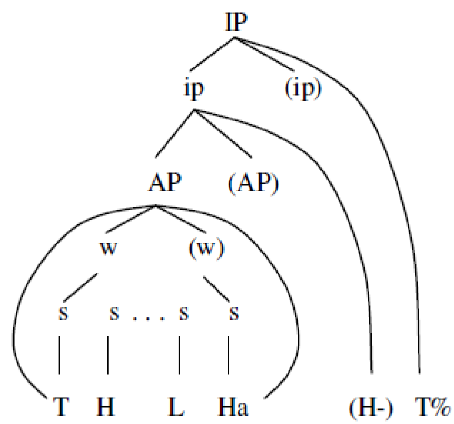

Figure 1. Intonational model of Seoul Korean (borrowed from Jun and Cha 2015).

While most previous studies investigate the pitch values of AP-initial syllables only, some previous studies find that an AP-initial consonant has an effect on the pitch value of an AP-second syllable (Cho and Lee 2016, Kang 2014, Lee 1999, Silva 2006). What the previous studies find is that an AP-second syllable is produced with a higher pitch when the AP starts with a High-pitch inducing consonant (aspirated or tense) than a Low-pitch inducing one. It indicates that the effect of an AP-initial consonant reaches beyond an AP-initial syllable. Lee (1999) examines 4 speakers of Seoul Korean (2 males, 2 females) and find that the second syllable of APs starting with a H-pitch inducing stop is produced with a higher pitch than those starting with a L-inducing one, and there is inter-speaker variation in the tonal realization of APs.[3] Kang (2014) demonstrates that there is an interaction with speakers' age and the pitch values of the AP-second syllable in that the pitch difference is larger for younger speakers than older ones. Cho and Lee (2016) examine the effect of an H-pitch inducing consonant in each syllable position of an AP. They conduct a production experiment with 8 young speakers of Seoul Korean, using phone-number strings and natural words, and find that APs starting with a H-inducing consonant are produced within a higher pitch range than those starting with a L-inducing one, which suggests that not only AP-second but also later syllables are produced with a high pitch when an AP-initial consonant is either aspirated or tense.

---

[3] Although the speakers' age is not known in Lee (1999), his second female speaker (F2) shows a similar pitch pattern to younger speakers (born after 1960) in our study, and the first female speaker (F1) shows a similar pattern to females born in the 1950s. See Section 3.4.

What the previous studies indicate is that an AP-initial onset consonant affects pitch values of later syllables of the same AP for younger speakers. However, much less is known about this effect. While there is evidence that VOT and pitch contrasts vary by speakers' age and gender and a H-pitch inducing consonant in the AP-initial position affects pitch values of non-initial syllables, the exact pattern of the diachronic development of the AP melody and its interaction with age and gender remains to be seen. For example, it is not clear if we see the same effect of H-inducing consonants on non-initial syllables for old speakers, as only younger speakers are studied in Cho and Lee (2016). If older speakers do not show similar patterns, an in-depth investigation of the change is needed to fully understand this tonogenetic change. Also, it is not known if the pitch differences of non-initial syllables are affected with the same rate of the development of the AP-initial pitch difference. Did the AP-initial pitch contrast develop first and start to affect non-initial syllables later? Or did the pitch range of entire H-initial APs become high concomitantly? When did the AP-initial H-inducing consonants start to affect pitch values of later syllables? These questions remain to be answered. Lastly, it is not clear how the AP tonal pattern and the AP-initial pitch contrast are realized in different AP sizes. APs that are 2-syllable to 5-syllable long are the most common sizes in Korean, and we hypothesize to see differences in pitch patterns depending on whether the AP melody, TH-LH, is fully realized (4-syllable or 5-syllable long) or the AP-medial tones (T**H-L**H) are undershot (2-syllable or 3-syllable long).

To observe a diachronic development of AP pitch patterns, a corpus study with a large number of speakers with a wide age range is necessary. Thus, in this study, we employ a large-scale corpus of Seoul Korean with 118 speakers to conduct an apparent-time study in investigating the diachronic pattern of the change.[4] With the above questions in mind, this study aims to provide a dynamic picture on the f0 dimension of the change by showing how the pitch trajectory of APs has been changed over time due to the effect of the AP-initial pitch contrast and how age, gender, and other linguistic factors affect the AP melody of Korean.

2. Methods

2.1. The Speech Corpus of Reading-Style Standard Korean

For the present study, we draw the speech data from *The Speech Corpus of Reading-Style Standard Korean* (hereafter the NIKL corpus), published by the National Institute of the Korean Language (NIKL 2005). The corpus consists of read speech of 60 male and 60 female speakers of Seoul Korean, who were born and raised in Seoul or the Seoul metropolitan area. The publisher of the corpus reports that the participants' parents are also speakers of Seoul Korean and have lived in the Seoul metropolitan area. The speakers' age ranges from 19 to 71 at the time of recording (2003). Their age is converted to their year of birth (ranging from 1932 to 1984) by subtracting their age from 2003, following Kang's study (2014), which employs the same corpus in investigating the trade-off between VOT and pitch cues in Seoul Korean. The analysis of the present study is based on 118 speakers out of 120, because the sound files of the other two

[4] An apparent-time study is one way of studying language change in sociolinguistics. In this method, variation by speakers' age in a single period of time (i.e., at the time of a study) is assumed to reflect the linguistic patterns when the speakers acquired the language. In this way, an apparent time study allows to study a diachronic pattern in language change for a relatively short time period. Apparent time studies make a contrast to real-time studies, where longitudinal studies on the same topic are done in distant time periods. See Bailey (2002), Guy (2003), or Sankoff (2006) for more information.

speakers have technical errors.[5] The number of speakers of the corpus, stratified by year of birth (YOB) and gender, is given in Table 2.

Table 2. Year of birth (aggregated by 10 year bands) and gender of the speakers in the NIKL corpus. The numbers in parentheses are the numbers of speakers in the original corpus data.

YOB	1930s	1940s	1950s	1960s	1970s	1980s	Total
Female	2	9 (10)	25	3	11	9	59 (60)
Male	4	12	4	7 (8)	27	5	59 (60)

The speech materials of the corpus are based on 19 well-known short stories, such as traditional folk tales and personal essays, and the total number of sentences in all 19 short stories is 930. Younger speakers (age under 50 at the time of recording) read all 19 stories, but older speakers (age 50 or over at the time of recording) read only 11 stories out of 19.[6] The number of sentences in those 11 stories is 404, and we draw the corpus data only from those sentences to include all available speakers of the corpus in our data.

2.2. Our data

For the present study, we select 59 sentences out of 404.[7] The basic melody of an AP, TH-LH, is greatly affected if an ip or IP boundary is overridden with the AP-final tone. For example, the final boundary L tone of an IP, which often found in a declarative sentence, may override the final boundary H tone of a sentence-final AP, obscuring the pitch pattern of the final AP. Since it is possible for sentence-medial or -final APs to be affected by such an effect, only sentence-initial APs, which are less likely to be affected by the boundary tones of larger prosodic units, are included in our analysis. Table 3 provides the number of the 59 sentence-initial APs stratified by manner of articulation of AP-initial onset consonants and Table 4 shows the number of the target APs by their size. Since there are few sentence-initial APs that are longer than 5 syllables, we only include 2- to 5-syllable APs in the analysis.

Although we have tried to include at least one AP for all onset categories and AP sizes, this is not impossible for the tense category, since only five out of the total 404 sentences begin with a tense onset. All of them begin with tense stops, leaving accidental gaps for the tense affricate /ts’/, the tense fricative /s’/, and 5-syllable APs with a tense onset.[8] However, the main goal of this study is to investigate the trajectory of change in Seoul Korean over time due to the introduction of the AP-initial pitch contrast (H or L), not the contrast among the H-pitch inducing categories (aspirated and tense), so the current data suffice to serve our purpose despite

[5] The speakers ID whose sound files contain errors are fy15, a female speaker who was born in 1948, and mw12, a male speaker who was born in 1970. Their sound files contain no information (0 bite), so we could not use those files for analysis. In the corpus, there were two speakers (mv15 and mv18) whose sound files could not be opened, because the files were headerless. We could recover them by converting them into .raw files, adding appropriate headers, and reconverting them into .wav files, so we included them in our analysis.
[6] The story ID numbers of those 11 stories are from t09 to t19.
[7] The sentences used in this study are provided in Appendix A.
[8] These accidental gaps seem to be inevitable, considering that there are not many words beginning with a tense affricate or a tense fricative in Korean in general.

the accidental gaps in the tense category.

Table 3. Number of the target APs by manner of articulation of AP-initial onset consonants and their laryngeal category. Cells highlighted in grey indicate H-pitch inducing categories. [9]

	Aspirated	Tense	Lenis	Total
Stop	5	5	12	22
Affricate	5	0	8	13
Fricative	14	0	NA	14
Sonorant or zero (vowel-initial)	NA	NA	NA	10

Table 4. Number of the target APs by AP size. Cells highlighted in grey represent H-pitch inducing categories. Again, /s/ and /h/ are counted as aspirated.

	Aspirated	Tense	Lenis	Sonorant or vowel	Total
2-syllable	2	1	4	2	9
3-syllable	10	1	5	2	18
4-syllable	10	3	7	4	24
5-syllable	2	0	4	2	8

2.3. Measurements

The sampling rate of the sound files was 16,000 Hz. For the 59 selected sentences, the onset and offset of syllables as well as the onset and offset of sentence-initial APs were forced-aligned with the Korean forced-aligner (Yoon and Kang 2012). The alignments of syllables and the boundaries of the target APs were manually checked and corrected afterwards. During this process, 20 target APs were excluded due to either reading errors, an unexpected pause within the target AP, or unusual AP boundaries. Also, there were 5 missing files, so a total of 6,937 APs (118 speakers x 59 sentence-initial APs – 25 incorrect or missing files) were analyzed.

As for the f0 measurement, we measured mean pitch values of all syllables within the target APs using *Praat* (Boersma and Weenink 2016) with f0 range set at 75–300 Hz for male speakers and 100–500 Hz for female speakers. Since the AP-initial pitch contrast stemmed from the tonogenetic sound change of onset consonants, the f0 measurements were taken from the entire syllable duration, including onset consonants, unlike previous studies' methods in which the f0 measurements were taken at the midpoint of vowels (Kang 2014), or onset, midpoint, and offset of vowels (Silva 2006).

We converted the obtained pitch values into a semitone scale (St), using speakers' baseline pitch values. Liberman and Pierrehumbert (1984) suggest that a natural scale for intonation appears to show exponential decay, decreasing proportionally to a speaker's baseline, where the baseline stands for the bottom of the speaker's pitch range. Following this idea, we first computed each speaker's baseline, which was defined as the 10^{th} percentile of his or her own

[9] /s/ and /h/ are counted as aspirated, because they pattern together with other aspirated stops in terms of their pitch patterns. (See Section 3.3.)

pitch range in this study.[10] Afterwards, St was calculated with each speaker's baseline as a reference f0, using the following formula: St = log2(f0/**baseline**)*12. One advantage of using this relative semitone scale over the one calculated with a fixed reference f0 is that it allows us to compare the pitch patterns of different age and gender groups directly, since the scale was calculated relative to each speaker's baseline.

3. Results

3.1. Stop-initial 4-syllable APs by Age

To begin with a controlled data set, this section only examines 4-syllable APs starting with a stop consonant. In our data, there are 11 stop-initial APs that are 4-syllable long. We select 9 APs out of 11 that do not have a low vowel in the AP-initial syllable. There are three APs starting with an aspirated stop, another 3 APs starting with a tense stop, and the other 3 APs starting with a lenis stop.[11] Table 5 shows the target APs and the number of syllables examined in this section.[12]

Table 5. 4-syllable APs starting with a stop consonant (number of syllables examined). A dot represents a syllable boundary. In total, 4,138 syllables are examined.

Aspirated	Tense	Lenis
/pʰi.sʌ.tsi.ɰi/ (467) 'resort-POSS'	/p'om.nɛ.tɨs.i/ (463) 'as if showing off'	/kʌ.ki.ɛ.nɨn/ (471) 'there-TOP'
/pʰi.la.mi.na/ (458) 'pale club or'	/t'ok.kat.ɨn.s'al/ (466) 'the same rice'	/kɨ.lʌ.tʌ.ni/ (456) 'after that'
/kʰɨ.ko.tsak.ɨn/ (438) 'of various sizes'	/k'um.sok.ɛ.sʌ/ (468) 'in the dream'	/kɨ.lʌ.ta.ka/ (451) 'and then'

Figure 2 shows the mean pitch values (St) of the target APs by the laryngeal categories of the initial stops and speakers' YOB (aggregated in 10 year bands). In Figure 2, it is clear that the AP pitch contours of older speakers are quite different from those of younger speakers. The pitch difference between the H-pitch inducing categories (aspirated and tense) and lenis in the AP-initial syllable is much larger for younger speakers than older ones, confirming the results of previous studies on the tonogenetic sound change (Jun 1996, Silva 2006, Wright 2007, Oh 2011, Kang 2014, Cho and Lee 2016, and among others). The AP-initial pitch difference is less than 1 St for speakers born in the 1930s, but the AP-initial pitch difference increases to about 3 St for speakers born after 1960, meaning that the pitch difference for younger speakers is three times larger that that of older speakers.

[10] We define a baseline as the 10th percentile of the total tokens of one's pitch range using a Python script, but see Yuan & Liberman (2014), where the authors use the 5th percentile as a baseline.
[11] Since there were a limited number of sentences in the corpus, it was impossible to control the place of articulation of the initial stops.
[12] The maximum number of syllables for each target AP is 472 (118 speakers x 4 syllables per AP), but the target APs in Table 5 have fewer syllables than that because some files were excluded from the analysis and sometimes *Praat* failed to track the pitch value of certain syllables due to either reduced vowels or strong aspiration.

Also, the result shows that the initial syllable of aspirated-initial APs is higher than that of tense-initial APs in all age groups. Speakers born in the 1930s do not show such a difference between the aspirated and tense contexts, but speakers born after 1940 produce the first syllable of aspirated-initial APs with a higher pitch than the one in the tense context. However, this pitch difference does not seem to change depending on speakers' YOB, suggesting that the difference between the two contexts is not attributed to the tonogenetic change. Also, it is noticeable that aspirated-initial and tense-initial APs do not seem to be different from the AP-second position to the final position, suggesting both aspirated and tense are the categories affected by the tonogenetic change.

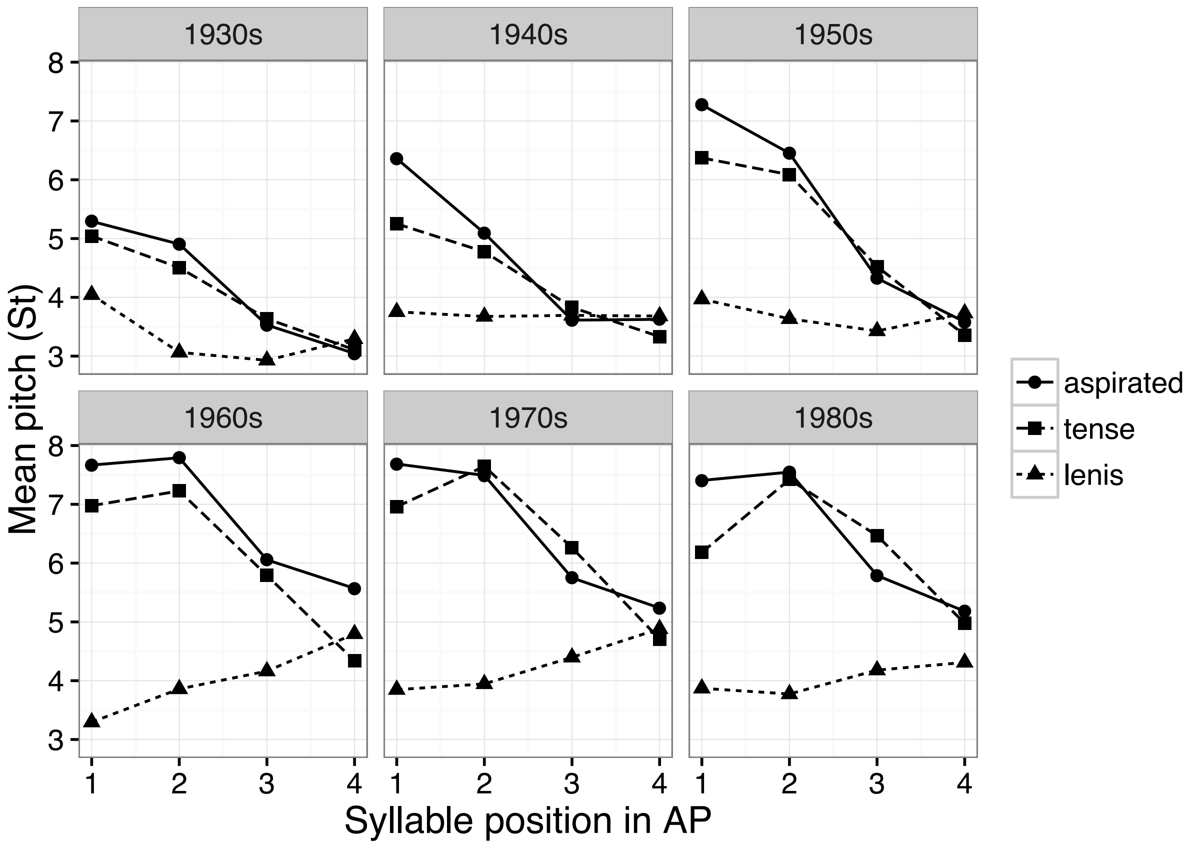

Figure 2. Mean pitch value (St) of each syllable in the target APs by the stop categories and speakers' year of birth, aggregated in 10 year bands. Syllable positions within the target APs are shown in the x-axis, where "1" means AP-initial and "4" means AP-fourth (final) syllables.

Figure 2 also shows that the pitch difference between H-initial and L-initial APs in the AP-second syllable increases in younger speakers, when compared to older ones. The difference among speakers born in the 1930s and 40s show that only the AP-initial syllable is affected by the change, but from speakers born after 1950, it is clearly seen that the AP-second syllable is also produced with a remarkably higher pitch when an AP starts with a H-pitch inducing segment than when it starts with a L-pitch inducing one. This result is in line with previous studies (Silva 2006, Kang 2014), which also find a pitch difference in the AP-second syllable.

What is interesting in our result is that the pitch difference between H-initial and L-initial APs is found not only in the first two syllables of an AP but also in the remaining syllables for younger speakers. For speakers born in the 1930s, 40s, and 50s, the pitch difference in the third and fourth syllables is not much noticeable. However, the pitch value of the AP-third syllable is higher in the H-initial APs than in the L-initial ones for speakers born after 1960. Considering that the AP-third syllable is the position where the intonational L of the final **L**H boundary tones occurs in the Korean ToBI model, it is noteworthy that the pitch difference that younger speakers show is about 2 St in the AP-third syllable position.

There also exist differences in the AP-fourth syllable between older and younger speakers. Older speakers born in the 1930s, 40s, and 50s do not show a pitch difference between L-initial and H-initial APs in the AP-fourth position. The mean pitch values of the fourth syllables of tense-initial and lenis-initial APs are not that different for speakers born in the 1960s and 70s, although that of aspirated-initial APs is slightly higher than those. In addition, the youngest speakers, those born in the 1980s, produce the fourth syllables of both aspirated and tense-initial APs with a higher pitch than that of lenis-initial APs. However, it is clear that the effect of the AP-initial pitch context considerably decreases in the AP-fourth syllable even for younger speakers, when compared to its effect in the first syllable position.

To see if the observed differences are statistically significant, we built four linear mixed-effects models, one for each syllable position. In the analyses, a dependent variable is speakers' pitch values in each position and the independent variables are the three stop categories and speakers' YOB. Each speaker is included as a random effect. The reference category for the stops is Lenis, and YOB is centered at 1961, which is the median value in the corpus, following the method used in Kang (2014). Table 6 summarizes the results of the linear mixed-effects analyses.

The results confirm that Aspirated and Tense are produced with a significantly higher pitch in all AP positions except the final one ($p < 0.001$ for the AP-initial, second, and third positions). For example, the estimated pitch values of aspirated-initial and tense-initial APs are 3.31 St and 2.45 St higher than that of lenis-initial APs in the AP-initial position, respectively ($p < 0.001$ for both comparisons). While both Aspirated and Tense show a higher pitch value than Lenis in the first syllable, the models show that the pitch difference from Lenis is larger for Aspirated (3.31 St) than Tense (2.45 St), confirming our observation made in Figure 2. This result is in line with some of the previous studies (Choi 2002, Kim 1994, Silva 2006, Lee and Jongman 2012) that also find a pitch difference between Tense and Aspirated in the AP-initial syllable.[13] Also, the models estimate that even the third syllables of Aspirated and Tense are 0.97 St and 1.26 St higher than that of Lenis ($p < 0.001$ for both comparisons), but the size of the pitch difference is larger for the Lenis-Tense comparison (1.26 St) than the Lenis-Aspirated in this case (0.97 St).

The effect of YOB on lenis-initial APs is not significant in the first two syllable positions, but it was significant in the last two positions ($p = 0.002$ for AP-third, $p = 0.002$ for AP-final). This seems to be because younger speakers tend to undershoot the intonational L tone of the AP-penultimate syllable in the lenis context. Speakers born in the 1930s, 40s, and 50s produce the third syllable of lenis-initial APs with a slightly lower pitch than the first and second syllables,

[13] It is not clear why we observe such a difference between Aspirated and Tense in the AP-initial position, but one possibility is that it is due to the physiological difference of the larynx when producing the two stop categories. Previous studies show that the tense category is characterized with a complete adduction of the vocal folds, whereas the aspirated category is associated with an abducted state of the vocal folds (Kagaya 1974, Hirose et al. 1974, Jun, Beckman & Lee 1998, Cho et al. 2002, among others).

but those born after 1960 do not show such a pitch lowering on the penultimate position, producing rather a LH-(L)H or even L-H pattern (Figure 2).[14] The estimated pitch value of the penultimate L tone of speakers born in 1932 is 2.99 St (= 3.86 + (0.03 x (1932 – 1961))), whereas that of speakers born in 1984 is 4.55 St (= 3.86 + (0.03 x (1984 – 1961))).[15]

Table 6. The outputs of linear mixed-effects models of stop-initial 4-syllable APs by Syllable Position and YOB. Lenis is the reference category for stops, and YOB is centered at 1961.

AP-initial	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.82	0.14	27.01	< 0.001 ***
YOB	0.00	0.01	-0.33	0.739
Aspirated	3.31	0.14	23.81	< 0.001 ***
Tense	2.45	0.14	18.05	< 0.001 ***
YOB*Aspirated	0.04	0.01	4.16	< 0.001 ***
YOB*Tense	0.04	0.01	4.03	< 0.001 ***

AP-second	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.73	0.13	28.47	< 0.001 ***
YOB	0.01	0.09	1.16	0.248
Aspirated	2.87	0.10	28.24	< 0.001 ***
Tense	2.67	0.10	26.31	< 0.001 ***
YOB*Aspirated	0.06	0.01	7.97	< 0.001 ***
YOB*Tense	0.07	0.01	9.32	< 0.001 ***

AP-third	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.86	0.13	30.91	< 0.001 ***
YOB	0.03	0.01	3.09	0.002 **
Aspirated	0.97	0.10	9.23	< 0.001 ***
Tense	1.26	0.10	12.11	< 0.001 ***
YOB*Aspirated	0.04	0.01	5.21	< 0.001 ***
YOB*Tense	0.05	0.01	6.24	< 0.001 ***

AP-final	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.18	0.14	29.84	< 0.001 ***
YOB	0.03	0.01	3.19	0.002 **
Aspirated	0.18	0.14	1.29	0.198
Tense	-0.21	0.14	-1.53	0.127
YOB*Aspirated	0.03	0.01	2.66	0.008 **
YOB*Tense	0.02	0.01	1.58	0.114

[14] Lee (1999) finds the same inter-speaker variation in the production of the intonational L tone on the penultimate syllable. He explains that the penultimate L tone undershoot is more frequently found in fast speech. Cho (2011) also finds a similar effect of speech rate on the realization of an AP pitch pattern. She shows that not all four intonational tones (LH-LH) are realized in fast speech.

[15] Since YOB is centered at 1961, the interaction coefficient is multiplied by the year difference from 1961 and the resulting value is added to the intercept in order to calculate the estimated value of a speaker's pitch value. A similar formula is used in Kang (2014), which uses the same corpus.

Even though younger speakers produce the penultimate and final syllables of lenis-initial APs with a higher pitch than older ones, the models still estimate that the pitch difference between H-initial and L-initial APs significantly varies by speakers' YOB. The two-way interaction of Aspirated and YOB are significant in all syllable positions ($p < 0.001$ for AP-initial, second, and third syllables, $p = 0.008$ for the AP-final position). That is, the pitch difference between lenis- and aspirated-initial APs increases for younger speakers in all syllable positions, confirming the observation made in Figure 2. For example, the lenis-aspirated difference in the AP-initial syllable for speakers born in 1932 is 2.15 St (= 3.31 + (0.04 x (1932 – 1961))), but this difference increases to 4.23 St (= 3.31 + (0.04 x (1984 – 1961))) for speakers born in 1984. Similarly, the model estimates that the lenis-aspirated difference in the final syllable increases 0.03 St/YOB, showing that the pitch trajectory of aspirated-initial APs is higher for younger speakers than older speakers.

Similarly, the lenis-tense difference significantly increases by a function of YOB in all syllable positions except the AP-final ($p < 0.001$ for the first three positions). For example, the difference increases by 0.04 St/YOB in the AP-initial, by 0.07 St/YOB in the AP-second, and 0.05 St/YOB in the AP-third positions. The lenis-tense difference in the AP-third syllable is estimated to -0.19 St (= 1.26 + (0.05 x (1932 – 1961))) for speakers born in 1932, meaning the pitch value of the third syllable in lenis-initial APs is higher than that of tense-initial ones. However, this difference increases to 2.41 St (= 1.26 + (0.05 x (1984 – 1961))) for speakers born in 1984, indicating that the pitch value of tense-initial APs is higher than that of lenis-initial ones. It confirms our observation in Figure 2 that tense-initial APs are produced in a higher pitch range for younger speakers than older speakers. The model also estimates that there is a 0.02 St of pitch increment per YOB in the AP-final position, but this difference is not found significant.

While both YOB x Aspirated and YOB x Tense are found to be significant in the first three syllables, it is interesting to note that the pitch increment per YOB is not consistently larger for one interaction than the other. For example, the estimated coefficient of Aspirated x YOB in the AP-initial position (0.041 St/YOB) is slightly larger than that of Tense (0.039 St/YOB). However, that of Tense is larger than that of Aspirated in the AP-second and third positions, suggesting that the pitch value of Aspirated increases faster than that of Tense in the AP-initial position, but not in the other positions.

3.2. Stop-initial 4-syllable APs by Age and Gender

In this section, we investigate how the AP pattern varies by age and gender, using the same data set (stop-initial 4-syllable APs) in the previous section (Table 5). Figure 3 shows the mean pitch (St) of each syllable position by YOB and Gender. Since the APs starting with an aspirated or a tense consonant show similar pitch patterns in the previous section, the two categories are combined together as the H-initial context in Figure 3.

Figure 3 shows that the gender difference for older speakers born in the 1930s, 40s, and 50s is not especially salient. The AP pitch patterns of female speakers born in the 1940s overlap with those of male speakers, and female and male speakers born in the 1950s also show somewhat overlapping pitch patterns. However, it is notable that the pitch difference between H- and L-initial APs increases rapidly for old female speakers, when compared to their male cohort. Female speakers born in the 1930s do not show any pitch difference between H-initial and L-initial APs, whereas females born in the 1940s show a pitch difference in the AP-first and second syllables and those born in the 1950s show a pitch difference from the first to the third syllables. Old male speakers, on the other hand, do not seem to change that much.

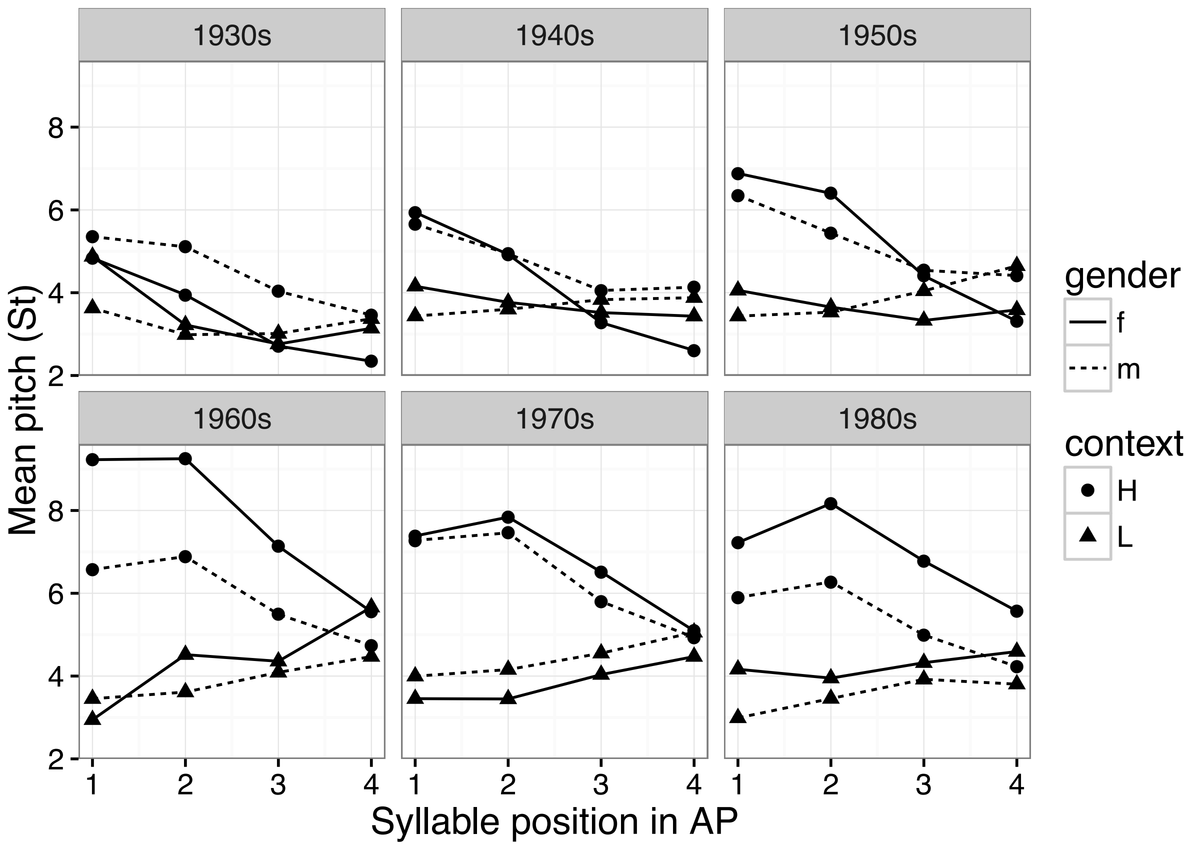

Figure 3: Mean pitch value (St) of each syllable in the target APs by speakers' gender (females: solid lines, males: dashed lines) and year of birth, aggregated in 10 year bands. Syllable positions within the target APs are shown in the x-axis, where "1" means AP-initial and "4" means AP-fourth syllables. The H-pitch inducing context includes APs starting with aspirated or tense consonants, and the L-pitch inducing context includes those starting with lenis stop consonants.

As for younger speakers born after 1960, female speakers generally show a larger pitch difference between H-initial and L-initial APs than male speakers.[16] In particular, it is notable that younger female speakers produce larger pitch differences than younger male speakers in all AP positions. For example, the pitch difference female speakers born in the 1970s show is about 1.5 St in the AP third syllable, whereas that of their male cohort is less than 1 St. Similarly, females born in the 1980s exhibit a larger pitch difference between H- and L-initial APs than their male cohort in all AP positions.

[16] The pitch difference between H- and L-initial APs for female speakers born in the 1960s is twice larger than that of their male cohort, especially in the first three AP positions. This seems to be because two out of the three female speakers born in the 1960s have an unusually wide pitch range. One of them (speaker ID: fx08) has the widest pitch range among all 118 speakers in the data, and the other speaker (ID: fx20) has the second widest pitch range.

As for statistical analyses, we built four linear mixed-effects models (one for each syllable position) to examine how the effect of AP-initial consonants varies according to speakers' YOB and gender. In each model, a dependent variable is a pitch value (St) in a given syllable position, and independent variables include Gender, YOB, Context (H-initial vs. L-initial), and their interactions. The reference category for Gender is males, and the reference of Context is L-initial. YOB is centered at 1961, and each speaker is added as a random effect. Table 7 summarizes the outputs of the linear mixed-effect analyses.

The main effect of Context is significant in the AP-initial, second, and third positions, except the final position ($p < 0.001$ for the three positions). The models estimate that the H-L pitch difference is the largest in the AP-initial position (2.77 St), followed by the AP-second position (2.54 St). However, this pitch difference considerably decreases in the AP-third position (0.91 St), indicating that the effect of the AP-initial pitch context is weakened in the penultimate syllable due to the intonational L tone (TH-**L**H). Accordingly, the model does not find a significant effect of Context in the AP-final position.

Although the main effect of Gender is not found significant in all AP positions, the results show that the gender difference in pitch varies by Context (in the AP-second and third positions) and by the interaction of Context and YOB (in the AP-second, third, and final positions).[17] The two-way interactions of Gender and Context in the AP-second and third syllables indicate that the pitch difference between the H and L contexts is 0.49 St and 0.46 St larger for female speakers than males in those positions, respectively ($p = 0.005$ for AP-second, $p = 0.012$ for AP-third). For example, the estimated difference in the AP-second syllable is 3.73 St for male speakers, but this difference increases to 4.22 St (= 3.73 + 0.49) for females. This effect is also shown in Figure 3; the H-L contrasts in the AP-second and third syllables are larger for females than males, except those born in the 1930s and 40s. Similarly, the estimated pitch difference in the AP-third position is 4.07 St for male speakers, but that of female speakers increases to 4.53 St (= 4.07 + 0.46).

The significant three-way interaction of YOB, Gender, and Context in the AP-second, third, and final positions ($p = 0.004$ for AP-second, $p < 0.001$ for AP-third, $p = 0.005$ for AP-final) suggests that the gender difference in the H-L contrast is modulated by a function of YOB. That is, younger speakers show a larger gender difference in the H-L contrast than older ones. For example, the gender difference between H- and L-initial APs (Gender x Context) in the AP-second syllable is 0.49 St, indicating that females, in general, show a 0.49 St larger H-L contrast than males. However, the model estimates that this gender difference increases by 0.036 St/YOB. For example, the estimated gender difference for speakers born in 1932 is -0.55 St (= 0.49 + (0.036 x (1932 – 1961))), suggesting that female speakers show a 0.55 St smaller H-L difference than male speakers. However, the difference increases to 1.32 St (= 0.49 + (0.036 x (1984 – 1961))) for speakers born in 1984, suggesting that female speakers born in 1984 show a 1.32 St larger H-L contrast in the AP-second syllable than their male cohort. This three-way interaction is also observed in Figure 3. For instance, male speakers born in the 1930s show a larger H-L contrast than their female cohort in the AP-second syllable, but males born in the 1980s show a smaller H-L contrast than their female cohort in that position. Similar three-way interactions are found in the AP-third and final positions, suggesting that female speakers in general produce a larger H-L contrast in non-initial positions than males, and this gender difference is larger for younger speakers than older ones.

---

[17] The reason that the main effects of Gender and the two-way interaction of Gender and YOB are not significant in all syllable positions is because pitch is normalized using the relative St scale in this study.

Table 7. The outputs of linear mixed-effects models of stop-initial 4-syllable APs by YOB, Gender and Context. L-initial is the reference category for the AP-initial context, and male speakers are the reference category for Gender. YOB is centered at 1961. Estimated coefficients are rounded at the second decimal place.

AP-initial	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.66	0.20	1786	< 0.001 ***
YOB	0.01	0.01	0.44	0.664
Gender	0.29	0.28	1.03	0.305
Context	2.77	0.18	15.64	< 0.001 ***
YOB*Gender	-0.02	0.02	-0.9	0.368
YOB*Context	0.03	0.01	2.74	0.006 **
Gender*Context	0.20	0.24	0.83	0.409
YOB*Gender*Context	0.02	0.02	1.05	0.292

AP-second	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.73	0.19	19.89	< 0.001 ***
YOB	0.02	0.01	1.34	0.183
Gender	-0.03	0.26	-0.11	0.915
Context	2.54	0.13	20.26	< 0.001 ***
YOB*Gender	-0.01	0.02	-0.74	0.464
YOB*Context	0.05	0.01	5.76	< 0.001 ***
Gender*Context	0.49	0.18	3.81	0.005 **
YOB*Gender*Context	0.04	0.01	2.87	0.004 **

AP-third	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.07	0.18	22.94	< 0.001 ***
YOB	0.02	0.01	2.05	0.042 *
Gender	-0.41	0.25	-1.66	0.099
Context	0.91	0.13	7.08	< 0.001 ***
YOB*Gender	0.00	0.02	0.24	0.814
YOB*Context	0.02	0.01	2.71	0.007 **
Gender*Context	0.46	0.18	2.52	0.012 *
YOB*Gender*Context	0.05	0.01	3.67	< 0.001 ***

AP-final	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.41	0.20	22.38	< 0.001 ***
YOB	0.03	0.01	2.06	0.040 *
Gender	-0.45	0.27	-1.64	0.102
Context	0.06	0.17	0.36	0.720
YOB*Gender	0.01	0.02	0.35	0.715
YOB*Context	0.00	0.01	-0.05	0.963
Gender*Context	-0.09	0.24	-0.39	0.695
YOB*Gender*Context	0.05	0.02	2.80	0.005 **

3.3. All 4-syllable APs by YOB

In this section, we examine different manners of articulation with all 4-syllable APs in our data to see if fricative-initial and affricate-initial APs show similar patterns to stop-initial ones observed in the previous section. Our data include 24 APs that are 4-syllable long. Out of 24 APs, 10 APs start with an aspirated consonant, 3 of them with a tense consonant, 7 of them with a lenis, and the other 4 with a vowel or sonorant. Fricative-initial APs are all coded as H-initial, as previous studies show that a fricative-initial AP induces a H pitch on the AP-initial syllable (Jun 1993, Cho et al. 2002, Kang 2014, among others). The corpus does not have a sentence-initial AP starting with an aspirated or tense affricate. Accordingly, all affricate-initial APs in our data begin with a lenis affricate, so all of them are coded as L-initial in the analysis. In total, 11,199 syllables are investigated in this section. Table 8 shows the target APs and the number of examined syllables by their manner of articulation and their AP-initial tonal context.[18]

Table 8. All 4-syllable APs in the data (number of examined syllables) by AP-initial onset consonants. A dot represents a syllable boundary. Since an AP-initial sonorant or vowel induces a L tone, no AP is listed in the H-initial cell of the sonorant or vowel-initial column.

	Stop	Affricate (L-initial) or Fricative (H-initial)	Sonorant or vowel
L-initial	/ka.jʌp.kɛ.to/ (472) 'pitifully' /kʌ.ki.ɛ.nɨn/ (471) 'there-TOPIC' /pa.tat.ka.ɛ/ (463) 'seashore-LOC' /kɨ.lʌ.ta.ka/ (456) 'and then' /kɨ.lʌ.tʌ.ni/ (451) 'then'	/tso.saŋ.ɛ.kɛ/ (469) 'ancester-from' /tsam.si.hu.ɛ/ (472) 'after a while'	/na.mu.k'un.ɨn/ (944) 'woodman-TOPIC' /nal.kɛ.o.sɨl/ (471) 'celestial robe-ACC' /ʌ.mʌ.ni.ka/ (468) 'mother-NOM'
H-initial	/pʰi.sʌ.tsi.ɯi/ (467) 'resort-POSS' /pʰi.la.mi.na/ (458) 'pale club or' /kʰɨ.ko.tsak.ɨn/ (438) 'of various sizes' /p'om.nɛ.tɨs.i/ (463) 'as if showing off' /t'ok.kat.ɨn.s'al/ (466) 'the same rice' /k'um.sok.ɛ.sʌ/ (468) 'in the dream'	/ho.laŋ.i.nɨn/ (1414) 'tiger-TOPIC' /hon.tsa.nam.ɨn/ (472) 'left alone' /sa.njaŋ.k'un.ɨn/ (472) 'hunter-TOPIC' /siŋ.siŋ.ha.ko/ (472) 'fresh' /sin.ha.tɨl.i/ (472) 'liege subjects-NOM'	

[18] There are three sentences starting with the same AP /ho.laŋ.i.nɨn/ 'tiger-TOPIC', and two sentences starting with /na.mu.k'un.ɨn/ 'woodman-TOPIC'.

Figure 4 shows the mean pitch values of sentence-initial 4-syllable APs by the manner of articulation, the tonal context of the AP-initial consonant and speakers' YOB. What is noticeable is that the pitch trajectories of APs starting with an aspirated fricative, /s/ or /h/, do not greatly differ from those starting with a H-pitch inducing stop in all age groups. There seems to be less than a 1 St difference between those APs in the H context (solid lines in Figure 4), yet their pitch patterns look remarkably similar to each other. This result is in line with those of the previous studies, which suggest that this tonogenetic sound change is a structural one, affecting all AP-initial [+ aspirated/tense] consonants (Kang and Guion 2008, Kang 2014).

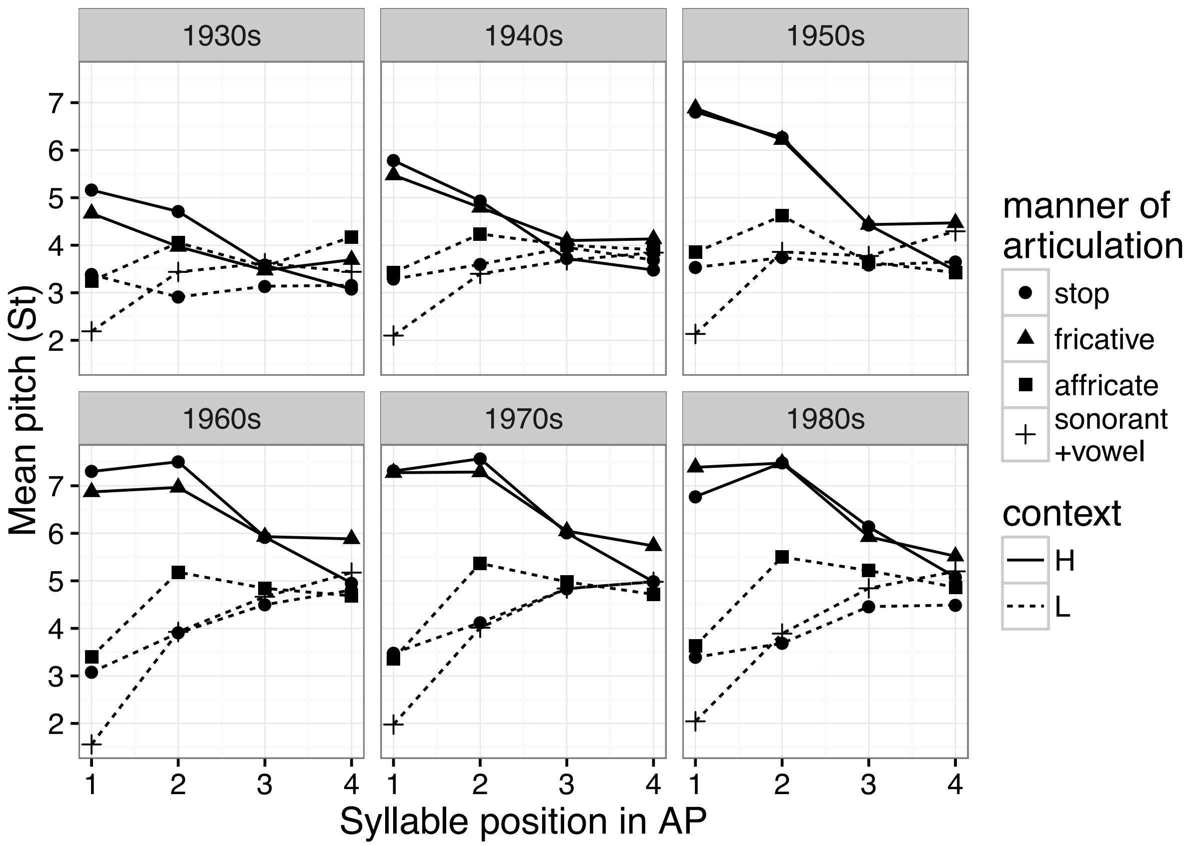

Figure 4: Mean pitch value (St) of each syllable in the target APs by manner of articulation and speakers' year of birth, aggregated in 10 year bands. The H-pitch inducing context (solid lines) includes APs starting with aspirated stops, tense stops, or aspirated fricatives, and the L-pitch inducing context (dashed lines) includes those starting with lenis stops, lenis affricates, sonorants, or vowels.

What is interesting in Figure 4 is that the pitch pattern of APs starting with an aspirated fricative also seems to diverge from L-initial ones in younger speakers. For speakers born in the 1930s, the AP-initial syllables show a small pitch difference between the two tonal contexts, but the other syllables do not show such a difference. The speakers born in the 1940s show a larger and clearer AP-initial pitch difference than those born in the 1930s, and they also exhibit a small pitch difference in the AP second syllable. However, their pitch values of the third and final syllables in H-initial APs almost overlap with those in L-initial ones. From speakers born after 1950, the effect of H-inducing consonants is clearly seen in the AP-initial, second, and third syllables, yet again the pitch values of H-initial and L-initial APs overlap in the AP-final syllable position due to the effect of the intonational L tone in the penultimate syllable.

While the pitch patterns of L-initial APs do not differ that much among all age groups, we observe that the first syllables of sonorant or vowel-initial APs are constantly about 1 St to 1.5 St lower than those starting with a lenis stop or a lenis affricate in all age groups. This seems to be due to the cross-linguistic pattern that a vowel following a voiceless segment is produced with a higher pitch than those following a voiced segment word-initially (Lehiste and Peterson 1961, Mohr 1971, Jun 1996, Hanson 2009, among others). Since all obstruents in Korean are voiceless word-initially, it is reasonable to observe such a pitch difference between APs starting with a lenis stop or affricate and those starting with a sonorant or vowel. However, considering that this pitch difference in the first syllable position is the effect size of physiological perturbation, the pitch difference between H-initial and L-initial APs among speakers born after 1950 (about 3 to 4 St) must not be attributed to automatic phonetic perturbation.

One more observation in Figure 4 is that APs starting with a lenis affricate show a higher pitch value on the AP-second syllable than the other L-initial APs. Also, this pitch difference in the AP-second position increases in younger speakers. For example, speakers born in the 1940s show about a 0.5 St pitch difference in the AP-second position, but this difference increases to about 1.5 St for speakers born in the 1980s. This seems to be because the AP-second syllable of APs starting with a lenis affricate has a fricative onset consonant. The two lenis affricate-initial APs, /tso.**saŋ**.ɛ.kɛ/ ‘ancestor-from’ and /tsam.**si**.hu.ɛ/ ‘after a while’, happen to have an aspirated fricative /s/ in the second syllable. On the other hand, all second syllables of APs starting with other L-pitch inducing consonants do not have a H-inducing onset consonant (Table 8). This segmental difference seems to cause the observed pitch difference on the second syllable among L-initial APs. However, the size of the increment for younger speakers is quite small, when compared to the pitch contrast from the AP-initial consonant context, suggesting that it seems to be due to a segmental effect.

As for statistical analyses, we built 4 linear mixed-effects models (one for each syllable position) to examine if APs starting with distinct manners of articulation and laryngeal gestures yield significant pitch differences. In the models, a dependent variable is pitch values (St) of a given syllable position, and independent variables are manner of articulation of AP-initial onsets and speakers’ YOB. As for the manner of articulation, stops are divided into H-inducing and L-inducing ones and APs starting with a lenis stop (L-initial Stop) are the reference category for manner of articulation.[19] Each speaker is added as a random effect. Table 9 summarizes the outputs of the linear mixed-effects models.

Table 9. The outputs of linear mixed-effects models of 4-syllable APs by YOB and manner of articulation of AP-initial onsets. A lenis stop is the reference category for Manner of articulation, and YOB is centered at 1961.

[19] Note that fricatives are not divided by their tonal context, because all fricative-initial APs are in the H context. Also, the models do not include H-inducing Affricate, because all AP-initial affricates in our data start with the lenis one.

AP-initial	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.39	0.12	29.41	< 0.001 ***
Lenis Affricate	0.13	0.12	1.14	0.255
Fricative	3.22	0.08	39.01	< 0.001 ***
H-inducing Stop	3.29	0.09	38.10	< 0.001 ***
Sonorant or Vowel	-1.36	0.09	-14.42	< 0.001 ***
YOB	0.00	0.01	-0.09	0.932
YOB*Lenis Affricate	0.00	0.01	-0.42	0.674
YOB*Fricative	0.05	0.01	8.78	< 0.001 ***
YOB*H-inducing Stop	0.04	0.01	6.14	< 0.001 ***
YOB*Sonorant or vowel	-0.01	0.01	-0.89	0.375

AP-second	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.77	0.12	31.92	< 0.001 ***
Lenis Affricate	1.08	0.10	11.12	< 0.001 ***
Fricative	2.50	0.07	36.72	< 0.001 ***
H-inducing Stop	2.73	0.07	38.56	< 0.001 ***
Sonorant or Vowel	0.03	0.08	0.33	0.740
YOB	0.01	0.01	1.67	0.097
YOB*Lenis Affricate	0.02	0.01	3.01	0.003 **
YOB*Fricative	0.06	0.01	12.58	< 0.001 ***
YOB*H-inducing Stop	0.06	0.01	11.77	< 0.001 ***
YOB*Sonorant or vowel	0.00	0.01	-0.47	0.641

AP-third	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.14	0.11	36.24	< 0.001 ***
Lenis Affricate	0.20	0.11	1.90	0.058
Fricative	0.89	0.08	11.89	< 0.001 ***
H-inducing Stop	0.83	0.08	10.69	< 0.001 ***
Sonorant or Vowel	0.09	0.09	1.04	0.299
YOB	0.03	0.01	3.92	< 0.001 ***
YOB*Lenis Affricate	0.01	0.01	1.10	0.270
YOB*Fricative	0.03	0.01	5.80	< 0.001 ***
YOB*H-inducing Stop	0.04	0.01	6.89	< 0.001 ***
YOB*Sonorant or vowel	0.01	0.01	0.52	0.606

AP-final	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.19	0.13	33.04	< 0.001 ***
Lenis Affricate	0.00	0.12	0.01	0.990
Fricative	0.75	0.08	8.85	< 0.001 ***
H-inducing Stop	-0.02	0.09	-0.26	0.793
Sonorant or Vowel	0.33	0.10	3.35	< 0.001 ***
YOB	0.04	0.01	4.18	< 0.001 ***
YOB*Lenis Affricate	-0.01	0.01	-0.87	0.387
YOB*Fricative	0.01	0.01	1.94	0.052
YOB*H-inducing Stop	0.01	0.01	2.40	0.017 *
YOB*Sonorant or vowel	0.00	0.01	-0.24	0.808

The models estimate that the pitch values of fricative-initial APs are significantly higher than those starting with a lenis stop (the reference category) in all syllable positions ($p < 0.001$ for all comparisons). The estimated pitch value of the AP-initial syllable is 3.39 St for APs with a lenis stop onset, but this increases to 6.61 St (= 3.39 + 3.22) for fricative-initial APs. A similar trend is found even in the AP-final syllables, but the pitch difference between the two APs (0.75 St) is not as large as the one found in the AP-first syllable. The models also estimate that the effect of Fricative is quite similar to that of H-inducing Stop in all syllable positions, except the final. For example, the estimated coefficient of Fricative is 3.22 St and that of H-inducing Stop is 3.29 St for the AP-initial position, showing that the first syllables of Fricative and H-inducing Stop are not that much different from each other. The two consonant categories are also similar in the AP-second (Fricative: 2.5 St, H-inducing Stop: 2.73 St) and AP-third positions (Fricative: 0.89 St, H-inducing Stop: 0.83 St). This result suggests that both aspirated fricatives and H-inducing stops belong to the same category (aspirated) and they pattern together with regard to this tonogenetic sound change.

In addition, the models find that the interaction of YOB and Fricative is significant in the first three AP-positions ($p < 0.001$ for AP-initial, second, and third syllables). This result indicates that the pitch difference between APs with lenis stop onsets and those with fricative onsets increases in younger speakers. The size of increment is the largest for AP-second syllables (0.06 St/YOB) and the smallest for AP-third syllables (0.03 St/YOB). For example, the estimated pitch difference in the AP-second syllables of Lenis Stop and Fricative is 1.48 St (= 3.22 + (0.06 x (1932 – 1961))) for speakers born in 1932, yet this difference increases to 4.6 St (= 3.22 + (0.06 x (1984 – 1961))) for those born in 1984. That is, speakers born in 1984 produce a 3.12 St larger pitch difference (= 4.6 – 1.48) on the AP-second position than those born in 1932. This difference between speakers born in 1932 and those born in 1984 decreases to 0.52 St (= 0.01 x (1984 – 1932)) in the AP-final position, indicating that the effect of AP-initial Fricative decreases in the final syllable, although the model finds this effect marginally significant (p = 0.052). Also, it is notable that the interaction of YOB and Fricative has a similar size of effect with the interaction of YOB and H-inducing Stop in all AP positions (Table 9), confirming again that this tonogenetic sound change is a structural one.

As for the comparison of Lenis Stop and Lenis Affricates, those two APs are not significantly different from one another in all syllable positions, except the AP-second. As observed in Figure 3, the estimated pitch value of Lenis Affricate is 1.08 St higher than that of Lenis Stop due to the effect of H-inducing consonant /s/ in that position ($p < 0.001$). Also, the interaction of Lenis Affricate and YOB in the AP-second syllable is found to be significant (p = 0.003), suggesting that the pitch difference between Lenis Stop and Lenis Affricate increases by 0.02 St/YOB. For example, speakers born in 1932 show a 0.5 St of pitch difference (= 1.08 + (0.02 x (1932 – 1961))) between Lenis Affricate and Lenis Stop, but this difference is augmented to 1.54 St for speakers born in 1984. These results indicate that a H-pitch inducing consonant in non-initial syllables may have an effect on pitch for younger speakers, raising the pitch value of the given syllables. This result is in line with Cho and Lee (2016), which also finds that younger speakers (in their 20s) produce a small pitch increment in non-initial syllables with a H-pitch inducing onset consonant. However, the fricative /s/ in the AP-second position does not play a more important role than H-inducing consonants in the AP-initial position, which show a global effect raising pitch values of all syllables in the given AP. The result shows that H-inducing consonants in the AP-initial position have a global effect on the pitch range of the AP, whereas those in non-initial APs show a local effect on the pitch value of the given syllable.

Lastly, APs starting with a sonorant or a vowel are found to be significantly different from those starting with a lenis stop in the AP-initial and AP-final syllables (p < 0.001 for both positions). The significant difference in the AP-initial position seems to be because lenis stops are voiceless in Seoul Korean. The crosslinguistic tendency for voiceless stops to induce a high pitch on the following vowel attributes to the result that the initial syllable of APs starting with a lenis stop shows a 1.36 St higher pitch value than those starting with a sonorant or vowel. Although it is not clear why the pitch difference in the AP-final syllable is significant, it is noteworthy that the interaction between YOB and Sonorant is not significant in any syllables, indicating that the pitch differences between Lenis Stop and Sonorant are not due to the tonogenetic sound change.

3.4. All sentence-initial APs by AP size, YOB, and gender

In this section, we look at all sentence-initial APs in our data by their AP size to investigate if APs of different sizes show similar patterns observed in the previous sections. Since the result of the previous section shows that APs starting with fricatives pattern together with those with H-inducing stops, we combine all APs starting with a H-inducing consonant as H-initial. Similarly, based on the result of the previous section that the pitch difference among L-initial APs is not due to the tonogenetic sound, we combine APs starting with a lenis consonant, sonorant, or a vowel as L-initial for the sake of simplicity.

3.4.1. 2-syllable APs by YOB and gender

We first begin with 2-syllable APs. Our data contain 9 2-syllable APs, and 2 of them start with aspirated consonants, 1 with a tense consonant, 4 with lenis consonants, and the other 2 with nasals. The total number of syllables examined is 2,080. Table 10 shows the target APs and their number of syllables by their AP-initial pitch context.

Table 10. 2-syllable APs by their AP-initial pitch context (number of syllables examined). A dot marks a syllable boundary.

H-initial	/ts^{h}a.ga/ (229) 'car-NOM'	/ts^{h}ʌŋ.so/ (236) 'cleaning'	/p'oŋ.p'oŋ/ (236) 'bang, bang!'
L-initial	/na.nɨn/ (236) 'me-TOPIC' /kɨ.t'ɛ/ (230) 'that time'	/na.ɰi/ (236) 'my' /kɨ.kʌ/ (220) 'that'	/tsʌ.lɨl/ (234) 'me (humble)-ACC' /tsʌ.nɨn/ (233) 'me (humble)-TOPIC'

Figure 5 shows the mean pitch values of the 2-syllable APs by Context, Gender, and YOB. Here, the main difference from 4-syllable APs is that the pitch difference between H-initial and L-initial APs does not dramatically decrease in the AP-final (second) position for younger speakers. Figure 5 clearly shows that the pitch differences between the H-initial and L-initial contexts in both AP-initial and second positions increase in younger speakers. For example, the pitch trajectories of the H and L contexts converge in the AP-second syllable for speakers born in the 1930s, but the pitch patterns do not converge in younger speakers, showing a large pitch difference (about 3 to 4 St) in the second syllable. The gender difference is not as large as the context difference, but in general, female speakers seem to produce a larger pitch difference between H-initial and L-initial contexts than male speakers.

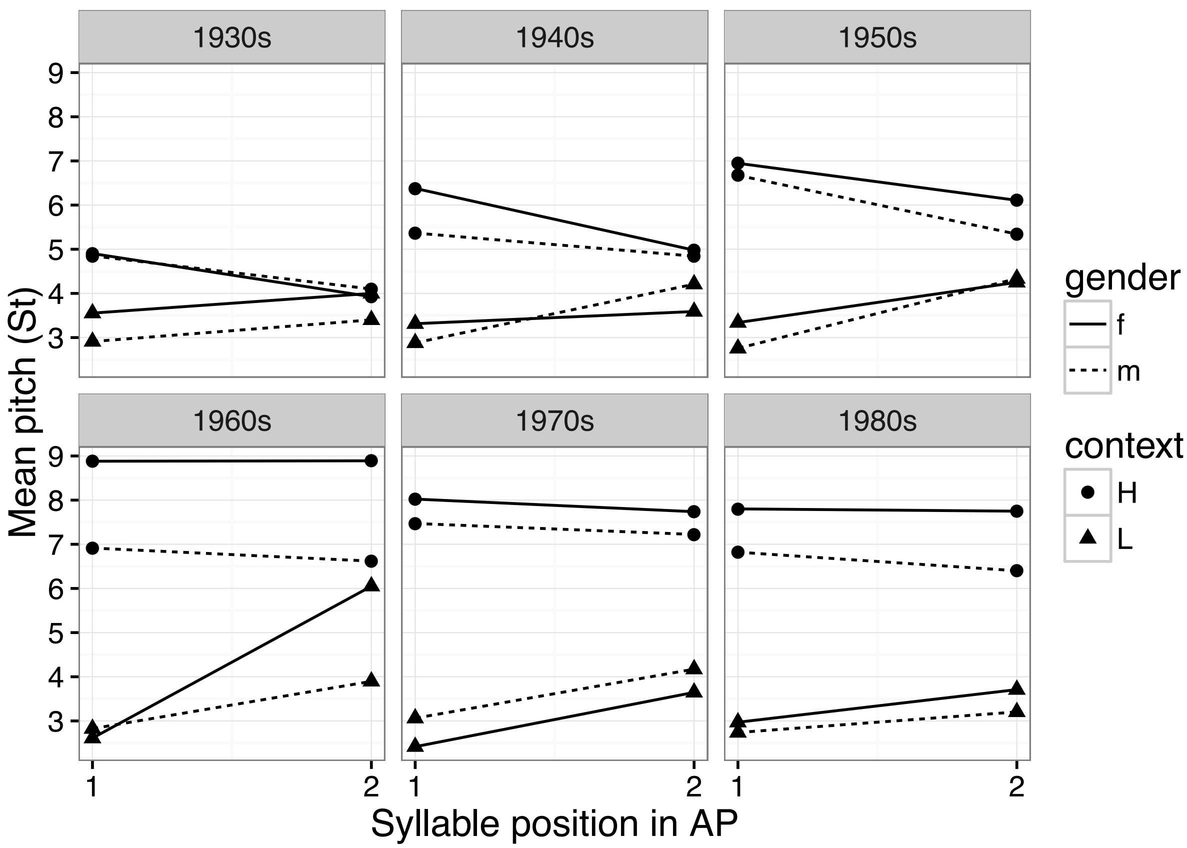

Figure 5. Mean pitch value (St) of each syllable in the 2-syllable APs by Context, Gender, and YOB. Solid lines show females, and dotted lines show males. H-initial includes all APs starting with aspirated or tense consonants, and the other APs are L-initial.

We conduct two linear mixed-effects analyses to examine the effect of Context, Gender, and YOB in 2-syllable APs. In the models, the dependent variable is the pitch values (St) of each syllable position and independent variables are their pitch contexts (H-initial vs. L-initial), Gender, and YOB. The reference category of Gender is males, and the reference of Context is L-initial. YOB is centered at 1961, and speakers are included as a random effect. Table 11 summarizes the outputs of the models.

The models estimate that the effect of Context and two-way interactions with Context (Gender x Context and Context x YOB) are significant in both positions, while the others are not. The significant main effect of Context ($p < 0.001$ in both positions) indicates that the syllables in the H-initial context are produced with a higher pitch value (3.59 St for AP-initial, 2.01 St for AP-second) than those in the L-initial context in both AP-initial and second positions. Also, the significant interaction of Context with Gender ($p = 0.009$ for AP-initial, $p = 0.015$ for AP-second) indicates that the pitch difference between the H and L contexts is larger for female speakers than male speakers in both AP positions. The models estimate that the pitch difference between

H-initial and L-initial APs is 0.53 St and 0.47 St larger for females than males in the AP-initial and second syllables, respectively.

It is also found that the two-way interaction of YOB and Context is significant, suggesting that the H-L contrast increases in younger speakers in both syllable positions (0.05 St/YOB for AP-initial and 0.07 St/YOB for AP-second). For example, the estimated H-L pitch difference of the AP-initial syllable is 2.14 St (= 3.59 + 0.05 x (1932 – 1961))) for speakers born in 1932, but it increases to 4.74 St (= 3.59 + 0.05 x (1984 – 1961))) for speakers born in 1984. This suggests that the youngest generation produce a twice-larger pitch difference than the oldest generation in the AP-initial position. The three-way interaction of YOB, Gender, and Context is not significant in both positions, indicating that the gender difference in the H-L contrast neither increase nor decrease over time.

Table 11. The outputs of linear mixed-effects models of sentence-initial 2-syllable APs by YOB, Gender, and Context. The reference category for Gender is males, and that of Context is L-initial. YOB is centered at 1961.

AP-initial	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	2.93	0.15	19.86	< 0.001 ***
Gender	0.15	0.21	0.73	0.469
YOB	0.00	0.01	0.00	0.998
Context	3.59	0.15	24.27	< 0.001 ***
YOB*Gender	-0.02	0.01	-1.60	0.111
Gender*Context	0.53	0.21	2.59	0.009 **
YOB*Context	0.05	0.01	5.35	< 0.001 ***
YOB*Gender*Context	0.02	0.01	1.41	0.158
AP-second	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.03	0.16	24.87	< 0.001 ***
Gender	0.01	0.23	0.05	0.963
YOB	0.00	0.01	-0.27	0.792
Context	2.01	0.14	14.55	< 0.001 ***
YOB*Gender	-0.01	0.02	-0.42	0.679
Gender*Context	0.47	0.19	2.45	0.015 *
YOB*Context	0.07	0.01	7.82	< 0.001 ***
YOB*Gender*Context	0.02	0.01	1.40	0.161

3.4.2. 3-syllable APs by YOB and gender

Now we turn our attention to sentence-initial 3-syllable APs in the data. There are 18 3-syllable APs, and 10 of them start with an aspirated stop or fricative consonant, 1 of them with a tense consonant, 5 of them with a lenis consonant, and the other 2 with a vowel. In total, 6,310 syllables (3,873 syllables in the H-initial context + 2,427 syllables in the L-initial context) are examined. Table 12 shows the target APs and the number of examined syllables by their AP-initial tonal contexts.[20]

[20] There are two sentences starting with the same AP /sʌn.njʌ.nɨn/ ‘angel-TOPIC’ in our data.

Table 12. Sentence-initial 3-syllable APs by their AP-initial tonal context (number of syllables examined). A dot marks a syllable boundary.

H-initial	/sʌn.njʌ.nɨn/ ‘angel-TOPIC’ (705)	/tsʰam.ki.lɨm/ ‘sesame oil’ (354)
	/ha.tsi.man/ ‘but’ (352)	/hun.hun.han/ ‘heartwarming’ (351)
	/t’a.sɨ.han/ ‘warm’ (354)	/tsʰak.po.lɨl/ ‘book wrapper-ACC’ (346)
	/tʰo.k’i.wa/ ‘rabbit and’ (346)	/tʰo.k’i.ka/ ‘rabbit-NOM’ (345)
	/sa.sɨm.ɨn/ ‘deer-TOPIC’ (354)	/sa.sɨm.ɰi/ ‘deer-POSS’ (354)
L-initial	/ʌm.ma.nɨn/ ‘mom-TOPIC’ (354)	/tsa.la.ɰi/ ‘turtle-POSS’ (354)
	/kɨ.k’ol.i/ ‘that form-NOM’ (352)	/tsa.la.nɨn/ ‘turtle-TOPIC’ (351)
	/i.lɨl.pon/ ‘seeing this’ (348)	/kɨ.lɛ.sʌ/ ‘so’ (352)
	/kɨ.lʌn.tɛ/ ‘then’ (336)	

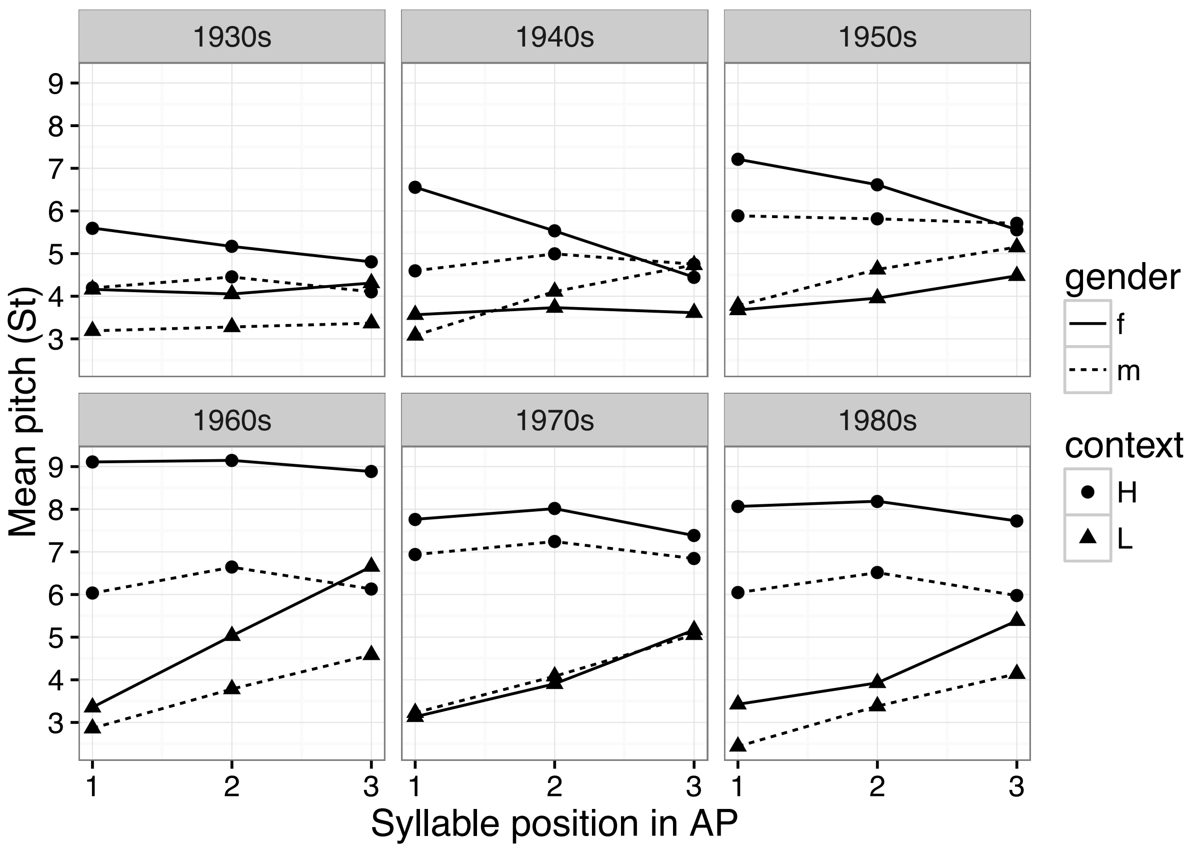

Figure 6. Mean pitch value (St) of each syllable in the 3-syllable APs by Context, Gender, and YOB. Solid lines show females, and dotted lines show males. H-initial includes all APs starting with aspirated or tense consonants, and the other APs are L-initial.

Figure 6 shows the mean pitch values of the target 3-syllable APs by YOB and Gender. In this figure, we observe a similar pattern to that of 2-syllable APs. An AP-initial pitch contrast is not clear for speakers born in the 1930s, but it is clearly seen for younger speakers (those born after 1950). Also, the pitch difference in the AP-second and third syllables between H-initial and

L-initial contexts increase in younger speakers, when compared to older ones. As for the gender comparison, female speakers in general show a larger pitch difference between H-initial and L-initial APs than male speakers. Also, the development of the AP-initial pitch contrast is more clearly observed in old female speakers (from the 1930s to the 1950s) than their male cohort, indicating that the tonogenetic sound change has been led by female speakers.

We build 3 linear mixed-effects models (one for each syllable position) for statistical analyses with the pitch values (St) as a dependent variable and Gender, YOB, and Context as independent variables. Male speakers are the reference category for Gender, and L-initial is the reference category for Context. Each speaker is added as a random effect, and YOB is centered at 1961. Table 13 summarizes the outputs of the analyses.

Table 13. The outputs of the linear mixed-effect models of 3-syllable APs by Gender, YOB, and Context. The reference category for Gender is males, and that of Context is L-initial. YOB is centered at 1961.

AP-initial	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.15	0.16	19.09	< 0.001 ***
Gender	0.37	0.23	1.60	0.112
YOB	-0.01	0.01	-0.69	0.493
Context	2.68	0.10	26.70	< 0.001 ***
YOB*Gender	-0.01	0.02	-0.43	0.665
Gender*Context	1.16	0.14	8.25	< 0.001 ***
YOB*Context	0.07	0.01	9.91	< 0.001 ***
YOB*Gender*Context	-0.01	0.01	-0.88	0.380
AP-second	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.98	0.17	24.13	< 0.001 ***
Gender	-0.01	0.23	-0.06	0.949
YOB	0.00	0.01	-0.20	0.840
Context	2.18	0.09	23.84	< 0.001 ***
YOB*Gender	0.00	0.02	0.18	0.858
Gender*Context	0.85	0.13	6.66	< 0.001 ***
YOB*Context	0.06	0.01	10.68	< 0.001 ***
YOB*Gender*Context	0.01	0.01	0.79	0.428
AP-third	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	4.70	0.19	25.06	< 0.001 ***
Gender	0.00	0.26	0.01	0.991
YOB	0.01	0.01	1.14	0.256
Context	1.10	0.09	12.23	< 0.001 ***
YOB*Gender	0.02	0.02	1.26	0.211
Gender*Context	0.36	0.13	2.85	0.004 **
YOB*Context	0.04	0.01	7.31	< 0.001 ***
YOB*Gender*Context	0.00	0.01	0.54	0.590

The models show that the main effect of Context and the two-way interactions with Context (Context x Gender and Context x YOB) are significant in all syllable positions in 3-syllable APs

($p = 0.004$ for Gender x Context in the AP-third syllable, $p < 0.001$ for the other comparisons), strikingly similar to the results of 2-syllable APs. The main effect of Context indicates that the AP-initial tonal context is an important factor in deciding the pitch values of all syllable positions within 3-syllable APs. For example, the pitch values of syllables in the H context are 2.68 St, 2.18 St, and 1.1 St higher than those in the L context in the AP-first, second, and third positions, respectively.

Also, the models estimate that female speakers show a larger pitch difference between H-initial and L-initial APs than male speakers. In the AP-initial position, female speakers show a 1.16 St larger H-L contrast than males, and female speakers are estimated to produce a 0.36 St larger H-L contrast than male speakers even in the AP-third position. These results again suggest that the tonogenetic sound change has been led by female speakers.

Lastly, the models reveal that the two-way interaction of YOB and Context is significant ($p < 0.001$ in all comparisons), indicating that the pitch difference between H-initial and L-initial APs increases in younger speakers. The estimated pitch difference between those two contexts in the AP-initial position is 0.65 St (= 2.68 + (0.07 x (1932 – 1961))) for speakers born in 1932, but this difference increases to 4.29 St (= 2.68 + (0.07 x (1984 – 1961))) for speakers born in 1984, which is about six to seven times larger than that of speakers born in 1932. This effect is significant even in the AP-third syllable ($p < 0.001$), where the model estimates that the difference in the H-L contrast between speakers born in 1931 and 1984 is 4.74 St (= 1.1 + (0.07 x (1984 – 1932))). The three-way interactions of Gender, YOB, and Context are not significant in all AP positions.

3.4.3. 4-syllable APs by YOB and gender

Moving on to 4-syllable APs, Figure 7 shows the mean pitch value of each syllable position in 4-syllable APs by Context, Gender, and YOB, aggregated in 10 year bands.[21] Here, we observe similar AP pitch patterns to those of 2-syllable or 3-syllable APs in the initial and second syllable positions. That is, the AP-initial pitch difference increases in younger speakers, and it is larger for females than for males. Similarly, the pitch difference in the AP-second position is larger for younger speakers than older ones, and also larger for females than males.

The main difference between 3-syllable and 4-syllable APs is that the effect of intonational L tone in TH-**L**H is clearly seen in 4-syllable APs. The H-L contrast is quite large in the third syllable position of 3-syllable APs (Figure 6), yet it is relatively small in the AP-third position in 4-syllable APs (Figure 7). However, it is still notable that the pitch difference in the AP-third syllable between the two tonal contexts increases in younger speakers in Figure 7. Speakers born in the 1930s and 40s do not show a pitch difference in the AP-third position, but female speakers born in the 1950s do exhibit a pitch difference in that position, indicating that females are the ones who seem to have started to raise pitch values of later syllables in the H-initial context. Speakers born after 1960 show a pitch difference in the third syllable and it is larger for females than males. The effect of the AP-initial tonal contexts decreases in the final syllable in general, yet younger generations still show a larger pitch difference than older ones.

[21] See Table 8 for the 4-syllable words used in this analysis. Also, note that all 4-syllable APs are examined in this section, whereas only 9 APs (stop-initial) are included in Section 3.2.

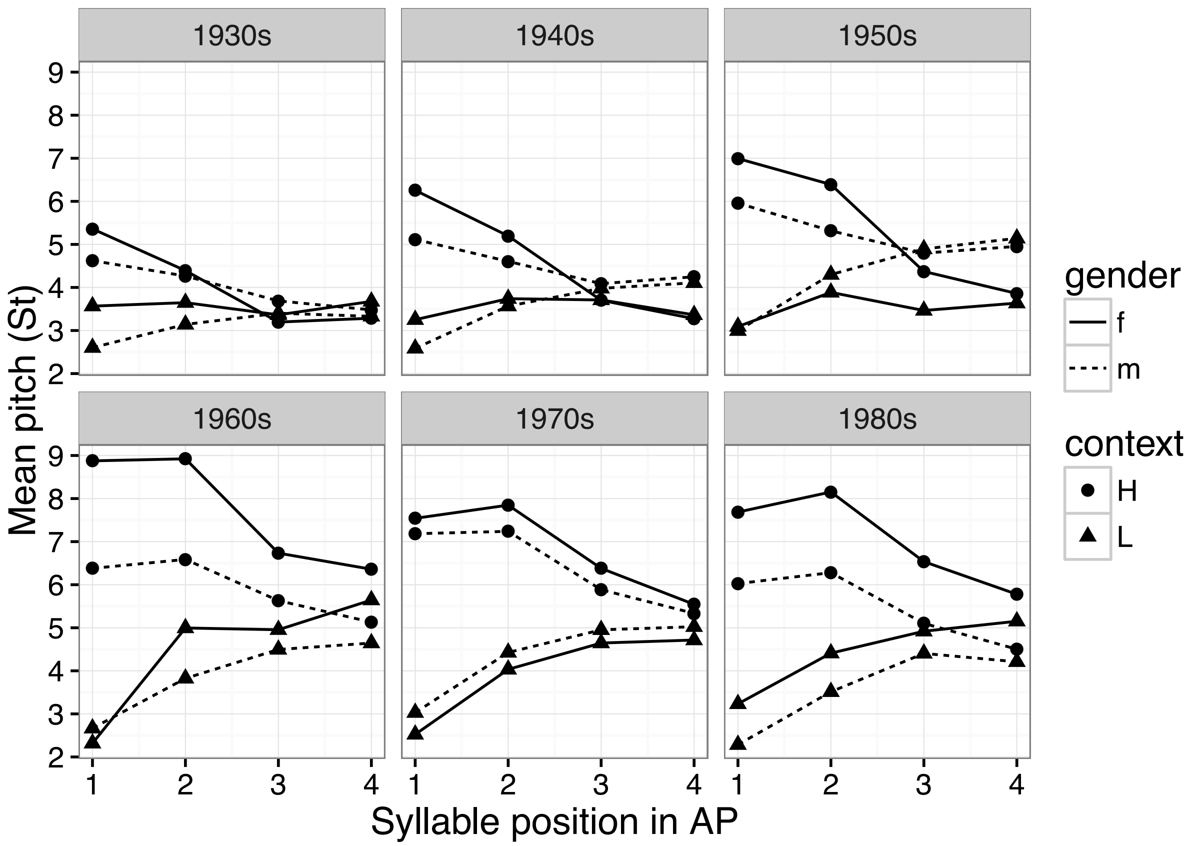

Figure 7. Mean pitch value (St) of each syllable in the 4-syllable APs by Context, Gender, and YOB. Solid lines show females, and dotted lines show males. H-initial includes all APs starting with aspirated or tense consonants, and the other APs are L-initial.

For statistical analyses, we build 4 linear mixed-effects analyses—one for each syllable position—with the pitch values (St) as a dependent variable and Gender, YOB, and Context as independent variables. Table 14 summarizes the outputs of the models.

The significant main effect of Context ($p = 0.008$ in AP-final, $p < 0.001$ in the other positions) indicates that the pitch values of syllables in H-initial APs are larger in all syllable positions than those in the L context. The estimated coefficient of Context is the largest in AP-initial (3.35 St) and the smallest in AP-final (0.23 St), confirming our observation in Figure 7 that the pitch difference between H and L-initial APs is the largest in the AP-initial position, but it decreases after the penultimate syllable.

The models also reveal that the two-way interactions with Context are significant in all AP syllables, except the final. The significant two-way interaction of YOB x Context ($p < 0.001$ in the AP-initial, second, and third positions) suggests that the effect of Context varies by a function of speakers' age. For example, the estimated pitch difference in the AP-initial position is 1.9 St (= 3.35 + (0.05 x (1932 - 1961))) for speakers born in 1932, but it increases to 4.5 St (= 3.35 + (0.05 x (1984 – 1961))) for speakers born in 1984. This effect is also found to be significant in the AP-third position, where the intonational L tone falls ($p < 0.001$). The model estimates that the pitch difference for speakers born in 1932 is 0.01 St (= 0.59 + (0.02 x (1932 – 1961))), meaning that the AP-third syllable in the H-initial context is almost the same with the one in the L-initial context. However, this difference increases to 1.05 St (= 0.59 + (0.02 x (1984

– 1961))) for speakers born in 1984. These results confirm our observation that the pitch difference between the H and L contexts increases in younger speakers.

Table 14. The outputs of the linear mixed-effect models of 4-syllable APs by Gender, YOB, and Context. The reference category for Gender is males, and that of Context is L-initial. YOB is centered at 1961.

AP-initial	Estimate	Std. Error	*t*-value	Pr ($>\vert t\vert$)
(Intercept)	2.78	0.15	19.00	< 0.001 ***
Gender	0.22	0.21	1.10	0.275
YOB	0.00	0.01	0.28	0.782
Context	3.35	0.09	38.80	< 0.001 ***
YOB*Gender	-0.01	0.01	-0.95	0.345
Gender*Context	0.75	0.12	6.26	< 0.001 ***
YOB*Context	0.05	0.01	8.89	< 0.001 ***
YOB*Gender*Context	0.00	0.01	0.06	0.955

AP-second	Estimate	Std. Error	*t*-value	Pr ($>\vert t\vert$)
(Intercept)	3.94	0.16	24.86	< 0.001 ***
Gender	0.07	0.22	0.33	0.741
YOB	0.02	0.01	1.76	0.081
Context	2.04	0.07	29.21	< 0.001 ***
YOB*Gender	0.00	0.02	-0.22	0.829
Gender*Context	0.73	0.10	7.43	< 0.001 ***
YOB*Context	0.05	0.00	11.87	< 0.001 ***
YOB*Gender*Context	0.01	0.01	1.49	0.137

AP-third	Estimate	Std. Error	*t*-value	Pr ($>\vert t\vert$)
(Intercept)	4.45	0.15	29.40	< 0.001 ***
Gender	-0.45	0.21	-2.14	0.034 *
YOB	0.03	0.01	2.69	0.008 **
Context	0.59	0.07	7.82	< 0.001 ***
YOB*Gender	0.01	0.01	0.87	0.385
Gender*Context	0.43	0.11	4.13	< 0.001 ***
YOB*Context	0.02	0.00	4.96	< 0.001 ***
YOB*Gender*Context	0.02	0.01	2.52	0.012 *

AP-final	Estimate	Std. Error	*t*-value	Pr ($>\vert t\vert$)
(Intercept)	4.53	0.17	27.22	< 0.001 ***
Gender	-0.42	0.23	-1.81	0.072
YOB	0.02	0.01	2.28	0.024 *
Context	0.23	0.09	2.67	0.008 **
YOB*Gender	0.02	0.02	1.21	0.230
Gender*Context	0.11	0.12	0.93	0.354
YOB*Context	0.01	0.01	1.54	0.124
YOB*Gender*Context	0.02	0.01	1.81	0.070

As for the gender comparison, the models find that the two-way interaction of Gender and Context is significant in AP-initial, second, and third positions ($p < 0.001$ in all three cases), indicating that the pitch difference between the H and L contexts is larger for females than males. For example, in the AP-initial position, the model estimates that female speakers show a 0.75 St larger pitch difference between the two contexts than male speakers. Similarly, female speakers produce 0.73 St and 0.43 St larger pitch differences than male speakers in the AP-second and third syllables, respectively. This result confirms that females are more advanced than males in terms of this sound change.

3.4.4. 5-syllable APs by YOB and gender

Lastly, we examine 5-syllable APs that are located sentence-initially. Our data include 8 5-syllable APs. Out of 8, 2 APs start with an aspirated consonant, 4 of them with a lenis consonant, and the other with a vowel. The total number of syllables examined is 4,637. Table 15 shows the target APs by the AP-initial tonal contexts, and Figure 8 provides the mean pitch value of each syllable of the target APs by Gender, Context, and YOB.

Table 15. Sentence-initial 5-syllable APs by their AP-initial context (number of syllables examined). A dot marks a syllable boundary.

H-initial	/tsʰu.u.sil.tʰɛn.tɛ/ '(I suppose you feel) cold-honorific' (560)	/ho.laŋ.i.ɛ.kɛ/ 'to the tiger' (590)
L-initial	/wit.toŋ.nɛ.ɛ.sʌ/ 'from an upper town' (583) /wit.ma.ɨl.ɛ.sʌ/ 'from an upper village' (585) /koŋ.sa.ha.nɨ.la/ 'while in construction' (580)	/twɛ.to.lok.i.mjʌn/ 'if possible' (589) /tsin.nun.k'ɛ.pi.ka/ 'sleet-NOM' (590) /tsik.tsaŋ.sɛŋ.hwal.ɨl/ 'working-ACC' (560)

In Figure 8, we observe that 5-syllable APs show a quite similar pitch pattern to 4-syllable ones. Younger speakers show a large pitch difference in the AP-initial, second, and third syllables, but this pitch difference decreases after the intonational L tone on the penultimate syllable. Younger speakers born after 1970 seem to produce a pitch difference on the AP-fourth position, where the intonational L tone falls, but the pitch values of the final syllables almost overlap even for those younger speakers. Similar to the results of the previous sections, female speakers show a larger pitch difference than males.

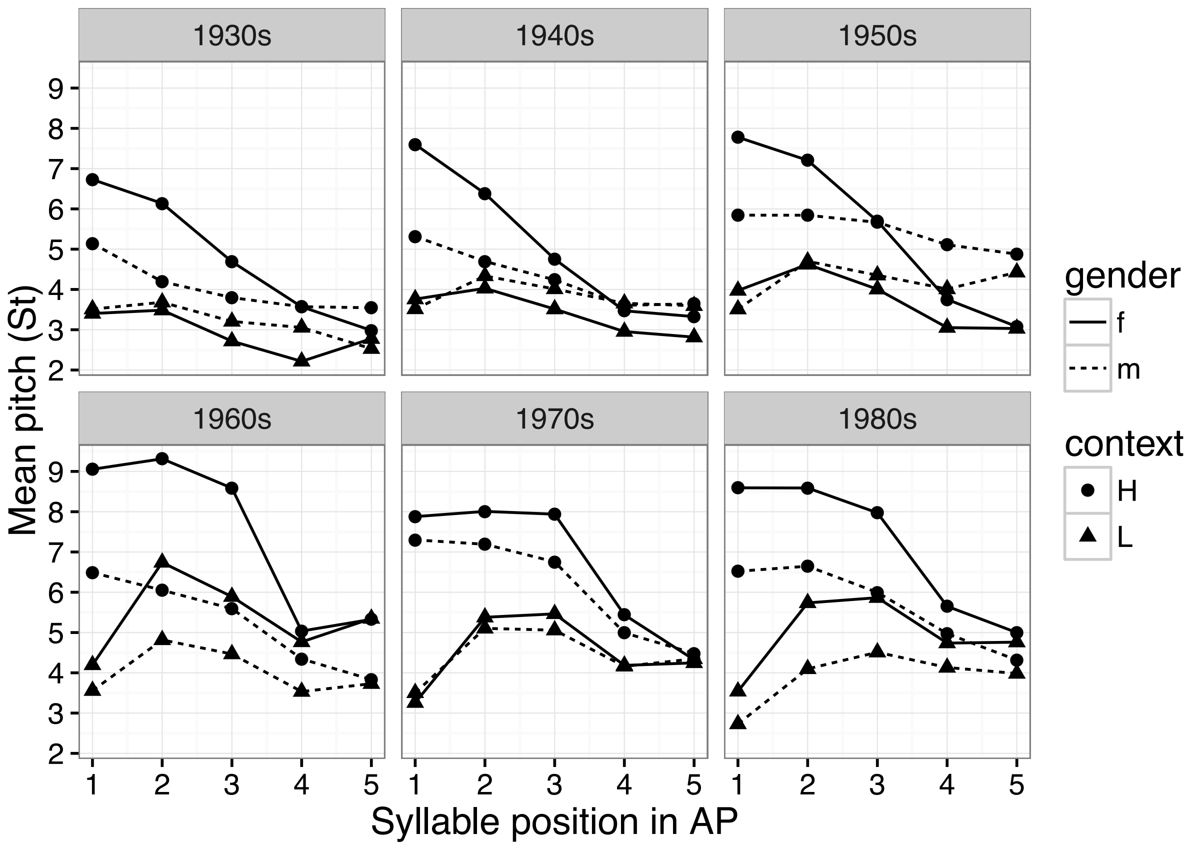

Figure 8. Mean pitch value (St) of each syllable in the 5-syllable APs by Context, Gender, and YOB. Solid lines show females, and dotted lines show males. H-initial includes all APs starting with aspirated or tense consonants, and the other APs are L-initial.

As for statistical analyses, we build 5 linear mixed-effects models to examine if the observations are statistically significant. In these models, pitch values are included as a dependent variable and Gender, Context, and YOB are added as independent variables. Each speaker is treated as a random effect. Table 16 summarizes the outputs of the models.

Table 16. The outputs of the linear mixed-effect models of 5-syllable APs by Gender, YOB, and Context. The reference category for Gender is males, and that of Context is L-initial. YOB is centered at 1961.

AP-initial	Estimate	Std. Error	*t*-value	Pr (>|*t*|)
(Intercept)	3.48	0.15	23.73	< 0.001 ***
Gender	0.25	0.20	1.21	0.229
YOB	-0.01	0.01	-0.98	0.330
Context	2.80	0.14	19.69	< 0.001 ***
YOB*Gender	0.00	0.01	-0.26	0.799
Gender*Context	1.38	0.20	6.99	< 0.001 ***
YOB*Context	0.06	0.01	6.80	< 0.001 ***

YOB*Gender*Context	-0.03	0.01	-1.86	0.063

AP-second	Estimate	Std. Error	*t*-value	Pr (>$\lvert t \rvert$)
(Intercept)	4.64	0.16	28.96	< 0.001 ***
Gender	0.25	0.22	1.14	0.258
YOB	0.02	0.01	1.75	0.080
Context	1.32	0.16	8.19	< 0.001 ***
YOB*Gender	0.03	0.02	1.67	0.098
Gender*Context	1.27	0.22	5.73	< 0.001 ***
YOB*Context	0.05	0.01	5.04	< 0.001 ***
YOB*Gender*Context	-0.04	0.02	-2.79	0.005 **

AP-third	Estimate	Std. Error	*t*-value	Pr (>$\lvert t \rvert$)
(Intercept)	4.44	0.15	28.74	< 0.001 ***
Gender	0.07	0.22	0.32	0.752
YOB	0.03	0.01	3.20	0.002 **
Context	1.09	0.16	6.68	< 0.001 ***
YOB*Gender	0.04	0.02	2.33	0.021 *
Gender*Context	0.79	0.23	3.47	0.001 **
YOB*Context	0.04	0.01	3.43	< 0.001 ***
YOB*Gender*Context	-0.01	0.02	-0.78	0.439

AP-fourth	Estimate	Std. Error	*t*-value	Pr (>$\lvert t \rvert$)
(Intercept)	3.82	0.15	25.08	< 0.001 ***
Gender	-0.28	0.21	-1.32	0.189
YOB	0.02	0.01	1.86	0.066
Context	0.61	0.17	3.53	< 0.001 ***
YOB*Gender	0.03	0.02	2.25	0.026 *
Gender*Context	0.19	0.24	0.82	0.413
YOB*Context	0.02	0.01	1.59	0.111
YOB*Gender*Context	-0.01	0.02	-0.44	0.658

AP-final	Estimate	Std. Error	*t*-value	Pr (>$\lvert t \rvert$)
(Intercept)	3.88	0.16	24.90	< 0.001 ***
Gender	-0.30	0.22	-1.38	0.169
YOB	0.03	0.01	2.53	0.013 *
Context	0.25	0.16	1.49	0.136
YOB*Gender	0.03	0.02	1.76	0.080
Gender*Context	-0.09	0.23	-0.39	0.695
YOB*Context	-0.01	0.01	-0.58	0.559
YOB*Gender*Context	0.00	0.02	0.17	0.865

The significant main effect of Context from AP-initial to AP-fourth positions ($p < 0.001$ for all cases) confirms our observation that the effect of the H-initial context reaches up to the AP-penultimate (fourth) syllable, where the intonational L tone falls, and the effect dramatically decreases after that. The models estimate that the syllables in the H-initial APs are produced with 2.8 St, 1.32 St, 1.09 St, and 0.61 St higher pitch values than those in the L-initial APs in AP-initial, second, third, and fourth syllables, respectively. The model still estimates that the final syllable of H-initial APs is 0.25 St higher than that of the L-initial ones, but this effect is not found significant ($p = 0.166$).

The two-way interactions with Context (Context x Gender and Context x YOB) are found to be significant in AP-initial, second, and third positions, similar to the results of the previous sections. That is, the effect of the AP-initial tonal contexts is modulated by a function of Gender or YOB. The models show that female speakers produce a larger pitch difference than male speakers in those positions ($p < 0.001$ for AP-initial and second, $p = 0.001$ for AP-third). For example, female speakers show a 1.38 St larger pitch difference than males in the AP-initial position, and they also produce a 0.79 St larger pitch difference than males in the AP-third position.

Also, the significant interactions of YOB and Context in the first three syllable positions ($p < 0.001$ in AP-initial, second, and third positions) suggest that younger speakers produce a larger pitch difference than older speakers in those positions. These results confirm the observation that younger speakers raise the pitch values of syllables in the H context, but this effect decreases after the intonational L tone. The three-way interaction of YOB, Gender, and Context is significant for AP-second, but insignificant for the other positions.

4. Discussion

The main goals of this study were to examine how the tonogenetic sound change has affected the intonational melody of Seoul Korean over time, how far the effect of the AP-initial H tone reaches within an AP, and if the pitch realization of APs varies by AP size, speakers' age and gender. The results of the present study showed that younger speakers produced syllables in H-initial APs with a higher pitch than those in L-initial ones. However, older speakers did not show any pitch difference between the two tonal contexts (those born in the 1930s), nor did they produce a pitch difference only in the AP-initial positions (those born in the 1940s). Also, the results showed that female speakers in general produced a larger pitch difference between H-initial and L-initial APs than male speakers, indicating that female speakers have led this tonogenetic change. Lastly, the results demonstrated that the effect of AP-initial H decreases in later syllables of longer APs. For example, the results of 4-syllable APs showed that the final position of H-initial APs was higher than that of L-initial ones, but the size of the pitch difference was smaller than that of the AP-initial position.

The results of this study provide an interesting interaction between the AP-initial H context and the intonational L tone in the penultimate syllable for younger speakers for APs that are 4-syllable and 5-syllable long. That is, for APs that are 2-syllable or 3-syllable long, the effect of the H-initial context lasts to the end of the phrase, showing a much higher pitch value on the final syllable. However, for longer APs, we observe that the effect of the H-initial context decreases substantially after the intonational L tone, only showing a fairly small pitch difference, if none, in the final syllable.

This pattern can be interpreted in two ways as schematized in Figure 9. The first possible interpretation is that the AP-initial H tone spreads to later syllables up until the intonational L tone in the penultimate syllable. In other words, the intonational L tone can be analyzed as blocking the spread of H tone. This approach explains why we observed such a difference between shorter APs and longer ones. In our data, 2-syllable and 3-syllable APs were produced with a T-H or TH-H melody, meaning that the intonational L tone was undershot and did not block the spread of the AP-initial H tone. Therefore, the H tone seemed to spread to the end of the phrase, resulting in a large pitch difference even in the final syllable position. On the other hand, 4-syllable and 5-syllable APs were produced with a TH-LH melody, and the effect of the AP-initial H context was hardly seen in the final syllable. It can be interpreted that the intonational L tone blocks the H tone spread. An alternative interpretation is that the style of interpolation from the intonational H tone of the second syllable to the intonational L tone of the penultimate syllable has been changed. In Jun's original theory of the Korean prosodic system (1993, 1996, 2005, 2006, and in her subsequent works), she explains that intermediate syllables that are not the first two or the last two ones receive their pitch values via linear interpolation from the second H (T**H**-LH) to the penultimate L (TH-**L**H) in longer APs. Since the AP-initial pitch context is highly predictable based on the AP-initial onset consonant, except the lexically specified H tone on [il] reported in Jun and Cha (2015), it might be just the case that the style of interpolation has been changed from a linear one to an elbow-like one. However, for now, it is hard to tell which approach is the correct interpretation of the phenomenon.

Figure 9. Direction of change in two approaches (H-initial APs): the H-tone spreading approach (left) and the interpolation approach (right). The direction of change is indicated with an arrow.

It is necessary to compare the tonogenetic sound change in Seoul Korean to the process of tonogenesis in other languages. In the case of Seoul Korean, we found that the AP-initial H-inducing consonants affected pitch values of later syllables. However, for various reasons, this effect is hardly seen in other languages that underwent tonogenesis previously. For example, tones seem to have developed based on syllables in Vietnamese, where one syllable corresponds to a single morpheme in most cases and many words are monosyllabic ones or compounds with monosyllabic morphemes (Thompson 1987).[22] Furthermore, unlike Korean, Vietnamese is an isolating language, meaning there is no grammatical marker for case, tense, (grammatical) gender, and agreement that attaches to words. Accordingly, previous studies on Vietnamese tonogenesis lack the explanation of polysyllabic words and the effect of consonants on later syllables within the same word (Matisoff 1973, Thurgood 2002, Kingston 2011, among others). For instance, Haudricourt's model of tonogenesis on Vietnamese (1954) explains that a syllable-final consonant determined a pitch contour and a syllable-initial onset decided the pitch height of the syllable (Thurgood 2002, 2007), suggesting that the domain of the development of tonal contrasts was a syllable or a morpheme.

In other Southeast Asian languages, such as Khmu (also known as Kammu) or Utsat (also known as Tsat or Hainan Cham), the loss of a word-initial syllable in a disyllabic (sesquisyllable) word resulted in many monosyllabic words in the languages (Thurgood 1992, Suwilai 2004, Kingston 2011), making it hard to see what happened in polysyllabic words in these languages. For example, in the case of Khmu, most words are monosyllabic or disyllabic (sesquisyllabic). In monosyllabic words, a High tone in tonal dialects of Western Khmu (e.g., /p**ó**k/ 'to take a bite')

[22] We do not explain Vietnamese morphology in detail, but those who are interested may refer to Thanh (1984) and Thompson (1987).

corresponds with a voiceless onset in Eastern Khmu (/**p**ok/ 'to take a bite'); A Low tone in Western Khmu (e.g., /p**ò**k/ 'to cut down a tree') corresponds with a voiced onset in Eastern Khmu (/**b**ok/ 'to cut down a tree'). In disyllabic words, the entire presyllable or the initial onset of presyllable was deleted in tonal dialects of Western Khmu (e.g., 'husked rice' in Eastern Khmu is /r^{ɨ}ŋ**koʔ**/, but /**kóʔ**/ in Western Khmu), because presyllables were unstressed and had reduced vowels. As a result, both monosyllabic and disyllabic words developed as monosyllabic ones in the tonal dialects. Similarly, monosyllabic words in Utsat were developed from what were previously disyllabic in proto-Chamic, due to the deletion of presyllables (Thurgood 1992). Some presyllables dropped without any trace (e.g., **ʔa**tas*** 'far' in proto-Chamic > /**ta**^{33}/ in Utsat), whereas in other cases, the deleted voiced stop resulted in a Low level tone of the next syllable without changing the voicing of the following onset (e.g., ****b**atəu* 'stone' in proto-Chamic > /**tau**^{11}/ in Utsat). As a result, it is also hard to see the effect of tonogenesis in polysyllabic words in these languages.

It would have been interesting to compare African tonal languages to Seoul Korean, but to our knowledge, there are not many documented cases of tonogenesis in African languages (Childs 2003). One previous study is a tone split in Lugbara, a Moru-Madi language spoken in Uganda and Congo, where a previous study states that an Extra High tone "arose as a result of a pitch raising of H on [+ATR] vowels" (Andersen 1986: 62). However, the case of Lugbara is different from the tonogenetic sound change of Seoul Korean in that Lugbara was already a tonal language when the tone split took place, and only High-toned syllables with [+ATR] vowels were affected by the tone split.

The case of Proto North Huon Gulf (PNHG) in the Oceanic Austronesian language family is comparable to that of Seoul Korean. During the development of PNHG from Proto Huon Gulf (PHG), vowels with a voiceless obstruent developed a H tone and those with a voiced obstruent acquired a L tone (Ross 1993). Tone spread also occurred such that all vowels in a morpheme (a foot) had the same tone (e.g., 'octopus' ****k**urit* in PHG > ***kúlíʔ*** in PNHG; 'nasal mucus' ****g**uluk* in PHG > ***gùlù*** in PNHG).[23] In Yabem, one of the daughter languages of PNHG, the voicing contrast and tonal contrast still coexist as in /ká-táŋ/ 'weep (1st sg. realis)', but in Bukawa, another daughter language, the voicing contrast has been destroyed such that the cognate of 'weep (1st sg. realis)' is /gá-táŋ/. However, it is noticeable that the same tone is shared within a foot in both Yabem and Bukawa. Ross (1993) also notes that if a verb stem has two syllables in Yabem, the prefix is outside the domain of the tone of the verb stem (e.g. ká-màdòm 'break into (realis)'), as the prefix by itself forms a separate foot, which indicates that the domain of tone and tone spread is a foot (two syllables) in these languages.

Considering previous studies, our finding suggests that Seoul Korean is a unique case as for a tonogenetic sound change. In most cases, the domain of tonogenesis is a syllable, only affecting the pitch value of the given syllable (Vietnamese, Khmu, Utsat, Lugbara). There are few cases of tonogenesis that have affected up to two syllables (PNHG and its daughter languages). However, the effect of the AP-initial H-inducing context reaches to the final syllable of the same AP for shorter APs and up to the penultimate syllable for longer APs in Korean. A question arises for why we see such a different pattern in Seoul Korean. One possible explanation is that an AP is a strongly tied prosodic unit, which is hardly separated. For example, previous studies show that

[23] Ross (1993) suggests that there is a difference between strong syllables starting with an obstruent and those starting with other consonants. When a strong syllable starts with an obstruent, its tone and voicing spread to the weak syllable; otherwise, the tone and voicing of a weak syllable spread to the strong one. Either direction, it does not change that all syllables within a foot share the same tone.

the effect of a prosodic focus in Seoul Korean spans over an entire phrase (Jun 2011, Lee 2012, Lee and Xu 2010, Lee et al. 2015). In particular, Lee et al. (2015) state that an AP is the domain of a prosodic focus in Seoul Korean, showing that when one numeric digit in a phone-number string receives a corrective focus, not only the focused digit but also the entire phrase containing the focused digit is affected. The result of previous studies seems to support the explanation that an AP is one prosodic unit that cannot be separated. This, in turn, has a broad implication that the domain of tonogenesis may be language-specific, varying according to the phonological and morphological systems of a language.

To conclude, our study investigated how the tonogenetic sound change affects the intonational melody of Seoul Korean. We confirmed previous findings that the AP-initial pitch difference increases in younger speakers. Our study also provided novel findings that the AP-initial pitch context affects later syllables of APs for younger speakers and this effect decreases after the intonational L tone in long APs. Since the pattern of tonogenesis varies depending on languages' morpho-/phonological features, a future study is needed to further investigate this relation. It remains to be seen how the pattern of Seoul Korean develops in the future.

Appendix A: Sentences that include the target APs of the study

Sentence ID	L-initial 2-syllable APs
t09_s08	**그거** 참 큰일이네 /**kikʌ** tsʰam kʰɨniline/
t09_s15	**나의** 충성스런 자라야, 네가 가서 토끼를 잡아오너라 /**naɰi** tsʰuŋsʌŋsɨlʌn tsalaja nɛka kasʌ tʰok'ilɨl tsapaonʌla/
t09_s37	**저를** 어서 풀어주세요 /**tsʌlɨl** ʌsʌ pʰulʌtsusɛjo/
t10_s12	**저는** 사냥꾼에게 쫓기고 있어요 /**tsʌnin** sanjaŋk'unɛkɛ ts'otkiko itʌjo/
t10_s27	**그 때** 아저씨가 선녀의 날개옷을 한 벌 감추세요 /**kit'ɛ** atsʌs'ika sʌnnjʌɰi nalkɛosɨl hanpʌl kamtsʰusɛjo/
t14_s12	**나는** 난처한 표정으로 고개를 끄덕였다 /**nanɨn** nantsʰʌhan pʰjotsʌŋɨlo kokɛlɨl k'ɨtukjʌtta/

Sentence ID	H-initial 2-syllable APs
t16_s10	**차가** 빠졌어요 /**tsʰaka** p'atsjʌsʌjo/
t18_s13	**뻥뻥** 빵차 왔어요 하는 음성에 옆을 보니 바께스에 희멀건 급식빵을 담아가지고 와서 내 앞에 내민다 /**p'oŋp'oŋ** p'aŋtsʰa wasʌjo hanɨn ɨmsʌŋɛ jʌpɨl poni pak'ɛsɨɛ hɰimʌlkʌnhan kɨpsikp'aŋɨl tamakatsiko wasʌ nɛapɛ nɛminta/
t18_s16	**청소** 검열을 할 때였다 /**tsʰʌŋso** kʌmjʌlɨl hal t'ɛjʌtta/

Sentence ID	L-initial 5-syllable APs
t13_s11	**윗마을에서** 배꽃잎이 떨어져 물을 따라 떠내려오면 봄은 지나가고 여름이 찾아옵니다 /**witmaɨlɛsʌ** pɛk'otnipi t'ʌlʌtsjʌ mulɨl t'ala t'ʌnɛljʌomjʌn pomɨn tsinakako jʌlɨmi tsʰatsaopnita/
t13_s28	**윗동네에서** 꽃잎이 흘러 내려오면 봄이 가듯이 나뭇잎이 떠내려오면 가을도 갑니다 /**wittoŋnɛɛsʌ** k'otnipi hɨlʌ nɛljʌomjʌn pomi katɨsi namupnipi t'ʌnɛljʌomjʌn kaɨlto kapnita/
t14_s05	**직장생활을** 하는 동안 홍보나 출판관계 일을 오랫동안 해온 터여서 언젠가부터 집으로 돌아가는 길에 다음 날 조간을 미리 사서 보는 것이 습관이 되었다 /**tsiktsaŋsɛŋhwalɨl** hanɨn toŋan hoŋpona tsʰulpankwankjɛ ilɨl olɛttoŋan hɛon tʰʌjʌsʌ ʌntsɛnkaputʰʌ tsipɨro tolakanɨn kilɛ taɨm nal tsokanɨl mili sasʌ ponɨn kʌsi sɨpkwani tøʌtta/
t16_s01	**진눈깨비가** 을씨년스럽게 내리는 11 월, 연극 연습시간에 늦은 나는 안절부절 못하며 차를 몰았다 /**tsinnunk'ɛpika** ɨls'injʌnsɨlʌpkɛ nɛlinɨn sipilwʌl jʌnkɨk jʌnsɨpsikanɛ nɨtsɨn nanɨn antsʌlputsʌl mothamjʌ tsʰalɨl molatta/
t16_s06	**공사하느라** 파놓은 구덩이에 빠져 버린 것이었다 /**koŋsahanɨla** pʰanoɨn kutʌŋiɛ p'atsjʌ pʌlin kʌsiʌtta/
t19_s34	**되도록이면** 적게 먹는다 /**tøtolokimjʌn** tsʌkkɛ mʌknɨnta/

Sentence ID	H-initial 5-syllable APs
t10_s51	**추우실 텐데** 우선 이 옷이라도 입으세요 /**tsʰuusiltʰɛntɛ** usʌn i osilato ipɨsɛjo/
t12_s27	**호랑이에게** 내려주신 동아줄은 썩은 동아줄이었거든요 /**holaŋiɛkɛ** nɛljʌtsusin toŋatsulɨn s'ʌkɨn toŋtsuliʌtkʌtɨnjo/

Sentence ID	L-initial 3-syllable APs
t09_s17	**그래서** 자라는 토끼 그림을 갖고서 부지런히 육지를 향하여 헤엄쳐 갔습니다 /**kɨlɛsʌ** tsalanɨn t^{h}ok’i kɨlimɨl katkosʌ putsilʌnhi juktsilɨl hjaŋhajʌ hɛʌmts^{h}jʌ katsɨpnita/
t09_s29	**자라는** 토끼를 살살 꾀었어요 /**tsalanɨn** t^{h}ok’ilɨl salsal k’øʌsʌjo/
t09_s32	**자라의** 속마음을 모르는 토끼는 설레이는 가슴을 안고 자라의 등에 올라탔어요 /**tsalaɰi** sokmaɨmɨl molɨnɨn t^{h}ok’inɨn sʌllɛinɨn kasɨmɨl anko tsalaɰi tɨŋɛ ollat^{h}asʌjo/
t10_s08	**그런데** 어느 날이었어요 /**kɨlʌntɛ** ʌnɨ naliʌsʌjo/
t11_s26	**엄마는** 어린애를 달래다가 지쳤습니다 /**ʌmmanɨn** ʌlinɛlɨl tallɛtaka tsits^{h}jʌtsɨpnita/
t12_s22	**이를 본** 호랑이도 똑같이 하나님께 기도를 했어요 /**ilɨlpon** holaŋito t’okkati hananimk’ɛ kitolɨl hɛsʌjo/
t18_s12	**그 꼴이** 하도 우스워 돌아서서 칠판을 향해 웃고 나니 까르르르 폭소가 터진다 /**kɨk’oli** hato usɨwʌ tolasʌsʌ ts^{h}ilp^{h}anɨl hyaŋhɛ utkonani k’alɨlɨlɨ p^{h}oksoka t^{h}ʌtsinta/

Sentence ID	H-initial 3-syllable APs
t09_s19	**따스한** 봄날이라 산에는 울긋불긋한 꽃들이 피어있고 새들이 반갑게 지저귀고 있었어요 /**t’asɨhan** pomnalila sanɛnɨn ulkɨtpulkɨthan k’ottɨli p^{h}iʌitko sɛtɨli pankapkɛ tsitsʌkwiko itʌtʌjo/
t09_s25	**토끼와** 자라는 바로 쉽게 친구가 되었어요 /**t^{h}ok’iwa** tsalanɨn palo ʃipkɛ ts^{h}inkuka twøʌsʌjo/
t09_s35	**토끼가** 용궁에 도착하자마자 용왕님의 신하가 나타나 토끼를 밧줄로 꽁꽁 묶었어요 /**t^{h}ok’ika** joŋkuŋɛ tots^{h}akhatsamatsa joŋwaŋnimɰi sinhaka nat^{h}ana t^{h}ok’ilɨl pattsullo k’oŋk’oŋ mukʌsʌjo/
t09_s44	**하지만** 토끼에게 좋은 꾀가 생각났어요 /**hatsiman** t^{h}ok’iɛkɛ tsoɨn k’øka sɛŋkaknasʌjo/
t10_s29	**사슴의** 말을 듣자, 나문꾼은 너무 신기한 일이어서 눈이 휘둥그레졌어요 /**sasɨmɰi** malɨl tɨttsa namuk’unɨn nʌmu sinkihan iliʌsʌ nuni hwituŋkɨlɛtsjʌsʌjo/
t10_s32	**사슴은** 나무꾼에게 몇 번이나 다짐을 하고는 숲 속으로 뛰어가 버렸어요 /**sasɨmɨn** namuk’unɛkɛ mjʌtpʌnina tatsimɨl hakonɨn supsokɨlo t’wiʌka pʌljʌsʌjo/
t10_s43	**선녀는** 발을 동동 굴렀지만, 날개옷을 찾을 수가 없었어요 /**sʌnnjʌnɨn** palɨl toŋtoŋ kullʌttsiman nalkɛosɨl ts^{h}atsɨlsuka ʌpsʌsʌjo/
t10_s53	**선녀는** 나무꾼이 건네주는 옷을 입고 하는 수 없이 나무꾼을 따라가서 살게 되었지요 /**sʌnnjʌnɨn** namuk’uni kunnɛtsunɨn osɨl ipko hanɨn su ʌpsi namuk’unɨl t’alakasʌ salkɛ tøʌttsijo/
t12_s14	**참기름** 바르고 올라왔지 하며 동생은 호랑이를 놀려 주었습니다 /**ts^{h}amkilɨm** palɨko ollawattsi hamjʌ toŋsɛŋɨn holaŋilɨl nolljʌ tsuʌtsɨpnita/
t18_s06	**훈훈한** 열기와 고조된 서정이 교실에 가득차고 아이들의 눈동자는 더욱 빛나고 초롱초롱해진다 /**hunhunhan** jʌlkiwa kotsotøn sʌtsʌŋi kjosilɛ katɨktsako aitɨlɰi nuntoŋtsanɨn tʌuk pitnako ts^{h}oloŋts^{h}oloŋ hɛtsinta/
t18_s09	**책보를** 싸세요 하는 나의 말이 떨어지자 교실은 떠들썩해지고 어수선해진다 /**ts^{h}ɛkpolɨl** s’asɛjo hanɨn naɰi mali t’ʌlʌtsitsa kjosilɨn t’ʌtɨls’ʌkhɛtsiko ʌsusʌnhɛtsinta/

Sentence ID	L-initial 4-syllable APs
t09_s56	**바닷가에** 도착한 토끼는 깡충 뛰어내리며 자라에게 말했어요 /**patakkaɛ** totsʰakhan tʰok'inɨn k'aŋtsʰuŋ t'wiʌnɛlimjʌ tsalaɛkɛ malhɛsʌjo/
t10_s13	**가엾게도** 사슴은 오들오들 떨고 있었어요 /**kajʌpkɛto** sasɨmɨn otɨlotɨl t'ʌlko isʌsʌjo/
t10_s15	**잠시 후에** 사냥꾼이 씩씩거리며 뒤쫓아 왔어요 /**tsamsihuɛ** sanjaŋk'uni s'iks'ikkʌlimjʌ twits'otsʰa wasʌjo/
t10_s18	**나무꾼은** 시치미를 뚝 떼었어요 /**namuk'unɨn** sitsʰimilɨl t'uk t'ɛʌsʌjo/
t10_s34	**거기에는** 정말 아름답고 맑은 연못이 있었어요 /**kʌkiɛnin** tsʌŋmal alɨmtapko malkɨn jʌnmosi isʌsʌjo/
t10_s47	**날개옷을** 찾거든 빨리 올라오너라 /**nalkɛosɨl** tsʰatkʌtɨn p'alli ollaonʌla/
t10_s69	**나무꾼은** 땅바닥에 털썩 주저앉아 한숨을 쉬며 사슴이 부탁한 말을 생각했어요 /**namuk'unɨn** t'aŋpatakɛ tʰʌls'ʌk tsutsʌantsa hansumɨl swimjʌ sasɨmi putʰakhan malɨl sɛŋkakhɛsʌjo/
t11_s02	**어머니가** 아무리 달래도 보채면서 울음을 그치지 않았습니다 /**ʌmʌnika** amuli tallɛto potsʰɛmjʌnsʌ ulɨmɨl kɨtsʰitsi anassɨpnita/
t18_s21	**조상에게** 가난을 먼저 배운 아이들 /**tsosaŋɛkɛ** kananɨl mʌntsʌ pɛun aitɨl/
t19_s11	**그러다가** 좀 더 무더워지면 내 고향 잔잔한 개울을 찾아 내려간다 /**kɨlʌtaka** tsomtʌ mutʌwʌtsimjʌn nɛ kohjaŋ tsantsanhan kɛulɨl tsʰatsa nɛljʌkanta/

Sentence ID	H-initial 4-syllable APs
t09_s10	**신하들이** 걱정스런 표정으로 말했어요 /**sinhatɨli** kʌktsʌŋsɨlʌn pʰjotsʌŋɨlo malhɛsʌjo/
t09_s43	**뽐내듯이** 자랑하는 자라의 옆에서 토끼는 벌벌벌 떨기만 했어요 /**p'omnɛtɨsi** tsalaŋhanɨn tsalaɰi jʌpɛsʌ tʰok'inɨn pʌlpʌlpʌl t'ʌlkiman hɛsʌjo/
t10_s16	**사냥꾼은** 사방을 두리번 거리더니 나무꾼에게 물었어요 /**sanjaŋk'unɨn** sapaŋɨl tulipʌn kʌlitʌni namuk'unɛkɛ mulʌsʌjo/
t10_s48	**혼자 남은** 선녀는 너무 슬퍼서 흐느껴 울고 있었어요 /**hontsa namɨn** sʌnnjʌnɨn nʌmu sɨlpʰʌsʌ hɨnɨk'jʌ ulko isʌsʌjo/
t11_s29	**호랑이는** 창문 옆에서 늑대란 말을 듣고 빙그레 웃었습니다 /**holaŋinɨn** tsʰaŋmun jʌpɛsʌ nɨktɛlan malɨl tɨtko piŋkɨlɛ usʌssɨpnita/
t11_s25	**호랑이는** 코를 벌름거리며 동아줄을 타고 오누이를 쫓아갔어요 /**holaŋinɨn** kʰolɨl pʌllɨmkʌlimjʌ toŋatsulɨl tʰako onuilɨl ts'otsakasʌjo/
t11_s32	**호랑이는** 자기 이름을 말하는 소리를 듣고 흠칫 뒤로 물러섰습니다 /**holaŋinin** tsaki ilɨmɨl malhanɨn solilɨl tɨtko hɨmtsʰit twilo mullʌsʌtsɨpnita/
t14_s02	**크고 작은** 좌판위에 갖가지 물건을 쌓아놓고 지나가는 이들의 눈길을 끈다 /**kʰɨkotsakɨn** tswapʰanwiɛ katkatsi mulkʌnɛ s'aanotko tsinakanɨn itɨlɰi nunkilɨl k'ɨnta/
t17_s08	**똑같은 쌀** 똑같은 솥으로 밥을 지어 먹었는데 어째서 한국 사람만이 숭늉을 만들어 마셨을까 /**t'okkatɨn** s'al t'okkatɨn sotɨlo papɨl tsiʌ mʌkʌtnɨntɛ ʌts'ɛsʌ hankuk salammani suŋnjuŋɨl mantɨlʌ maʃʌsɨlk'a/
t18_s25	**싱싱하고** 튼튼하게 자라도록 심고 가꾸어야 할 이 십자목에 정성과 지혜를 바치고 싶다 /**siŋsiŋhako** tʰɨntʰɨnhakɛ tsalatolok simko kak'uʌja hal i siptsamokɛ tsʌŋsʌŋkwa tsihyɛlɨl patsʰiko sipta/

t18_s26	**꿈 속에서** 가끔 북한의 어린이들을 만나보고 안타까와 가슴 앓다가 깨곤 한다 /**k'um sokɛsʌ** kak'ɨm pukhanɰi ʌlinitɨlɨl mannapoko ant^{h}ak'awa kasɨm alt^{h}aka k'ɛkon hanta/
t19_s03	**피서지의** 시설이 그렇고, 오고 가는 교통편이 그렇고, 더구나 그 곳에 모여든 사람들이 그러하다 /**p^{h}isʌtsiɰi** sisʌli kɨlʌk^{h}o oko kanɨn kjot^{h}oŋp^{h}jʌni kɨlʌk^{h}o tʌkuna kɨ kosɛ mojʌtɨn salamtɨli kɨlʌhata/
t19_s19	**피라미나** 송사리, 챙기름쟁이 같은 어진 개울 고기들이 내 몸을 스쳐가기도 하고, 쫑쫑 주둥이로 쪼기도 하고 장난도 친다 /**p^{h}ilamina** soŋsali ts^{h}ɛŋkilɨmtsɛŋi katɨn ʌtsin kɛul kokitɨli nɛ momɨl sɨts^{h}jʌkakito hako ts'oŋts'oŋ tsutuŋilo ts'okito hako tsaŋnanto ts^{h}inta/

Acknowledgment
[Acknowledgment to be added later]

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Andersen, T. (1986). Tone splitting and vowel quality: evidence from Lugbara. *Studies in African Linguistics, 17*, 55-68.

Bailey, G. (2002). *The Handbook of Language Variation and Change.* Oxford: Blackwell.

Boersma, P., & Weenink, D. (2016). *Praat: Doing phonetics by computer* [computer program]. Version 6.0.16. <http://www.praat.org/>.

Childs, G. T. (2003). *An Introduction to African Languages.* Amstredam: John Benjamins Publishing Company.

Cho, H. (2011). The timing of phrase-initial tones in Seoul Korean: A weighted-constraint model. *Phonology, 28*, 293-330.

Cho, S., & Lee, Y. (2016). The effect of consonant-induced pitch on Seoul Korean intonation. *Linguistic research, 33(2),* 299-317.

Cho, T., Jun, S.-A., & Ladefoged, P. (2002). Acoustic and aerodynamic correlates of Korean stops and fricatives. *Journal of Phonetics, 30,* 193-228.

Choi, H. (2002). Acoustic cues for the Korean stop contrast: Dialectal variation. *ZAS Papers in Linguistics, 28,* 1-12.

Diffloth, G. (1989). Proto-Austroasiatic creaky voice. *Mon-Khmer Studies, 15,* 139-154.

Eckert, P. (1989). The whole woman: Sex and gender differences in variation. *Language Variation and Change, 1(3),* 245-267.

Eckert, P., & McConnell-Ginet, S. (2003). *Language and Gender.* Cambridge: CUP.

Guy, G. R. (2003). Variationist approaches to phonological change. In B. D. Joseph, & R. D. Janda (Eds.), *The Handbook of Historical Linguistics* (pp. 369–400). Malden, MA: Blackwell.

Haudricourt, A.-G. (1954). De l'origine des tons en vietnamien. *Journal Asiatique, 242,* 69-82.

Han, M. S., & Weitzman, R. S. (1970). Acoustic features of Korean /P, T, K/, /p, t, k/ and /p^h, t^h, k^h/. *Phonetica, 22(2),* 112-128.

Hanson, H. M. (2009). Effects of obstruent consonants on fundamental frequency at vowel onset in English. *Journal of Acoustical Society of America, 125*, 425-441.

Hirose, H., Lee, C. Y., & Ushijima, T. (1974). Laryngeal control in Korean stop production. *Journal of Phonetics, 2,* 145-152.

Hombert, J.-M. (1978). Consonant types, vowel quality, and tone. In V. A. Fromkin (Ed.), *Tone: A Linguistic Survey* (pp. 77–111). New York: Academic Press.

Hyman, L. (1978). Historical tonology. In V. A. Fromkin (Ed.), *Tone: A Linguistic Survey* (pp. 257–269). New York: Academic Press.

Jin, W. (2008). Sounds of Chinese Korean: A variationist approach. Doctoral dissertation. Arlington, Texas: University of Texas at Arlington.

Jun, S.-A. (1993). The phonetics and phonology of Korean prosody. Doctoral dissertation. Ohio: The Ohio State University. [published in 1996 by Garland Publishing Inc.]

Jun, S.-A. (1996). Influence of microprosody on macroprosody: A case of phrase initial strengthening. *UCLA Working Papers in Phonetics, 92,* 97-116.

Jun, S.-A. (2005). Korean intonational phonology and prosodic transcription. In S.-A. Jun (Ed.), *Prosodic Typology: The Phonology of Intonation and Phrasing* (pp. 201–229). Oxford University Press.

Jun, S.-A. (2006). Intonational phonology of Seoul Korean revisited. *Japanese-Korean Linguistics, 14,* 15-26. Stanford: CSLI.

Jun, S.-A. (2007). The intermediate phrase in Korean intonation: Evidence from sentence processing. In C. Gusserhoven, & T. Riad (Eds.), *Tones and Tunes: Studies in Word and Sentence Prosody* (pp. 143–167). Berlin: Mouton de Gruyter.

Jun, S.-A. (2011). Prosodic marking of complex NP focus, syntax, and the pre-/post-focus string. In M. B. Wshburn et al. (Eds.), *Proceedings of the 28th West Coast Conference on Formal Linguistics* (pp. 214–230).

Jun, S.-A., Beckman, M., & Lee, H.-J. (1998). Fiberscopic evidence for the influence on vowel devoicing of the glottal configurations for Korean obstruents. *UCLA Working Papers in Phonetics, 96,* 43-68.

Jun, S.-A., & Cha, J. (2015). High-toned [il] in Korean: Phonetics, intonational phonology, and sound change. *Journal of Phonetics, 51,* 93-108.

Kagaya, Ryohei. 1974. A fiberscopic and acoustic study of the Korean stops, affricates, and fricatives. *Journal of Phonetics 2,* 161–180.

Kang, K.-H., & Guion, S. G. (2008). Clear speech production of Korean stops: Changing phonetic targets and enhancement strategies. *Journal of Acoustical Society of America, 124*, 3909-3917.

Kang, Y. (2014). Voice Onset Time merger and development of tonal contrast in Seoul Korean stops: A corpus study. *Journal of Phonetics, 45,* 76-90.

Kim, M.-R. (1994). Acoustic characteristics of Korean stops and perception of English stop consonants. Doctoral dissertation. Wisconsin: University of Wisconsin-Madison.

Kim, M.-R. (2000). Segmental and tonal interactions in English and Korean: A phonetic and phonological study. Doctoral dissertation. Michigan: University of Michigan, Ann Arbor.

Kim, M. (2004). Correlation between VOT and F0 in the perception of Korean stops and affricates. In *Interspeech 2004–8th Interanational Conference on Spoken Language Processing at Jeju, Korea*, 49-52.

Kingston, J. (2011). Tonogenesis. In M. van Oostendorp, C. J. Ewen, & K. Rice (Eds.), *The Blackwell Companionto Phonology* (pp. 2304–2333). Blackwell Publishing.

Kirby, J. (2014). Incipient tonogenesis in Phnom Penh Khmer: Acoustic and perceptual studies. *Journal of Phonetics, 43,* 69-85.

Kong, E. J., Beckman, M., & Edwards, J. (2011). Why are Korean tense stops acquired so early: The role of acoustic properties. *Journal of Phonetic, 39,* 196-211.

Labov, W. (1990). The intersection of sex and social class in the course of linguistic change. *Language Variation and Change, 2,* 205-254.

Labov, W. (2001). *Principles of Linguistic Change, vol. 2: Social Factors.* Oxford: Blackwell.

Lee, H.-J. (1999). Tonal realization and implementation of the Accentual Phrase in Seoul Korean. MA thesis. LA: University of California, Los Angeles.

Lee, Y., Cho, S., & Liberman, M. (2015). An interaction effect between tonogenesis and focus in Seoul Korean. Paper presented at the 39th Penn Linguistics Conference (PLC), University of Pennsylvania, Philadelphia, Pennsylvania.

Lee, H., & Jongman, A. (2012). Effects of tone on the three-way laryngeal distinction in Korean: An acoustic and aerodynamic comparison of the Seoul and South Kyungsang dialects. *Journal of the International Phonetic Association, 42,* 145-169.

Lee, Y., & Xu, Y. (2010). Phonetic realization of contrastive focus in Korean. *Proceedings of Speech Prosody 2010,* 1-4.

Lehiste, I., & Peterson, G. E. (1961). Some basic considerations in the analysis of intonation. *Journal of Acoustical Society of America, 33,* 419-425.

Liberman, M., & Pierrehumbert, J. (1984). Intonational invariance under changes in pitch range and length. In M. Aronoff, & R. Oehrle (Eds.), *Language sound structure* (pp. 157–233). Cambridge: MIT Press.

Lisker, L., & Abramson, A. S. (1964). A cross-language study of voicing in initial stops: Acoustic measurements. *Word, 20,* 384-422.

Matisoff, J. A. (1973). Tonogenesis in Southeast Asia. In Larry M. Hyman (Ed.), *Consonant Types and Tone: Southern California Occasional Papers in Linguistics 1,* (pp. 71–95). CA: University of Southern California.

Maran, L. R. (1973). On becoming a tone language: A Tibeto-Burman model of tonogenesis. In L. Hyman (Ed.), *Consonant Types and Tone: Southern California Occasional Papers in Linguistics 1* (pp. 98–114). CA: University of Southern California.

Mohr, B. (1971). Intrinsic variations in the speech signal. *Phonetica, 23,* 65-93.

Thanh, N. N. (1984). The syllabeme and patterns of word formation in Vietnamese. Doctoral dissertation. New York: New York University.

The National Institute of the Korean Language. 2005. *A speech corpus of reading-style Standard Korean* [DVDs]. Seoul: The National Institute of the Korean Language.

Oh, E. (2011). Effects of speaker gender on voice onset time in Korean stops. *Journal of Phonetics, 39,* 132-142.

Ross, M. D. (1993). Tonogenesis in the North Huon Gulf Chain. *Oceanic Linguistic Special Publications, 24,* 133-153.

Sankoff, G. (2006). Age: Apparent time and real time. In K. Brown (Ed.), *Encyclopedia of Language and Linguistics, 2nd edition.* (pp. 110–116). Elsevier Ltd.

Silva, D. J. (2006). Acoustic evidence for the emergence of tonal contrast in Contemporary Korean. *Phonology, 23,* 287-308.

Suwilai, P. (2004). Register complex and tonogenesis in Khmu dialects. In S. Kaji (Ed.), *Cross-linguistic Studies of Tonal Phenomena: Historical Development, Phonetics of Tone, and Descriptive Studies* (pp. 13–28)*.* Tokyo: ILCAA.

Thompson, L. C. (1987). *A Vietnamese Reference Grammar.* Hawaii: University of Hawaii Press.

Thurgood, G. (1992). From atonal to tonal in Utsat (a Chamic language of Hainan). In L. A. Buszard-Welcher, J. Evans, D. Peterson, L. Wee, and W. Weigel (Eds.), *Proceedings of the 18th Annual Meetings of the Berkeley Linguistics Society* (pp. 145–156).

Thurgood, G. 2002. Vietnamese and tonogenesis. *Diachronica, 19*, 333-363.

Thurgood, G. 2007. Tonogenesis revisited: Revising the model and the analysis. In J. G. Harris, S. Burusphat, and J. E. Harris (Eds.), *Studies in Tai and Southeast Asian Linguistics,* (pp. 263–291). Bangkok: Ek Phim Thai Co.

Wright, J. D. 2007. The phonetic contrast of Korean obstruents. Doctoral dissertation, University of Pennsylvania.

Yoon, T.-J., & Kang, Y. (2012). A forced-aligned-based study of declarative sentence-ending 'ta' in Korean. In *Proceedings of the 6th International Conference on Speech Prosody 2012.* Shanghai: Tongji University Press.

Yuan, J., & Liberman, M. (2014). F0 declination in English and Mandarin broadcast news speech. *Speech Communication, 65,* 67-74.

Highlights

- We examined a tonogenetic change and its effect on intonation in Seoul Korean.
- Young speakers show an f0 enhancement in later syllables of High-initial phrases.
- Young females show a larger pitch difference in all syllables than young males.
- Short phrases show non-overlapping pitch ranges between H- and L-initial contexts.
- The pitch difference decreases after the intonational L tone in long phrases.