The phonology and phonetics of Korean stop laryngeal contrasts

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1. Introduction

Korean has a three-way laryngeal contrast in stops and affricates and a two-way contrast in fricatives. Table 8.1 presents the consonant inventory of Korean and (1) provides some relevant words illustrating the contrast. Aspirated consonants are described as strongly or heavily aspirated. Lenis consonants are variously referred to as plain, lax, weak, or slightly aspirated while fortis consonants are referred to as tense, reinforced, forced, unaspirated, or constricted.

Table 8.1 Consonant Inventory of Korean

		Labial	Coronal		Dorsal	Glottal
Stops/Affricates	Lenis	p	t	t͡s	k	
	Aspirated	pʰ	tʰ	t͡sʰ	kʰ	
	Fortis	p'	t'	t͡s'	k'	
Fricatives	Non-Fortis		s			h
	Fortis		s'			
Nasals		m	n		ŋ	
Liquids			l/ɾ			

(1)	pul	'fire'	tal	'moon'	koŋ	'ball'	t͡sa-ta	'to sleep'
	pʰul	'grass'	tʰal	'mask'	kʰoŋ	'bean'	t͡sʰa-ta	'to kick'
	p'ul	'horn'	t'al	'daughter'	k'oŋ	'frozen'	t͡s'a-ta	'to be salty'

This particular three-way contrast in voiceless stops is unusual if not unique cross-linguistically, and the contrast is signaled by a combination of phonetic attributes that varies across contexts, leading to much research into its phonetics as well as a debate on its phonological analysis. More recently, the synchronic and diachronic variation in the realization of the contrast has drawn a lot of attention, adding further challenge to understanding this system. In this paper, we first review the literature on the phonetic and phonological characterizations of the contrast. The second half of the article presents a survey of dialectal and diachronic variation in realization of the contrasts, ending with a case study comparing synchronic variation in three dialects of Korean.

2. Phonetic characteristics

Korean aspirated stops are produced with the longest VOT (Voice Onset Time) and fortis stops, with the shortest VOT. In word-initial position, lenis stops fall in the intermediate range between aspirated and fortis stops in VOT but in word-medial position, lenis stops are generally voiced (Kim-Renaud 1974; Silva 1992; Jun 1993). While VOT, an acoustic manifestation of the timing and the size of glottal opening, is undeniably an important contrastive feature of Korean laryngeal distinctions (Lisker and Abramson 1964; Kim 1970; Kagaya 1974; Kim, Honda, and Maeda 2005; Kim, Maeda, and Honda 2010), many have observed that VOT alone is not sufficient to make a reliable three-way distinction, especially in word-initial position, where all three categories are realized as voiceless and where there is a substantial overlap in VOT values among the categories (Kim 1965; Han and Weitzman 1970; Cho, Jun, and Ladefoged 2002). Subsequent studies have shown that the stops differ along many additional acoustic, articulatory, and aerodynamic dimensions.

One important additional cue to the stop contrast is the fundamental frequency (f0) of the following vowel: lenis stops show consistently lower f0 than fortis or aspirated stops, and there is substantial individual and dialectal variation in terms of the relative f0 of fortis and aspirated stops (Kim 1965; Han and Weitzman 1970; Hardcastle 1973; Kagaya 1974; Jun 1993; Kim 1994; Cho, Jun, and Ladefoged 2002; Silva 2006; Wright 2007). Stops are further differentiated by the voice quality of the following vowel. Fortis stops are associated with a more pressed or creaky quality, as indicated by low or negative values of H1-H2, the amplitude difference between the first two harmonics (Ahn 1999; Cho, Jun, and Ladefoged 2002; Kang and Guion 2006; 2008), while lenis and aspirated stops show higher H1-H2 values, indicating breathier voice, with the relative breathiness of lenis vs. aspirated varying across studies and dialects. These vocalic differences in f0 and voice quality are not confined to the onset of the following vowel but extend to the entire syllable and, in the case of f0, into subsequent syllables in the phrase (Jun 1996; Cho, Jun, and Ladefoged 2002; Silva 2006), indicating that the segmentally induced f0 difference is phonologized into tonal distinctions in the intonational phonology of Korean (Jun 1993).

Articulatorily, stops also differ in laryngeal muscle activation, with fortis stops associated with increased tension of vocal folds and glottal constriction and aspirated stops showing a marked suppression of vocal folds adductor muscles, while lenis stops lack the same degree of muscle activation (Hirose, Lee, and Ushijima 1974). Fortis and aspirated plosives also show a raised glottal position which lengthens and stiffens the vocal folds, leading to a higher f0 on the following vowels (Kim, Honda, and Maeda 2005; Kim, Maeda, and Honda 2010).

Along with the aforementioned differences in laryngeal attributes, stops also vary in their supralaryngeal articulation. Stops differ in oral constriction duration; fortis and aspirated stops have greater closure duration than lenis stops with some, but not all, studies finding a significantly longer closure duration for fortis than aspirated stops. While the closure duration difference is only audible and most substantial in word-medial position, some studies have found that the duration differences also hold in word-initial position (Silva 1992; Kim 1994; Han 1996; Cho and Keating 2001; Cho, Jun, and Ladefoged 2002; Kim, Maeda, and Honda 2010). Along with the longer duration, articulatory studies have found that fortis and aspirated stops also have a wider linguo-palatal contact area (Kim 1965; Shin 1997; Cho and Keating 2001; Kim, Honda, and Maeda 2005; Kim, Maeda, and Honda 2010; Kochetov and Kang 2017) and more lip muscle activity (Kim 1965) than lenis stops, indicating a generally stronger articulation for the former. More generally, it is proposed that fortis and aspirated stops have increased tension not only in the vocal folds but also in the primary oral articulators and vocal tract walls (Dart 1987; Kim, Honda, and Maeda 2005; Kim, Maeda, and Honda 2010). As a consequence of these differences in laryngeal and supralaryngeal articulations, the stops also differ in their aerodynamic characteristics. Aspirated and fortis stops have higher intraoral air pressure than lenis stops (Dart 1987; Cho, Jun, and Ladefoged 2002), and aspirated stops have the highest airflow at stop release, followed by lenis, then fortis stops (Hardcastle 1973; Cho, Jun, and Ladefoged 2002).

3. Phonological representations

A variety of proposals on phonological representations of Korean laryngeal contrasts reflect the complexity of the phonetic facts. Studies generally agree that the lenis category is the unmarked member of the contrast. Phonetically, they are characterized by a general lack of positive laryngeal activity (Hirose, Lee, and Ushijima 1974; Kagaya 1974) and the presence of contextual voicing (Kim-Renaud 1974; Silva 1992; Jun 1993), which does not affect aspirated or fortis consonants (Iverson 1983; Cho, Jun, and Ladefoged 2002).

Historically fortis and aspirated consonants are newer additions to the language – Proto-Korean lacked fortis and aspirated consonants, with aspirated stops arising in Middle Korean, and fortis consonants in early Modern Korean (Cho (2011) and references cited therein). Reflecting their more recent entry into the language, fortis and aspirated consonants are less frequently attested in corpora and rank toward the bottom of the phoneme frequency ranking (Shin, Kiaer, and Cha 2012). Phonologically, lenis consonants are targets of a phonological process, i.e., post-obstruent tensing, and the output of neutralization, i.e., coda neutralization, typical of unmarked elements of phonological contrasts (Rice 2007). In post-obstruent tensing, lenis but not aspirated consonants become fortis following another obstruent, as illustrated in (2). The full obstruent contrast is available in onset position as shown in (1); however, in coda position, marked laryngeal structures are not supported, with underlying fortis and aspirated plosives neutralizing to corresponding lenis stops in coda position as shown in (3) (Kim-Renaud 1977; Lombardi 1994; Kim-Renaud 1997; Ahn and Iverson 2004).

(2) Post-obstruent tensing of lenis (a) but not aspirated stops (b)

a. /sik-tɑn/ [ʃik**t'**ɑn] ‘menu’
/pɑk-t͡sɑ/ [pɑk**t͡s'**ɑ] ‘tempo’
b. /sʌk-tʰɑn/ [sʌk**tʰ**ɑn] *[sʌk**t'**ɑn] ‘coal’
/mɑk-t͡sʰɑ/ [mɑk**t͡sʰ**ɑ] *[mɑk**t͡s'**ɑ] ‘last train’

(3) Coda neutralization

/t͡sip/ [t͡si**p̚**] ‘house’
/pɑtʰ/ [pɑ**t̚**] ‘field’
/k'ʌk'-tɑ/ [k'ʌ**k̚**t'ɑ] ‘break off’
/puʌkʰ/ [puʌ**k̚**] ‘kitchen’

Proposals differ in how the three stop categories are differentiated from each other phonologically, and the representation of the fortis stops has been controversial in particular. Kim (1965) proposed “*tensity”* as an autonomous feature of Korean stop classification, orthogonal to voicing/aspiration. The feature [tense] is proposed as an omnibus feature that subsumes various laryngeal and supralaryngeal phonetic attributes, including longer constriction duration and increased f0 and vocal fold tension due to a raised larynx position (Kim 1965; Kim, Honda, and Maeda 2005; Kim, Maeda, and Honda 2010). Specifically, fortis and aspirated consonants share a [+tense] feature and are distinguished by [spread glottis] specification, as shown in Table 8.2.

Table 8.2 Korean stop feature specification (Kim, Maeda, and Honda 2010) based on (Kim 1965)

	Lenis	Fortis	Aspirated
[tense]	-	+	+
[spread glottis]	-	-	+

Halle and Stevens (1971)'s feature system, on the other hand, utilizes features that are more closely linked to laryngeal articulation. Specifically, they propose feature specifications that define laryngeal contrasts along two dimensions of laryngeal articulation using four binary features: [±Spread Glottis] and [± Constricted Glottis] for glottal width and [±Stiff Vocal Folds] and [±Slack Vocal Folds] for glottal tension. In this system, Korean contrasts are defined as shown in Table 8.3. Iverson (1983) revised Halle and Stevens (1971)'s feature specifications to represent the lenis category as having a negative value for all four features, in line with the observation that the lenis stops generally lack positive laryngeal gestures (Hirose, Lee, and Ushijima 1974; Kagaya 1974).

Table 8.3 Korean stop feature specification (Halle and Stevens 1971; Iverson 1983)

	Lenis	Fortis	Aspirated
[Spread Glottis]	+ (H&S)/ - (Iverson)	-	+
[Constricted Glottis]	-	+	-
[Stiff Vocal Folds]	-	+	+
[Slack Vocal Folds]	-	-	-

Subsequent phonological proposals were concerned with constraining the space of possible laryngeal contrasts, while being consistent with the phonetic characteristics and the phonological patterning of the sound classes. Cho and Inkelas (1994) and Lombardi (1994) proposed a privative feature analysis of laryngeal contrasts where Korean fortis and aspirated consonants are specified as [Constricted Glottis] and [Spread Glottis], respectively, while lenis consonants are unspecified (Table 8.4). Cho, Jun and Ladefoged (2002) adopt this privative feature-based underspecification analysis and propose that [Stiff Vocal Folds] specification is added to the fortis and aspirated stops via redundancy rules.

Table 8.4 Korean stop feature specification (Cho and Inkelas 1994; Lombardi 1994; Cho, Jun, and Ladefoged 2002)

	Lenis	Fortis	Aspirated
[Spread Glottis]			√
[Constricted Glottis]		√	
[Stiff Vocal Folds]		(√)	(√)

Note: The parentheses mark redundant derived features.

Another line of analyses proposed that fortis consonants are underlying geminates (Han 1996; Avery and Idsardi 2001; Ahn and Iverson 2004). In particular, Avery and Idsardi (2001) and Ahn and Iverson (2004)'s analysis of Korean is couched under the theory of laryngeal contrasts which limits possible underlying contrasts to a single privative specification for each of three glottal *dimensions* – glottal width (GW), glottal tension (GT), and glottal height (GH). According to this system, a language cannot have underlying contrasts of two different specifications along a single dimension (i.e., [Spread Glottis] and [Constricted Glottis] for GW). Applying this theory to Korean, aspirated consonants are the only category positively specified for a laryngeal dimension (GW), while lenis consonants are unspecified and fortis consonants are underlying geminates. All surface laryngeal specifications, [Constricted Glottis] and [Stiff Vocal Folds], are filled in by language-specific redundancy rules.

(4) Korean stop feature specification (Ahn and Iverson 2004)

a. Underlying specification

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    Lenis             Fortis          Aspirated
      C               C   C           C
      |                \ /            |
    [obst]            [obst]        [obst]
                                      |
                                      GW
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b. Surface specification

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    Lenis             Fortis              Aspirated
      C               C   C               C
      |                \ /                |
    [obst]            [obst]            [obst]
                       / \                / \
                     GW  GT             GW   GT
                      |   |              |    |
            [constricted] [stiff]   [spread] [stiff]
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Silva (2006) similarly proposes featural representations where fortis consonants are underlying geminates and only aspirated consonants have a positive laryngeal specification. Instead of GW or [Spread Glottis], Silva proposes [stiff] as the primary feature that contrasts aspirated consonants from lenis consonants, consistent with the findings that the tonal distinction is taking over VOT difference as a primary cue for the aspirated vs. lenis contrast in Seoul Korean. Similarly concerned with the restrictiveness of feature theory and prominence of consonant-induced tonal patterns, Kim and Duanmu (2004) propose that Korean lenis stops, which are voiced in medial position, are underlyingly specified as [+voice] while aspirated stops are [+aspirated] and fortis stops are neither. Under this view, the consonant-induced tonal patterns (aspirated-high, fortis-high, and lenis-low) follow from the cross-linguistically well-established correlation between voicing and tone – voiced-low and voiceless-high (Hombert, Ohala, and Ewan 1979; Kingston and Diehl 1994). However, this proposal is not fully supported by the phonetic evidence, given the fact that lenis stops are generally devoid of any positive laryngeal target and the fact that their voicing realization is not a categorical phonological rule but a passive by-product of a gradient phonetic process affected by speech rate, prosodic position, and segmental contexts (Jun 1995; Jun, Beckman, Niimi, and Tiede 1997).

4. Diachronic change

Although traditionally analyzed as a three-way VOT contrast (e.g. Lisker and Abramson 1964), phonetic studies have long recognized that Voice Onset Time alone is not a sufficient cue to differentiate the three-way distinction of Korean stops reliably, especially in word-initial position where all three categories are realized as voiceless (Kim 1965; Han and Weitzman 1970; Kagaya 1974; Abramson and Whalen 2017). Additional phonetic dimensions, including the voice quality and f0 of the following vowel, play crucial roles in the contrast (Cho, Jun, and Ladefoged 2002). Phonological analyses differ in terms of which of the phonetic attributes they consider to be "primary" and which are derived as redundant or enhancement features. Such freedom of analysis is likely available to the learners of the language as well, leading to re-analysis and change. An expanding body of literature documents the diachronic and dialectal variation in the realization of Korean laryngeal contrasts. Jun (1993; 1996), in particular, observed that the consonant-induced pitch difference has developed beyond a minor perturbation at the vowel margin to distinct phonological tones, with the pitch difference extending far into the vowel and subsequent syllables. Specifically, Jun proposed that the onset of the Accentual Phrase is marked by different boundary tones depending on the laryngeal feature of the initial segment; the boundary tones are LH when the initial segment is lenis and HH when the initial segment is aspirated or fortis. Kim, Beddor and Horrocks (2002)'s study took this finding one step further and demonstrated that the vocalic portion of the signal contains more dominant perceptual cues for laryngeal contrasts (including pitch and voice quality) than the consonantal portion (i.e., VOT) for younger Seoul listeners.

While recognizing the prominence of the consonant-induced f0 distinction, studies have also observed diachronic change in VOT. Silva (2002) conducted a meta-analysis of phonetic studies published between 1965 and 2000 and observed a diachronic trend whereby the VOT difference between aspirated and lenis stop consonants was decreasing. A more recent meta-analysis of published data from 1965 to 2011 by Beckman, Li, Kong and Edwards (2014) further corroborated this diachronic trend. Instrumental data from an earlier period of Seoul Korean is sparse, but available data are consistent with the proposed diachronic trend of reduction in VOT distinction and also suggests an increase in f0 contrast between lenis aspirated stops. Kang and Han (2013) examined the speech of a 41-year old male Seoul speaker (born in 1894) recorded in 1935 and found that the speaker relied exclusively on VOT for the lenis and aspirated stop contrast unlike the present-day Seoul speakers of comparable age and gender, who make use of both VOT and F0 cues to signal the stop contrast. Byun (2016) discusses Obata and Toyoshima (1932)'s study of Korean stops by speakers estimated to be born around 1915 or earlier and similarly finds that while aspirated and lenis stops are well differentiated by VOT, the f0 difference is inconsistent across speakers.

Silva (2006) supported this diachronic trend of VOT change in an *apparent time* study, which compares the speech of different age groups at one timepoint as evidence for the change in real time, under the assumption that adult speakers' pronunciation norms remain largely stable after adolescence (Labov 1994; Sankoff 2013). Silva (2006) found that in younger Seoul Korean speakers' speech, the VOT difference between aspirated and lenis stops is merging, and as a result, f0 is replacing VOT as the primary cue to the aspirated-lenis distinction. Age-based VOT variation in aspirated-lenis consonants in Seoul Korean has been replicated in multiple subsequent studies (Wright 2007; Kang and Guion 2008; Kang, Han, Kochetov, and Kong 2012; Kang 2014; Byun 2016; Bang, Sonderegger, Kang, Clayards, and Yoon 2018). Some studies find stable f0 patterns across age groups (Silva 2006; Byun 2016) suggesting that VOT reduction and f0 enhancement may take place in distinct stages of diachronic development, with the VOT merger set in motion after the f0 distinction is already robustly established. Other studies have found that younger speakers also expand the f0 distinction between the two stop categories compared to the older speakers. This suggests that VOT reduction and f0 enhancement are concurrent, linked by adaptive dispersion of the f0 distinction that compensates for the loss of VOT distinction (Kirby 2013; Kang 2014; Bang, Sonderegger, Kang, Clayards, and Yoon 2018). In particular, Bang, Sonderegger, Kang, Clayards and Yoon (2018) found that both VOT contrast reduction and f0 contrast enhancement are more advanced in frequently used words, which are associated with higher predictability and articulatory reduction. This finding suggests that the change is production/lenition-driven rather than (mis)perception-driven (Lindblom, Guion, Hura, Moon, and Willerman 1995). Bang, Sonderegger, Kang, Clayards and Yoon (2018) also found that younger Seoul speakers who make a greater use of f0 cue suppress vowel height-conditioned intrinsic f0 effects (high vowels raise f0 compared to low vowels due to anatomical links between the tongue and the larynx) suggesting that as the contrastive use of f0 for stop contrast emerges, non-contrastive perturbation in f0 (due to vowel height) is attenuated.

Kang and Guion (2008) examined how speakers approximate the phonetic targets of Korean stops by enhancing contrasts in clear speech—elicited by asking the speakers to imagine reading the words to second language learners of Korean—and found that while older speakers (year of birth: 1946-1966) enhance the VOT difference between aspirated and lenis stops in clear speech, younger speakers (year of birth: 1977-1986) enhance both f0 and VOT differences. Byun (2016) found that even the oldest speakers in her study (year of birth ranging from 1953) enhance both f0 and VOT distinctions in clear speech, and that the generational difference was subtle: older speakers enhanced the f0 pattern by raising the f0 of aspirated (and fortis) stops while younger speakers both raised the f0 of aspirated/fortis stops and also lowered the f0 of lenis stops, further expanding the f0 contrast.

Kim (2015) raises the possibility that the generational difference –i.e., older speaker's greater reliance on VOT over f0—may be due to increased difficulty of f0 control due to aging and cautions against equating synchronic age-based variation with real time change. Kang and Han (2013), on the other hand, compared the speech of a 10-year old speakers' production from 1935 and the same speaker's speech in 2005 and found that this particular male speaker's speech did change over their lifespan but the direction of change was to expand, rather than reduce, the reliance on f0. In other words, this particular speaker's speech underwent a lifespan change where f0 cue use *increased* consistent with the direction of sound change in progress in the community (cf. Sankoff 2018). While the evidence of a single case study must be interpreted with caution, this finding suggests that the apparent time study, if anything, likely underreports the actual rate of sound change, and that age-based synchronic variation cannot be explained away as the effect of aging alone.

Additional evidence that the synchronic VOT variation in Seoul Korean is indeed sound change in progress is that the change in Seoul Korean is led by female speakers (Oh 2011; Kang 2014), as is common with sound change (Labov 1990). Furthermore, Oh (2011) points out that young female Seoul speakers produce substantially shorter VOT values for aspirated stops than their male counterparts, a pattern which is unexpected given the physiological differences—males' longer vocal folds and larger supraglottal cavity—that predict shorter VOTs for male speakers.

5. Dialectal variation

The evidence for diachronic change discussed above is largely based on the Korean spoken in Seoul and surrounding areas. The substantial dialectal variation present in Korean provides an opportunity to examine whether and to what extent sound change progresses similarly across diverse dialects. Given the fact that the proposed change involves an increased role for f0, one question is whether dialects that have lexical pitch-accent (i.e., where f0 already used for lexical contrast), will be less inclined to use of f0 to signal the laryngeal contrast, and in turn be less likely to participate in the change described above. In this section, we review studies on the stop laryngeal contrast realization in several dialects of Korean. We start with non-pitch accent dialects followed by pitch accent dialects.

5.1.Non-pitch accent dialects

Seoul Korean in diaspora

Similar change is reported for diasporic varieties of Seoul Korean spoken in North America. In fact, Silva (2006)'s study that originally brought attention to this phenomenon was based on the speech of Seoul Korean speakers residing in Dallas-Fort Worth, Texas; the participants in the study grew up in Seoul and moved to the US as an adult. Kang and Nagy (2016)'s apparent time corpus study based on sociolinguistic interviews of heritage Korean speakers—speakers who grew up in Toronto and speak English as their dominant language while they learned and speak Korean as their home language—showed that Toronto Korean is undergoing a similar change, although there is an indication that younger female speakers may be reversing the trend of VOT merger (arguably due to the interference with English, where VOT is the primary cue for stop laryngeal contrasts). Given that the Korean community in Toronto was established fairly recently and the community has been in close contact with Homeland Korean, the parallel development is not surprising.

Jeonnam Korean

Jeonnam Korean is spoken in the southwestern part of the Korean peninsula and is a non-pitch accent dialect like Seoul Korean. Choi (2002) investigated how the dialectal difference in prosodic systems may interact with the use of f0 and VOT cues in stop contrasts. Choi (2002) found that while Seoul speakers make a three-way distinction in f0 (Aspirated > Fortis > Lenis) and a two-way distinction in VOT (Aspirated ~ Lenis > Fortis), Jeonnam speakers make a three-way distinction in VOT (Aspirated > Lenis > Fortis) and a two-way distinction in f0 (Aspirated ~ Fortis > Lenis). In Jeonnam, phrase boundaries are marked by initial boundary tones, similar to Seoul (Jun 1993), but Choi (2002) proposes that the phrase-initial tonal realization is "more salient" in Jeonnam than Seoul Korean, minimizing the consonant-induced f0 perturbation effect. The retention of three-way VOT contrast, on the other hand, is attributed to the retention of vowel length contrast in Jeonnam – which is almost lost in Seoul – and increased "durational sensitivity". Lee and Oh (2010), on the other hand, did not replicate this dialectal difference and instead found that both Seoul and Jeonnam speakers make a three-way distinction in VOT and f0 with no discernible dialectal difference. Kim (2000) similarly found no systematic dialect difference in the consonant-induced f0 effect in Seoul and Jeonnam dialects.

Jeju Korean

Jeju Korean is spoken in Jeju Island located south of the Korean peninsula. While Jeju Korean is not mutually intelligible with the rest of Korean and is generally considered a separate language, the difference is in the morphosyntax and the lexicon, with the sound system remaining largely similar to the rest of Korean. Cho, Jun and Ladefoged (2002) compared the phonetic realization of stops by eight native Jeju speakers (mid 50s ~ mid 70s) with that of Seoul speakers and found no systematic difference except that Jeju speakers tend to produce shorter VOT values for lenis stops than Seoul speakers. Han (2011; 2014) similarly found a three-way distinction in VOT and f0 in the speech of younger Jeju speakers in their 20s and 30s, although aspirated and lenis stops showed a greater degree of overlap in VOT than they did for speakers from Daegu (a pitch accent dialect, discussed below). Holliday and Kong (2011) found that younger Jeju speakers' stop production was indistinguishable from that of younger Seoul speakers with a substantial VOT overlap of aspirated and lenis stops.

Kim and Byun (2014) compared the speech of 48 Jeju speakers in their 20s, 50s, and 70s and found the same trend of VOT contrast reduction (lengthening of VOT for lenis stops and shortening of VOT for aspirated stops) and f0 contrast enhancement (raising of f0 for aspirated stops) in younger speakers' speech. They also found the younger Jeju speakers produced a reduced burst energy for aspirated stops, comparable to that of lenis stops, while older speakers produced a substantially larger difference in burst energy between aspirated and lenis stops. Shin (2015) examined the speech of 160 Jeju speakers balanced for gender and age, and found a similar trend of VOT contrast reduction between lenis and aspirated stops although unlike Seoul, younger speakers still make a three-way VOT distinction. The use of f0 was stable across age groups.

Phyeongan Korean
Phyeongan Korean is spoken in the northwestern region of the Korean peninsula. There is no published instrumental study of the Phyeongan Korean as currently spoken in North Korea, but there are studies on diasporic varieties spoken in Northern China. Jin (2008) and Jin and Silva (2017) examined the speech of 35 native speakers (age range: 18-74) of the Phyeongan variety of Chinese Korean residing in Shenyang, the capital city of Liaoning province. These are descendants of those who migrated from the Korean peninsula between the mid 19th century and the end of World War II. The study found a generational shift in VOT, with younger speakers showing merged values for aspirated and lenis stops in a pattern practically identical to that of Seoul Korean. Given that the Chinese Korean community has developed with no systematic contact with South Korea for the most part of the second half of 20th century, the VOT change in Shenyang is likely an independent development, not an effect of dialect contact. Kang and Han (2012) examined the speech of 25 older Chinese Korean speakers (average age: 61) residing in Dandong, Liaoning, who speak the Phyeongan variety of Korean. The study found that compared to older Seoul Korean speakers, the Phyeongan speakers produced a larger VOT difference between lenis and aspirated stops (shorter VOTs for lenis and longer VOTs for aspirated stops) and less f0 difference between the two stops, although their production was more Seoul-like compared to the speakers of the Hamkyeong variety of Korean (a pitch accent dialect, discussed below). The fortis stops were well differentiated from lenis and aspirated stops in H1-H2 (lenis > aspirated > fortis). Below we present a more recent case study on the Phyeongan variety spoken in Dandong, reporting production patterns from both older and younger speakers, where we find evidence for an ongoing VOT merger similar to that found in Seoul and Shenyang, except that the change is at a slightly earlier stage than these other two communities.

5.2. Pitch accent dialects

Kyeongsang Korean
Kyeongsang dialects are pitch accent dialects, spoken in the Southeastern region of Korea; Southern and Northern Kyeongsang varieties differ in the inventory of lexical pitch accent but they pattern similarly in terms of phonetics of stop consonants. Jo and Shin (2003) compared the VOT of stops produced by Seoul and Southern Kyeongsang speakers and Jo (2004) similarly compared Seoul and Northern Kyeongsang Korean (Daegu, specifically) and found that lenis and aspirated stops retain a much larger VOT difference in Kyeongsang Korean than in Seoul Korean. They suggested that this dialectal difference is due to the fact that Kyeongsang dialects are pitch accent systems: given that f0 is already used for lexical contrast, it is more difficult to increase its role as a cue the laryngeal contrast, as is occurring in Seoul Korean. Without this cue, it is necessary to retain the VOT distinction. Kenstowicz and Park (2006) found that despite the fact that f0 is utilized for pitch accents, Kyeongsang speakers do produce systematic consonant-

induced pitch differences in addition to the pitch accent distinction. However, the degree of consonant effect on f0 is much smaller than that reported for Seoul in Cho et al. (2002).

Subsequent studies directly compared Kyeongsang and Seoul Korean dialects along the dimensions of VOT, F0 and H1-H2. Holliday and Kong (2011) compared the speech of younger Seoul, Daegu, and Jeju speakers (year of birth: 1980-1991). All three groups made use of f0 to signal the contrast between aspirated and lenis stops but they differed in the use of VOT cues; while Seoul and Jeju speakers completely merged the aspirated and lenis stops in VOTs, Daegu speakers, especially Daegu male speakers, produced shorter VOT for lenis stops and hence retained a reliable VOT distinction between aspirated and lenis stops. Lee and Jongman (2012) also found that South Kyeongsang speakers produced a shorter VOT for lenis stops and hence a larger distinction between lenis and aspirated stops, while making a smaller f0 contrast, compared to Seoul speakers. There was no dialectal difference in the use of H1-H2 cues, contrary to the findings of some previous studies (Kenstowicz and Park 2006; Holliday and Kong 2011), indicating that H1-H2 differences across dialects are likely not as systematic as VOT and f0 differences. Jang and Shin (2010) also verified that in perception, younger Seoul listeners rely on f0 while Daegu listeners rely on VOT when classifying stimuli that present conflicting VOT and f0 cues. Seoul speakers tend to classify any stimuli with low f0 as lenis, regardless of their VOT, while Daegu speakers are more likely to classify the same stimuli with low f0 as fortis, lenis, or aspirated according to their VOT. Lee and Jongman (2013) similarly found that while younger Kyeongsang listeners make use of both F0 and VOT cues for lenis vs. aspirated contrast, younger Seoul listeners primarily rely on f0 only. Finally, Lee and Jongman (2018) found the evidence of generational shift in the use of VOT and f0 in signaling the laryngeal contrast in South Kyeongsang; younger South Kyeongsang Korean speakers produce a larger f0 contrast between lenis and aspirated stops while producing a much reduced VOT contrast. But importantly, this change is accompanied by a change toward the loss of pitch accent contrast in the younger speakers' speech, suggesting that a lexical pitch accent may indeed inhibit an increased role for f0 in the laryngeal contrast.

Hamkyeong Korean

Hamkyeong dialects are spoken in the Northeastern region of Korea, and they are also pitch accent dialects. Similar to Phyeongan Korean, direct access to native speakers residing in North Korea is difficult. However, there are instrumental studies on Hamkyeong Korean based on the speech of recent North Korean refugees. Chung (2011) analyzed the speech of 10 native speakers (Age: 20-70) of Yukjin dialect (a dialect spoken in the northern most area of Hamkyeong) who have been residing in South Korea for less than two years. The study found superlong VOT values (around 100 ms) for aspirated stops while lenis stops have very short VOTs (10-30ms) overlapping with fortis stops. These values are similar to those reported for Seoul Korean from the 1960s and 1970s (Lisker and Abramson 1964; Han and Weitzman 1970) and are some of the most "conservative" VOT patterns found in recent instrumental studies. Kang and Yun (2018) examined the speech of Northern Hamkyeong speakers varying in age and the length of stay in Seoul and found a similar pattern of large VOT contrast between short-VOT lenis stops and superlong-VOT aspirated stops, especially for older speakers who have been in South Korea for less than 3 years. Interestingly, however, we found that younger speakers produce significantly longer VOT values for lenis stops regardless of their length of residence in Seoul, suggesting a possible dialect-internal change toward a more Seoul-like pattern, although a claim of such change needs further corroboration. In addition, speakers who have resided in Seoul longer tend to produce a generally shorter VOT for aspirated stops than the speakers who arrived in Seoul more recently, suggesting accommodation to the speech pattern of the ambient dialect over time.

Similar to Phyeongan dialects, there is a sizable population of Chinese Korean speakers in Northern China who speak the Hamkyeong variety of Korean. The largest concentration of these speakers is found in Yanbian Autonomous Prefecture, which borders the northeastern regions of North Korea. Ito and Kenstowicz (2009) report VOT, f0, and H1-H2 of stops produced by a single female speaker (age = 35) and found a much shorter VOT for aspirated stops (mean = 60ms) and almost identical mean VOT values for lenis (12ms) and fortis (11ms) stops. F0 of the following vowels were reliably higher for aspirated stops, while lenis and fortis stops were not consistently differentiated in f0; they found a small difference in f0 between fortis and lenis (fortis > lenis) when the pitch accent is H, but no difference between the two when the pitch accent is L. What distinguished all three stop categories reliably was H1-H2 (Aspirated > Lenis > Fortis). Kang and Han (2012) examined the speech of 21 older speakers (average age: 61) of the Hamkyeong variety of Chinese Korean, residing in Qingdao, China. These speakers produced a more "conservative" VOT pattern (i.e., a larger VOT difference between lenis and aspirated) compared to the speakers of the Phyeongan variety of Chinese Korean (see the Phyeongan section for more details) who in turn had larger difference than Seoul Korean speakers. The f0 difference between aspirated and lenis stops was inconsistent across pitch accent and the speaker gender conditions. As for the lenis vs. fortis contrast, the f0 difference was more consistent across pitch accent and gender conditions, albeit very small, but the H1-H2 difference was substantial and systematic (lenis > aspirated >> fortis) and more enhanced compared to Seoul Korean.

Note that the Hamkyeong variety of Korean spoken in China is a pitch accent dialect similar to Kyeongsang Korean but unlike Kyeongsang Korean, developed without systematic contact with Seoul Korean for the most part of the latter half of 20th century during which Seoul Korean underwent the reorganization of the laryngeal system. The Hamkyeong variety of Chinese Korean seems to resolve the problem of VOT overlap in three-way voiceless stop contrast differently from Seoul and the rest of Korean dialects discussed so far. The laryngeal contrast of Seoul Korean has essentially transformed into a 2-way VOT contrast, with younger speakers showing a complete VOT merger in aspirated and lenis stops, and concurrently more differentiation between fortis and lenis VOT, as compared to their older counterparts. At the same time, the lenis-aspirated contrast is increasingly differentiated by f0. On the other hand, Chinese Hamkyeong Korean retains a large VOT difference between aspirated stops and lenis/fortis stops, and the lenis/fortis contrast is accompanied by a larger difference in voice quality (H1-H2) as compared to Seoul Korean. These patterns are consistent with the idea that a merger on one dimension (VOT: lenis-aspirated merger in Seoul and lenis-fortis merger in Hamkyeong) leads to selective enhancement of other cues (f0 in Seoul and voice quality in Hamkyeong) in order to maintain the three-way phonological contrast. However, there have not been any direct comparisons of apparent-time patterns across the two dialects, making it difficult to evaluate this hypothesis. The case study presented below includes a multigenerational comparison of speakers of a Hamkyeong dialect with those from Seoul and Phyeongan. (While overall dialectal differences are robust, we find little clear evidence for any change in cue-weighting in Hamkyeong: the difference between lenis and fortis VOT, while small, is stable, as is the use of H1-H2.)

To summarize, the literature presents a picture of pan-dialectal change in Korean stops, where the VOT distinction between the two long-lag stops is replaced with f0 contrast. Seoul Korean leads the change, where the change is mostly complete, while the Hamkyeong varieties of Korean represent the opposite, the most conservative, end of continuum. For the dialects at intermediate stages of this change, the extent of participation and progress seems to be modulated by two factors; pitch accent deters the change while close contact with Seoul promotes the change. Questions remain as to the relative timing of change in f0 and VOT and the change and variation of H1-H2 across dialects with different VOT and f0 distributions.

6. Case studies

6.1.Description of dialects

As a case study, we present multigenerational data from three dialects of Korean: the well-studied Seoul dialect as well as two dialects spoken in the Chinese border cities of Hunchun and Dandong. Most speakers in these communities, similar to the majority of ethnic Koreans living in China, are descendants of immigrants to China between the mid 19th century and the end of the Second World War (Jin 2008). While there is increasing influence of Mandarin, with the majority of speakers being bilingual in Korean and Mandarin, these communities have traditionally maintained strong ties to Korean culture and language, and all speakers in the current study learned Korean as their first language.

Distinct dialects are spoken in Hunchun and Dandong, providing an interesting testing ground for comparing the time course of sound change. The dialect spoken in Hunchun is representative of the Yanbian dialect discussed above, stemming from the North Korean Hamkyeong dialect, which maintains the lexical pitch accent distinction of Middle Korean (which is also maintained in the Kyeongsang dialect, discussed above). On the other hand, the dialect spoken in Dandong stems from the Phyeongan dialect, which, like Seoul, has lost the pitch accent distinction. While there is substantial exposure to South Korean media in both dialects, direct contact with Seoul Korean is less pervasive than for e.g. Kyeongsang speakers.

Along with providing a systematic comparison of the laryngeal realization in three dialects, balanced for age, gender, and in multiple vowel contexts, this comparison represents the first apparent-time study of the Yanbian/Hamkyeong dialect of Korean.

6.2.Participants, Procedure, and Materials

We report data from 194 speakers ranging in year of birth from 1933 to 1997, balanced for dialect and gender (Table 8.5). Data was collected in a quiet room in Hunchun, Dandong, or Seoul in 2015-2016. Participants were asked to read words from a Microsoft Surface 3 tablet. Recordings were made using a high-quality lapel microphone (AT831B) and a Zoom H4N digital recorder (44.1 kHz, 16-bit).

Speakers produced di- or tri-syllabic Korean stop-initial words. The wordlist was balanced across laryngeal category (fortis, lenis, aspirated), place of articulation (p, t, k), and vowel height (low, non-low). Hunchun and Dandong speakers produced two such sets of words, one with H-initial pitch accent, and the other L-initial (this was only contrastive for Hunchun speakers), for a total of 36 words. Seoul speakers produced only one set of words (18 words). Each speaker produced two randomized repetitions of the wordlist.

Table 8.5 Summary of participants by dialect, with mean year of birth (YOB) and standard deviation (in parentheses)

	Hunchun (n=61)		Dandong (n=66)		Seoul (n=67)	
	n	YOB	n	YOB	n	YOB
Older	17 F, 13 M	1952 (8)	20 F, 14 M	1950 (9)	26 F, 16 M	1953 (10)
Younger	15 F, 16 M	1986 (8)	15 F, 17 M	1985 (10)	10 F, 15 M	1988 (8)

6.3.Measurements

After omissions due to words being skipped, mispronounced, too noisy, or lacking a visible vowel (n=289), 10,967 tokens were measured for VOT, f0, and H1-H2.

VOT was measured automatically using AutoVOT (Keshet, Sonderegger, and Knowles 2014). The program was trained on 100 manually-annotated tokens. To check accuracy of the automated method, we compared the automatic measurements from 100 randomly selected tokens to manual annotations. The automatic measurements differed from the manually-annotated duration by 5 ms on average, suggesting good overall accuracy in the automatic measurements.

f0 was measured using the PSOLA algorithm in Praat (Boersma and Weenink 2014) at 20 ms after vowel onset, using speaker-specific pitch parameters determined based on initial manual inspection of the data. Tokens were manually checked and corrected if necessary. 789 tokens for which f0 was not measurable due to very creaky or breathy voice at the point of measurement were omitted from f0 (and H1-H2) analysis, although these were retained in the VOT analysis. As shown in Figure 8.1, the vast majority (82%) of the omitted tokens were from fortis stops (vs. 10% lenis and 8% aspirated). Furthermore, the number of omitted fortis tokens was not consistent across dialects and ages. Specifically, there were fewer tokens omitted from younger speakers in Seoul and Dandong. Given that the lack of pitch tracking in fortis tokens is generally due to creaky voice, this asymmetry indicates that there may be a decreasing number of creaky-voiced tokens in younger Seoul and Dandong speakers.

Insert Figure 8.1 here.

H1-H2 was calculated as the intensity difference between the first and second harmonics. Since harmonics are based on f0, H1-H2 was only calculated for those tokens where pitch was defined.

6.4.Statistical analysis and results

We examined speakers' use of VOT, f0, and H1-H2 as cues to the Korean stop laryngeal contrast using linear mixed-effects models from the *lme4* package in R (Bates, Maechler, Bolker, and Walker 2015). For each of the three cues, we created a separate model for each dialect, for a total of nine models.

Models were structured to address our primary questions of how much speakers of each dialect "use" each acoustic cue, and whether there are age-related differences in cue use that may signal diachronic change. The response variable was the acoustic cue: VOT (in ms), f0 (scaled to semitones, with 0 semitones corresponding to 100 Hz; statistical results are presented in units of 1/10 of a semitone for ease of presentation), and H1-H2 (in dB). Predictor variables were laryngeal category (LAR), speaker age (via year of birth: YOB), speaker gender, and all interactions. A fourth predictor, vowel height, was included as a control variable (without interactions) since vowel height has been shown to affect all three acoustic variables. The maximal random effects structure appropriate for the model was included: a by-speaker random intercept and slopes for laryngeal category and vowel height, as well as a by-word random intercept.

Predictor variables were transformed and/or coded as follows. Laryngeal category was simple-coded, with the reference level chosen depending on the cue (see below). Gender and Vowel Height were also simple-coded, with female and non-low as the reference levels. YOB was treated as a continuous variable and centered prior to analysis. Given this coding scheme, the intercept of a model can be interpreted as the average value of a given cue across both genders, all laryngeal categories, and the mean year of birth of the participants, while coefficients corresponding to main effects for each variable can be interpreted as the difference between the levels of that factor (for categorical variables) or for a one-unit increase in year of birth (for the continuous variable). Follow-up tests were done using the *phia* package, with no p-value adjustment (De Rosario-Martinez 2015). When we wanted to explore differences for younger and older groups separately, we used a median split to create a binary variable, with speakers born on or after 1970 consider "younger" and those before 1970 considered "older," and ran models with this instead of the continuous YOB variable.

We interpret main effects and interactions for which the absolute t-value is greater than 2 as significant. As our main question of interest is how the use of cues patterns across laryngeal categories, we focus on main effects of LAR and its interactions with Age and Gender, setting aside overall effects of Age and Gender, although full results are presented in the statistical tables.

6.4.1. Voice Onset Time

Insert Figure 8.2 here.

Table 8.6 Statistical results from a mixed-effects model predicting VOT (ms) from laryngeal category, year of birth, gender, and vowel height for each dialect separately. Coefficients for each main effect represent the difference in VOT between the given level and the reference level (in italics). Beta-coefficients, standard errors, and t-values are given, and those factors considered significant (|t| > 2) are shaded.

	Hunchun			Dandong			Seoul		
	β	SE	t	β	SE	t	β	SE	t
Intercept	44.10	1.85	23.90	51.09	2.00	25.54	49.43	2.43	20.31
LAR Asp-*Len*	60.14	4.20	14.34	40.01	4.46	8.97	14.62	5.59	2.61
LAR For-*Len*	-11.16	3.94	-2.83	-29.74	4.38	-6.79	-42.41	5.65	-7.51
Year of birth (YOB)	-0.18	0.05	-3.46	-0.08	0.05	-1.55	-0.19	0.05	-3.88

Gender Male-*Female*	4.40	1.94	2.27	-4.13	2.10	-1.97	2.69	1.86	1.45
V. Height Low-*Nonlow*	0.94	3.18	0.29	1.33	3.44	0.39	9.50	4.53	2.10
LAR Asp * YOB	-0.33	0.09	-3.75	-0.57	0.09	-6.65	-0.63	0.06	-10.90
LAR For * YOB	0.06	0.05	1.39	-0.17	0.07	-2.52	-0.10	0.07	-1.56
LAR Asp * Gender	-1.83	3.33	-0.55	-0.34	3.35	-0.10	13.25	2.22	5.98
LAR For * Gender	0.88	1.74	0.51	5.77	2.60	2.22	8.17	2.56	3.20
YOB * Gender	-0.09	0.10	-0.93	-0.09	0.11	-0.80	-0.20	0.10	-2.09
LAR Asp * YOB * Gender	-0.02	0.17	-0.12	-0.13	0.17	-0.75	-0.03	0.12	-0.27
LAR For * YOB * Gender	0.11	0.09	1.19	-0.07	0.13	-0.52	0.29	0.13	2.17

Figure 8.2 shows by-speaker VOT means for each laryngeal category, as well as the predicted best-fit line across the age range, for each dialect and gender separately. As shown in the graph, there are clear dialectal differences in use of VOT to distinguish the laryngeal contrast in the three dialects. While all three dialects show near-zero VOT (i.e. unaspirated) fortis stops, the aspirated and lenis stops are furthest apart in Hunchun, closest together in Seoul, and intermediate in Dandong. In Hunchun, lenis stops are close to fortis stops in terms of VOT, whereas lenis and fortis stops are well-separated in Dandong and Seoul. In all dialects, there is a decrease in duration of aspirated stop VOT in younger speakers, and in Seoul and Dandong, it appears that lenis stops are slightly increasing in VOT. There is a complete lenis-aspirated merger in young Seoul speakers. Statistical results are shown in Table 8.6. Lenis stops were used as the reference level for LAR.

Hunchun: VOT differs significantly across all three laryngeal categories, with fortis showing slightly shorter and aspirated showing much longer VOTs than lenis stops. A significant interaction of LAR-aspirated-lenis with YOB indicates that the aspirated-lenis difference is smaller in younger speakers; however, the two categories remain widely separated, even in the youngest speakers.

Dandong: The three laryngeal categories are again all separated in terms of VOT (Fortis < Lenis < Aspirated). We again see a decrease in the aspirated-lenis contrast across age, as shown by the interaction of LAR and YOB, of a larger magnitude (approximately twice) than in Hunchun. There is also an increase in the fortis-lenis contrast across age, corresponding to the overall increase in lenis VOT values seen in the graphs. We also see an interaction between the fortis-lenis contrast and gender, with a smaller difference for males.

Seoul: We again see the same overall VOT pattern across laryngeal categories (Fortis < Lenis < Aspirated); however, in this case, the separation between aspirated and lenis is much smaller, and the interaction of this laryngeal contrast with YOB is again significant, indicating age-related change and corresponding to the complete merger of aspirated and lenis stops seen in the graph. Furthermore, there are significant interactions of both levels of LAR with gender, indicating that males have a larger difference between aspirated and lenis, and a smaller difference between fortis and lenis, than females.

Summary: Overall, the diachronic pattern for Seoul replicates previous work: we see a clear age-related VOT merger of aspirated and lenis stops, and this merger is further advanced in females than males, with younger Seoul females actually showing longer values for lenis than aspirated stops. We see a similar pattern and magnitude of age-related change in Dandong, although the merger has not progressed as far as it has in Seoul. In Hunchun, although we do see a reduction in VOT in aspirated stops (which remains even when normalizing for vowel duration, an analysis not shown here), this is of smaller magnitude, and given the fact that lenis stops have such low

VOT, does not seem to indicate a potential lenis-aspirated VOT merger. Although the VOT of lenis and fortis stops are very close together in Hunchun, the distinction appears to be stable with no indication of a merger.

6.4.2. Fundamental frequency at vowel onset (f0)

Insert Figure 8.3 here.

Table 8.7 Statistical results from a mixed-effects model predicting f0 (in increments of 1/10 of a semitone) from laryngeal category, year of birth, gender, and vowel height for each dialect separately, and separately for words beginning with High and Low pitch-accent in Hunchun. Coefficients for each main effect represent the difference in f0 between the given level and the reference level (in italics). Beta-coefficients, standard errors, and t-values are given, and those factors considered significant ($|t| > 2$) are shaded.

	Hunchun (H PA)			Hunchun (Low PA)			Dandong			Seoul		
	β	SE	t	β	SE	t	β	SE	t	β	SE	t
Intercept	59.25	2.14	27.72	44.71	2.16	20.70	56.39	1.89	29.8	67.94	2.14	31.68
LAR Len-*For*	-7.54	1.31	-5.77	-3.82	1.89	-2.03	-19.72	1.5	-13.11	-22.6	2.21	-10.23
LAR Asp-*For*	1.03	1.32	0.79	3.11	1.88	1.66	1.24	1.13	1.09	10.9	2.03	5.36
Year of birth (YOB)	0.28	0.11	2.53	0.34	0.11	3.24	0.02	0.10	0.20	0.26	0.10	2.49
Gender Male-*Female*	-69.03	4.21	-16.41	-67.67	4.07	-16.65	-63.81	3.71	-17.19	-65.08	4.00	-16.26
V. Height Low-*Nonlow*	-7.00	1.10	-6.38	-5.07	1.46	-3.48	-5.10	0.83	-6.16	-7.20	1.59	-4.54
LAR Len * YOB	0.14	0.05	2.89	0.26	0.05	4.72	0.19	0.05	3.64	-0.07	0.06	-1.19
LAR Asp * YOB	0.07	0.05	1.42	0.17	0.05	3.32	0.13	0.04	3.38	0.08	0.04	1.97
LAR Len * Gender	-5.85	1.84	-3.18	-4.31	2.08	-2.08	1.76	2.02	0.87	1.78	2.28	0.78
LAR Asp * Gender	-4.64	1.86	-2.49	-3.10	2.00	-1.55	0.07	1.46	0.04	-4.06	1.62	-2.50
YOB * Gender	-0.27	0.22	-1.23	-0.34	0.21	-1.61	-0.81	0.19	-4.25	-0.57	0.21	-2.72
LAR Len * YOB * Gender	0.12	0.10	1.26	0.00	0.11	0.03	-0.03	0.10	-0.33	0.13	0.12	1.11
LAR Asp * YOB * Gender	0.07	0.10	0.67	-0.09	0.11	-0.85	0.09	0.08	1.19	0.20	0.09	2.34

Figure 8.3 shows by-speaker f0 means (in z-score normalized semitones) for each laryngeal category, as well as the predicted best-fit line across the age range, for each dialect and gender separately. For Hunchun speakers, separate graphs are shown for words beginning with high vs. low pitch-accent. Overall, lenis stops show the lowest f0 in all three dialects, but there is clear dialect difference in the extent of separation, and age-related differences can be seen in all dialects. Statistical results are shown in Table 8.7. Fortis was used as the reference level for LAR, as it was expected, at least in Seoul, to be intermediate between the other two categories.

Hunchun: In order to examine whether effects were similar across pitch-accent categories, we first ran a model identical to the others, but additionally pitch-accent as a simple-coded binary factor: H (reference level) vs. L, and its interactions with laryngeal category, age, and gender. This model included significant three-way interactions of pitch-accent with age and both laryngeal comparisons, indicating that the laryngeal effect of f0 differed in high and low pitch-accent words; therefore, we ran a separate model for the two pitch-accent classes separately, analogous to the graphs shown above. Results of these models are those reported in the statistical table.

For both pitch-accent classes, lenis stops are produced with low f0 compared to fortis and aspirated stops, which do not differ significantly from one another in terms of f0. Furthermore, in both sets of words, at least one of the laryngeal comparisons interacts with age and gender. We first discuss the patterns in high, followed by low, pitch-accent words.

In high pitch-accent words, the fortis-lenis difference is smaller in younger speakers, but this does not result in a complete merger: a second model run on younger speakers showed that there was still a significant difference. Both laryngeal comparisons interact with gender: There is a larger difference between fortis and lenis for male than female speakers, and the two genders show different patterns for the aspirated-fortis comparison. Follow-up tests showed that females produce significantly higher f0 for aspirated than fortis stops, while males show no significant difference.

In low pitch-accent words, there are more substantial qualitative changes in the realization of the f0 contrast across ages. As seen in the graphs, fortis stops pattern with aspirated stops in older speakers but lenis stops in younger speakers. This is supported by interactions of both the fortis-aspirated and fortis-lenis contrasts with age. Follow-up tests show that fortis and aspirated stops do not differ in f0 for older speakers but do for younger speakers, while fortis and lenis stops *do* differ for older, but not for younger speakers. The fortis-lenis difference is overall greater for males than females.

To sum up the use of f0 for the laryngeal contrast in Hunchun speakers, there is an overall use of f0 to signal the difference between lenis vs. fortis (and aspirated) stops, but the difference is smaller in younger speakers, and in low pitch-accent words, the fortis stops are much lower, patterning with lenis stops. Given the small number of words in our study, these findings should be interpreted with caution; however, it is worth noting that this is consistent with previous work. Ito and Kenstowicz (2009), in measurements of a *younger* speaker, found that lenis and fortis stops did not differ in f0 for low pitch-accent words in measurements of a younger speaker, while Kang and Han (2012), whose work looked at *older* speakers, found that they did differ.

Although not our primary question of interest, we also wanted to assess whether the use of f0 for the pitch-accent contrast itself was stable across ages, as Lee and Jongman (2018) reported less separation between high and low pitch-accent words in younger speakers. The first model we ran (not reported here) that included both pitch-accent categories showed that high and low pitch-accent words were well-separated in terms of f0 difference for all speakers; however, there was a significant interaction with age, indicating a somewhat compressed f0 space used to signal the contrast in younger speakers. However, unlike in Lee and Jongman (2018), this did not correspond with an increased use of f0 in the laryngeal contrast in these speakers.

Dandong: In Dandong speakers, lenis stops are clearly separated from fortis and aspirated stops in terms of f0, whereas there is no overall significant difference between fortis and aspirated stops. Both LAR comparisons interact with YOB: the difference between lenis and fortis stops is smaller in younger speakers, and visual inspection of the graph suggests that this is due to increased f0 for lenis stops in younger speakers. Use of f0 to signal the fortis-aspirated contrast also differs based on age: follow-up tests showed that younger speakers show significantly higher f0 for aspirated than fortis stops, while older speakers produce no significant difference in f0 (but show the opposite pattern numerically).

Seoul: Seoul speakers also show clear separation of lenis stops from the other two categories in terms of f0, and aspirated stops have overall higher f0 than fortis stops. The aspirated vs. fortis contrast differs by age and gender, as indicated by the significant three-way interaction between the three factors. In follow-up tests, as seen in the graph, we found that in males, there is an age-related increase in the f0 difference between aspirated and fortis stops, while there is no change in females.

Summary: As with VOT above, we see age-related changes in use of f0 in Seoul Korean that is consistent with previous work: lenis stops are clearly lower in f0 than fortis and aspirated, and we see evidence of diachronic change in that males are increasing the f0 distinction between fortis and aspirated stops via heightened f0 for aspirated stops. Dandong speakers also show age-related changes in f0, although they are less straightforward to interpret. On the one hand, the increase in f0 of lenis stops results in a smaller f0 difference in the contrast overall, contrary to expectations and moving away from the pattern found in Seoul. On the other hand, younger speakers are producing aspirated stops with higher f0 than fortis stops, similar to the pattern in Seoul (and in contrast to their older Dandong counterparts). Hunchun speakers show overall less use of f0 to signal the contrast (as evidenced by more overlap between the categories), and this difference is, if anything, decreasing in younger speakers.

6.4.3. Voice quality: H1-H2

Insert Figure 8.4 here.

Table 8.8 Statistical results from a mixed-effects model predicting H1-H2 (dB) from laryngeal category, year of birth, gender, and vowel height for each dialect separately. Coefficients for each main effect represent the difference in H1-H2 between the given level and the reference level (in italics). Beta-coefficients, standard errors, and t-values are given, and those factors considered significant (|t| > 2) are shaded.

	Hunchun			Dandong			Seoul		
	β	SE	t	β	SE	t	β	SE	t
Intercept	3.26	0.53	6.11	3.80	0.34	11.09	2.64	0.41	6.38
LAR Asp-*Len*	-0.86	0.42	-2.04	-2.12	0.44	-4.84	-0.38	0.85	-0.45
LAR For-*Len*	-5.06	0.45	-11.17	-5.26	0.49	-10.73	-4.88	0.88	-5.52
Year of birth (YOB)	-0.01	0.03	-0.35	0.02	0.02	1.06	-0.06	0.01	-4.01
Gender Male-*Female*	-1.70	1.02	-1.66	-0.73	0.62	-1.18	-2.62	0.53	-4.98
V. Height Low-*Nonlow*	2.86	0.38	7.56	2.92	0.35	8.26	2.70	0.69	3.94
LAR Asp * YOB	0.02	0.01	1.60	0.03	0.01	2.13	0.00	0.02	0.10
LAR For * YOB	0.02	0.02	1.28	0.01	0.02	0.82	0.04	0.02	1.76
LAR Asp * Gender	0.23	0.52	0.44	-0.28	0.52	-0.53	-1.90	0.68	-2.79
LAR For * Gender	1.69	0.61	2.79	-0.29	0.66	-0.43	0.26	0.83	0.32
YOB * Gender	0.05	0.05	0.96	-0.03	0.03	-0.85	-0.02	0.03	-0.89
LAR Asp * YOB * Gender	-0.01	0.03	-0.43	0.00	0.03	0.11	0.09	0.04	2.59
LAR For * YOB * Gender	-0.02	0.03	-0.57	0.01	0.04	0.4	0.00	0.04	-0.06

Figure 8.4 shows by-speaker H1-H2 (dB) means for each laryngeal category, as well as the predicted best-fit line across the age range, for each dialect and gender separately, while Table 8.8 shows the statistical results. All dialects show the lowest H1-H2 values for fortis stops, as expected, whereas lenis and aspirated stops do not show a consistent difference. Recall that a substantial number of tokens have been omitted because of a lack of pitch track, the majority of which were due to creaky voice, and the bulk of which were fortis stops. Furthermore, while a comparable number of fortis tokens were omitted from all three dialects in older speakers, there were fewer omissions (about half as many) for younger speakers of Dandong and Seoul. This

could in and of itself be taken as evidence for a decrease of the use of voice quality to signal the stop contrast in Seoul and Dandong younger speakers, but such an analysis is outside the scope of this work.

Hunchun: The aforementioned lower H1-H2 values for fortis (vs. lenis) stops is significant in Hunchun speakers, and there is a very small but significant difference between aspirated and lenis stops, with lenis stops having slightly higher values. Males show a slightly smaller H1-H2 difference in the fortis-aspirated contrast, but their values remain well-separated. There are no age-related differences.

Dandong: Dandong speakers also show the highest H1-H2 values for lenis, followed by aspirated, then fortis stops. The aspirated-lenis distinction is slightly smaller for younger speakers (but still significant in a model run on only the younger speakers), but there is no difference in the fortis-lenis contrast.

Seoul: Seoul speakers also showed the lowest H1-H2 values for fortis stops. While there is no overall significant difference between lenis and aspirated stops, there is a three-way interaction of this comparison with YOB and gender. This corresponds to the differences seen on the graph in which females show higher aspirated than lenis, while males show the opposite pattern, with some changes across time. However, there is no significant difference between the H1-H2 of lenis and aspirated stops for any of the age-gender groups, suggesting that there is no consistent pattern or evidence for change.

6.5.Case Studies: Discussion

Here we discuss how our results compare to previous work showing a change in cue-weighting for the lenis-aspirated contrast, with decreasing use of VOT (i.e. a merger) and increasing use of f0. We expected to see this pattern in our Seoul speakers, given that it has been well-documented in this dialect. We also expected similar patterns in Dandong, given previous work on a cognate dialect spoken in Shenyang China, but did not expect to see a similar change in Hunchun (Hamkyeong dialect), where the use of f0 for lexical pitch-accent may inhibit its ability to be recruited for use in the laryngeal contrast. Rather, based on previous work, we thought we might find a VOT merger in the fortis-lenis contrast, accompanied by an increase in the use of voice quality (H1-H2).

Our results from Seoul speakers are generally consistent with the previously reported change. An ongoing VOT merger is clearly seen across our age range in both genders, and it was further advanced in females. On the other hand, for f0, we saw the expected change, in terms of an increasingly high f0 for aspirated stops, in males only. The most straightforward explanation for the lack of visible change in Seoul females' use of f0 is that the change has already reached completion. Under this interpretation, this suggests that the change in f0 has reached completion before the change in VOT.

In Dandong, as expected, we saw a similar pattern of ongoing VOT merger, although there was more separation between aspirated and lenis stops for all age groups than Seoul, suggesting that the change is at an earlier stage. We also saw age-related differences in use of f0, which may be partially suggestive of a Seoul-like change, but the interpretation is not straightforward. If the change mirrors that occurring in Seoul, we would expect younger speakers to show increased f0 for aspirated stops and/or greater separation between aspirated and lenis stops in terms of f0. While we saw neither of these, there was a change in which aspirated stops have increasingly higher f0 than fortis stops in younger speakers, as in Seoul. However, this appears to be more straightforwardly attributable to a lowering of f0 of fortis stops rather than a heightening of f0 of aspirated stops. Further work is necessary to more precisely determine the trajectory of the f0 change.

In Hunchun, there is no clear evidence of a change in cue-weighting for the laryngeal contrast. While younger speakers show shorter VOTs for aspirated stops, as in Seoul and Dandong, this change is smaller, and crucially, not approaching a merger with lenis stops, which remain very close in VOT to the unaspirated fortis stops. There is overall less use of f0 in differentiating the laryngeal contrast, as expected, and if anything, this is only decreasing in younger speakers.

In terms of H1-H2, there was no clear evidence of age-related change in the statistical results. There is a slight reduction in use in Dandong, but overall the dialects look similar, with lower H1-H2 values for fortis stops and no consistent differences between lenis and aspirated, which is in accordance with previous work. We do note, however, that fewer fortis tokens were omitted due to creaky voice in younger Seoul and Dandong speakers. Most work does not take into account the number of omitted tokens, but it may be worth exploring this further in future work, as unequal numbers of omissions could skew the numerical results.

7. Conclusion

The three-way laryngeal contrast of Korean has generated a lot of research contributing to the typology of laryngeal contrasts. More recently, the diachronic change showing redistribution of cue weights from the consonantal to the vocalic portion of the signal renewed the research interest in Korean laryngeal contrast. While the change is limited to phrase-initial position, it mirrors a common historical process of tonogenesis, whereby lexical tones arise from transphonologization of segmental distinctions to tonal ones (Kingston 2011). Coupled with the availability of spoken corpora and advances in acoustic research tools, Korean provides an ideal opportunity to observe the progression of change in vivo, providing a testing ground for theories of sound change. The dialectal variation and the diversity of dialect contact situation also provides an opportunity to examine how these variables that are largely below the level of consciousness are perceived and acquired in dialect contact situations. We anticipate that Korean laryngeal contrast will continue to be an active area of research.

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