An Exploratory Study of Acoustic Cues in Stop Production in Gangneung Korean

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ABSTRACT

This study investigated voice onset time (VOT) in Korean stop consonants and the fundamental frequency (f0) of post-stop vowels in Gangneung Korean (a tonal variety). These aspects were compared with those of Seoul Korean (non-tonal), considering phonation types, place of articulation, and vowel context. Twenty speakers provided a total of 1,620 speech samples, and 3,240 measurements were taken. Linear mixed effect modeling was conducted using *R*. The results showed that Gangneung and Seoul speakers produced similar VOTs for aspirated and lenis stops but revealed f0 differences among phonation types despite the gradual loss of pitch accent in young Gangneung Korean speakers. Place of articulation and vowel context effect did not vary significantly between dialects. This paper discusses the implications for the ongoing changes in VOT and f0 in stop productions in tonal languages.

Keywords: Gangneung Korean, Korean stop production, voice onset time, fundamental frequency, tonoexodus, pitch accent language, sound change

1. Introduction

Korean stop consonants have a three-way distinction of lenis, aspirated, and fortis, which are all underlyingly voiceless (Sohn, 1999). The acoustics of Korean stops constitutes a major issue in phonetics research. Both aspirated and lenis stops are produced with long VOTs, while fortis stops show very short VOTs, showing a considerable overlap in the consonantal cues in the production and perception of aspirated and lenis stops and raising suspicions that the VOT cue might not contribute to the differentiation of aspirated and lenis stops. Studies have revealed that a significantly lower f0 of the post-lenis vowel plays a crucial role in distinguishing these two phonation types (Ahn, 2000; Silva, 2006a, b; Kang & Guion, 2008; Kim & Duanmu, 2004).

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This study builds on the aforementioned previous research to explore dialectical differences between Seoul and Gangneung Korean. While previous studies explored regional dialects such as North Kyungsang (Jo & Shin, 2003; Han, 2014, 2020; Jang & Shin, 2010; Jang, 2013), South Kyungsang (Ahn, 2021; Lee & Jongman, 2012; Lee & Jongman, 2019; Lee et al., 2013), Chonnam (Choi, 2002), and Cheju (Cho et al., 2002; Han, 2014), this study focuses specifically on Gangneung Korean.[1] Gangneung is located in Gangwon Province, the northeastern region of South Korea. Geographically, Gangwon Province is divided into eastern and western regions, and Gangneung is located in the eastern part. Linguistically, Gangwon Province shows a complicated division by the tonology of its regional varieties, with a mixture of tonal, non-tonal, and intermediate varieties. Gangneung Korean is traditionally considered a tonal language that shares common characteristics of North Kyungsang dialect. In sum, geographically, it is spoken in Gangwon Province, but prosodically, it is considered a variety of the North Kyungsang dialect (Choi, 2015).

Gangneung Korean, traditionally classified as a pitch accent language, is gradually losing its accent (Koh, 2014), as are other tonal dialects in Korea (Lee & Jongman, 2015), and currently appears to be undergoing rapid changes. Notably, there is a significant difference in tone usage between generations, with the younger generation trending toward a non-tonal language in contrast to the tonal language of the older generation. However, another study has shown that speakers of the Gangneung Korean are still proficient in recognizing and using tones (Choi, 2017), suggesting that it retains some aspects of a tone language.

This dialectal characteristic raises interesting topics regarding tonogenesis, which is a subject of active research in the context of Seoul Korean regarding how tone in Seoul Korean, which plays a decisive role in the distinction between lenis and aspirated stops in Korean (Choi, et al., 2020; Kang & Han, 2013; Kim & Duanmu, 2004), is realized in dialects in which tonoexodus is in progress. It would thus be interesting and meaningful to investigate how Gangneung speakers utilize tones in lexical contrasts in their native language and in segmental contrasts in Seoul Korean, with which they are in frequent contact. Thus, the Gangneung Korean has significant research value for understanding sound change and contact-induced language variation. In addition, the Gangneung Korean may provide a deeper understanding and anticipation of ongoing changes in the VOT-f0 distinction in tonal languages

1) Romanizations of the names of dialects follow those of previous research, and there is inconsistency in the way the names of the dialects are romanized.

and offer further implications for our understanding of language change over time.

The present study aims to investigate the overall phonetic characteristics of the stop consonants in the Gangneung Korean, by addressing the following research questions:

1. How does phonation type affect the realization of VOT and f0 in Gangneung and Seoul Korean?
2. How does the place of articulation affect the realization of VOT and f0 in Gangneung and Seoul Korean?
3. How does the vowel context affect the realization of VOT and f0 in Gangneung and Seoul Korean?

2. Background

2.1. Acoustics of Korean stops

2.1.1. Acoustic cues according to phonation types

Korean stops are known to have three-way phonemic distinction: aspirated, lenis, and fortis. Over the past 20 years, numerous studies have investigated the acoustic cues that differentiate the three types of Korean stop consonants. The following findings regarding voice onset time (VOT) and fundamental frequency (f0) to differentiate lenis from aspirated stops have been reported (Ahn, 2000; Silva, 2006a, b; Kang & Guion, 2008; Kim & Duanmu, 2004):

1. The VOT of aspirated stops has gradually decreased.
2. The VOT of lenis stops has gradually increased over time.
3. As a result of changes 1 and 2, the VOTs of aspirated stops and lenis stops have merged for younger speakers.
4. The lower f0 of a vowel after a lenis stop contributes to its distinction from an aspirated stop.
5. The vowel following a fortis stop has a high f0, similar to that of an aspirated stop, but is characterized by a very short VOT.

Some studies suggest that tonogenesis, which distinguishes consonants based on

their tones, is in progress in Seoul Korean, a non-tonal language (Bang, et al., 2018; Kang & Han, 2013; Kim & Duanmu, 2004), while others have not reached a conclusive position on this matter (Choi et al., 2020).

2.1.2. Place of articulation and vowel context effects

Korean stops are produced at three points of articulation: bilabial, alveolar, and velar. Combined with the three phonation types, the Korean language has a total of nine stop categories. Studies have investigated the effect of place of articulation in the production of stop VOT. VOT duration is influenced by the place of articulation of stop consonants. Overall, the VOT duration of bilabial stops is the shortest, and the velar stops show the longest VOT duration (Cho & Ladefoged, 1999).

Although not extensively studied in experimental research on Korean stop sounds, there is a notable phenomenon related to the effect of the following vowel on the stop VOT. Some studies have suggested a correlation between VOT and vowel length in relation to the perception or production of stop consonants (Allen & Miller, 1999; Choi, 2011, 2012; Machač & Skarnitzl, 2007). According to Machač and Skarnitzl (2007), tautosyllabic consonants and vowels can affect each other's durations. The effect of postvocalic consonants has long been verified, but prevocalic stops can also affect the length of following vowels, and vice versa. For example, the inherent length of a vowel can affect the duration of the preceding stop consonants. Because low vowels are longer in duration than high vowels, stop consonants preceding a low vowel may have shorter durations than those preceding a high vowel.

Among Korean stop consonants, Oh (2011) examined the place of articulation and vowel context effects on VOT length, finding significant effects of both place of articulation and vowel height on VOT. Since many studies have focused on the VOT merger between aspirated and lenis stops, it would also be interesting to see how dialectal differences (i.e., tonal and non-tonal variety speakers) interact with the effect of place of articulation and vowel contexts on VOT and f0.

2.2. Gangneung Korean

Informally, the Korean language spoken in Gangwon Province is divided into eastern and western varieties, but this is not accurate terminology. The varieties spoken in Gangwon Province show mixed characteristics of tonal, non-tonal, and

intermediate languages. Specifically, tonal varieties are spoken in the south of Gangwon Province and part of the east (Samcheok, Gangneung, and Yeongwol). Non-tonal varieties are found in the west (Wonju, Chuncheon, etc.) and part of the east (Sokcho, Goseong); they are considered a variety of Gyeonggi dialect. Other areas such as Pyeongchang and Jeongseon are said to display characteristics of both tonal and non-tonal varieties (Jung, 2018; Lee, 1987). In this sense, it is considered inappropriate to categorize the regional varieties of Gangwon Province as a dialect (Kim, 2014).

Among the regional varieties in Gangwon Province, Gangneung Korean has received more attention than other areas in the province (Kim, 2014). According to Kim (2003), Kim (1999), and Ito (2015), Gangneung Korean uses a pitch accent. Ito (2015) described Gangneung Korean as a Southeastern dialect, and Choi (2015) classified it as the same type as North Kyungsang Korean. According to Kim (2014), Gangneung Korean exhibits characteristics of contact between two dialects: the Southeastern dialect spoken in Kyungsang Province and the Northeastern dialect in Hamgyeong Province, another tonal variety. Historically, it is significantly different from Seoul Korean.

The following are examples of tones for lexical contrasts of Gangneung Korean from Koh (2015) and Choi (2017).

(1) H mal 'horse' pam 'night'
L mal 'talk' pam 'chestnut'

As shown in the above example, *mal* means 'talk' when it is produced with low tone, while it denotes 'horse' with high tone. Similarly, *pam* means 'night' with high tone versus 'chestnut' with low tone. Also, the low tone is accompanied with a long vowel.

Recently, the pitch accent of Gangneung Korean appears to be rapidly disappearing. Although drastic changes in pitch accent that are readily noticeable to people living in Gangneung have sometimes been described in non-academic documents, there have been few experimental phonetic studies of this topic. The only article reporting a loss of pitch accent in Gangneung Korean is Koh (2014), which compared Gangneung and the Kagoshima dialect of Japanese and found that the use of pitch accent and duration is changing among middle-aged Gangneung Korean speakers. Six participants, three men and three women, aged from their

mid-20s to their late 40s, tended not to produce the distinctive pitch accent patterns of words that had them previously. Living in Gangneung and hearing the variety regularly, I noticed that the pitch accent pattern distinguishing Gangneung Korean from Seoul Korean is scarcely evident in the speech of the younger generation in their 20s. Although this has yet to be experimentally verified, it appears, although impressionistically, that tonoexodus has already made significant progress among the younger generation of Gangneung Korean, setting it apart from the North Kyungsang dialect.

Studies of the acoustic correlates of Korean stop consonants in Gangneung Korean have not yet been conducted, despite the changes promising interesting insights into the main acoustic signals of the Korean three-way stop distinction. As Seoul Korean mainly uses the f0 cue for stop consonant classification (Kang & Han, 2013; Kang, 2013; Kim & Duanmu, 2004; Kim, 2014, among others), and as the pitch accent change of Gangneung Korean is viewed as a contact-induced change due to increased contact with Seoul Korean, it is an interesting research question to see how Gangneung Korean, which is losing tones for lexical contrast, interacts with Seoul Korean, which is developing tonal cues for segmental contrast.

In this exploratory and preliminary study, Gangneung Korean is expected to resemble Seoul Korean in the production of stop consonants. The VOT pattern in utterances of Korean stop consonants in Gangneung speakers might not differ significantly from that of Seoul speakers. However, in a recent perception experiment, it was reported that speakers' ability to perceive tones was maintained by Gangneung speakers (Choi, 2017), suggesting that there may be some differences in the use of f0.

3. Methods

3.1. Participants

This study was conducted at a university in Gangneung, with the voluntary participation of 10 native speakers of Gangneung Korean and 10 native speakers of Seoul Korean. The participants were either undergraduate students or graduates of the university. At the time of recording (January–April 2023), the mean age of the Gangneung speakers was 21.6 years (19–25; birth year 1998–2004), whereas that

of the Seoul speakers was 21.2 years (19–23; birth year 2000–2004). The biological information on each participant is presented in Table 1.

Table 1. Participant information

No.	Gangneung speakers			No.	Seoul speakers		
	Gender	Age	Birthyear		Gender	Age	Birthyear
1	Female	21	2002	1	Female	20	2003
2	Female	25	1998	2	Female	21	2002
3	Female	24	1999	3	Female	22	2001
4	Female	25	1998	4	Female	22	2001
5	Female	21	2002	5	Female	19	2004
6	Female	21	2002	6	Female	21	2002
7	Female	20	2003	7	Female	23	2000
8	Female	20	2003	8	Female	21	2002
9	Female	20	2003	9	Female	22	2001
10	Female	19	2004	10	Female	21	2002

To control for any variability caused by the gender, all participants were female. The speakers of Gangneung Korean were born and raised in Gangneung, while the speakers of Seoul Korean were born and raised in Seoul and adjacent areas of Gyeonggi Province before entering the university. Gangneung speakers were asked before recording how often they use Gangneung Korean, especially its intonation, and all of them reported that they think they scarcely speak Gangneung Korean, and that their intonation is distinct from their parents' or grandparents'. However, they also mentioned that people from Seoul sometimes point out their Gangneung accent features, and that when they are angry, they might reveal their Gangneung accents. None of the participants had any experience living in another country. The participants received financial compensation for their involvement in the study.

3.2. Materials

To observe VOT in Korean stop consonants and the effect of stop consonants on the f0 of the following vowel, CVn syllables (consonant + vowel + nasal) were recorded. The recordings consisted of 27 syllables, each with one of the three types

of Korean phonation types (lenis, aspirated, fortis), combined with one of the three places of articulation (bilabial, alveolar, and velar) and one of three vowels (*a*, *u*, *i*) to examine durational compensation based on the inherent length of the high and low vowels. Participants were asked to repeat each syllable three times, resulting in 81 recordings for each participant. The CVn syllable was presented within the carrier sentence "*igeo* _____ *haseyo*," meaning "please say this _____." The 27 syllables used in the recording were thus *p^{h}an*, *p'an*, *pan*, *t^{h}an*, *t'an*, *tan*, *k^{h}an*, *k'an*, *kan*, *p^{h}un*, *p'un*, *pun*, *t^{h}un*, *t'un*, *tun*, *k^{h}un*, *k'un*, *kun*, *p^{h}in*, *p'in*, *pin*, *t^{h}in*, *t'in*, *tin*, *k^{h}in*, *k'in*, and *kin*.

Despite the decreasing use of pitch accent among speakers in their 20s, Gangneung Korean can still be considered a tonal language according to Choi (2017). Furthermore, previous research has shown that the f0 of pitch-accent realization and segmental contrast can be interrelated in tonal languages, as demonstrated by Lee and Jongman (2019). Therefore, to minimize the potential variability caused by pitch-accent patterns in words with two or more syllables, monosyllabic words were used as recording materials in this study.

3.3. Recordings

Speech samples were recorded in a quiet room at a sampling rate of 44,100 Hz. The recording equipment used was a Sony PCM-M10 recorder with a built-in microphone at a fixed distance of approximately 20 cm from the speakers. To maintain a consistent speech rate, participants were presented with recorded sentences displayed on a computer screen at intervals of 4 seconds. The participants were asked to repeat each spoken word three times, and the words were presented randomly. The recorded data were analyzed using Praat software (version 6.2.14), and Praat scripts were used in the analysis process.

3.4. Measurements

Two types of acoustic information (VOT and f0) were obtained from the recorded data. The VOT of Korean stop consonants was set as the interval from the start of the release burst in the waveform to the start of the first regular cycle of the following vowel, and the measurement was confirmed by referring to the spectrogram and auditory information. To examine the effect of the phonation type on the f0 of following vowels, f0 was measured at the vowels' midpoints. In many

studies examining the effect of consonants, f0 is measured at the onset of the following vowel. However, other research has revealed that the differences in f0 by phonation type persist throughout the vowels (e.g., Ahn, 2000), and recently a corpus study by Bang et al. (2018) obtained f0 values at the midpoint of the following vowel. Additionally, Byun (2016) reported that the f0 value at the midpoint of the vowel showed a high correlation with that at the onset. The present study thus measured f0 at the midpoint of the vowel to obtain a stable value. In total, 3,240 measurements were obtained (three phonation types × three places of articulation × three vowels × three repetitions × two measurements (VOT and f0) × twenty speakers = 3,240).

3.5. Statistical analysis

The mean values of VOT and f0 were calculated for each of the 27 syllables by taking the average of three repetitions. VOT and f0 values were used as dependent variables for linear mixed effect models, with dialect as the between-subject effect and phonation, place of articulation, and vowel as the within-subject effects. We performed two linear mixed effect model analyses, one each for VOT and f0, using the lmer function (lme4 package) in *R* (version 4.1.3).

4. Results

4.1. Descriptive characteristics

4.1.1. Dialectal differences by phonation type

Figure 1 shows the overall patterns of VOT and f0 produced by Gangneung and Seoul speakers. Gangneung speakers had, on average, slightly shorter VOTs than Seoul speakers. Additionally, the Seoul speakers showed a wider distribution of VOTs than the Gangneung speakers. The range of f0 changes was larger in Seoul speakers than in Gangneung speakers, as appears in Figure 1.

Table 2 presents the descriptive statistics of the VOT and f0 measurements in Gangneung and Seoul Korean by phonation type.

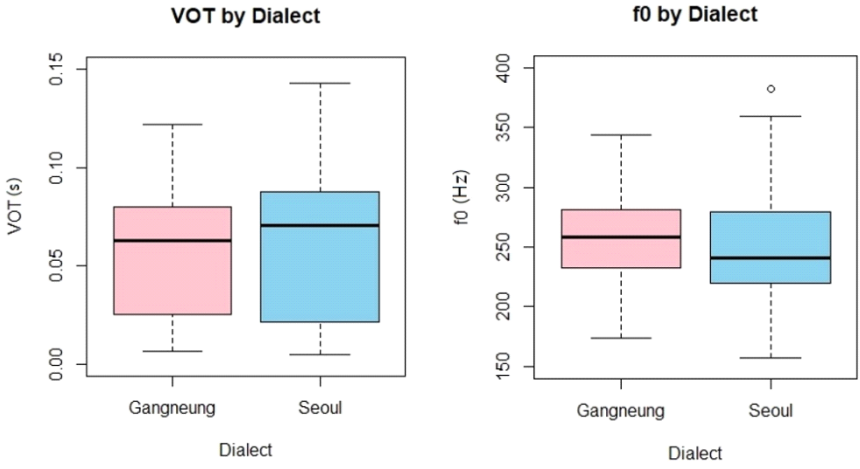

Figure 1. VOT and f0 values by dialect.

Table 2. Descriptive statistics on VOT and f0: Dialect and phonation type

Dialect	Phonation	VOT (s)		f0 (Hz)		*N*
		Mean	*S.D.*	*Mean*	*S.D.*	
Gangneung	Aspirated	0.079	0.016	278.7	21.0	90
	Lenis	0.069	0.009	224.1	20.2	90
	Fortis	0.019	0.009	265.7	23.9	90
Seoul	Aspirated	0.089	0.016	277.7	41.1	90
	Lenis	0.077	0.018	210.3	25.0	90
	Fortis	0.018	0.009	265.0	38.9	90
Total	Aspirated	0.084	0.017	278.2	32.5	180
	Lenis	0.073	0.019	217.2	23.7	180
	Fortis	0.019	0.009	265.3	32.2	180

On average, the 20 participants showed a VOT of 0.084 s for aspirated stops, 0.073 s for lenis stops, and 0.019 s for fortis stops. There was only a slight difference (about 0.011 s) in VOT between the lenis and aspirated stops. Gangneung speakers had an average VOT of 0.079 s for aspirated stops, 0.069 s for lenis stops, and 0.019 s for fortis stops, while Seoul speakers showed 0.089 s, 0.077 s, and 0.018 s for these phonation types, respectively.

The average f0 value for vowels following the aspirated stop was 278.2 Hz for Gangneung and Seoul speakers combined, 217.2 Hz for lenis, and 265.3 Hz for fortis. The difference between post-lenis and post-aspirated f0 was 61 Hz, while f0 following the fortis stops was slightly lower than following the aspirated stops. Gangneung speakers had an average f0 value of 278.7 Hz for the aspirated stop, 224.1 Hz for the lenis stop, and 265.7 Hz for the fortis stop. Similarly, the Seoul speakers also had the lowest f0 after the lenis stop (210.3 Hz) and the highest f0 after the aspirated stop (277.7 Hz).

In order to scrutinize the production of VOT and f0, scatter plots were generated for the two speaker groups (Gangneung and Seoul), as well as for the twenty individual speakers (ten from each group). Figure 2 displays the scatter plot for the production of VOT and f0 by Gangneung and Seoul Speakers.

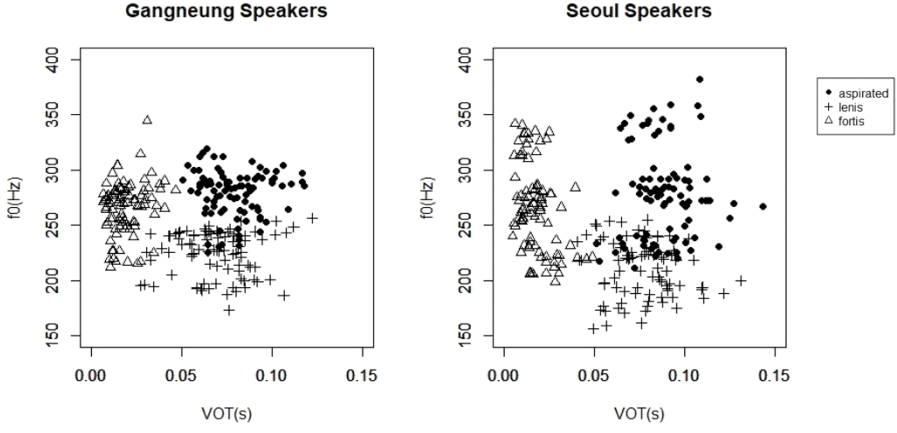

Figure 2. Groups differences: Gangneung and Seoul speakers.

Both the Gangneung and Seoul speaker groups displayed very short VOTs and a wide distribution of f0 for fortis stops with roughly covering the f0 value ranges of aspirated stops. Both groups produced longer VOTs for lenis and aspirated stops compared to fortis stops, with the distribution of VOT duration being wider for lenis than for aspirated stops. The distribution of f0 values for lenis and aspirated stops was separated at approximately 250 Hz for both groups. When examining the data for the two groups, the difference arose from the distribution of f0, with the Seoul speaker groups exhibiting greater variation for both aspirated and lenis stops. Moving on to individual differences, Figure 3 displays the data from Gangneung speakers, while Figure 4 presents the data from Seoul speakers.

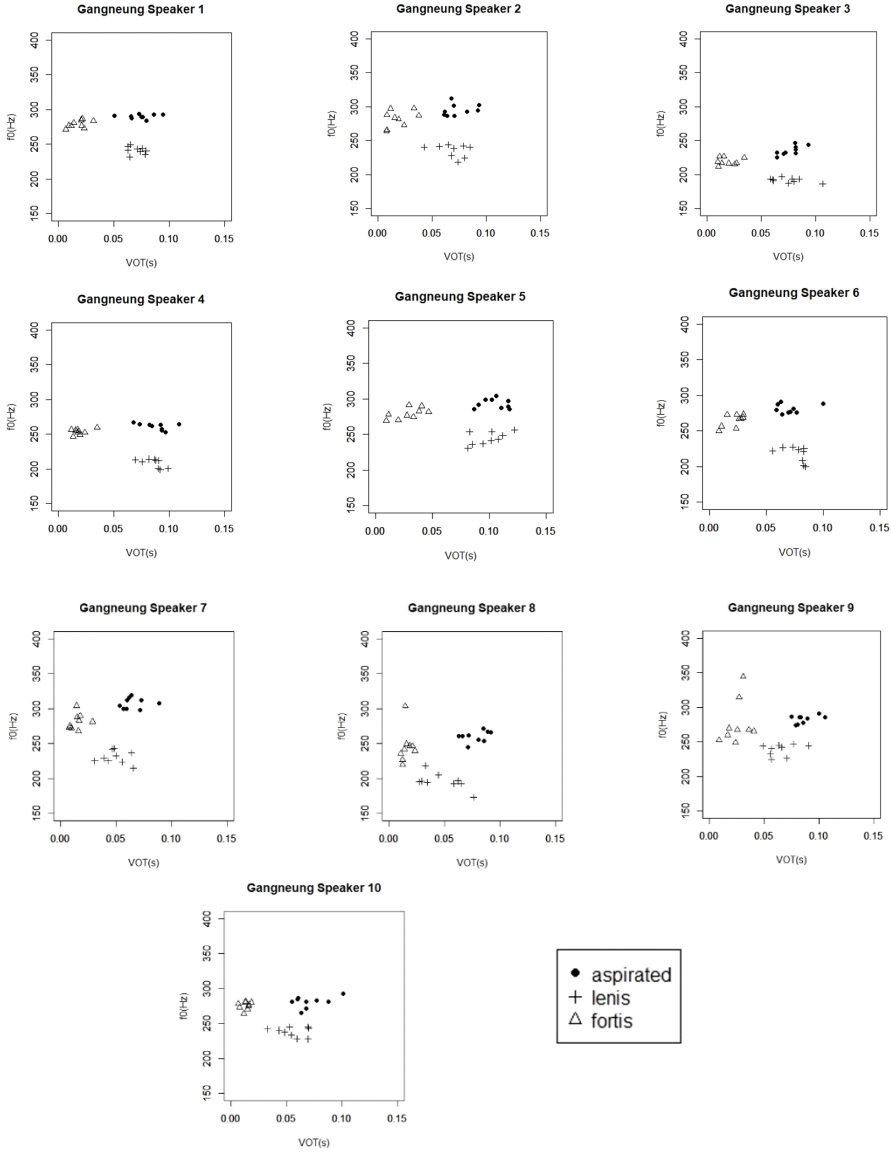

Figure 3. Individual differences: Gangneung speakers.

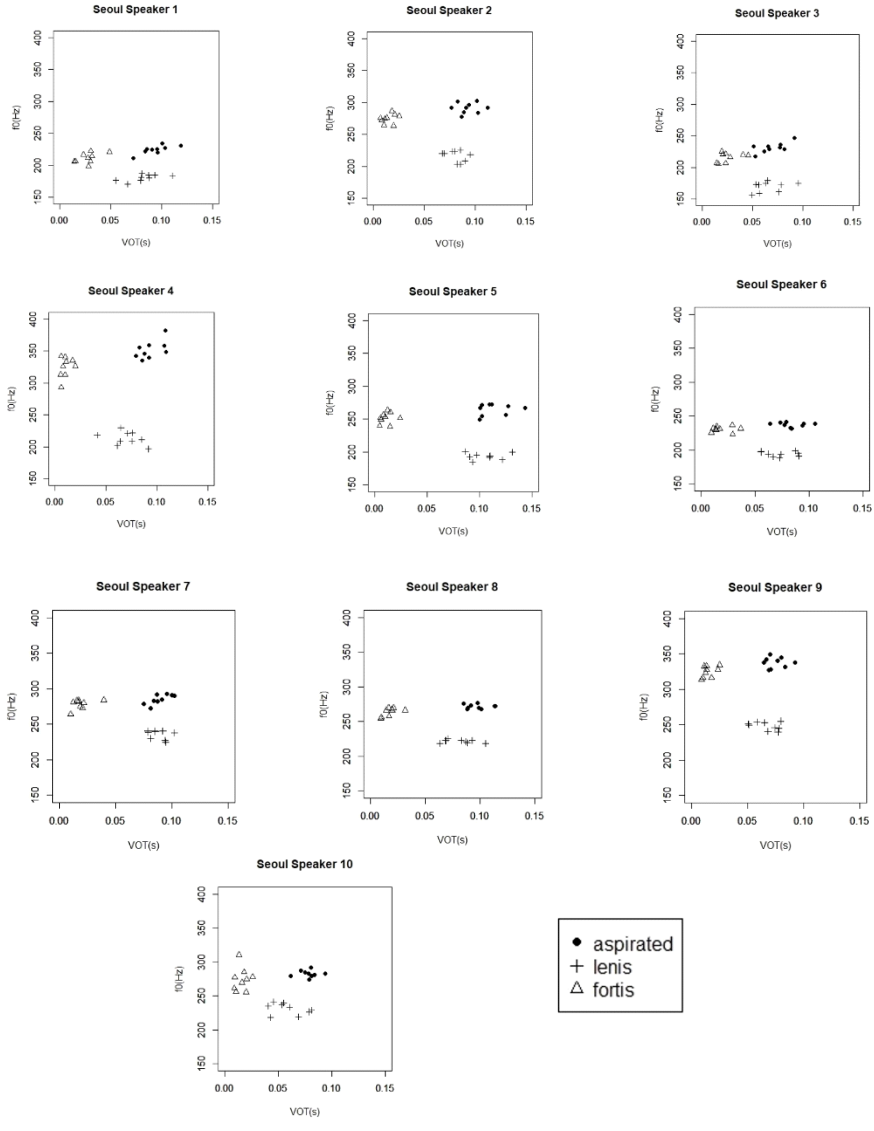

Figure 4. Individual differences: Seoul speakers.

An examination of individual differences reveals interesting aspects of VOT and f0 production among Gangneung and Seoul speakers. Six out of the ten Gangneung speakers exhibit almost complete overlap in their VOT duration production, while four of the ten (Speaker 7, 8, 9, 10) show partial overlap in VOT duration. Among Seoul speakers, VOT distribution displays almost complete overlap for most speakers

except the speaker 4 and 10. However, the more notable difference in data from the Seoul speakers is the f0 distinction between aspirated and lenis stops. Overall, Seoul speakers exhibit a more distinguishable f0 difference than Gangneung speakers, indicating that the f0 plays a more crucial role in Seoul Korean than in Gangneung Korean.

4.1.2. Place of articulation and vowel context effects on VOT and f0

Table 3 shows the descriptive statistics of the VOT and f0 measurements of Gangneung and Seoul Korean by place of articulation.

Table 3. Descriptive statistics of VOT and f0 by dialect and place of articulation

Dialect	Place of articulation	VOT (s)		f0 (Hz)		*N*
		Mean	*S.D.*	*Mean*	*S.D.*	
Gangneung	Bilabial	0.050	0.029	257.1	31.8	90
	Alveolar	0.053	0.029	255.7	33.0	90
	Velar	0.064	0.031	255.8	31.0	90
Seoul	Bilabial	0.053	0.031	250.9	45.9	90
	Alveolar	0.059	0.034	250.3	45.7	90
	Velar	0.072	0.036	251.7	47.2	90
Total	Bilabial	0.052	0.030	254.0	39.5	180
	Alveolar	0.056	0.032	253.0	39.8	180
	Velar	0.068	0.034	253.7	39.9	180

The descriptive statistics indicate that Gangneung and Seoul speakers, on average, pronounced bilabials with the shortest VOTs, while velar stops had the longest VOTs. These patterns were consistent across both groups. Measurements of f0 did not show any noticeable differences by place of articulation, consistently across both groups.

Table 4 shows the descriptive statistics of VOT and f0 measurements from the Gangneung and Seoul Korean according to vowel context.

Table 4. Descriptive statistics of VOT and f0 by dialect and vowel context

Dialect	Vowel context	VOT (s)		f0 (Hz)		*N*
		Mean	*S.D.*	*Mean*	*S.D.*	
Gangneung	a	0.054	0.032	248.1	30.9	90
	i	0.055	0.030	260.3	32.8	90
	u	0.058	0.030	260.2	30.5	90
Seoul	a	0.060	0.036	243.4	45.0	90
	i	0.063	0.035	255.0	46.0	90
	u	0.061	0.033	254.6	46.8	90
Total	a	0.057	0.034	245.7	38.6	180
	i	0.059	0.033	257.6	40.0	180
	u	0.059	0.031	257.4	39.5	180

The speakers in this study produced shorter VOTs on average before low vowels and longer VOTs before short vowels. Both Gangneung and Seoul speaker groups displayed the same tendency, but Gangneung speakers produced the longest VOT before the high front vowel /i/, Seoul speakers before the high back vowel /u/. The mean differences of VOT between low and high vowels are 0.004 s for Gangneung speakers between /a/ and /u/ and 0.003 s for Seoul speakers between /a/ and /i/. As for f0, in both groups, the low vowel was pronounced with a lower f0 value than the high vowel, which is predictable. Also, the difference in mean f0 between high and low vowels was similar for Gangneung speakers (12.1 ∼ 12.2 Hz) and Seoul speakers (11.2 ∼ 11.6 Hz).

4.2. Linear mixed effect model analyses

Table 5 summarizes the linear mixed effect model for VOT. The main effect of dialect on VOT was not significant, $F(1, 18) = 1.8121$ ($p = .19$), indicating that the Gangneung speakers displayed similar VOT values to the Seoul speakers on average. The main effect of phonation type on VOT was significant, $F(2, 508) = 1{,}958.525$ ($p < .001$), showing that the speakers in this study produced distinct VOTs for the three phonation types. The main effect of place of articulation on VOT was significant with $F(2, 508) = 111.0503$ ($p < .001$). The main effect of vowel context on VOT was also significant at $F(2, 508) = 3.2635$ ($p < .05$).

Table 5. Linear mixed effect model analysis for VOT

DV: VOT	Sum Sq	Mean Sq	Num*df*	Den*df*	*F*-value	Pr (> *F*)
Dialect	0.0002	0.000204	1	18	1.8121	0.19
Phonation	0.44099	0.220496	2	508	1,958.525	0.00***
Place	0.025	0.012502	2	508	111.0503	0.00***
Vowel	0.00073	0.000367	2	508	3.2635	0.039*
Dialect:phonation	0.00336	0.001678	2	508	14.903	0.00***
Dialect:place	0.00037	0.000185	2	508	1.6466	0.19
Dialect:vowel	0.00044	0.000219	2	508	1.9449	0.14

*p<.05, **p<.01, ***p<.001.

The interaction effect between dialect and phonation was significant, with $F(2, 14) = 14.903$ ($p < .001$), while the interaction effect between dialect and place of articulation/vowel context was not significant.

Table 6 presents a summary of the linear mixed effect models for f0.

Table 6. Linear mixed effect model analysis for f0

DV: f0	Sum Sq	Mean Sq	Num*df*	Den*df*	*F*-value	Pr(> *F*)
Dialect	24	24	1	18	0.1738	0.68
Phonation	372,481	186,240	2	508	1338.57	0.00***
Place	98	49	2	508	0.3522	0.70
Vowel	16,610	8305	2	508	59.6925	0.00***
Dialect:Phonation	5,075	2,538	2	508	18.2392	0.00***
Dialect:Place	102	51	2	508	0.3675	0.69
Dialect:Vowel	17	8	2	508	0.0601	0.94

*p<.05, **p<.01, ***p<.001.

The main effect of dialect on f0 was not significant, $F(1, 18) = 0.1738$ ($p = .68$). The main effect of phonation on f0 was significant, $F(2, 508) = 1336.57$ ($p < .001$). Place of articulation did not have a significant effect on f0, $F(2, 508) = 0.3522$ ($p = 0.70$). Vowel context had a significant main effect on f0 $F(2, 508) = 59.6925$ ($p < .001$). The interaction effect between dialect and phonation showed significance,

$F(2, 508) = 18.2395$ ($p < .001$). No significant interaction effect was reported for dialect and place of articulation/vowel context.

Figure 5 shows an interaction plot between dialect and phonation type for VOT and f0.

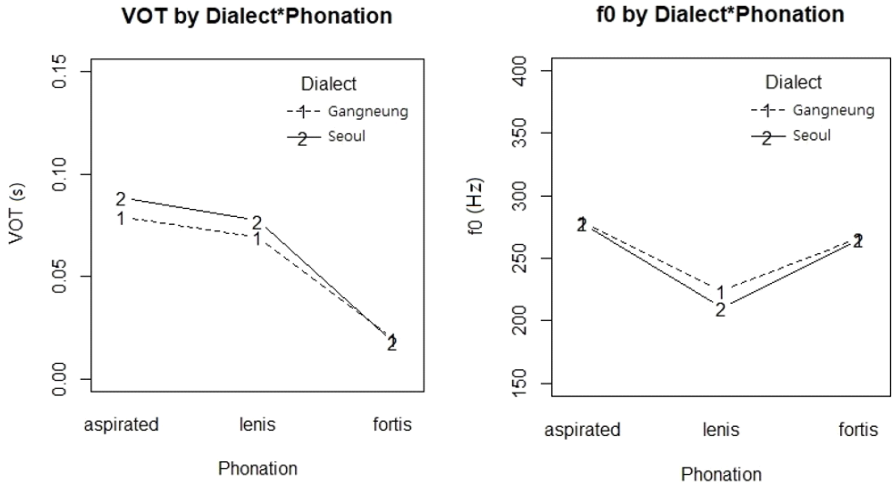

Figure 5. VOT and f0 values by dialect × phonation type.

As shown in Figure 5, the mean difference in VOT between aspirated and lenis stops was slightly smaller for Gangneung speakers (0.010 s) than Seoul speakers (0.012 s). Also, the difference in f0 values between aspirated and lenis stops was about 54 Hz for Gangneung speakers and 67 Hz for Seoul speakers. In sum, the speakers from Gangneung produce VOTs even with smaller differences between aspirated and lenis than Seoul speakers do, and have smaller f0 manipulations than Seoul speakers do.

5. Discussion

This study explored the acoustics of stop consonants in Gangneung and Seoul Korean, measuring VOT and f0. The three phonation types of Korean stops (aspirated, lenis, fortis), place of articulation (bilabial, alveolar, velar), and vowel context (high and low vowel: *a*, *i*, *u*) were considered within-subject effects and dialect a between-subject effect. Overall, Gangneung and Seoul speakers produced

Korean stops very similarly. The VOT duration of aspirated and lenis stops considerably overlapped for the two groups. Furthermore, Gangneung and Seoul speakers both produced post-lenis vowels with a significantly lower f0, although the mean f0 difference between aspirated and lenis stops was smaller for Gangneung speakers. Furthermore, the effects of place of articulation and vowel context on VOT did not differ in the two groups. These results have implications for our understanding of Gangneung Korean phonetics and the ongoing issue of VOT-f0-related sound change, especially for tonal languages.

First, overall, stop VOTs did not differ between Gangneung and Seoul speakers. In both dialects, the longest VOT was observed for aspirated stops and slightly shorter VOTs were observed for lenis stops. The VOTs of the fortis stops were very short. These patterns are almost consistent with those of previous studies of Seoul Korean (Ahn, 2000; Kim & Duanmu, 2004; Silva, 2006). As there has been no research on the acoustics of stop consonants in Gangneung Korean, we compare the results with those for Kyungsang dialect, another tonal variety of Korean, whose studies of stop consonants have been ongoing for the past 20 years. The following table summarizes the relevant research in chronological order with reference to biological ages of the speakers. In this study, we are primarily interested in VOT and F0 in production, but we also consider perceptual aspects for a more comprehensive understanding.

Table 7. Recent research on VOT and f0 for Kyungsang Korean stops

Year	Author(s)	Dialect	Age of the subjects	Mode	Main acoustic cue(s) to signal stops
2003	Jo and Shin	North Kyungsang (Daegu)	20s to 30s	Production	VOT
2006	Kenstowicz and Park	North and South Kyungsang	20s to 40s	Production	VOT
2010	Jang and Shin	North Kyungsang (Daegu)	22 to 30	Perception	VOT
2012	Lee and Jongman	South Kyungsang	24 to 48	Production	VOT
2012 & 2013	Jang	North Kyungsang (Daegu)	20 to 31 for younger speakers	Production and perception	VOT toward f0 for younger speakers
2013	Lee et al.	South Kyungsang	20 to 65	Perception	VOT

Table 7. Continued

Year	Author(s)	Dialect	Age of the subjects	Mode	Main acoustic cue(s) to signal stops
2014	Han	North Kyungsang (Daegu)	20s	Production	VOT
2019	Lee and Jongman	South Kyungsang	19 to 23 for younger speakers	Production	F0 for younger speakers
2020	Han	North Kyungsang (Daegu)	20 to 24 for younger speakers	Production	VOT, but f0 for young female speakers
2021	Ahn	South Kyungsang	19 to 30	Perception	F0

Note: For studies comparing younger and older speakers, the age of younger speakers is provided since the focus of the present study is on young female speakers in their 20s.

Summarizing previous research, it appears that speakers of the Kyungsang dialect primarily signal the three-way stop distinction in Korean with VOT, because f0 in the Kyungsang dialect marks a lexical contrast. However, recent studies (within the past five years) have shown that the use of pitch accents for lexical contrast is decreasing in the younger generation in the Kyungsang area, although a pitch accent pattern that differs from the Seoul Korean is observed (Lee & Jongman, 2015). With these changes, the contribution of f0 to the production and perception of Korean stops has gradually increased (Lee & Jongman, 2019).

The observed patterns of Gangneung Korean are comparable to those reported in previous studies on the Kyungsang dialect. In the Kyungsang dialect, the VOT difference between aspirated and lenis stops decreased as the VOT of the lenis stop gradually lengthened in the stop production of the younger generation, but the VOT realization range did not completely overlap (e.g., Jang, 2013). However, recently, Han (2020) showed that young female speakers from Daegu produced longer VOT for lenis stops than male speakers in the same age range, resulting in the very small mean difference in VOT for aspirated and lenis stops. In the production of Gangneung Korean by people in their 20s, there was almost no difference in VOT from that of the Seoul Korean, suggesting that Gangneung Korean has greatly converged toward Seoul Korean.

Second, the average difference in the f0 of the vowel following aspirated and lenis stops in Gangneung Korean is smaller than in Seoul Korean. The smaller difference in f0 between post-aspirated and post-lenis vowels among Gangneung speakers could be attributed to their sensitivity to tones, and they may use smaller f0 differences

to signal segmental differences in the following vowels. As described in Koh (2014), pitch accents in Gangneung Korean have changed among the speaker in their 20s and above, and the young female speaker participants in their early 20s in the present study reported that they don't produce pitch accents in their daily life. However, according to Pinget et al. (2020), in sound change, people retain the perceptual ability after the change in production completes. Choi (2017) also examined tone perception using cross-modal priming tasks among native listeners who use tone (Gangneung speakers), those who use the length of segments, and those who are natives in the dialect contact area. Despite the recent loss of pitch accent in the dialect, Gangneung native listeners have been shown to discriminate the meaning of sentences well using tones. Alternatively, there may be an interrelation in the f0 usage for lexical and segmental contrasts, which would require a carefully designed study using speech materials with disyllabic words and a consideration of pitch accents. In summary, for the young female speakers in their early 20s in Gangneung, the tones may not be salient in their production, but still maintained in their perception. This may have led a smaller difference in f0 of the production of post-aspirated and lenis vowels.

Lastly, VOT and f0 values did not differ by place of articulation between the Gangneung and Seoul speakers. For Kyungsang speakers, Han (2014) also reported no observed difference in the effect of place of articulation on VOT between Cheju and Kyungsang (Daegu) speakers, which seems reasonable considering that the difference in VOT length by place of articulation originates from physiologically determined phonetics. Moreover, the influence of vowels on the realization of VOT is the same for Gangneung and Seoul speakers: Both Gangneung and Seoul speakers produced shorter VOT before the low vowel */a/* than before the high vowels */i/* and */u/*as previous studies found a negative correlation between VOT and vowel duration (Allen & Miller, 1999; Choi, 2011, 2012; Machač & Skarnitzl, 2007). In this study, both Gangneung and Seoul speakers showed sensitivity to vowel length, suggesting that Gangneung speakers behave in the same way when perceiving vowel length and compensating for duration.

6. Conclusion

This study explored dialectal differences in the VOT and f0 of stop consonants in Seoul (non-tonal) and Gangneung (tonal) Korean, considering phonation type,

place of articulation, and vowel context. Gangneung speakers displayed very similar VOTs to Seoul speakers, but a limited use of f0 of the vowel following aspirated and lenis stops. Although the results showed statistically significant differences, the sample size was limited, emphasizing the need for future research with larger samples. Further studies should also investigate generational differences in VOT and f0 production among Gangneung speakers to better understand the ongoing language changes in this tonal language.

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