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Electroglottographic-Phonetic Study on Korean Phonation Induced by Tripartite Plosives in Yanbian Korean

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Abstract

This paper examined the phonatory features induced by the tripartite plosives in Yanbian Korean, broadly considered as Hamkyungbukdo Korean dialect. Electroglottographic (EGG) and acoustic analysis was applied for five elderly Korean speakers. The results show that fortis-induced phonation is characterized with more constricted glottis, slower spectral tilt, and higher sub-harmonic-harmonic ratio. Lenis-induced phonation is shown to be breathier with smaller Contact Quotient and faster spectral tilt. Most articulatory and acoustic measures for the aspirated are shown to be patterned with the lenis; However, sporadic difference between the two indicates that the lenis induces more breathier phonation. The diplophonia phonation is argued to be a salient feature for the fortis-head syllables in Yanbian Korean. The vocal fold medial compression and adductive tension mechanisms are tentatively argued to be responsible for the production of the fortis. At last, gender difference is shown to be salient in the fortis-induced phonation.

Index Terms: phonation, electroglottography (EGG), Yanbian Korean, tripartite plosives

1. Introduction

The three-way contrast of Korean plosives has complex laryngeal specifications. In [1] Kim contended that tensity and voicing were the autonomous features for Korean plosives: fortis and aspirated plosives are tense and unvoiced, and lenis plosives are lax and have voiced allophones. Later studies have largely adhered to these phonetic features and substantiated with more phonetic details through various experimental techniques. In [2, 3] the three-way distinction is associated with two features, [±tense] and [±spread glottis], which are associated with independent supra-laryngeal and laryngeal configurations. Beside, studies on the activation of adductive or abducting laryngeal muscles in the production of Korean plosives have provided physiological evidences for the laryngeal mechanism for the three-way contrast [4, 5].

Another line of research has focused on the phonation of vowels following the Korean tripartite plosives, assuming that the phonation of the vowels carries the critical information of the the phonation contrast [6-9]. Fortis-induced phonation was labeled as "creaky" [9] or "larygnealized" [10], lenis-induced phonation as "breathy" [7] or "harsh whispery" [8], and aspirated-induced phonation as "breathy" [7] or "modal" [11]. The onset F0 plays an important role in perceiving the contrast for tonal and non-tonal varieties of Korean [12]. The rationale for this line of study is to substantiate the laryngeal mechanism through observing the fine-grained phonetic details over the vocalic interval as a result of the carryover effect of the consonant laryngeal configuration. The current study adopted the premises of this line of research and carried out an electroglottographic (EGG)-phonetic study on Yanbian Korean, which has been broadly defined as Northeast, or Hamkyungbukdo, dialect of Korean [13].

The majority of previous studies have focused on Seoul Korean while little attention has been paid to Hamkyungbukdo dialect, which is mainly spoken in Hamkyungbukdo in North Korean and Yanbian Korean Prefecture in China. Three points were worthy of being mentioned for this dialect in China. First, it retains the conservative pronunciation of Korean [12], and is the least-studied dialect through experimental approach. Second, stark difference on plosive production was observed between Yanbian and Seoul Korean in terms of laryngeal features [14], but little physiological mechanism for the former was known. Third, apparent-time sound changes have been under way for Yanbian Korean, which was shown to follow a different route from Seoul Korean [15]. In the current study, the phonation of elderly speaker aged over 60 was studied because their accent, encapsulated in dialectal lexicon, largely retained the characteristics of Hamkyungbukdo dialect.

The ongoing experimental studies on Yanbian Korean have found systematic phonation difference for the tripartite distinction for plosives. In [16] it was found the VOT varied from short to long in the order of fortis<lenis<aspirated. In a recent EGG study it was found fortis-induced phonation was characterized by more constricted glottis, faster vocal folds closing gesture, and higher onset F0; lenis-induced phonation had relaxed glottis, more symmetrical EGG wave shape, and lower onset F0; aspirated-induced phonation had highest onset F0 and frequent composite EGG wave shape at vowel onset [17]. In a socio-phonetic study on Yanbian Korean, it was found that elderly speaker retained the VOT contrasts; Onset F0 was overlapped for fortis and aspirated plosives, and lowest for lenis plosives; The H1-H2 was a reliable spectral measure for fortis/lenis distinction, but it did not differ between lenis and aspirated plosives. However, none of the above studies have touched upon the fortis-related creaky phonation, which we found a salient feature for Yanbian Korean. Thus this study focused on the phonatory features associated with the tripartite Korean plosives, and discussed the phonetic properties for such contrast in Yanbian Korean.

2. Method

2.1. Speech stimuli and speakers

The speech stimuli were a small portion of the Hamkyungbukdo lexicon from [18]. They were selected by the second author through consulting a number of elderly Yanbian Korean speakers with differing socio-economic status. Only the words with the first open syllables headed by 9 plosive /p, p^h, p*, t, t^h, t*, k, k^h, k*/ were selected. The syllable rhyme

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consisted of either single vowels or combinations of a glide and a vowel ([jʌ (ㅕ)] as an example). Since words in Hamkyungbukdo are tonally specified with a high tone in citation form, normally at the final or penultimate position, the initial syllable with a high tone was excluded. Additionally, the frequencies for the 9 Korean plosives were unbalanced, with lenis velar plosive having highest frequency and fortis and aspirated having lower frequency in the first syllables of Hamkyungbukdo words.

Two male speakers (M1 and M2) aged 78 and 61 respectively, and three female speakers (F1, F2, and F3) aged between 86 and 61, participated into the experiment. M1 and F1 were born in Hamkyungbukdo in North Korea, and immigrated into Yanbian in their childhood. M2, F2 and F3 were born and brought up in Yanbian. All speakers used Yanbian Korean in daily communication, and their proficiency of Chinese was far inferior to their native language except M1. Their accent was judged to be the vernacular Yanbian Korean. All speakers reported no voice pathology or disorders, and were paid for the participation.

2.2. Recording and annotation

The speakers were instructed to read the word list at comfort-table speech rate. Each recording session was limited to 15-20 minutes with inter-session rest time lasting for 5-10 minutes. The number of word varied among speakers because they were instructed to read familiar words. Recording time length was cut short for F1 who was 86.

EGG and acoustic signals were recorded simultaneously on Audition with a sampling rate of 44100 Hz. The EGG signal was acquired by Laryngograph EGG-D200. The acoustic signal was acquired by a head-mounted AKG condenser micro-phone and was fed into the EGG-D200.

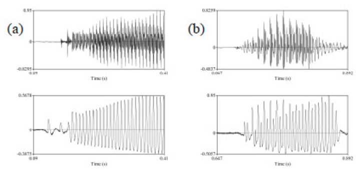

Figure 1: *Pre-vocalic EGG pulsation (a) and diplophonia EGG wave shape (b).*

The speech samples were screened for excluding pronunciation errors or ambiguous pronunciations. After screening, 1,183 words spoken by five speakers were selected and submitted for phonetic analysis. The EGG and acoustic signals were annotated in PRAAT [19]. For fortis plosives, the first periodic pulsation in acoustic waveform was taken as the start of vowels. Two types of EGG wave shape were annotated. The first was the pre-vocalic EGG pulsation, which is indicative of laryngealization (Figure 1(a)). The second was the diplophonia EGG wave shape starting from vowel onset and possibly covered the whole syllable (Figure 1(b)). The demarcation for syllables headed by lenis or aspirated was determined by the first periodic pulsation in both EGG and acoustic waveforms. For the latter, the aspirated interval manifested at vowel initial interval was included as long as consecutive periodic low-amplitude EGG pulsations were identified.

2.3. Data acquisition and statistical analysis

CQ_{EGG} and SQ_{EGG} were obtained via mixed method [20]. The glottal closure instant (GCI) was determined by positive maximum in derivative EGG (DEGG), and the glottal opening instant (GOI) was at the 3/7 threshold in the EGG decontacting phase. CQ_{EGG} is the ratio of the duration of closed phase (Between a GCI and a following GOI) to period. This measure has been considered to reliably reflect the glottal constriction. SQ_{EGG} was defined differently from previous studies. It was measured as the ratio of the duration of contacting phase to that of decontacting phase, divided by the point of peak EGG in the closed phase [21]. This measure reflects the skewness of EGG waveform. $F0_{EGG}$ was calculated as the reciprocal of the duration between two consecutive GCIs. The Peak Increase of Contact (PIC) was determined by the positive peak in the DEGG, which reflects the peak rate of increase of vocal fold contact [22]. Three consecutive values for CQ_{EGG}, SQ_{EGG} and PIC at initial, middle and final portion of syllable interval were averaged respectively and z-scored for each speaker. Only initial and medial averages were submitted to statistical analysis. The onset $F0_{EGG}$ was also z-scored to normalize the inter-personal variation.

The acoustic measures included H1*-H2*, H4*-H2K*, H1*-A1*, H1*-A3*, H2*-H4*, H2K-H5K*, H1*-A2*, Cepstral Peak Prominence (CPP), Harmonic-to-Noise Ratio (HNR), and Sub-harmonic-to-Harmonic Ratio (SHR). The measures were obtained via VoiceSauce [23], and their relevance to phonation was detailed in [24]. The spectral measures of vowels were adjusted in VoiceSauce. Each acoustic measure was averaged for initial, medial, and final one third portion of syllable respectively, and the z-scored data for the first two portions were used for analysis.

Generalized Linear Model in SPSS 22 was applied for main effect and interaction effect. The fixed factors include manner of plosive and gender. One-way ANOVA was administered for simple effect in case of significant interaction effect, and Bonferroni method was used for post-hoc comparison tests.

3. Results

3.1. EGG measures

Table 1 shows the GLM results for the main effects of manner, gender, and their interaction on EGG measures. The main effect of manner is significant for CQ_{EGG} and PIC at both positions. The main effect of gender is significant for CQ_{EGG} at middle position, and SQ_{EGG} and PIC at initial position. The manner by gender interaction is found for PIC at initial position, and all three measures at middle position.

Table 1: *The p values for main and interaction effects on EGG measures.*

Position	Measure	Manner	Gender	Manner*Gender
Initial	CQ_{EGG}	***0.000***	0.254	0.563
	SQ_{EGG}	0.105	***0.000***	0.084
	PIC	***0.000***	***0.000***	***0.000***
	$F0_{EGG}$	***0.000***	***0.021***	***0.000***
Middle	CQ_{EGG}	***0.000***	***0.000***	***0.011***
	SQ_{EGG}	0.887	0.558	***0.000***
	PIC	***0.001***	0.165	***0.000***

Figure 1 shows the averaged z-scored EGG measures by plosive manner and gender. The fortis induces significantly higher CQ_{EGG} than the lenis at both positions regardless of gender. The aspirated is patterned with the lenis at onset, but in the middle position it is patterned with the lenis for female speakers and with the fortis for male speakers (Figure 2(a, d)). SQ_{EGG} is shown to be a less reliable measure for fortis/lenis distinction, and the significant interaction derives from gender-related patterning of the aspirated with the fortis or lenis (Figure 2(b, e)). PIC is shown to effectively distinguish the fortis/lenis contrast for female speakers with significantly lower PIC for the fortis versus the lenis. The aspirated is patterned with the lenis for female speakers, indicating breathy phonation for the two manners compared with the fortis [22]. A different picture arises for male speakers in terms the fortis/lenis distinction: while no significant difference was found at onset, the fortis brings about significantly higher PIC at middle position. The aspirated induced breathy phonation at the onset, complying with the data for female speakers, but is patterned with the fortis (Figure 2(c, f)).

These results suggest that the fortis plosives induce more constricted glottis whereas lenis and aspirated plosive induce less constricted glottis at two positions; Aspirated-induced phonation shows gender-related variation in the course of syllables. The ineffectiveness of SQ_{EGG} in the fortis/lenis distinction and the patterning regarding the aspirated with the other two classes is unexpected, for the lenis was found to induce more symmetrical EGG wave shape in our previous study [17]. This might be attributed to the physiological aging effect [25-27]. PIC is proved to be an effective measure in distinguishing breathy phonation from more "laryngealized" phonation for female at both position, and for male speakers at onset. However, these results are tentative due to the limited number of speakers, and lack of comparison with the data from younger and middle-aged speakers.

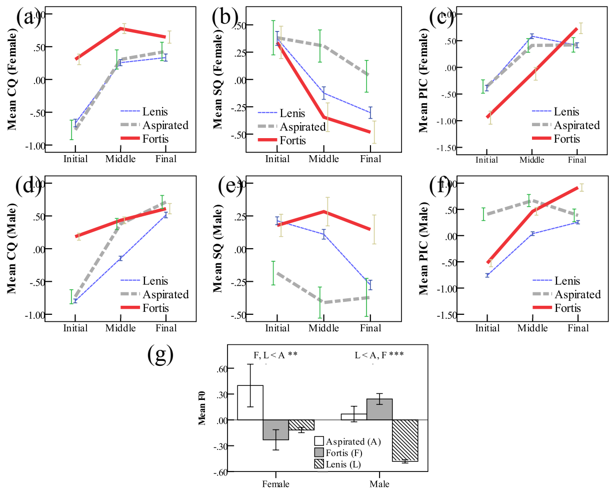

Figure 2: *Averages of z-scored EGG measures by plosive manner and gender (Error bars stand for standard error of the mean).*

The manner factor significantly affects onset $F0_{EGG}$, which is interacted with gender factor. Separate one-way ANOVA results show that the aspirated brings about significantly higher $F0_{EGG}$ than the lenis across genders (Figure 2(g)). However, the patterning for the fortis-induced $F0_{EGG}$ is different between genders. For female speakers, the fortis is patterned with the lenis and induces significant lower $F0_{EGG}$ than the aspirated. For male speakers the fortis is patterned with the aspirated and induces significant higher $F0_{EGG}$ than the lenis. While the aspirated/lenis contrast in onset F0 complies with previous study (See [9] for a review), the patterning of the fortis needs further explanation.

In our EGG data, four patterns of EGG wave shape were identified for fortis-induced phonation. The first type (Type I) is characterized by the one or two EGG pulsations either before plosive release or before vowel onset (Figure 1 (a)), which resembles vowel-initiated words and is suggestive of laryngealization. The second type (Type II) is characterized by the diplophonia phonation with periodic variation for EGG amplitude (Figure 1 (b)). This type of EGG waveform corresponds with the creaky phonation. The third type (Type III) is characterized by the combination of Type I and Type II. The fourth type (Type IV) has neither pre-vocalic EGG pulsation nor diplophonia phonation over the vocalic interval. This suggests multiple laryngeal realizations for the production of the fortis in Yanbian Korean.

Table 2: *Frequency of the four types in percentage by fortis plosives and speakers.*

Fortis	Type	F1	F2	F3	M1	M2
/p*/	Type I	0	25	50	100	100
	Type II	60	0	10	0	0
	Type III	40	75	0	0	0
	Type IV	0	0	40	0	0
/t*/	Type I	0	33	25	100	86
	Type II	0	33	0	0	0
	Type III	100	22	0	0	0
	Type IV	0	11	75	0	14
/k*/	Type I	29	23	61	88	76
	Type II	29	35	0	0	0
	Type III	42	23	0	12	24
	Type IV	0	19	39	0	0

Table 2 shows the frequency of four types of EGG realization for the fortis. It can be seen that the laryngeal behavior associated with the fortis differs considerably across speakers and fortis plosives. Male speakers show predominately high frequency for pre-vocalic EGG pulsation, indicating the longitudinal tensing mechanism [28]; The frequency of the diplophonia slightly increases for fortis velar plosives. Considerable variation is found for female speakers. For F1 and F2 the majority of tokens fall into Type II or Type III category, suggestive of the medial compression and adductive tension mechanism responsible for low F0. However, F3 tends to laryngealize the fortis. These frequency distribution of the realization for the fortis corresponds with the gender-related $F0_{EGG}$ results. The lower $F0_{EGG}$ for female speakers is strongly associated with diplophonia phonation. On the contrary, male speakers tend to laryngealize the fortis in their production, which leads to higher vowel onset F0.

3.2. Acoustic measures

Several observations emerge from Table 3 which shows the GLM results for the main effects of meaner, gender, and their interaction on acoustic measures. First, the GLM results show predominate main effect of manner on spectral measures, except H2*-H4* at both positions and H4*-H2K* in middle position. The sole significant interaction was found for H1*-H2* at both portions. One-way ANOVA results indicate that the fortis induce significant lower H1*-H2* than the lenis across genders at both positions. The significant interaction is largely caused by the patterning of the aspirated for two genders. The aspirated is generally patterned with the lenis for female, and is intermittent between the fortis and the lenis at onset position for male speaker (See Figure 3 (a, b)). The H1*-A1*, H1*-A2* and H1*-A3* differ significantly between the fortis and lenis at both positions. The aspirated is generally patterned with the lenis (Figure 3 (c-e)). The fortis induces significantly lower H4*-H2K* than the aspirated at onset position, but no significant difference is found between the fortis and the lenis (Figure 3 (f)). H2K*-H5K* does not differ between the fortis and the lenis, but is significantly lower for the aspirated (Figure 3 (g)). Altogether, the spectral measures converge to show that the fortis brings about slower spectral tilt and thus greater vocal fold effort than the lenis does. The lenis tends to bring about more breathier phonation compared with the aspirated, which is already breathier than the fortis.

Table 3: *The p values for main and interaction effects on acoustic measures*.

Position	Measure	Manner	Gender	Manner*Gender
	H1*-H2*	***0.000***	0.189	***0.002***
	H2*-H4*	0.820	0.243	0.853
	H1*-A1*	***0.000***	0.692	0.717
	H1*-A2*	***0.000***	0.282	0.602
	H1*-A3*	***0.000***	0.727	0.182
	H4*-H2K*	***0.028***	0.09	0.564
Initial	H2K*-H5K*	***0.010***	0.772	0.088
	CPP	0.109	***0.012***	***0.000***
	HNR0-0.5kHz	***0.013***	***0.002***	***0.000***
	HNR0-1.5kHz	0.310	***0.000***	***0.000***
	HNR0-2.5kHz	0.082	***0.004***	***0.000***
	HNR0-3.5kHz	0.065	***0.001***	***0.000***
	SHR	***0.000***	0.162	0.410
	H1*-H2*	***0.000***	0.054	***0.033***
	H2*-H4*	0.908	0.738	0.956
	H1*-A1*	***0.000***	0.976	0.909
	H1*-A2*	***0.000***	0.307	0.125
	H1*-A3*	***0.000***	0.837	0.180
	H4*-H2K*	0.157	0.600	0.455
Middle	H2K*-H5K*	***0.007***	0.546	0.213
	CPP	0.439	0.794	***0.000***
	HNR0-0.5kHz	***0.025***	0.242	***0.000***
	HNR0-1.5kHz	0.524	0.090	***0.000***
	HNR0-2.5kHz	0.619	0.271	***0.000***
	HNR0-3.5kHz	0.682	0.262	***0.000***
	SHR	***0.000***	0.188	0.782

Second, the CPP and the HNR measures are shown to be more related with gender. Female speakers generally produce lower values for the fortis versus lenis whereas the reverse is true for male speakers at both positions, indicating that noise component is much salient for female speakers (Figure 3 (h-k)). Third, the SHR measure is shown to be significantly affected by the manner factor regardless of gender (Figure 3 (l)). The fortis induces significant higher SHR than lenis plosives at two positions while no significant difference is found between the lenis and aspirated.

4. Discussion and conclusion

The EGG-acoustic properties of vocalic phonation are shown to be affected by the tripartite plosives in Yanbian Korean. A novel finding is that the fortis incurs the diplophonia phonation, which is seldom reported in previous studies. Though diplophonia is generally considered pathologically-related, it is by no means a rare phonetic property. This type of creakiness is termed as "double-pulse creak" [29], and is manifested as glottalization at prosodic boundaries [30]. Physiologically, it might be involved with both ventricular and vocal fold vibration [31, 32]. Besides, four types of EGG waveform are identified for fortis-incurred phonation, which vary between genders and place of plosives, and the articulatory and acoustic results converge to show that they are characterized with constricted glottis, slow spectral tilt, and higher SHR. Lenis-induced phonation is shown to be breathier with smaller Contact Quotient and fast spectral tilt. Most articulatory and acoustic measures for the aspirated are shown to be patterned with the lenis. However, sporadic difference between the two indicates that the lenis induces more breathier phonation. Gender difference is salient in term of fortis production, as female speakers tend to adopt medial compression and adductive tension mechanisms, and male speakers the longitudinal tensing mechanism.

Yanbian Korean shows a stark difference from Seoul Korean in how the fortis is produced in word-initial syllables. The tonal specification for word-initial syllable might be an important factor conditioning the phonatory difference across the two Korean accent (See [33] for tonal specification in Seoul Korean). The salient creaky phonation provides the phonetic basis for [tense] feature. The possible involvement of ventricular folds, which press on vocal folds and add the vibrating mass [34], might explain the low $F0_{EGG}$ for female speakers. These altogether indicate that [tense] feature is substantiated by active constricting the vocal folds and ventricular folds. However, this result should be taken caution because creak is not the only way of fortis-induced phonation, and high-toned and word medial or final syllables were not taken into consideration. The resemblance of breathier phonation between the lenis and the aspirated complies with the previous studies. However, this conclusion should also be taken into caution because of gender difference, which deems further research by increasing speaker number.

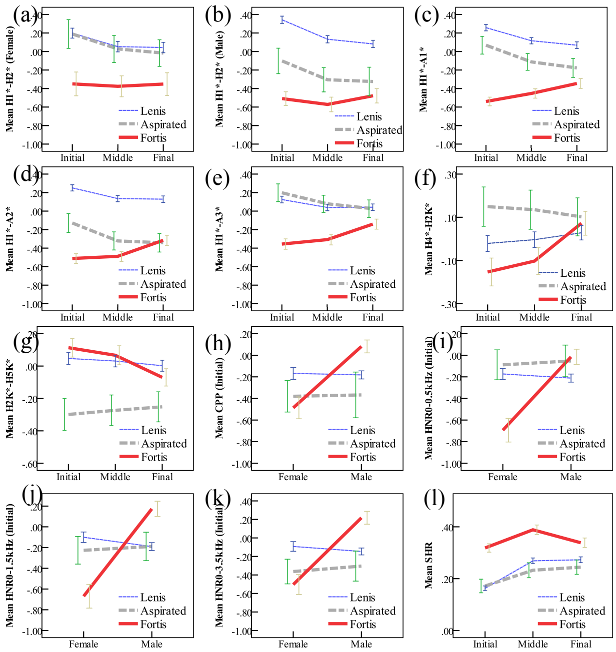

Figure 3: *Averages of z-scored acoustic measures by plosive manner and/or gender.*

5. Acknowledgements

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