ePGG, airflow and acoustic data on glottal opening in Korean plosives

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ABSTRACT

This paper is concerned with glottal opening in the Korean lenis (/p t k/), aspirated (/p^h t^h k^h/) and fortis (/p' t' k'/) plosives, using a new non-invasive technique called external lighting and sensing photoglottograph (ePGG) as well as airflow and acoustic data. From the simultaneous recording of ePGG, airflow and acoustic data, we have investigated (a) the timing relations among glottal opening onset and peak, glottal closing onset, airflow onset and peak, and aspiration onset in relation to acoustic events such as a consonant release onset and a vowel onset; (b) how much the peak of glottal opening area, glottal closing speed and airflow peak height occur; and (c) what acoustic conditions arise in accordance with the three-way phonation contrast.

Keywords: ePGG, glottal opening, Korean three-way phonation contrast, [±spread glottis]

1. INTRODUCTION

The present study is to investigate what aerodynamic and acoustic aspects arise in accordance with glottal opening in the production of Korean plosives and whether glottal opening between word-initial aspirated and lenis consonants is different or not in the production of the consonants by young Korean speakers. In recent MRI studies ([1], [2], [3]), glottal opening as one of two independent systematic controls in the production of Korean consonants has been proposed to be incorporated into the articulator-bound feature [±spread glottis] in line with Halle and Stevens ([4]). Our examination of simultaneous recording of ePGG, airflow and acoustic data on the Korean lenis (/p t k/), aspirated (/p^h t^h k^h/) and fortis (/p' t' k'/) plosives in the present study would provide further evidence for the articulator-bound feature if airflow and acoustic data covary with glottal opening specific to the three-way phonation contrast. In addition, it has been suggested that Korean aspirated and lenis plosives are distinguished not in VOT but in the H and L tonal difference in word-initial position especially by young Seoul Koreans who were born after 1982 (e.g., [5]). If the distinction of word-initial aspirated and lenis consonants were tonal, then glottal opening between the two types of consonants would not be different in word-initial position in the case of young Korean speakers. In order to address these issues, we obtained ePGG, airflow and acoustic data on the Korean plosives.

2. METHODS

2.1. Materials and participants

The test words in the present study are given in (1) with the Korean plosives /p p^h p' t t^h t' k k^h k'/ put in the context /_a_a/ word-initially and word-medially.

(1)	/papa/	/tata/	/kaka/
	/p^{h}ap^{h}a/	/t^{h}at^{h}a/	/k^{h}ak^{h}a/
	/p'ap'a/	/t'at'a/	/k'ak'a/

Four native speakers (2 male and 2 female) of Seoul Korean participated in the present experiment. Three of them were born between 1985-1991, and one subject in the late 1950s. All the subjects read the test words in (1) embedded in the frame sentence /næka __ palɨmhapnita/ 'I pronounce __' five times at a normal speaking rate. The 180 tokens (9 test words x 5 repetitions x 4 subjects) were then analyzed.

2.2. Procedure

The adduction-abduction movement of the glottis during the production of the Korean plosives was monitored with the light source being infrared light emitting diodes (IR LEDs) placed on the neck exterior surface between the hyoid bone and the thyroid cartilage. Normally, two IR LEDs are placed on the sides of the larynx to illuminate the phypopharyngeal wall, as shown in Figure 1 (a). When a subject has a thick layer of the subcutaneous fatty tissue, the LED light is placed on the midline neck surface to illuminate the base of the epiglottis reducing the light transmission through the fatty tissue, as in Figure 1 (b). The IR light illuminates the cavity above the glottis, which allows glottal transillumination to be detected by a photodiode placed on the neck surface below the cricoid cartilage. A new ePGG technique in the present study is non-invasive and applicable to unrestricted speech materials. Another advantage of our ePGG method is that it is possible to obtain the multichannal (i.e., ePGG, airflow and acoustic) data on natural speech from as many subjects as possible. Airflow rate was measured by the principle of pressure-difference anemometry using a protection mask made of soft tissue and a differential pressure sensor, as in Figure 2.

Figure 1: External lighting and sensing photoglottograph (ePGG) system with a high-power light emitting diode (LED) on the surface of (a) a side and of (b) the front of the neck of a subject.

a. b.

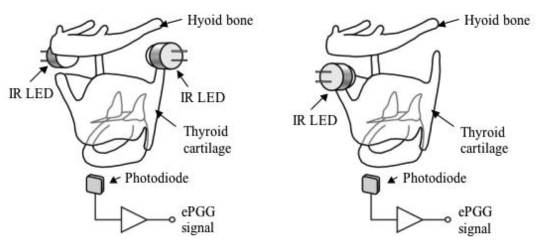
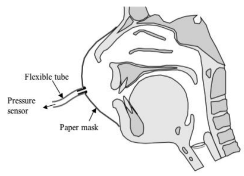


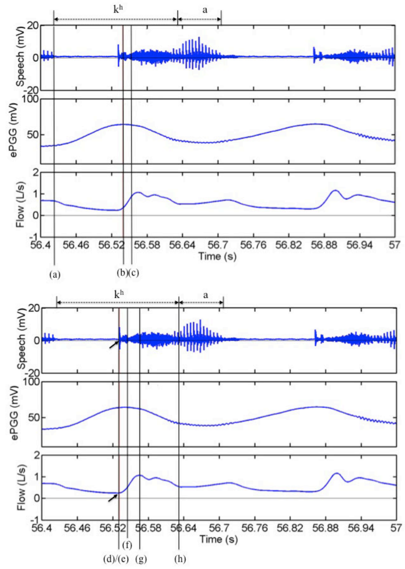
Figure 2: A method for recording oral airflow with a protection mask made of soft tissue.



Eight temporal reference points were measured using Matlab. For example, in the case of the word-initial aspirated plosive /k^h/ in Figure 3, we measured, as indicated at the bottom of the third panel, the time (a) at which a glottal opening onset occurs (t_{GOO}), (b) at which a glottal opening peak occurs (t_{GOP}) and (c) at which a glottal closing onset occurs (t_{GCO}), along the ePGG curve seen as in the upper figure; and (d) at which a consonant release occurs (t_{CRO}), as marked by the upper little arrow in the lower figure, (e) at which airflow onset occurs (t_{FWO}), as marked by the lower little arrow, (f) at which aspiratation starts (t_{ASPO}) after a consonant release with a little frication noise, (g) at which airflow reaches its peak (t_{FWP}) and (h) at which a following vowel starts (t_{VO}), as in the lower figure.

Five temporal variables were then considered, as listed in (2). Since the time at a consonant release, i.e., the consonant release onset (t_{CRO}) is an important acoustic event in the production of all the three-way phonation contrast in the Korean plosives, we calculated time intervals between the consonant release onset and four other events for the variables T_{GOO}, T_{GOP}, T_{GCO} and T_{FWP}, as in (2 a-d). The duration of aspiration, T_{ASP} was defined as the time interval between aspiration onset and a vowel onset ($T_{ASP} = t_{VO} - t_{ASPO}$), as in (2e).

Figure 3: Our temporal reference points



(2) a. $T_{GOO} = t_{CRO} - t_{GOO}$
b. $T_{GOP} = t_{CRO} - t_{GOP}$
c. $T_{GCO} = t_{CRO} - t_{GCO}$
d. $T_{FWP} = t_{FWP} - t_{CRO}$
e. $T_{ASP} = t_{VO} - t_{ASPO}$

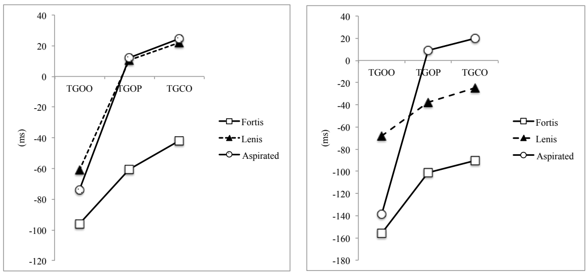
In addition, we measured ePGG values at the time of glottal opening peak (t_{GOP}) and at the time of glottal opening onset (t_{GOO}) and deducted the latter from the former in order to examine how much the peak of glottal opening area occurs during the production of the Korean plosives. Not only the peak of glottal opening area but also glottal closing speed was measured. The difference in ePGG values between glottal closing onset at t_{GCO} and vowel onset at t_{VO} was divided by the time interval between vowel onset (t_{VO}) and glottal closing onset (t_{GCO}). Airflow values were also measured at the time of airflow peak (t_{FWP}) and at the time of airflow onset (t_{FWO}), and by deducting the airflow value at t_{FWO} from that at t_{FWP} we obtained the airflow peak height.

3. RESULTS

In word-initial position the time of glottal opening onset (t_{GOO}) starts much earlier in the fortis plosives than in the aspirated and lenis ones, in all our four subjects, before a consonant release which is marked as "0" on the vertical axis, as shown in Figure 4 (a). In the case of glottal opening peak (t_{GOP}) and glottal closing onset (t_{GCO}), they occur before a consonant release in the fortis plosives, and after the release in the order the lenis < aspirated ones. In word-medial position, the subjects M1, M2 and W1 who were born after 1982 had a phonetic voicing of lenis plosives. In contrast, the subject W2 had no voicing, which made it possible to measure t_{GOO}, t_{GOP} and t_{GCO} in the lenis plosives as in the fortis and aspirated ones. As shown in Figure 4 (b), the subject W2 had the glottal opening onset in the order fortis < aspirated < lenis plosives before a consonant release, and the glottal opening peak and closing onset in the order fortis < lenis <aspirated ones with the first two before the release and the other after the release.

Figure 4: The average time intervals between a consonant release onset and three other events for the variables T_{GOO}, T_{GOP}, T_{GCO} in the fortis, lenis and aspirated plosives (a) word-initially (for our four subjects) and (b) word-medially (for the subject W2).

a. b.



Though the average time intervals for T_{GOO}, T_{GOP} and T_{GCO} in the lenis plosives are more similar to those in the aspirated ones in word-initial position in our four subjects, as in Figure 4 (a), the peak of glottal opening ranges from low to high in the order fortis < lenis < aspirated plosives word-initially, as shown in Figure 5. A repeated measures ANOVA showed a significant main effect of Laryngeal Category on glottal opening peak [$F(2, 18) = 10.310$, $p = 0.001$] for the subjects M1, M2 and W1 in Figure 5 (a). In word-medial position, the subjects M1, M2 and W1 had a similar glottal opening peak of the fortis and aspirated plosives to that of the word-initial counterparts. In the case of the subject W2 who had no voicing of lenis plosives in intervocalic position, the glottal opening peak of lenis plosives is lower than that of fortis ones, as in Figure 5 (b). Note that the scales of glottal opening peak in Figure 5 (a) and (b) are different, because ePGG data were obtained for the subjects M1, M2 and W1, as in Figure 1 (a), and for the subject W2, as in Figure 1 (b).

The glottal closing speed also ranges from low to high in the order fortis < lenis < aspirated word-initially in our four subjects, as in Figure 6. In particular, Figure 6 (b) shows that the pattern of glottal closing speed in word-medial position is the same as that in word-initial position, in the case of the subject W2.

Figure 5: The average glottal opening peak of the fortis, lenis and aspirated plosives in word-initial (WI) and word-medial (WM) positions in (a) the subjects M1, M2 and W1 and (b) the subject W2.

a. b.

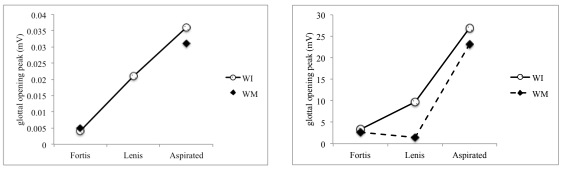
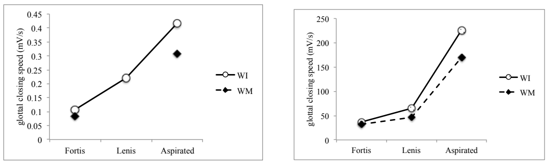


Figure 6: The average glottal closing speed of fortis, lenis and aspirated plosives in word-initial (WI) and word-medial (WM) positions in (a) the subjects M1, M2 and W1 and (b) the subject W2.

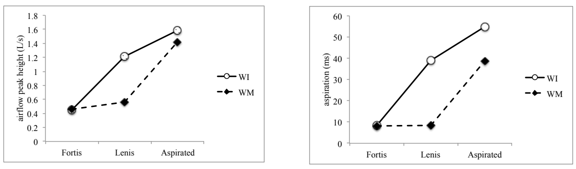
a. b.



After a consonant release of each plosive, aspiration and airflow peak height also occur in accordance with the glottal opening in the three-way phonation contrast. As shown in Figure 7, the duration of aspiration ranges from short to long in the order fortis < lenis < aspirated plosives, and airflow peak height ranges from low to high in the same order in word-initial position in our four subjects. A repeated measures ANOVA showed a significant main effect of Laryngeal Category on airflow peak height [$F(2, 27) = 8.932$, $p = 0.001$] and on aspiration [$F(2, 27) = 23.335$, $p < 0.001$]. In word-medial position, we also noted a significant main effect of Laryngeal Category on airflow peak height [$F(2, 27)=15.117$, $p<0.001$] and on aspiration [$F(2, 27) = 141.777$, $p < 0.001$].

Figure 7: The average of (a) airflow peak height and (b) aspiration in word-initial (WI) and word-medial (WM) positions in our four subjects.

a. b.



4. DISCUSSION

The results of our experimental data have shown the laryngeal-oral coordination of glottal opening and a consonant release and the covariance of airflow peak and aspiration with glottal opening in the production of the three-way phonation contrast in Korean plosives. The similar pattern in glottal closing speed, airflow peak height and aspiration to that in glottal opening peak suggests that the more the glottis opens during the oral closure of a plosive, the higher the glottal closing speed and airflow peak height occurs and the more aspiration arises in both word-initial and word-medial positions. This provides another piece of evidence for glottal opening as one of the two independent and systematic controls in Korean consonants (e.g., [1], [2]. [3]). In addition, our phonetic data have shown that the subjects M1, M2 and W1 who were born after 1982 had intermediate glottal opening peak, closing speed, airflow peak height and aspiration in the word-initial lenis plosives between the fortis and aspirated counterparts like the subject W2. In word-medial position, however, the airflow peak height and aspiration of the lenis plosives are significantly reduced in our four subjects [$t(11)=3.615$, $p=0.004$ in airflow peak height; $t(11)=7.324$, $p<0.001$ in aspiration]. In contrast, the fortis and aspirated plosives had no significant difference in airflow peak height, no matter whether they are in word-initial or word-medial position. Aspiration is significantly reduced in word-medial aspirated plosives, compared to word-initial ones, but the difference is not that big as in the lenis plosives. This leads us to suggest that the significant difference in airflow peak height and aspiration between word-initial and word-medial lenis plosives has to do with the laxness of the lenis plosives in comparison with the fortis and aspirated ones which are classified as tense (e.g., [1], [2], [3], [6]). In both word-initial and word-medial positions, the oral closure duration and glottal raising of lenis plosives have been found to be shorter and lower, respectively, than the fortis and aspirated counterparts ([1], [2], [3]). F0, which is articulatorily correlated with glottal raising, that is, the tensing of the vocal folds, is lower after lenis plosives than after the other ones (e.g., [6], [7]). Thus, we suggest that the laxness of lenis plosives leads to context-dependent glottal opening, whereas the tenseness of fortis and aspirated ones makes their glottal opening relatively consistent in both word-initial and word-medial position, as in Figure 5. That is, the lenis plosives are likely to have a larger glottal opening than the fortis ones and a smaller one than the aspirated ones in word-initial position. When placed in intervocalic word-medial position, the lenis plosives are easily affected by surrounding vowels, resulting in either phonetic voicing, as in the subjects M1, M2 and W1, or a smaller glottal opening than fortis ones when the phonetic voicing does not occur, as in the subject W2 in Figure 5 (b).

Given the context-dependent glottal opening of the lenis plosives due to their laxness as well as the covariance of airflow peak height and aspiration with glottal opening, we propose that glottal opening is incorporated into the articulator-bound feature [+spread glottis] (henceforth, [+s.g.]) and that the lenis plosives are specified as [-s.g.] like the fortis ones in both word-initial and word-medial positions. The specification of the lenis plosives as [-s.g.] in word-initial position is phonologically supported by the sound pattern in (3). Some word-initial lenis consonants change into their fortis counterparts in order to convey speakers' intensified feelings ([8], [9]). No aspirated counterparts occur. The phonological grouping of the lenis and fortis consonants to the exclusion of aspirated ones in (3) is given an account in terms of the feature [±s.g.], and lenis consonants which are lax (i.e. [-tense]) change to fortis counterparts which are [+tense] in the intensified expressions.

(3) Intensified expression in native Korean words

pɛ.k'i.ta	p'ɛ.k'i.ta	* p^hɛ.k'i.ta	'to copy'
ka.si	k'a.si	* k^ha.si	'thorn'
taŋ.ki.ta	t'aŋ.ki.ta	* t^haŋ.ki.ta	'to pull'

5. REFERENCES

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