This paper is concerned with the phasing of glottal opening and three-way phonation contrast in the Korean lenis (/p t k/), aspirated (/pʰ tʰ kʰ/) and fortis (/p’ t’ k’/) plosives based on simultaneous recordings of articulatory, aerodynamic and acoustic data, in an attempt to refine our understanding of laryngeal features involved in the phonation contrast. For this purpose we have obtained a new non-invasive technique called external lighting and sensing photoglottograph (ePGG) as well as Pio (intra-oral air pressure), airflow and acoustic data, and the following investigations were made: (a) the timing relations among glottal opening onset and peak, 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 and airflow peak height occur; and (c) what acoustic and Pio conditions arise in accordance with the three-way phonation contrast.

All the ePGG, airflow and acoustic data were simultaneously recorded using Dash8x at a soundproof recording room. The adduction-abduction movement of the glottis during the production of the plosives in the context / a a/ was monitored with light emitting diodes (IR LEDs) placed on the neck exterior surface between the hyoid bone and the thyroid cartilage, as shown in Figure 1. Normally, two IR LEDs are placed on the sides of the larynx to illuminate the pharyngaryngeal wall. When a subject has a thick layer of the subcutaneous fatty tissue, the LED light tends to transmit through the fatty layer without sufficient lighting the cavity. In this case, the LED is placed on the midline neck surface to illuminate the base of the epiglottis reducing the light transmission through the fatty tissue. 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. Compared with previous photoglottograph (PGG), our new ePGG technique is non-invasive and applicable to unrestricted speech materials. Airflow rate was also measured by the principle of pressure-difference anemometry using a protection mask made of soft tissue and a differential pressure sensor. The use of the soft-tissue mask permits both measurement of air pressure inside the mask relative to the atmosphere pressure and speech recording with minimal audio distortion. The relation between air pressure and airflow rate is established by a calibration procedure on the individual mask using a 1 liter syringe. Pio was measured by inserting a pressure probe to the pharyngeal cavity via the nostril with the help of a medical doctor and also obtained simultaneously with airflow and acoustic data of the Korean plosives using Dash8x. Four native speakers (2 male and 2 female) of Seoul Korean participated in the experiment. All the subjects read the test words in (1) embedded in the frame sentence /næka__palimhapnita/ ‘I pronounce __’ five times at a normal speaking rate. The 180 tokens (9 test words x 5 repetitions x 4 subjects) were then analyzed.

The results of our experimental data have shown (a) the laryngeal-oral coordination of glottal opening and a consonant release and (b) the covariance of airflow peak and aspiration with glottal opening in the production of the three-way phonation contrast in the plosives. That is, after a consonant release of each plosive, we have found that airflow peak height and aspiration occur in accordance with glottal opening in the three-way phonation contrast. Thus, the more the glottis opens at a consonant release onset, the higher airflow peak height occurs and the more aspiration arises in the order fortis (<) lenis < aspirated plosives in both word-initial and word-medial positions. The relative timing between an airflow peak and a consonantal release onset and between an aspiration onset and a vowel onset mostly varies from short to long in the same order. We have also found that the duration of consonant oral closure and that of the corresponding high Pio plateau are independent of glottal opening, varying from short to long in the order lenis < aspirated, fortis plosives across the contexts.

From the covariance of airflow peak and aspiration with glottal opening as well as the laryngeal-oral coordination of glottal opening and a consonant release, we propose that the pattern of glottal opening – a wider glottal opening in aspirated plosives than in the other non-aspirated ones – at a
consonant release onset is incorporated to the binary articulator-bound laryngeal feature [±spread glottis] (henceforth, [±s.g.]), using the feature in Halle and Stevens (1971). Thus, aspirated consonants are specified for [+s.g.] and the other for [-s.g.] in both word-initial and word-medial positions, as in (2a). As for the phonation-type specific duration of consonant closure and a high Pio plateau which is independent of glottal opening, we propose that it is correlated with the tensing of the primary articulator (i.e. the lips, the tongue blade or dorsum) and the vocal folds, thus being incorporated into the other articulator-bound laryngeal feature [±tense] in line with Kim, Maeda and Honda (2010, 2011). Hence, aspirated and fortis plosives are specified for [+tense] and lenis for [-tense], as in (2b). It is concluded that ePGG, Pio, airflow and acoustic data in the present study provide empirical evidence for the articulator-bound laryngeal features [±s.g.] and [±tense] in the three-way phonation contrast, in addition to the MRI data in Kim, Honda and Maeda (2005) and Kim, Maeda and Honda (2010).

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.

(1) The test words in the present study
/papa/ /tata/ /kaka/
/pʰa⁴pʰa/ /tʰa⁴tʰa/ /kʰa⁴kʰa/
/p’ap’a/ /t’a⁴t’a/ /k’a⁴k’a/

(2) The laryngeal feature specification of Korean consonants

<table>
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<tr>
<th></th>
<th>lenis</th>
<th>aspirated</th>
<th>fortis</th>
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<tr>
<td>a. [spread glottis]</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>b. [tense]</td>
<td>-</td>
<td>+</td>
<td>+</td>
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Selected references


