

# Laryngeal control in Korean stop production

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## Abstract:

An electromyographic (EMG) study was made to investigate the actions of the intrinsic laryngeal muscles in the production of Korean stops. The results indicated that coordinated action of the intrinsic laryngeal muscles characterized the different types of Korean stops. Type III (aspirated) stop appeared to be characterized by marked suppression of all the adductor muscles immediately before the articulatory release. In type I (forced) stop, thyroarytenoid (VOC) showed a sharp increase in activity before the stop release, which presumably resulted in an increase in inner tension of the vocal folds as well as in constriction of the glottis during or immediately after the articulatory closure. In type II (lax) stop, the suppression of adductors was less predominant and there was no transient increase in VOC activity before release. It seems reasonable to consider, at least for Korean stops, that the laryngeal articulatory adjustment is not limited in a simple dimension of adduction-abduction of the vocal folds, but another dimension, represented by VOC activity for example, also must be taken into consideration.

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## Introduction

In Korean there is a three-way distinction in both manner and place of articulation that differentiates nine stop consonant phonemes. Linguists have disagreed about the manner classifications, describing them phonetically in various ways for initial position. Thus, Category I is characterized as voiceless, tense, long, strong, forced, and/or glottalized; Category II is voiceless, lax, slightly aspirated, and/or weak; Category III is voiceless, heavily aspirated, and lax according to some phoneticians but tense according to others (Martin, 1951; Umeda & Umeda, 1965; Abramson & Lisker, 1972). It is also known that the Category II stop typically becomes voiced intervocalically.

Much has been published in an effort to clarify the acoustical and physiological properties that differentiate these three manner categories. Among those, Lisker & Abramson (1964) made an acoustical investigation into various languages and showed that values of voice onset time (VOT), the temporal relation between stop release and onset of glottal pulsing, provide the most useful measure for differentiating various conditions of voicing and aspiration in word-initial stops. They noted, however, that Korean is peculiar in that the resolution of VOT values between Categories I and II is not clearcut but shows overlapping values, while Category III as well separated from the others. Similar observations have been reported by others (Kim, 1965; Han & Weitzman, 1970).

Abramson & Lisker (1972) later studied the phonetic significance of the VOT values from a perceptual viewpoint by giving a continuum of synthetic VOT variants (Lisker &

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Abramson, 1970) to native speakers for identification as Korean syllables. Their results indicated that there must be another dimension that works with VOT in distinguishing the categories, although the timing of glottal adjustments relative to supraglottal articulation does contribute to the consonant distinctions.

Kagaya (1971) investigated laryngeal gestures in Korean stop production closely in a native speaker using fiberoptic observations. He found that there are differences between the stop types in both the time course of glottal width and the apparent glottal conditions in the succeeding vowel segment. In particular, the adjustment of the vocal folds was found to be substantially different for Category I or "forced" type when compared to the other two. In Category I the glottis closed rapidly and there was complete contact of the vocal processes before the onset of voicing, while a slight opening still remained in the membranous portion of the glottis.

Lee & Smith (1971) measured both intraoral and subglottal air pressures simultaneously during the production of the three kinds of Korean stops. They found that subglottal pressure was higher for Category III, the highly aspirated stop, than for the other two categories. They also compared the dynamic patterns of subglottal pressure slope for the three categories and found that the Category III stop showed the most rapid increase in subglottal pressure in the time period immediately before the stop release. They concluded that the highly aspirated stop was the most "dynamic" in this respect.

In recent years, a considerable number of electromyographic (EMG) studies of the laryngeal muscles have been reported. Among those, the Haskins' group (Hirose & Gay, 1972; Hirose, Lisker & Abramson, 1972) investigated EMG patterns of the intrinsic and extrinsic laryngeal muscles for different kinds of languages and reported that there was a reciprocal pattern of activity between the adductor and abductor muscle groups of the larynx for voiced-voiceless and aspirated-unaspirated contrasts.

The primary purpose of the present study was to investigate electromyographically the actions of the intrinsic laryngeal muscles in production of Korean stop consonants. A native speaker of Korean served as the subject. In a separate experiment an attempt was made to take fiberoptic motion pictures of the glottis of the same subject during stop production.

## Method

### *EMG experiment*

One of the present authors (C.Y.L.), a native Korean speaker from Kyung-sang-book-do, Hwa-dong-myun, was the subject in this experiment. He read randomized lists of test sentences 16 times each. In each sentence a test word was embedded in the frame /ikəsi — ita/ (*This is —*). In the first part of the experiment, test words in the form of CV1 with a short, unstressed vowel were used. The consonant (C) was labial, dental, or velar, and the vowel (V) was /i/, /a/ or /u/. About half of the 27 phonemic sequences thus formed for the test words were nonsense syllables, but they did not violate any phonological constraints of the dialect in question. In the second part of the experiment, test words of the form VCV1 were used.<sup>1</sup>

EMG recordings were made using hooked-wire electrodes. The electrodes were inserted into the interarytenoid muscle (INT) perorally by indirect laryngoscopy using a curved

<sup>1</sup>It was noted in listening tests and oscillographic observations that the vowel /i/ after /s/ in the frame sentence /ikəsi/ was consistently devoiced by this subject yielding [igəʃi] as the pronunciation.

probe, but a percutaneous approach was employed for insertion into the vocalis (VOC),<sup>2</sup> the lateral cricoarytenoid (LCA) and the cricothyroid (CT) muscles. Insertion into the posterior cricoarytenoid (PCA) was also attempted perorally but proved unsuccessful because of anatomical difficulty. EMG activities from the orbicularis oris (OO) and the sternohyoid (SH)<sup>3</sup> were also recorded percutaneously. A more detailed description of the electrode preparation and insertion techniques can be found in previous reports (Hirose, 1971a; Hirose, Gay & Strom, 1971).

EMG signals were recorded on a multichannel data recorder simultaneously with acoustic signals and automatic timing markers. The signals were then reproduced and fed into a computer after appropriate rectification and integration. The EMG signal from each electrode pair was averaged over more than 14 selected utterances of each test sentence with reference to a line-up point on the time axis representing a predetermined speech event. In the present experiment, the release of stop closure in each test word was used for the line-up. The data-recording and computer-processing systems used in the present experiment are described in more detail by Port (1971).

#### *Fiberoptic observation*

Separately from the EMG experiment, motion pictures of the glottis of the same subject were taken using a fiberscope at a film rate of 60 frames/s. As the test utterances isolated nonsense /CVCV/ and /VCV/ words were used, where /V/ was always /i/. Appropriate frame sequences for each type of stop were then examined frame-by-frame with special reference to the time course of glottal width as measured at the vocal processes.

#### **Results**

Figure 1 illustrates averaged EMG curves of VOC and CT for the three different bilabial stops in word-initial position. The zero on the abscissa marks the line-up point for averaging, which corresponds to the release of the stop closure. The time axis is marked off every 100 ms. In each type three curves are superimposed for the postconsonantal vowels /i/, /a/, and /u/, which are represented respectively by thin, thick, and dashed lines.

We note in Fig. 1 that the curves are similar for a given stop type, i.e. those for different postconsonantal vowels coincide fairly well. This holds true both for VOC and CT as shown in the figure, and also for INT and LCA, which are not shown here.

Figure 1 also shows that the pattern of CT activity is more or less constant for the three stop types, being characterized by two peaks separated by a temporal suppression in the middle portion of the test utterance.

Figure 2 compares the activity of INT and VOC for the test utterances containing the three types of bilabial stops in word-initial position followed by the vowel /i/. The INT activity starts to increase before initiation of the test utterance and, after reaching its peak near the beginning of the first vowel [i], activity decreases for the voiceless segment [ʃj]. In the case of Category III /p<sup>h</sup>/, INT activity continues to be suppressed and then steeply increases again near the stop release. In Category II /p/ and Category I /P/, INT activity shows a slight increase after a marked suppression for the [ʃj] segment and then stays on a moderate level.

The activity of VOC also starts to increase before the initiation of the utterance but there is a slight delay in timing when compared with that of INT. The pattern for /p<sup>h</sup>/

<sup>2</sup>Recordings from VOC were not obtained in the session using VCV1 type test words.

<sup>3</sup>The data for SH will not be discussed in this report.

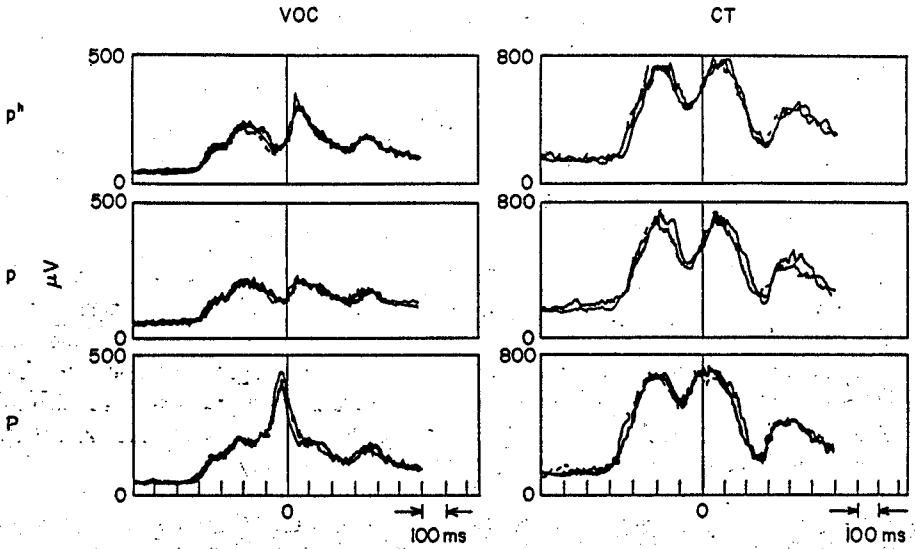


Figure 1

Averaged EMG curves of VOC (left) and CT (right) for the three bilabial stops in word-initial position. In each type, three curves are superimposed for the postconsonantal vowels /i/, /a/ and /u/, represented respectively by thin, thick, and dashed lines. The zero on the abscissa marks the line-up, which corresponds to the release of the stop closure.

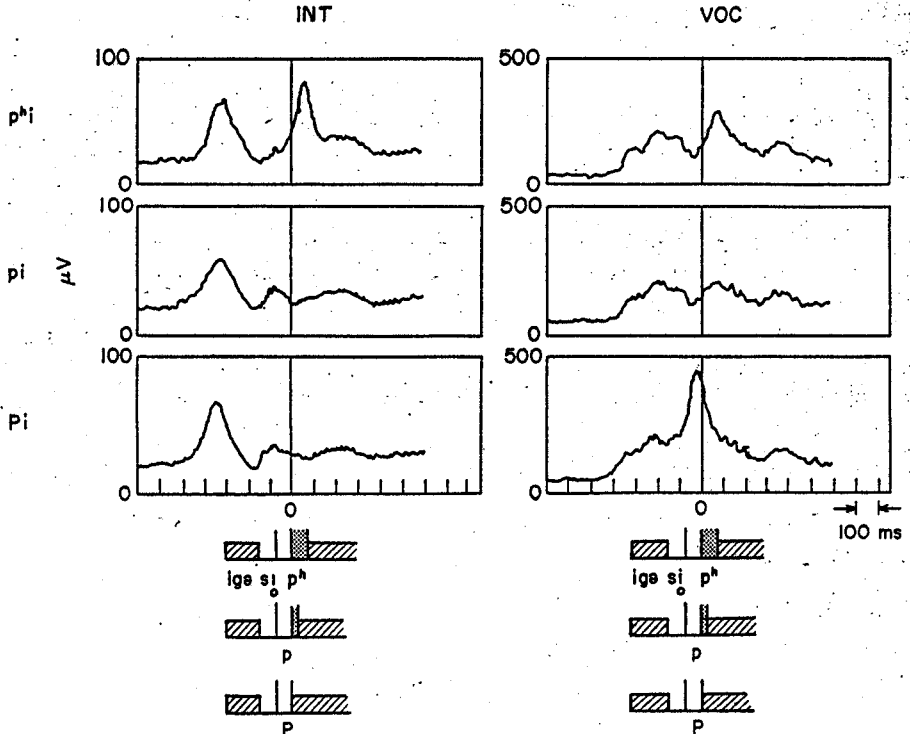


Figure 2

Averaged EMG curves of INT (left) and VOC (right) for the three bilabial stops in word-initial position. The postconsonantal vowel is /i/ for all cases. Timings of speech events are given below the graphs; striped areas represent voiced segments, open areas represent voiceless segments, and dotted areas represent the period of aspiration.

and /p/ is characterized by two peaks, with suppression between the peaks possibly reflecting the voice cessation around the word boundary. For /P/, on the other hand, VOC shows a marked increase in activity immediately before the release.

Figure 3 illustrates the patterns of INT, LCA, and OO activities for the three bilabial stops in word-initial position (left) and in word-medial position (right). The postconsonantal vowel is /i/ for all cases. For the test words with the stop consonant in word-medial position, the onset of the phonated vowel segment at the beginning of the word after the devoiced vowel of the carrier was taken as the line-up point.

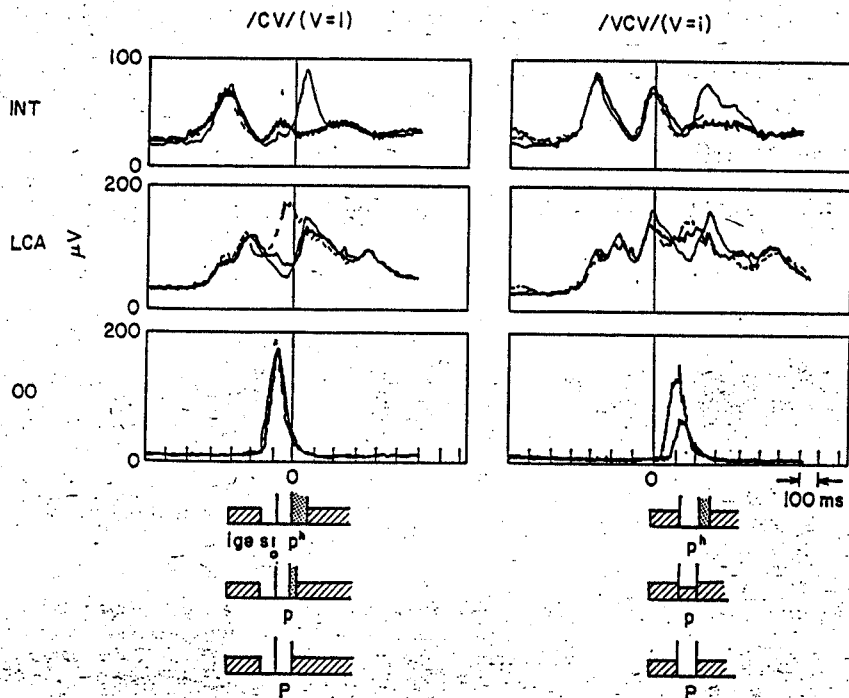


Figure 3

Averaged EMG curves of INT, LCA and OO for the three bilabial stops in word-initial position (left) and in word-medial position (right). For test words with the stop consonant in word-medial position, the onset of the vowel segment after [s] in the carrier is taken as the line-up. —, p<sup>h</sup>; —, p; —, P.

The general pattern of LCA activity is similar to that of VOC in that LCA also shows increasing activity before the stop release in the case of /P/, regardless of the position of the consonant, while it shows two separate peaks for both /p<sup>h</sup>/ and /p/. There is no discernible difference in the pattern of OO activity among the three different stop types when the consonants are in word-initial position. In word-medial position, however, OO activity is definitely less for Category II /p/, here pronounced [b], than for the other two.

The activity of INT for test utterances with the stop consonants in word-medial position increases before the initiation of the utterance and shows a peak approximately 300 ms before the line-up point, followed by a steep decline appropriate for voiceless [s]. The activity increases again approximately 100 ms before the line-up point probably for the vowel segment that precedes the stop closure period and, after reaching the second peak

near the line-up, it is then suppressed for the consonantal segment. The suppression is most marked for /p<sup>h</sup>/ in both degree and duration. For /p<sup>h</sup>/, there is a steep elevation of activity after the period of suppression. For /P/, INT suppression reaches its greatest point earlier than for /p<sup>h</sup>/, and is followed by a slight elevation toward a moderate level of activity. For /p/, which is voiced in word-medial position, INT activity gradually decreases after the peak near the line-up point and then sustains a moderate level of activity.

In the case of LCA, the pattern for /p<sup>h</sup>/ also appears to be characterized by a marked suppression followed by a steep increase. For /p/ in word-medial position, LCA activity stays moderate for the consonantal segment as well as for the subsequent portion of the test utterance. There is a definite increase in LCA activity for /P/ in word-medial position approximately 150 ms after the line-up, corresponding roughly to the stop closure period.

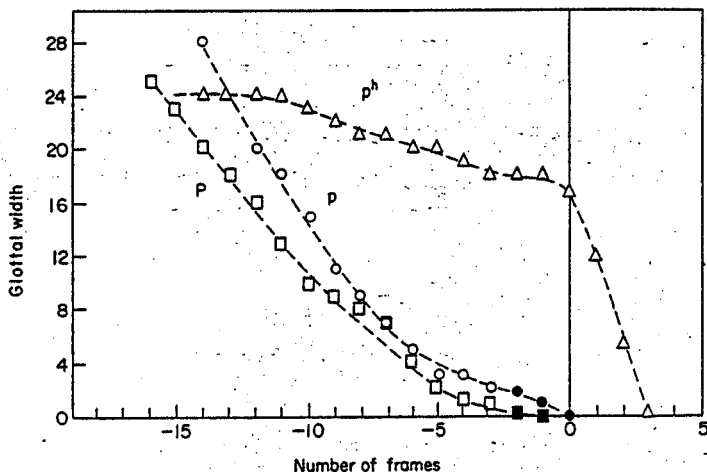


Figure 4

Time courses of the glottal width for representative utterance samples of the three bilabial stops in absolute word-initial position. The rectangles represent /P/ (Category I), the circles /p/ (Category II), and the triangles /p<sup>h</sup>/ (Category III). Filled rectangles and circles indicate that vocal fold vibration was observed in that frame. The zero on the abscissa marks the release of stop closure. The film was taken at a rate of 60 ft/s.

Figure 4 shows time courses of the glottal width for representative utterance samples by the same subject of the three bilabial stops in absolute initial position. The rectangles represent /P/ (Category I), the circles /p/ (Category II), and the triangles /p<sup>h</sup>/ (Category III). Filled rectangles and circles indicate that vocal fold vibration was observed in that frame. The zero on the abscissa marks the release of stop closure.

The figure shows that the glottis begins to close earlier relative to the stop release in Categories I and II, while it stays wide open until the release in Category III. In other words, it seems that there is a considerable difference in glottal width during the consonantal closure period between Category III and the other two. When we compare Category I and Category II, it appears that in Category I the glottis closes somewhat more rapidly and a complete contact of the vocal process is found before the stop release, while in Category II the glottis closes gradually.

The results for dental and velar stops were essentially comparable to those obtained for bilabial stops in both EMG and fiberoptic experiments.

## Discussion

The experimental results of the present study clearly suggest that coordinated actions of the laryngeal muscles characterize the different types of Korean stops.

The "aspirated" stop (Category III) appeared to be characterized by suppression of all the adductor muscles of the larynx immediately preceding the articulatory release. This suppression was always followed by a steep increase in activity which seemed to correspond to the rapid closure of the glottis after stop release, as noted in fiberoptic observations both in this study and elsewhere (Kagaya, 1971).

The pattern of INT activity was almost the same for Category I and Category II stops in word-initial position. It has been observed in previous studies that INT actively participates in the adduction of the vocal fold in speech articulation (Hirose, 1971*b*; Hirose & Gay, 1972). The pattern of INT activity is usually known to be reciprocal with that of PCA, the only known abductor of the vocal fold not examined in the present study. In the phonetic environment examined here, INT activity was found to be markedly suppressed for the voiceless segments of [ʃi] (where the glottis seemed to be wide open) after an initial increase for the voiced segment in the preceding context. The glottal width during the stop closure period has been found to be narrower in Category I and II stops than in Category III. In the light of this fiberoptic finding it is expected that in the case of Categories I and II the glottal width during the stop closure becomes narrower than for the preceding voiceless [ʃi]. A slight increase in INT activity observed in Categories I and II immediately before the onset of the articulatory closure seems to indicate the active narrowing of the glottis described above.

The patterns of VOC and LCA activity were most characteristic for Category I. Both muscles, VOC in particular, showed a marked increase in activity before the stop release in Category I, which presumably resulted in an increase in inner tension of the vocal folds as well as in constriction of the glottis during or immediately after the articulatory closure. It should be reasonable to assume that these activity patterns of VOC and LCA are the physiological correlates of the Category I stop associated with the subjective impression—possibly including laryngeal sensations in production—of "laryngealization" or "glottalization" which has often been claimed for this type of stop (Abramson & Lisker, 1972; Ladefoged, 1973). On the basis of fiberoptic and acoustic data, Fujimura (1972) stated that Category I stops were expected to show a marked activity of VOC. The present EMG result seems to support this prediction. We cannot be certain, however, that these findings of VOC and LCA activity in Category I stops should be taken as physiological evidence of so-called "tenseness" of Category I.

It is quite evident, at any rate, that the patterns of VOC and LCA activity are different from that of INT in the production of Category I stops. Our previous studies indicated that the pattern of VOC and/or LCA activity often differed from that of INT in laryngeal articulatory adjustments. For example, LCA and VOC always show marked activity for glottal stop production, while INT does not (Hirose & Gay, 1973). In our preliminary EMG experiment on Danish subjects, VOC often showed a marked increase in activity for the production of Danish *stød*, while INT did not show any activity related to the *stød* production. In the light of these findings, it seems reasonable to assume that VOC and LCA play a different role from INT in certain types of laryngeal adjustments. In other words, it can be assumed that there is a functional differentiation of the adductor muscles of the larynx, although INT, VOC and LCA are often grouped together as adductor muscles in the classical sense.

It is also interesting to note that the pattern of OO activity was different between word-

initial and medial positions; i.e. it was markedly low for Category II stops in word-medial position, while it was almost the same for all the stop types in word-initial position. One may argue that the lower OO activity for Category II stops in word-medial position could be related to the so-called *laxness*. The exact nature of the *tense-lax* feature has not been well documented. In particular, its physiological correlates are still ambiguous, although there have been several reports claiming that tenseness exists in reality in terms of overall tensing of the speech muscles or of a stronger organic pressure (Fischer-Jørgensen, 1968; Malécot, 1970). In any event, it should be stressed that this difference in OO activity is observed only in word-medial position where the occlusion of a Category II stop is completely voiced; in word-initial position OO activity is not distinctive. It is inappropriate at this point to come to a conclusion about the reality of *tense-lax* opposition as a universal feature in many different languages. However, at least for Korean stops, the laryngeal articulatory adjustment is not limited in a simple dimension of adduction-abduction of the vocal folds: another dimension, represented by VOC activity for example, also must be taken into consideration.

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