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AN ELECTROMYOGRAPHIC STUDY OF LARYNGEAL ADJUSTMENTS FOR THE KOREAN STOPS*

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Introduction

It is known that in Korean there is a three-way distinction in both manner and place of articulation that serves to differentiate nine stop consonant phonemes. For classification, the three types are generally referred to as "forced" (Type I), "lax" (Type II) and "aspirated" (Type III). All stop types may occur in the syllable-initial position to be realized as voiceless, while in the medial position, the lax stops are usually manifested by voiced allophones. In the final position, the three stop types are phonetically realized as voiceless "applosives," being claracterized by the absence of oral release.

There are numerous reports aiming to clarify the acoustical and physiological properties that differentiate the three manner categories. Lisker and Abramson (1964) reported in their comprehensive study of values of voice onset time (VOT) that the resolution of VOT values between the "lax" type and the "forced" type in Korean is not clearcut but shows overlapping, despite the notion that VOT values provide the most useful measure in most languages for differentiating various conditions of voicing and aspiration in word-initial position.

Umeda and Umeda (1965) reported on the acoustic characteristics of the "forced" stops of the Seoul and Taegu dialects. According to them, the two dialects are different in the acoustic characteristics in that in the Seoul dialect, the transition of the vowel portion becomes forced and long, whereas the Taegu dia-

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lect is characterized by the reinforcement of high frequency components, which is considered by the authors as an indication of glottal tension secondary to shortening of the laryngeal cavity.

Han and Weitzman (1970) reported in their speech synthesis and perception studies that "lax" and "forced" stops differed primarily in terms of a gradual versus relatively rapid intensity build-up of the following vowel after stop release.

Based on his cineradiographic studies, Kim (1970) reported that the glottal width in each type of the Korean stops at the articulatory explosion correlated well to the length of aspiration.

Kagaya (1974) made fiberscopic and acoustic studies of the Korean stops, affricates and fricatives and concluded that "forced" and "aspirated" types were characterized by some positive inherent laryngeal gestures. In particular, the "forced" type appeared to be characterized by the completely adducted state of the vocal folds before the explosion, stiffening of the vocal folds and their abrupt relaxation near the voice onset, associated with increasing subglottal pressure and/or lowering of the glottis immediately before the explosion.

Hirose, Lee and Ushijima (1974) conducted an electromyographic (EMG) study on one subject of the Taegu dialect. They found that in the "forced" stop, the thyroarytenoid 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.

These studies would suggest that, at least for Korean stops, laryngeal articulatory adjustment is not limited in a simple dimension of adduction-abduction of the vocal folds, but that another dimension, represented by thyroarytenoid activity for example, can be taken into consideration.

As for the basic laryngeal feature of the Korean syllable-final applosives, Sawashima et al. (1980) performed a fiberscopic study and concluded that it was characterized by a small glottal opening at or slightly after the oral closure. They also found that, when the final applosives were followed by the initial stops or fricatives, the laryngeal feature in abduction-adduction dimension of the final applosives appeared to be assimilated by that of the following consonant irrespective of the difference in the

place of articulation.

The purpose of the present study is to further investigate electromyographically the laryngeal adjustments for Korean stops both in the syllable-initial and final positions in various phonological conditions.

Procedures

1) Subjects and test utterances

Two native Korean speakers of the Seoul dialect, one male (subject C) and one female (subject P, one of the present authors) served as the subjects of the present experiment.

Test words were prepared so as to place the stop consonants in different phonological environments. They are all meaningful words with one exception and presented below in both orthography and phonetic transcription. In orthography, the "forced" stops were presented in the form of geminates.

i) Syllable initial stops

a) "k^hul" [k^hul] ("nonsense word")
"kul" [kul] (oyster)
"kkul" [k'ul] (honey)

These words were uttered in a frame sentence "ike _____ita".

b) "k^hal" [k^hal] (knife)
"kaci" [kadʒi] (kind)
"kkaci" [k'adʒi] (till or to)

These words were uttered in a frame sentence "ike cə_____ (i)ta".

ii) Syllable-final applosives followed by the syllable-initial stops. In this case, the initial "lax" stop is said to become the "forced" stop.

"pɛk kaci" [pɛk' k'adʒi] or [pɛk' adʒi] (a hundred kinds)
"pɛk kkaci" [pɛk' k'adʒi] or [pɛk' adʒi] (up to hundred)
"kyɔt^h kaci" [kjɔt' k'adʒi] or [kjɔk' adʒi] (nearby branch)
"ses kkaci" [set' k'adʒi] or [sek' adʒi] (up to three)
"yɔp^h kaci" [jəp' k'adʒi] (side branch)
"tɛk k^hi" [tɛk' k^hi] (your key)
"puək^{h}i" [puək' k^hi] (key of the kitchen)

In this series, a test word with the forced syllable-initial stop was added as a reference.

pɛ kkaci [pɛk'adʒi] (to the boat)

These test words were uttered in a frame "ike _____ta".

2) Data recordings and processings

EMG recordings were made using hooked-wire electrodes. The electrodes were inserted percutaneously into the thyroarytenoid (VOC) and the cricothyroid muscles. In subject C, the insertion into the cricothyroid was not successful.

With the electrodes in position, the subjects read the utterance samples ten to twelve times each repeatedly, at the speaking rate and intensity being kept as constant as possible within the natural ranges of the subjects.

EMG signals were recorded on a multichannel data recorder simultaneously with acoustic signals. The signals were then reproduced and computer-processed after appropriate rectification and integration, in which an average indication of the muscle activity was obtained over more than 10 selected tokens of each test sentence with reference to two different line-up points on the time axis representing two independent predetermined speech events. In the present series, the implosion of stop closure and voice onset after the oral release were used for the line-up points. In this report, data presentation will be confined to VOC activities of the two subjects.

Separately from EMG data processing, sound spectrographic analysis was made on the speech samples recorded simultaneously with EMG signals.

Results

1) EMG findings on syllable-initial stops

Figure 1 illustrates averaged EMG curves of VOC of subject P for the three different velar stops in the syllable-initial position. In both Fig. 1-A and Fig. 1-B, three curves are superimposed for the stop types, forced, lax and aspirated, which are represented by thick, thin and dash lines, respectively. The lower curves in the figure represent the averaged acoustic envelops. The zero on the time axis marks the line-up point for averaging. In Fig. 1-A, the line-up point corresponds to the implosion of the stop closure, while in Fig. 1-B, it corresponds to the voice onset after oral release. It is clearly demonstrated

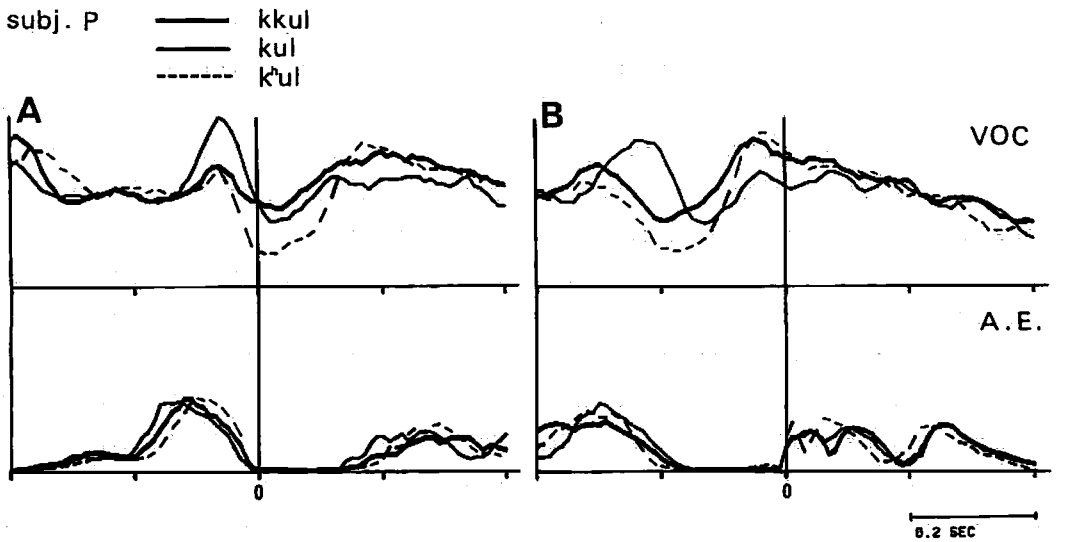

Fig. 1 Averaged EMG curves of the thyroarytenoid (VOC) of subject P for the utterance type "ike C̲ulita," where "C̲" stands for the forced (thick line), the lax (thin line) and the aspirated (dashed line). The lower curves are averaged audio-envelopes (A.E.). The line-up for averaging was taken at the implosion of each stop consonant "C̲" (Fig. 1-A) and at the voice onset of the following vowel (Fig. 1-B).

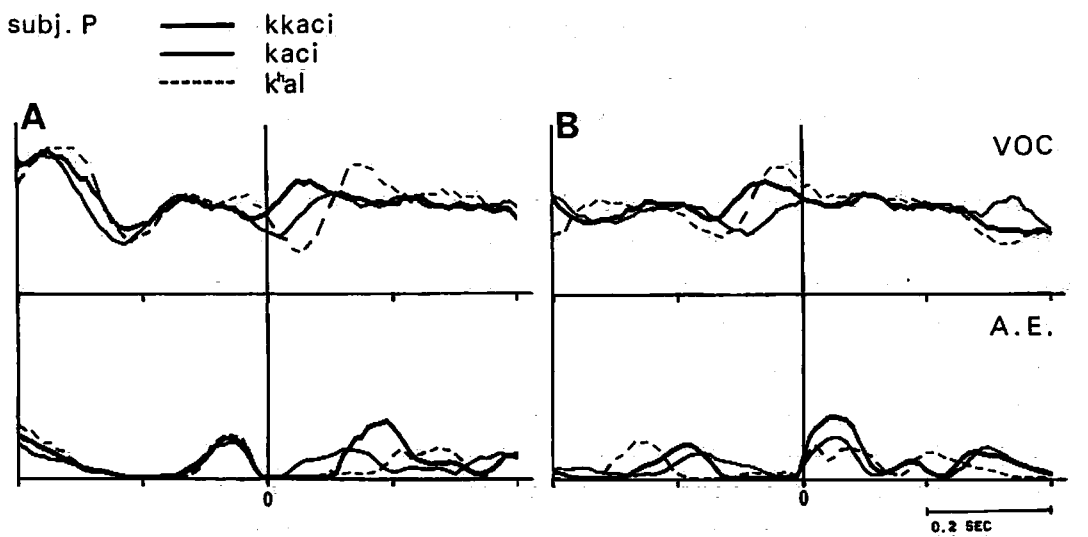

Fig. 2 Averaged EMG curves of VOC of subject P for the utterance type "ike cə C̲ac(or l)ita." Similar comparison to Fig. 1 is made with reference to different types of stop consonant.

in Fig. 1-A that VOC activity is suppressed for the production of the stop consonants in question, the degree of which is slightest for the forced type and most marked for the aspirated type, while it is moderate for the lax type. VOC activity increases again toward the voice onset of the postconsonantal vowel after the suppression, as shown in Fig. 1-B. The timing of the reactivation is earliest for the forced type followed by the aspirated and the lax types in that order. The peak of the reactivation is higher for the forced and the aspirated that for the lax type.

Incidentally, there is a marked activation of VOC immediately before the period of suppression for consonant production. The VOC activation preceding the suppression period appeared to be corresponding to the tendency toward laryngealization of preconsonantal vowel [e] of the frame /ike/, which was revealed by sound spectrographic analysis of the test utterances.

Figure 2 shows averaged EMG curves for the utterance type "ike cə Cac(or 1)ita" of subject P. The line-up points were again taken at the two different speech events. The general patterns are essentially similar to those observed in Fig. 1, and there is apparent suppression in VOC activity for each type of consonant "C" in various degree; markedly for the aspirated, moderately for the lax and slightly for the forced.

Figure 3 shows averaged EMG curves of subject C for the utterance type "ike Culita." In subject C, a high vowel /u/ following the aspirated stop /k^h/ was always devoiced. Therefore, the EMG curves for the aspirated type are eliminated from the figure and, as a result, only a comparison between the lax and forced type is made. It is apparent in Fig. 3-A that VOC activity is suppressed for stop consonant production, the degree of which is more marked for the lax than for the forced type. After the suppression, VOC appears to be reactivated for postconsonantal vowel production. The reactivation starts earlier and its peak is higher for the forced than for the lax (Fig. 3-B). Thus, general patterns are essentially the same as those observed in subject P.

Figure 4 shows averaged VOC activities of subject C for the utterance type "ike cə Cac(or 1)ita." Here again, the EMG curve for the aspirated type is eliminated because of devoicing of the postconsonantal vowel. In this case, the degree and timing of VOC suppression for the stop consonants in question are not very dif-

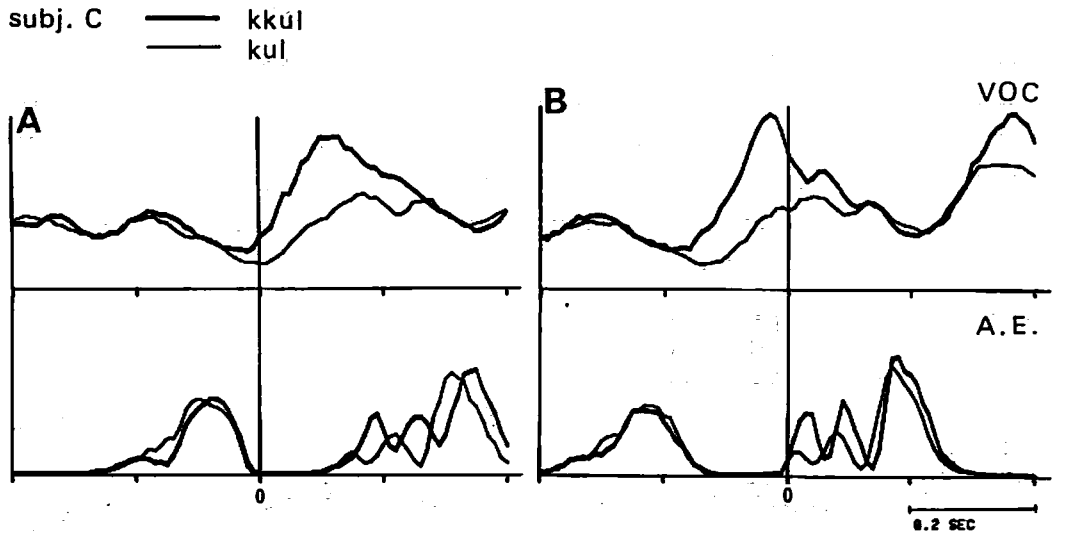

Fig. 3 Averaged EMG curves of VOC of subject C for the utterance type "ike Culita." The curves for the aspirated type is eliminated because the post-consonantal vowel was devoiced.

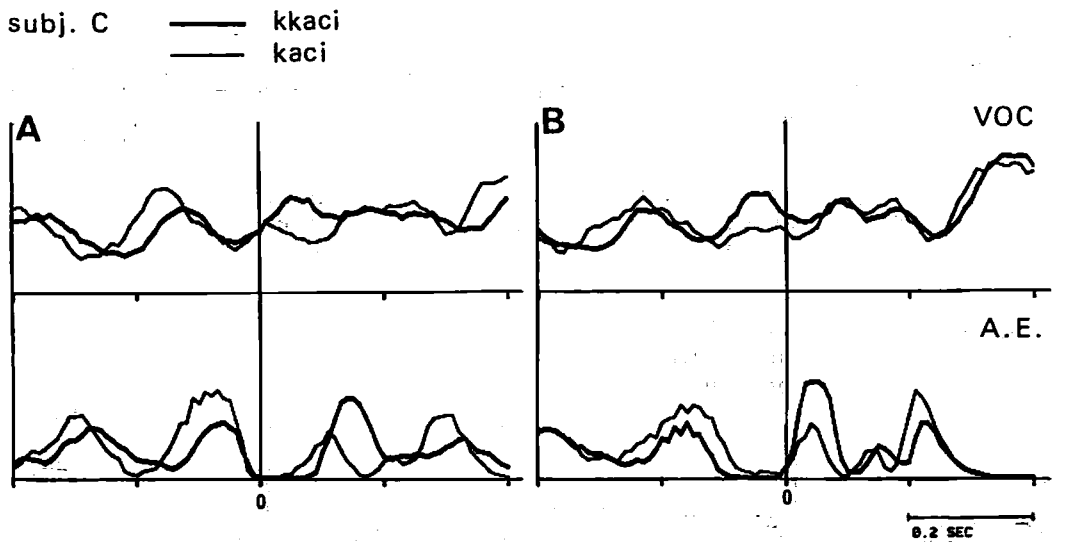

Fig. 4 Averaged EMG curves of VOC of subject C for the utterance type "ike cə Cac(or l)ita."

ferent between the lax and forced types, whereas VOC reactivation for the postconsonantal vowel is more marked for the forced than for the lax.

2) EMG findings on syllable-final stops

Figure 5 compares averaged EMG curves of VOC of subject P for

the utterance types "ike pɛk kacita" and "ike pɛk kkacita." As a reference, averaged EMG curves of VOC for the utterance type "ike pɛ kkacita" containing a syllable initial forced stop is superimposed (dashed line). It can be seen that these curves are extremely similar to each other in terms of the degree and timing of VOC suppression for consonant segments and those of its reactivation for postconsonantal vowels.

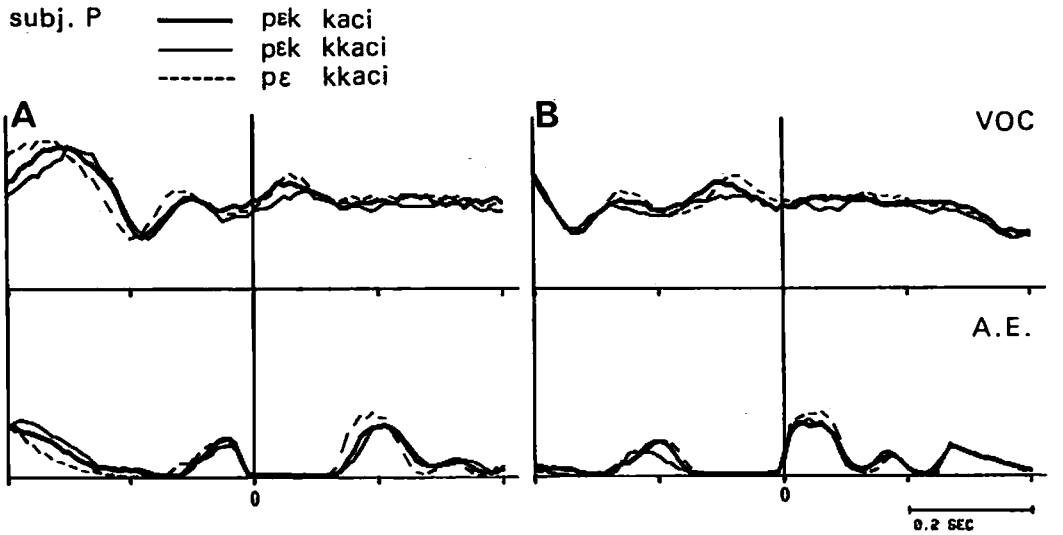

Fig. 5 Averaged EMG curves of VOC of subject P for the utterances "ike pɛk kacita" (thick line), "ike pɛk kkacita" (thin line) and "ike pɛ kkacita" (dashed line).

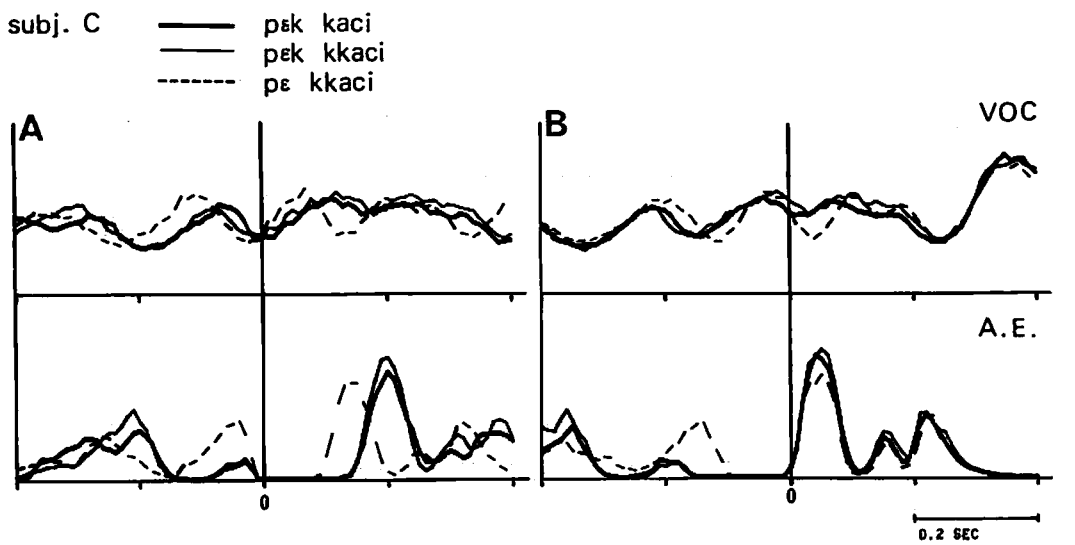

Fig. 6 Averaged EMG curves of VOC of subject C for the utterance types compared in Fig. 5.

Similar findings are obtained in subject C as shown in Fig. 6, where the same three utterance types as presented in Fig. 5 are compared. In this figure, the timing of VOC peak preceding its suppression for the stop consonant segment is apparently earlier only for the utterance type "ike pɛ kkacita" (dashed line). This is presumably because the duration of the preconsonantal vowel /ɛ/ is longer for this utterance type than that for the other two.

EMG patterns are found to be similar even when the place of anticulation of syllable final applosives is different from that of the following syllable-initial stop, as shown in Fig. 7, where different types of cluster /t^h#k/ and /s#kk/ are compared to the sequence of /k#kk/.

Figure 8 compares averaged EMG curves of VOC of subject P for

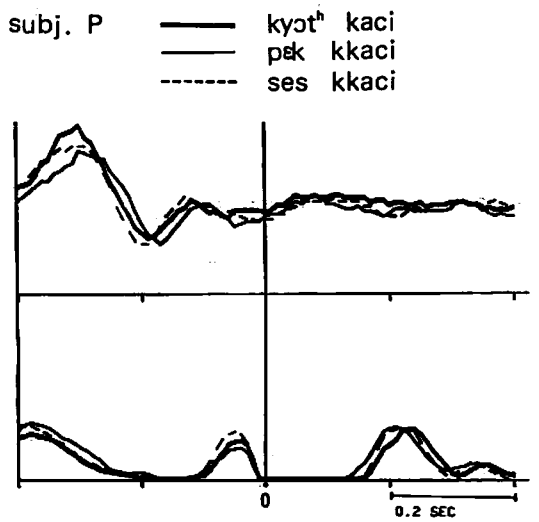

Fig. 7

Averaged EMG curves of VOC of subject P for the utterance types "ike kyɔt^h kacita" (thick line), "ike pɛk kkacita" (thin line) and "ike ses kkacita" (dashed line).

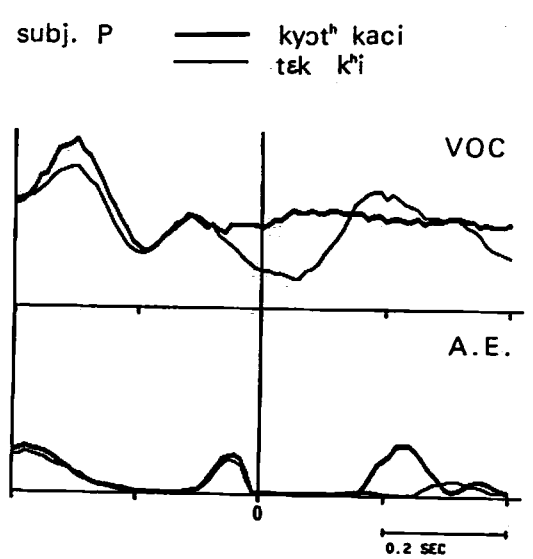

Fig. 8

Averaged EMG curves of VOC of subject P for the utterance types "ike kyɔt^h kacita" (thick line) and "ike tɛk k^hita" (thin line).

different sets of consonant cluster /k#k^{h}/ and /t^{h}#k/. In the case of /k#k^{h}/ represented by a thin line, VOC activity is markedly suppressed for the production the cluster similarly to the pattern observed for the syllable-initial aspirated stop. On the other hand, VOC suppression is minimum for the cluster type /t^{h}#k/, the pattern for which was already presented in Fig. 7 and considered to be similar to that of the syllable-initial forced stop.

3) Acoustic correlates of different stop types and consonantal segments

Based on sound spectrographic analysis, duration of closure period of the stops and voice onset time (VOT) are obtained. Fundamental frequencies (F_0) of a vowel segment preceding and following each stop segment are also obtained by averaging five consecutive

Table I Acoustic parameters

	Subject		(ike) kkul	(ike) kul	(ike) k^{h}ul	(ike cə) kkaci	(ike cə) kaci	(ike cə) k^{h}al	(ike) pɛ kkaci	(ike) pɛk kaci	(ike) pɛk kkaci
closure period (msec)	P	$\bar{x}$	207	146	145	159	56	116	155	185	186
		SD	1.1	1.1	0.7	0.8	0.5	0.9	20	35	27
		n	15	15	16	14	14	15	16	16	16
	C	$\bar{x}$	150	115	143	119	55	111	115	183	175
		SD	0.5	0.7	0.7	0.5	0.3	0.5	11	14	13
		n	12	12	12	12	10	12	12	12	12
VOT (msec)	P	$\bar{x}$	22	59	116	21	73	120	22	22	21
		SD	3	8.3	6.7	4	14	10	4	3	2
		n	15	15	15	15	14	15	15	15	15
	C	$\bar{x}$	28	57	-	19	56	-	20	19	20
		SD	2	7	-	2	14	-	2	1	1
		n	12	12	-	12	11	-	12	12	12
F_0 following vowel (Hz)	P	$\bar{x}$	344	282	327	262	240	267	241	243	243
		n	17	17	14	16	15	16	10	10	10
	C	$\bar{x}$	170	132	-	153	127	-	161	161	164
		n	12	12	-	12	10	-	10	10	10
preceding vowel (Hz)	P	$\bar{x}$	229	215	234	208	210	216	155	167	127
		n	7	7	7	6	6	6	10	10	10
	C	$\bar{x}$	127	125	135	126	131	131	139	-	-
		n	8	8	8	8	8	8	9	-	-

pitch periods on the sound-spectrogram. The results are summarized in Table I.

Discussion

The present study reveals that the three types of Korean stops in the syllable-initial position are characterized by different patterns of VOC activity. For the production of the aspirated type, VOC is markedly suppressed and then reactivated for the following vowel. Such activity patterns seem to correspond to a marked abduction gesture of the glottis for the aspirated type, which has been confirmed by fiberoptic observation.

EMG patterns for the lax type can also be considered to correspond to the glottal abduction gesture for this type of stop, in which a moderate degree of glottal opening is always observed by fiberoptic observation. In some cases, e.g. in subject C shown in Fig. 4, the degree of VOC reactivation for the vowel segment following the lax stop is very slight. This finding can be attributed, at least in part, to the tendency toward low amplitude and F_0 of the vowel segment in that condition.

It has been observed by fiberoptic study that the glottal opening is smallest for the forced type among the three stop types of Korean, and the glottis tends to close earlier relative to the voice onset of the following vowel. Minimum suppression and early reactivation of VOC activity found in the present study for the syllable-initial forced stop seem to correspond at least to the temporal feature of glottal dynamics for the forced type. However, the increase in VOC activity before the voice onset of the vowel following the forced type, the degree of which is relatively higher than that for the lax type and comparable to that for the aspirated type, can not be explained by a simple dimension of glottal abduction-adduction. Rather, as already suggested by Hirose et al. (1974), the relatively steep increase in VOC activity for the forced type must be taken as a characteristic feature of this type of Korean stop. This activity pattern may correspond to the acoustic feature of "laryngealization" described by Abramson and Lisker (1972) and Ladefoged (1973), and can be a physiological correlate of the rapid intensity build-up after stop release which was found to be characteristic for the forced type by Han and Weitzman (1970).

Even so, the degree of increase in VOC activity observed in

the two present subjects for the forced stop or, more specifically, for the vowel after the forced stop, is less marked compared to that reported previously by Hirose et al. (1974). The difference in the degree of VOC activation between the two studies may be due to a dialectal difference among the experimental subjects. In the study of Hirose et al. (1974), a subject of the Taegu dialect was examined, in whom the distinction between the lax and forced types could not be made by a difference in VOT value. However, in the present subjects of the Seoul dialect, the distinction between the two types can be made solely by VOT difference (cf. Table I). In any case, tendency toward high VOC activation may well be taken as a physiological correlate of the forced type of Korean, although further EMG and acoustic studies on a large number of subjects of different dialects are mandatory.

Results of the present study also indicate that the patterns of VOC activity for the consonant clusters consisting of a syllable-final applosive and a syllable-initial forced or lax stop is quite similar to that of the syllable-initial forced type. It is also shown that the pattern of VOC activity for the cluster type consisting of a syllable-final applosive followed by a syllable-initial aspirated stop resembles that of the syllable-initial aspirated type. These EMG results are comparable to those of fiberoptic observations reported by Sawashima et al. (1980), who claimed that for consonant clusters with an intervening word boundary the laryngeal feature of the final stop is assimilated to the following syllable-initial stop, regardless of the difference in the place of articulation.

It is reasonable to consider that the dynamics of glottal configuration observed by a fiberscope is under the muscle control of the larynx. The present study suggests that the pattern of VOC activity is an important physiological correlate for differentiating the three stop types of Korean as well as for phonetic realization of consonant clusters with an intervening word boundary in Korean with reference to the dynamic control of glottal configuration.

Summary

An electromyographic (EMG) study was conducted to investigate the laryngeal control in Korean stop production. The results obtained so far are summarized as follows:

1) The pattern of thyroarytenoid (VOC) activity appeared to characterize the three different types of Korean stops.

2) Specifically, for the production of the forced stop, VOC showed marked increase of activity with relatively earlier timing before onset of the following vowel.

3) When the final stop was followed by the syllable-initial lax or forced stop, the EMG pattern for the cluster resembled that for the initial forced stop. In contrast, when it was followed by the aspirated stop, the pattern resembled that for the single syllable-initial aspirated stop.

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