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ABDUCTOR(PCA) AND ADDUCTOR (INT) MUSCLES OF THE LARYNX IN VOICELESS SOUND PRODUCTION

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Fiberoptic and electromyographic observations of the laryngeal opening and closing gestures during speech have suggested that there is a reciprocal pattern of activities between the abductor (posterior cricoarytenoid) and adductor (interarytenoid) muscles, the time course and the extent of the glottal aperture being better represented by the activity pattern of the posterior cricoarytenoid.[1] [2] These reports were, however, based on averaged EMG patterns over repeated utterances of limited types of voiceless consonants. This paper reports a more detailed observation of laryngeal movements in correspondence with the EMG patterns for each of the utterance samples with various types of voiceless sounds and sound sequences.

Experimental Procedures

Two adult male speakers of the Tokyo dialect, M.S. and H.H., served as subjects. Twelve meaningful words containing voiceless sounds and sound sequences were prepared. The test words were:

1. 異性 /iseH/,	2. 時制 /ziseH/,	3. 実勢 /ziQseH/,
4. 市政 /siseH/,	5. 失政 /siQseH/,	6. 異体 /iteH/,
7. 次弟 /ziteH/,	8. 実弟 /ziQteH/	9. 指定 /siteH/,
10. しってー /siQteH/,	11. 失計 /siQkeH/,	12. 疾病 /siQpeH/

The vowel [i] between voiceless consonants is devoiced in the test words Nos. 4, 5, and 9 through 12. Consequently, these words have voiceless sound sequences consisting of voiceless consonants and the [i̥]. No accent kernel is contained in the test words in the Tokyo dialect. Each word was pronounced with a frame sentence "Sore o ______ to yuu" (We call that ___).

A flexible fiberscope was inserted through the nose of the subject and the laryngeal view was filmed simultaneously with the speech and the EMG recordings. For the EMG recording, hooked wire electrodes were inserted, through the mouth, into the posterior cricoarytenoid (PCA) and the interarytenoid (INT) muscles. These instrumentations have been described elsewhere.[3] In this experiment, no averaging of the EMG data was made, but the integrated EMG curve was smoothed by plotting running averages with a time window of 50 msec for each utterance sample. The distance between the tips of the vocal processes of the arytenoid cartilages was measured, frame by frame, on a magnified image of the laryngeal film.

For each subject, the number of utterance samples obtained for each of the text words was 2 to 4.

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Results and Comments

In this paper, we present the time course for the glottal opening and dosing movements in correspondence with smoothed, integrated EMG curves for INT and PCA for typical utterance samples.

Utterance samples of /iteH/, one for each of the two subjects, are shown in Fig. 1. In the figure, GW indicates the time curve of the glottal aperture represented by the distance between the tips of the vocal processes, INT and PCA indicate smoothed, integrated curves for the INT and PCA muscles respectively, and AUDIO indicates the envelope of speech waves. All the curves are aligned on the same time axis. The vertical line indicates the time point of the onset of the vowel [e] following the voiceless sound.

In the subject MS, the glottis opens to some extent for the word-medial voiceless stop [t]. There is a small peak of PCA activity approximately 50 msec prior to the glottal abduction, the two curves being very similar to each other. At the same time as the increase in PCA activity, there is a decrease in the activity of INT, giving a time curve which is nearly an inverse figure of that for PCA activity. Subject HH also shows a small degree of glottal abduction for the word-medial [t]. The corresponding increase in PCA activity with a small peak is seen approximately 100 msec in advance of the glottal movement. There is a decrease in the activity of the INT beginning earlier and more gradually than the increase in PCA activity. Thus, the time curve for INT activity does not show an inverted pattern compared to the PCA activity in this subject. The time curve of the INT reaches the bottom of the trough at the same time as the peak of PCA activity.

Examples of /iseH/ are presented in Fig. 2. For both subjects, a considerable amount of glottal opening is seen for the word medial [s], with a steeper slope for the time curve than that found for the medial [t] (Fig. 1). In subject M. S., the peak of PCA activity and the dip of INT activity are both greater than those in the case of /iteH/. The timing relationship between the activity patterns of the two muscles is seen to be exactly the same as that observed in Fig. 1. Activity patterns of the two muscles in subject H. H. are also similar to those in Fig. 1., except for a greater peak in PCA activity and a greater increase of INT activity following the dip for the voiceless consonant in the case of /iseH/ as compared with /iteH/.

Examples of /ziQteH/ are shown in Fig. 3. Because of the geminate [tt] in this test word, the duration of the silent period for the word-medial voiceless sound becomes longer than that of /iteH/. In subject M. S., the peak glottal width also becomes larger to an extent comparable to that found in the fricative [s] in /iseH/, the slope of the time curve being less steep. The increase in PCA activity is seen for a longer duration and with a greater peak value than that for [s]. The descending curve of the PCA activity appears to be somewhat more gradual than its ascending curve. The onset of the decrease in INT activity is seen exactly at the same moment where the PCA activity begins to increase. The activity curve reaches its lowest level at the time point where the PCA activity reaches its peak. The INT activity maintains its lowest level unchanged for the time period of approximately 100 msec and then recovers its phonatory level at the same time when the PCA activity decreases to the noise level. The

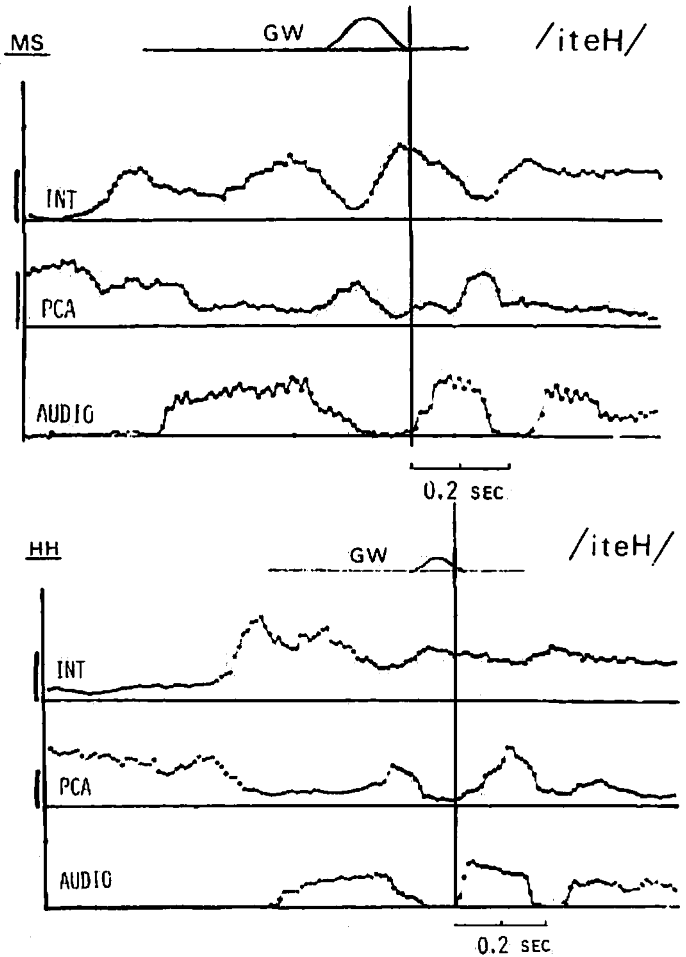

Fig. 1. : Time curve of the glottal width (G. W.), smoothed integrated EMG curves of INT and PCA, and speech envelope (AUDIO) for /iteH/. The curves are aligned on the same time axis. The vertical line indicates the voice onset for the vowel [e].

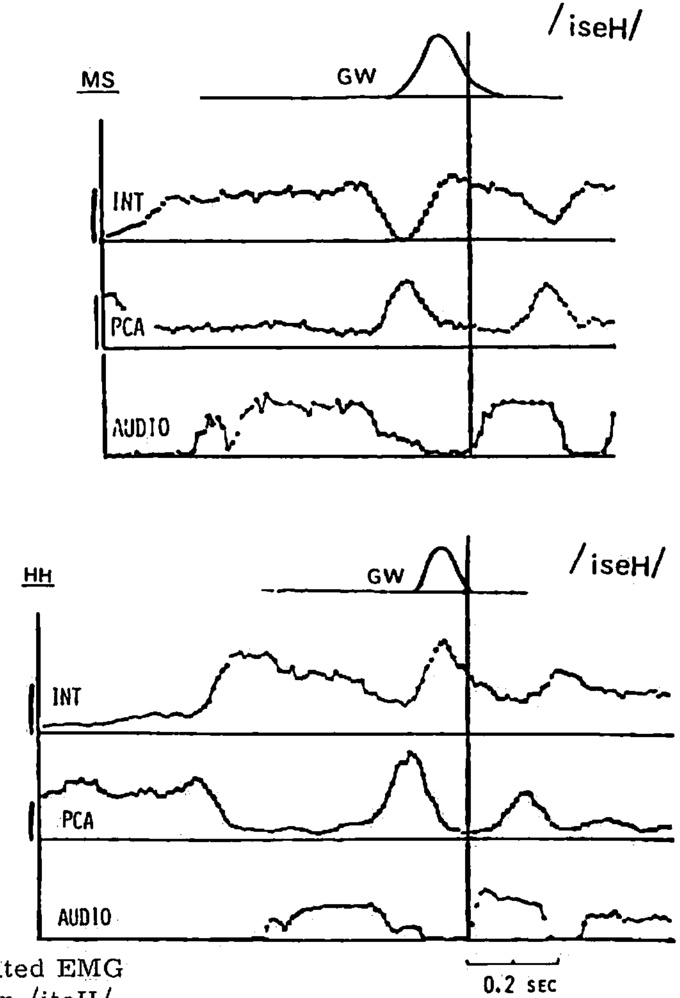

Fig. 2. : Same display as Fig. 1. for /iseH/

slope of the descent is almost comparable to that of the ascent in the INT activity curve, the temporal pattern giving a symmetric curve along the time course. The extent of the decrease in INT activity is seen to be comparable to that for [t] in /iteH/ and less than that for [s] in /iseH/. The glottal width in subject H. H. for the geminate [tt] is seen to be as small as the non-geminate [t] in /iteH/ although the duration where the glottis is open is definitely longer than that for [t], and also longer than that for the [s] in /iseH/. There is a small amount of increase in PCA activity for the time period corresponding to the glottal abduction. The decrease in INT activity is very slight.

In the test word /siseH/, the vowel [i] between the [s]'s is devoiced and a sequence of voiceless sounds [si̥s] results. A glottal opening with a long duration and a large maximum glottal width is generally observed for this kind of sound sequence involving a devoiced vowel. Examples are shown in Fig. 4. In subject M. S., the glottis opens rapidly to a large extent and then closes rather gradually. The activity pattern of the PCA correspondingly shows a rapid increase and then a gradual decrease after its peak activity. At the same time as the increase in PCA activity, a rapid decrease in INT activity, which is followed by a gradual recovery, takes place. The recovery tends to slow down temporarily before it accelerates to reach the phonatory level. In subject H. H. also, a large glottal width is reached by a rapid opening movement of the glottis. The closing movement is seen to be slower than that of the opening movement and shows a convex time curve. The PCA activity in this case shows a peak corresponding to the glottal abduction. The peak is followed by a temporary decrease in the activity and then by a second peak which is smaller than the initial one. This second peak is considered to be due to the [s] of the second mora in /siseH/ and responsible for the convex time curve of the glottal adduction. It is interesting to note that in subject M. S., there is neither the second peak for PCA activity nor the convexity in the glottal time curve, but there is a tendency for the recovery of INT activity to temporarily slow down instead. The INT activity of subject H. H. shows a gradual decrease beginning much earlier than the onset of the increase in PCA activity. The lowest level of INT activity is reached at the time of the initial peak in PCA activity and is maintained until the time corresponding to the second peak of the PCA activity. The INT activity then increases with a time course well matched to that of the final decrease in PCA activity.

For the test word /siQseH/ where the geminate [ss] follows the devoiced vowel ([i̥]), there is a longer duration of glottal separation as well as a longer voiceless period as compared with /siseH/. Examples are presented in Fig. 5. In subj. M. S., the time curve of the glottal abduction is almost identical to that for /siseH/ in Fig. 4, while the closing movement of the glottis is more gradual than that in /siseH/. Thus a longer duration for glottal separation is observed in Fig. 5 as compared to Fig. 4. In Fig. 5, another finding to be noted is that there is a clear temporary slow-down in the closing movement in the time curve of the glottal adduction. This particular phenomenon is probably due to the [s] in the third mora of the test word, i. e., /s/ following /Q/ in /siQseH/. The time curve of PCA activity, on the other hand, shows little difference between /siseH/ and /siQseH/. Instead, the difference between the two test words is reflected

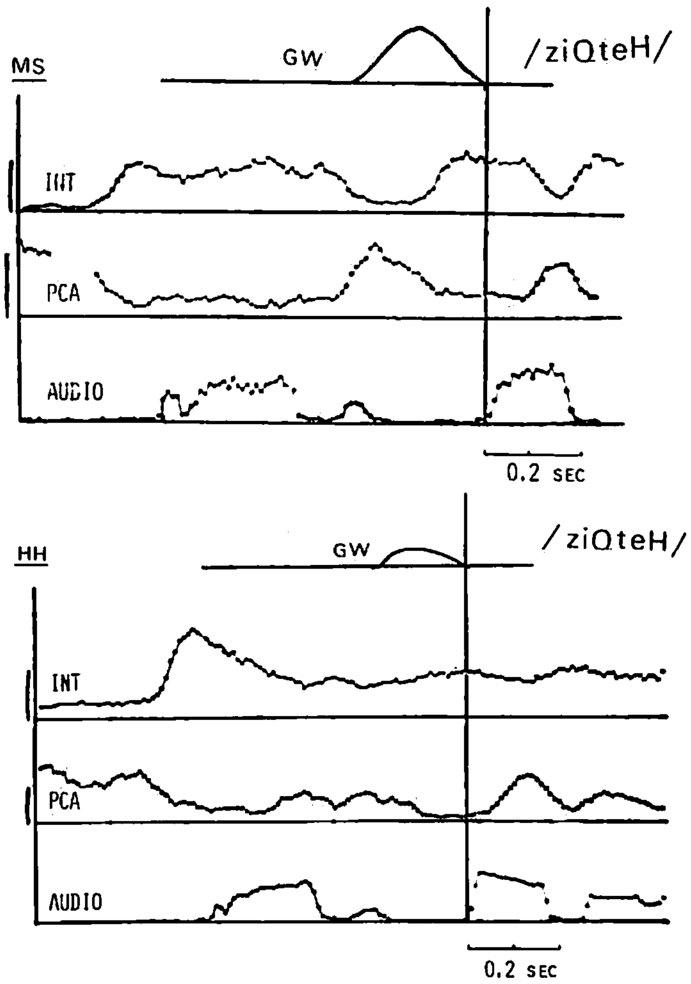

Fig. 3. : Same display as Fig. 1. for /ziQteH/

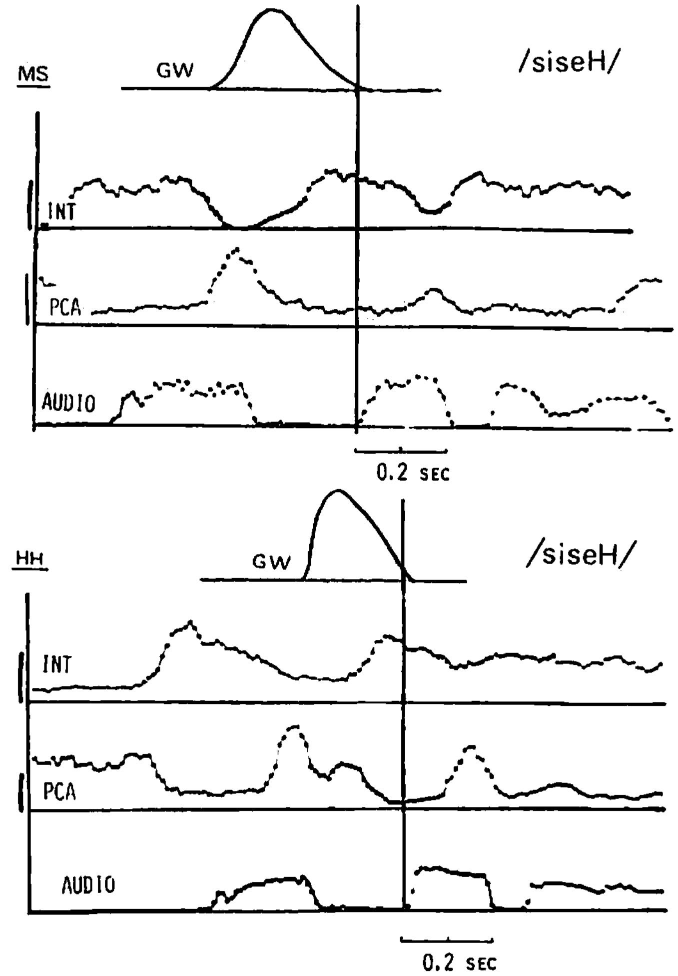

Fig. 4. : Same display as Fig. 1. for /siseH/

in the time course of the recovery of INT activity. The recovery of INT activity in /siQseH/ is more gradual than in /siseH/ and shows a temporal standstill before the phonatory level is finally reached with a rather steep time curve. This standstill appears to be responsible for the temporary slow-down in glottal adduction. The time duration where the glottis is open is well represented by that where INT activity is suppressed. In subject H. H., the glottis is kept wide open throughout the voiceless period. The glottal time curve consists of two smoothed peaks with steep slopes both for the opening movement at the beginning and the closing movement at the end. There are two peaks in the activity of the PCA with a steady activity level maintained for approximately 100 msec in between. The second peak can be considered to correspond to the [s] in the third mora of the test word /siQseH/ and is probably responsible for the second peak in the glottal time curve. The time period where the glottis is open is well represented by that where PCA activity is increased. The decrease of INT activity begins very early and the lowest activity level is maintained for a time span that covers the two peaks of PCA activity. The increase in INT activity forms a peak for the voice onset of the following vowel [e].

In the test word /siQpeH/, the geminate stop [pp] follows the voiceless sequence [si̥]. The geminate stop [pp] usually shows a smaller glottal opening compared to [s] and [ss] [4]. Thus, the glottal aperture for the time segment of the geminate sound in this test word is expected to be smaller compared with that in /siQseH/ of Fig. 5. Examples are presented in Fig. 6. In both subjects, the glottal time curve shows a large peak at the beginning of the voiceless period corresponding to the segment [si̥]. The glottal width then decreases immediately and a small degree of glottal aperture is maintained for the rest of the voiceless period which corresponds to the segment [pp]. Thus the time curve of the glottal width shows a contrastive difference between /siQseH/ and /siQpeH/. In subject M. S. however, there is little difference in the PCA activity pattern between the two test words, except for a very low degree of activity following the initial peak activity observed for /siQpeH/. For subject M. S., the difference is observed in the time curve of INT activity. In Fig. 6, the INT activity reaches its lowest level at the same time as the initial peak of PCA activity as was seen in the other test words. The activity then immediately recovers to a certain level and the level is maintained for the rest of the voiceless period. This activity pattern appears to explain the particular time curve for glottal width in /siQpeH/. In H. H., the PCA activity for /siQpeH/ shows only an initial peak instead of two peaks shown for /siQseH/. The activity of the INT decreases in the beginning and then gradually recovers during the rest of the voiceless period. The activity pattern of the PCA represents the glottal time curve in the case of subject H. H. Results obtained inthe test words /siQteH/ and /siQkeH/ for each subject are quite similar to those obtained for /siQpeH/.

The experimental results above reveal that glottal opening varies with different voiceless sounds and sound sequences both in grade and temporal pattern. The results also reveal, at least qualitatively, that the opening and closing of the glottis during speech is controlled by a reciprocal pattern of PCA and INT activity. It should be noted, however, that there is a subject to subject difference in the mode of the laryngeal

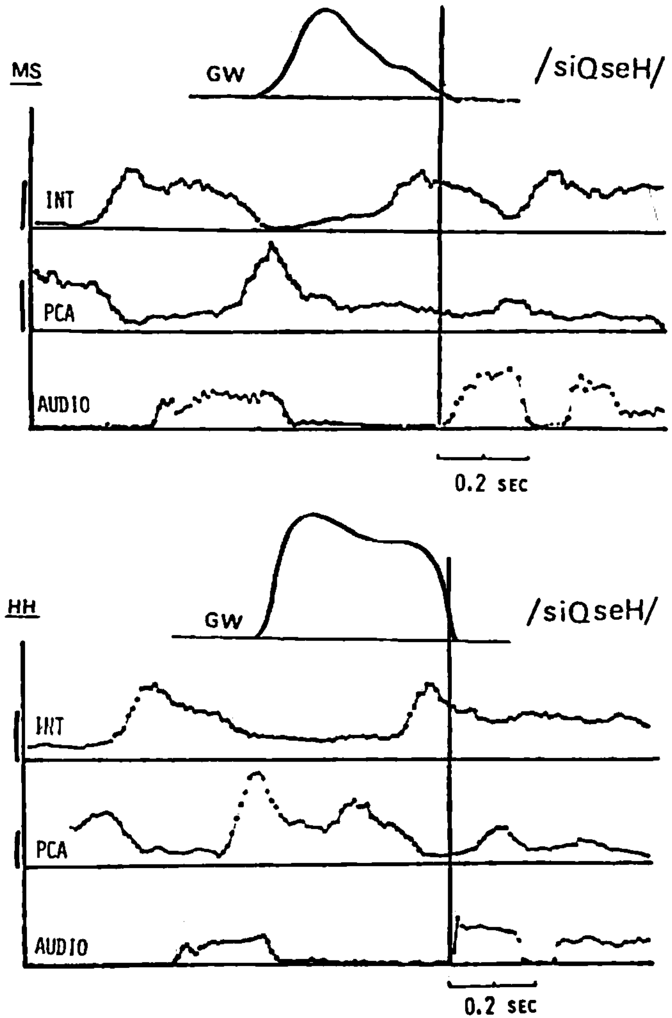

Fig. 5. : Same display as Fig. 1. for /siQseH/

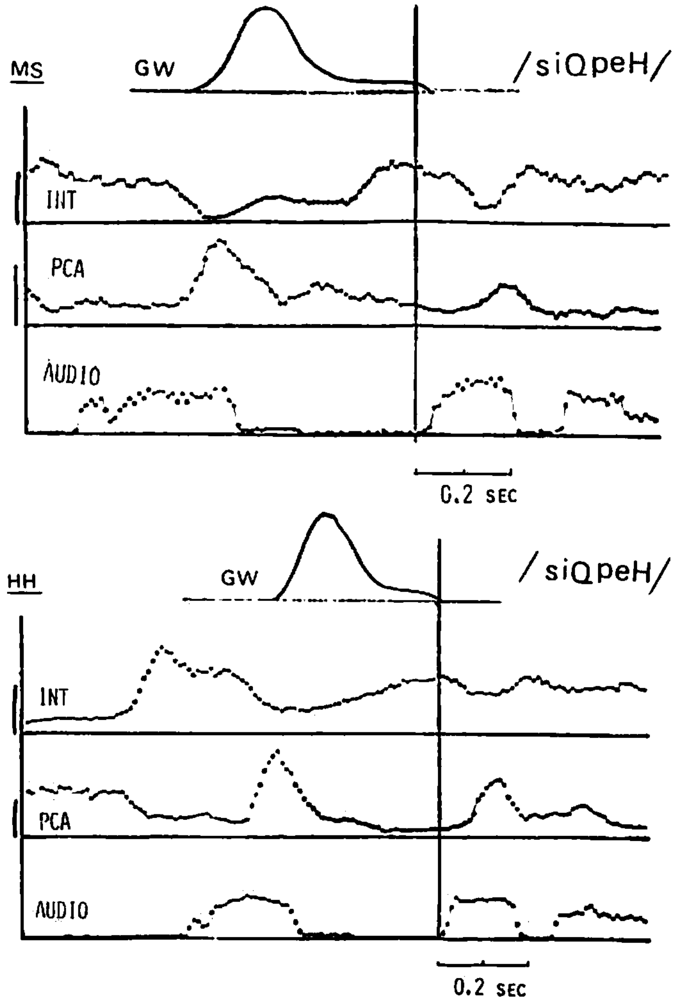

Fig. 6. : Same display as Fig. 1. for /siQpeH/

control using the two muscles. In subject H. H., the glottal aperture is mainly represented by PCA activity with an associated decrease of INT activity. The time curve of the glottal width in this case can be interpreted as a kind of mechanically smoothed pattern of PCA activity. In subject M. S., on the other hand, the activity of the INT appears to actively contribute, in combination with the PCA, to the control of the gottal condition.

In our previous report [5] on the glottal control in utterance initiation, using the same two subjects as the present experiment, a temporal delay in the closing movement was observed for voiceless consonants in utterance-initial position. The temporal delay in glottal adduction was achieved by the suppression of INT activity in subject M. S. while the same effect was achieved by an increase of PCA activity in subject H. H. Our interpretation of those data was that subject M. S. used the "respiratory mode" of laryngeal control while subject H. H. used the "speech mode" in the glottal adjustments for utterance-initial voiceless consonants, and that this kind of difference in the mode of control for a given laryngeal condition was observed only in a particular circumstance such as the initiation of an utterance, i. e., the transition from respiratory mode to the speech mode of the larynx. Having the additional data obtained in the present experiment, one can now assume in a more general sense that there are some individual variations in laryngeal control and the subject M. S. is more dependent on the INT muscle, while subject H. H. relies more on the PCA, at least for the glottal abduction.

A quantitative analysis on the contributions of the two muscles to laryngeal control is to be made next. For this purpose, an analysis-by-synthesis approach, using an adequate modeling of the laryngeal mechanism which derives the glottal opening and closing movements from EMG data of the two muscles, should be useful.

References

1) H. Hirose and T. Gay: The activity of the intrinsic laryngeal muscles in voicing control: an electromyographic study. Phonetica 25, 140-164, 1972.

2) H. Hirose: Posterior cricoarytenoid as a speech muscle. Ann. Otol. Rhinol Laryng. 85, 334-343, 1976.

3) M. Sawashima: Current instrumentation and techniques for observing speech organs. Technocrat 9, No. 4, 19-26.

4) M. Sawashima, H. Hirose and S. Niimi: Glottal conditions in articulation of Japanese voiceless consonants. XVIth Int. Congr. Logopedics and Phoniatrics, Interlaken 1974, 409-414, 1976.

5) M. Sawashima, H. Hirose, T. Ushijima and S. Niimi: Laryngeal control in Japanese consonants, with special reference to those in utterance-initial position. Ann. Bull. RILP, No. 9, 21-26, 1975.