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A CROSS LANGUAGE STUDY OF LARYNGEAL ADJUSTMENT IN CONSONANT PRODUCTION

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Recent advances in electromyography (EMG) and fiberoptics have revealed that there is a reciprocal activity pattern between the adductor and abductor muscle groups of the larynx during consonant productions and that the posterior cricoarytenoid (PCA) is particularly important for active vocal fold abduction for those speech sounds produced with an open glottis (Hirose, 1976). The reciprocity between the PCA and the adductors, and the interarytenoid (INT) in particular, has been observed for different languages including American English, Japanese, Danish and French.

Figure 1 shows an example of raw EMG traces of the PCA and the INT for a pair of test words /əpʌp/ and /əbʌp/ produced by an American English speaker. It is shown that PCA activity is suppressed for the voiced portion of the test words, while it increases for the production of the intervocalic voiceless stop /p/ as well as for word final /p/. On the other hand, the INT shows a reciprocal pattern when compared with that of the PCA, in that the activity of the INT increases for the voiced portion and decreases for the voiceless portion of the test words.

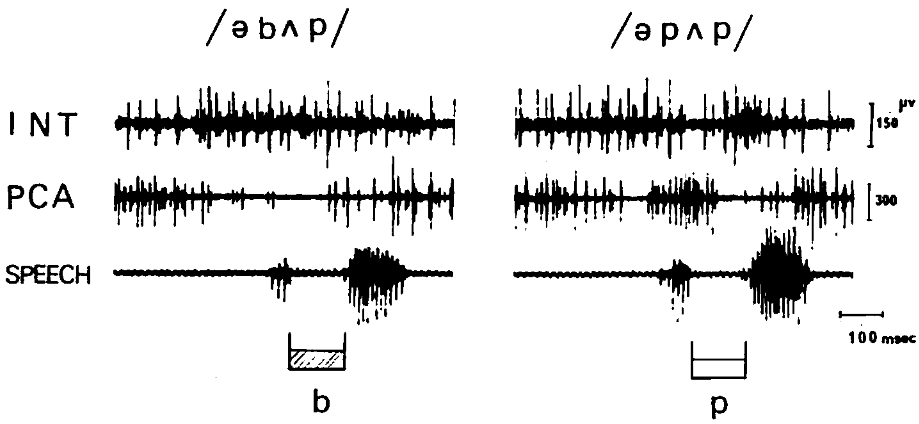

Fig. 1. Raw EMG traces of PCA and INT for a pair of test words /əpʌp/ and /əbʌp/

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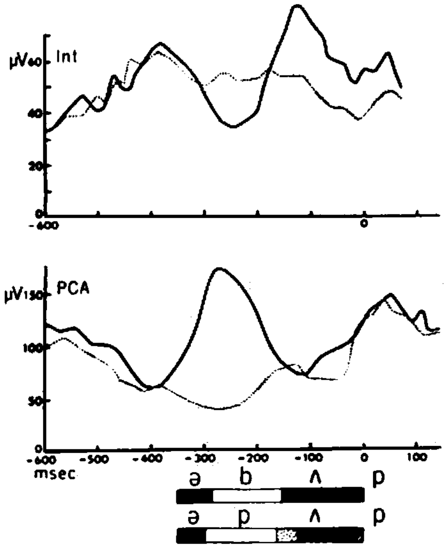

Figure 2 illustrates the reciprocal pattern between these two muscles more clearly. These curves were obtained by computer-averaging of EMG signals in reference to the line-up point on the time axis, which was taken at the voice offset of the stressed vowel. The solid lines show the EMG pattern for the production of /əpʌp/, while the dotted lines show the pattern for /əbʌp/. PCA activation and INT suppression for voiceless /p/ are clearly demonstrated.

Fig. 2. Computer averaged EMG patterns of PCA and INT for the test words in Fig. 1.

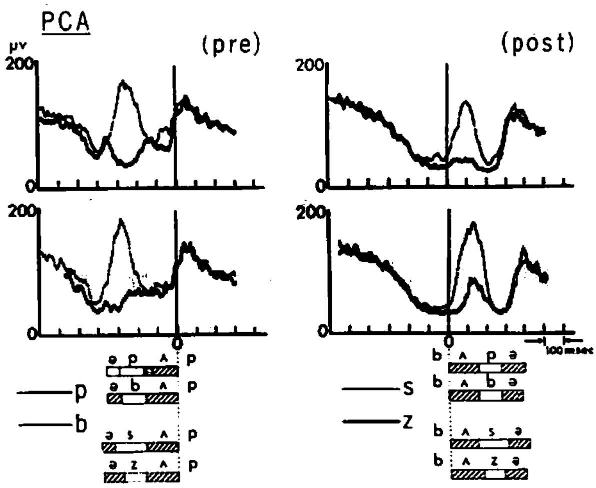

Fig. 3. Examples of averaged EMG patterns of PCA for the pairs comparing /p/ vs. /b/ and /s/ vs. /z/.

In Figure 3, an averaged pattern of PCA activity is compared for the pairs /p/ vs. /b/ and /s/ vs. /v/ in the same American English speaker as in the previous figures. The comparison was made in different phonetic environments, namely, in prestressed position in the left half of the figure and in poststressed position in the right. Zero on the time axis indicates the line-up point for the averaging. A marked elevation of PCA activity is always noted for the production of voiceless consonants /p/ and /s/. For voiced consonant production, on the other hand, PCA activity is generally suppressed. However, the PCA shows a relatively higher activity for the segment /z/, particularly in the poststressed position, when compared to the neighboring vowel segments. This finding would suggest that the glottal closure is less tight for voiced /z/ than for vowel segments, as has been found on other studies using transillumination of the larynx (Lisker, Abramson and Cooper, 1969) and fiberoptic observation (Sawashima, 1970).

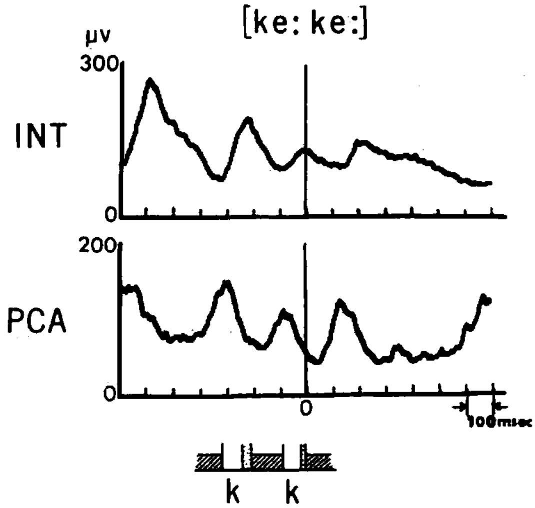

Fig. 4. Averaged EMG curves of PCA and INT in a Japanese subject producing a test utterance "soreo kee kee to yuu".

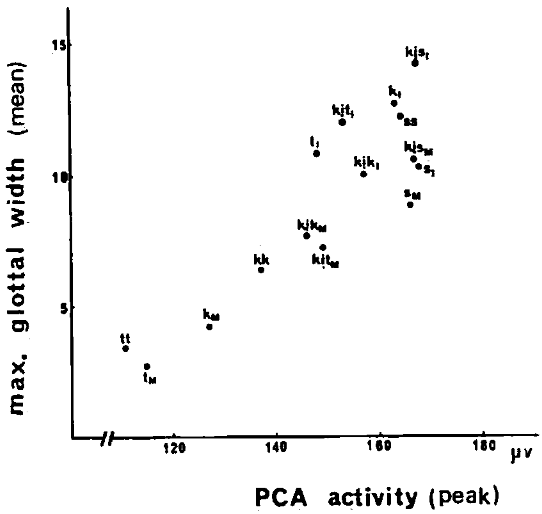

Fig. 5. Relationship between peak values of averaged PCA activity and maximum glottal width.

Figure 4 shows averaged EMG curves of the PCA and the INT in a Japanese subject for the test utterance "soreo Keekee to yuu", where the four mora meaningful word "keekee" with initial and medial voiceless tops is embedded in a frame sentence. The PCA shows an increasing activity for /k/ in the test utterance but the peak value is clearly higher for the word-initial /k/ than for the word-medial /k/. Incidentally, PCA activity also increases for the voiceless /t/ in the frame.

In the same Japanese subject, a fiberoptic movie of the glottis was taken for various kinds of test utterances, in order to investigate the relationship between glottal dynamics and PCA activity. It was always observed that there was a separation of the arytenoids and widening of the glottis for the voiceless portion of the test utterences, including voiceless stops, voiceless fricatives, geminates and devoiced vowels.

Figure 5 shows the relationship between peak values of averaged PCA activity and maximum glottal width for all types of voiceless segments used in the experiments. It is shown that the maximum glottal width is generally larger when the peak PCA activity is higher. A statistical test shows that a significant positive correlation exists between these two parameters at the 0.01 level of confidence ($r = 0.86$). It is also shown here that PCA activity is higher and glottal width is larger for voiceless stops in word initial position, (which are marked by a capital letter "I" subscript), than those in word medial position, which are labelled "M".

However, there is no appreciable difference for the voiceless fricative /s/ with regard to the difference in phonetic envoironment.

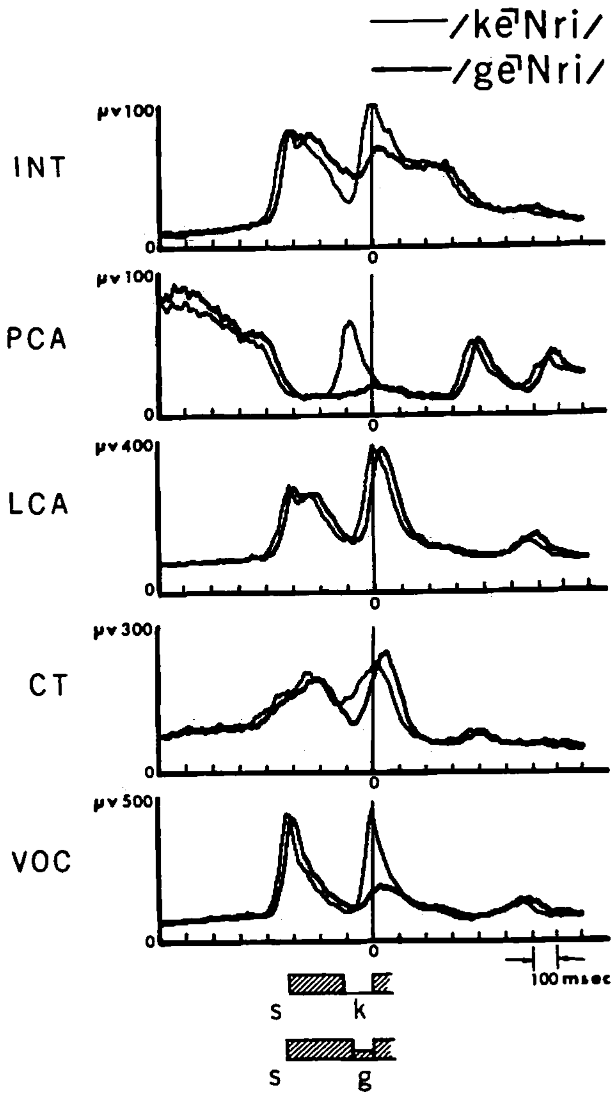

Fig. 6. Activity patterns of five intrinsic laryngeal muscles for the production of a pair of Japanese test words. For a detailed description, refer to text.

Figure 6 compares activity patterns of the five intrinsic laryngeal muscles for the production of a pair of Japanese test words, /keNri/ vs. /geNri/, embedded in a frame sentence "sore wa --- desu". The reciprocal relationship between the PCA and the INT can be seen again in this figure. For the lateral cricoarytenoid (LCA) and thyroarytenoid (VOC), these two muscle activities increase at the initiation of each utterance, namely, for the carrier portion preceding the test word, and decreases for word initial consonant production, where the degree of suppression is similar regardless of the voicing distinction in the paired consonants. The activity increases again after the suppression, apparently for the nuclear vowel following the initial consonant. In the case of the VOC, the activity sharply increases after the voiceless consonant particularly when the accent kernel is attached to the vowel following the voiceless consonant, whereas the increase is less marked after the voiced pair. The pattern of LCA activity in terms of suppression for the initial consonant and increase for the following vowel is essentially uniform regardless of the voicing distinction in the initial consonant. Similar findings were also obtained from American-English speakers, in that both the VOC and the LCA appeared to be suppressed for consonantal segments regardless of the voicing contrast.

For most voiced-voiceless pairs, the general pattern of cricothyroid (CT) activity is similar and characterized by two peaks separated apparently by suppression for the initial consonant of the test words. It should be noted, however, that the degree of suppression is different depending on whether the initial consonant is voiced or voiceless, in that the suppression is less marked for the voiceless cognate than for the voiced. The difference is also related to the degree of reactivation after the suppression, and it is apparently more marked for the voiced cognate (Hirose and Ushijima, 1978). The pattern of the CT in relation to the voicing distinction will be discussed again later.

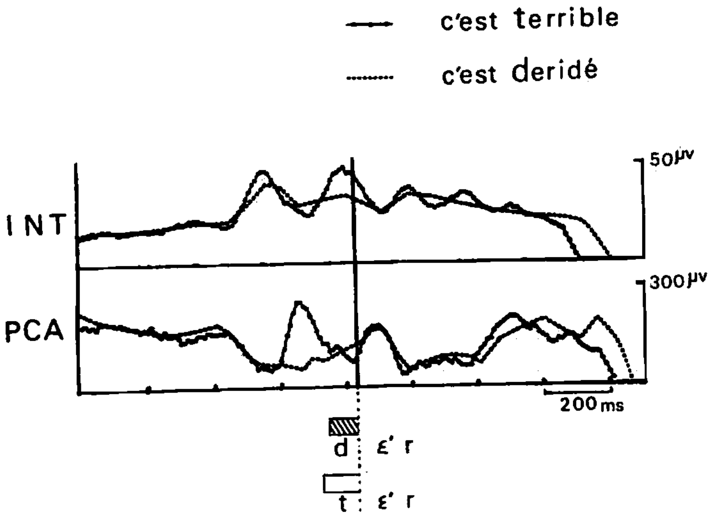

Fig. 7. Averaged EMG curves of PCA and INT for /t/ vs. /d/ contrast in French.

EMG and fiberoptic experiments were also performed with a native speaker of Swiss-French. Fugire 7 illustrates an example of averaged EMG curves for the PCA and the INT in the /t/ vs. /d/ contrast in word initial position. It can be seen that there is a reciprocal pattern between the two muscles in this case too, and that PCA activity increases for voiceless /t/. It should also be noted here that there is PCA activation and INT suppression for the post-vocalic /r/. A fiberoptic study made on the same subject showed that the vocal folds were abducted for the production of /t/ and other voiceless segments, and for /r/, as well.

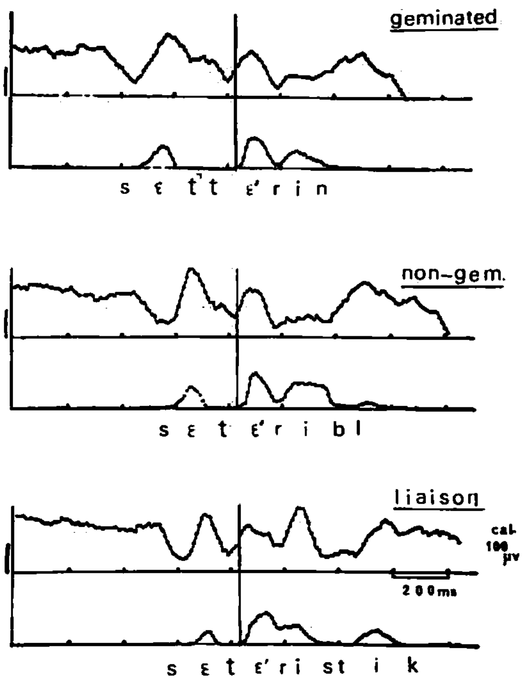

Fig. 8. Comparison of PCA patterns for the French voiceless /t/ in the three way contrast in different conditions.

Figure 8 compares the various pattern of the PCA for the voiceless /t/ sound in the three-way contrast between liaison, non-geminated and geminated conditions. The contrast appeared to be evidenced primarily by the duration of oral closure and thus reflected in the timing of laryngeal gestures and of the corresponding EMG activity. In other words, the PCA peak occurred earliest, and duration of PCA activation is longest, for the geminated voiceless stop, while the peaking is latest, and the duration is shortest, for the liaison stop. The order exactly corresponds to that of glottal gesture in terms of the timing of vocal fold abduction. Fiberoptic studies also showed that the maximum glottal aperture during the oral closure of a geminated stop was not a simple function of the duration of glottal separation. The finding is also consistent with these EMG patterns, where the peak value of PCA activity for the geminated stop is similar to that for the non-geminated stop, while the duration itself of PCA activation is longer for the geminated case (Benguerel, Hirose, Sawashima and Ushijima, 1978).

A similar finding was obtained for Danish. In this language, both "p, t, k" and "b, d, g" groups are voiceless in word initial position but the degree and timing of glottal opening is different for the two groups. Figure 9 compares the time course of the glottal opening for /p/ vs. /b/ embedded in a frame. Glottal aperture is much larger for /p/ and the glottal width becomes widest near the oral release, whereas the glottis is less open and the peaking is earlier for /b/. Figure 10 compares the Danish words [pha:nə] and [ba:nə] preceded by a carrier [han sa]. It can be seen here that there is a large dip for s and p and a somewhat smaller dip for b in averaged INT activity. In the PCA curves, there are peaks corresponding to the INT dips. It should be noted that PCA activity lasts longer and the peak is higher for p than for b. These EMG patterns seem to be consistent with the glottal gestures presented in Fig. 9 (Fischer-Jørgensen and Hirose, 1974a).

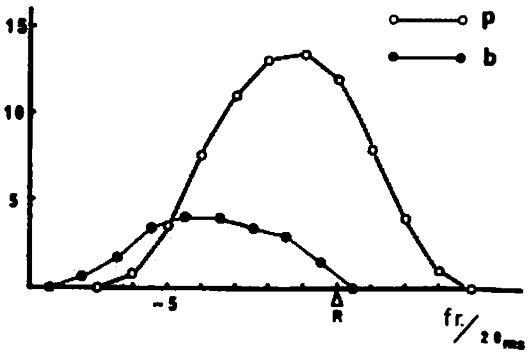

Fig. 9. Time course of the glottal opening for /p/ vs. /b/ pair in Danish.

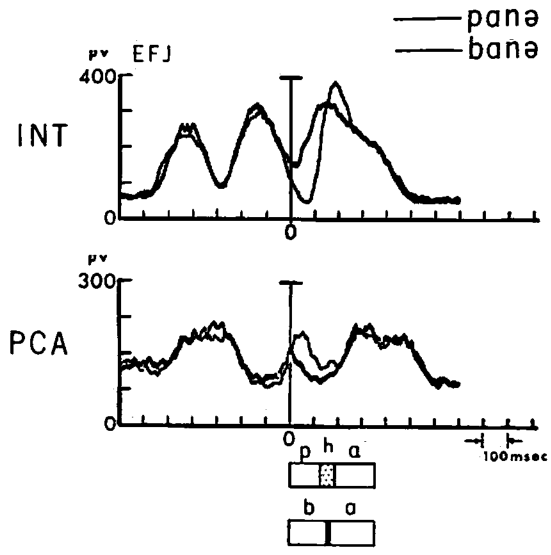

Fig. 10. EMG patterns of PCA and INT for the production of Danish words with the contrast between /p/ and /b/.

Reciprocity between the PCA and the INT was found to exist even for a five way distinction using the same manner of articulation examined with the aid of an American English speaker, a phonetician who produced labial stops of five phonetic types. Figure 11 illustrates the averaged PCA and INT activity for, from the top to bottom, voiced inaspirates, implosive voiced inaspirates, voiced aspirates, voiceless aspirates and voiceless inaspirates. It can be seen that PCA activity sharply increases for the bottom three types, namely for voiced aspirates, voiceless aspirates and voiceless inaspirates, whereas reciprocal suppression is found in the INT curves. Supplemental fiberoptic observation of the same subject revealed that separation of the arytenoids was always observed for these three types and there was a good agreement in both timing and degree between PCA activity and the opening gesture of the glottis, both factors being considered physiological determinants of different phonetic types in greater than two-way distinction.

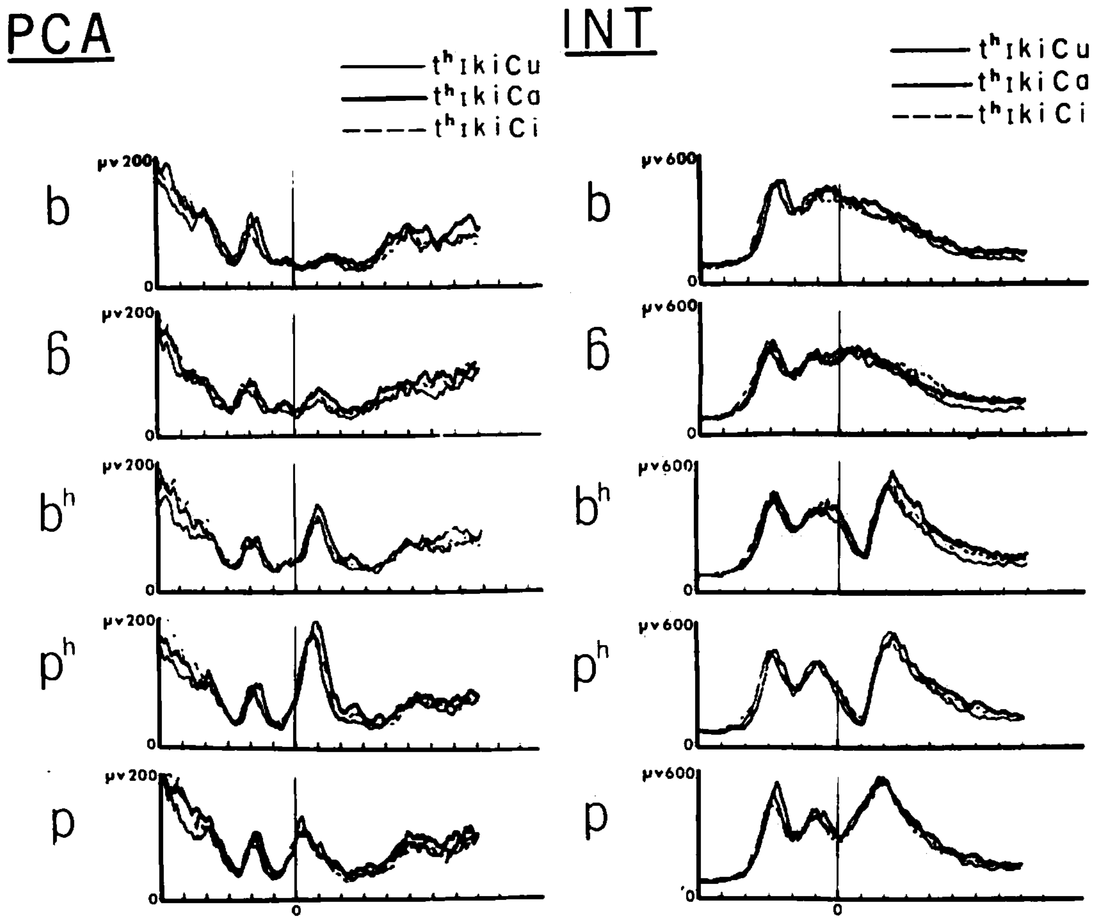

Fig. 11. Comparison of PCA and INT activity patterns in five different phonetic categories. (Time scale: 100 msec)

There are certain cases where another physiological dimension must be taken into consideration. Figure 12 shows an example of the averaged EMG curves of the VOC and the INT for three types of Korean stops in word initial position. For all types, an opening gesture of the glottis was evidenced by fiberoptic observation. It can be seen that for type I, forced stop, which is illustrated at the bottom of the figure, there is a sharp increase in VOC activity before the articulatory release. This vocalis activity presumably results in an increase in the inner tension of the vocal fold and can be taken as a physiological correlate of so-called laryngealization (Hirose, Lee and Ushijima, 1973).

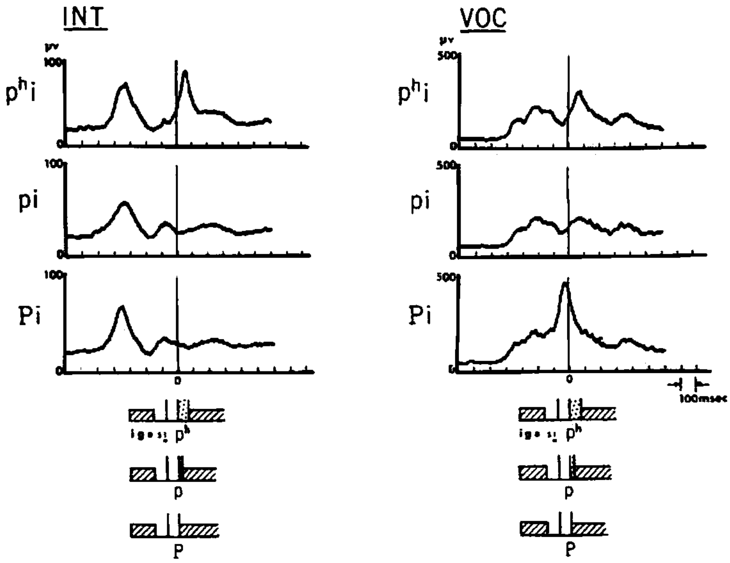

Fig. 12. Averaged EMG curves of VOC and INT for three types of Korean stops.

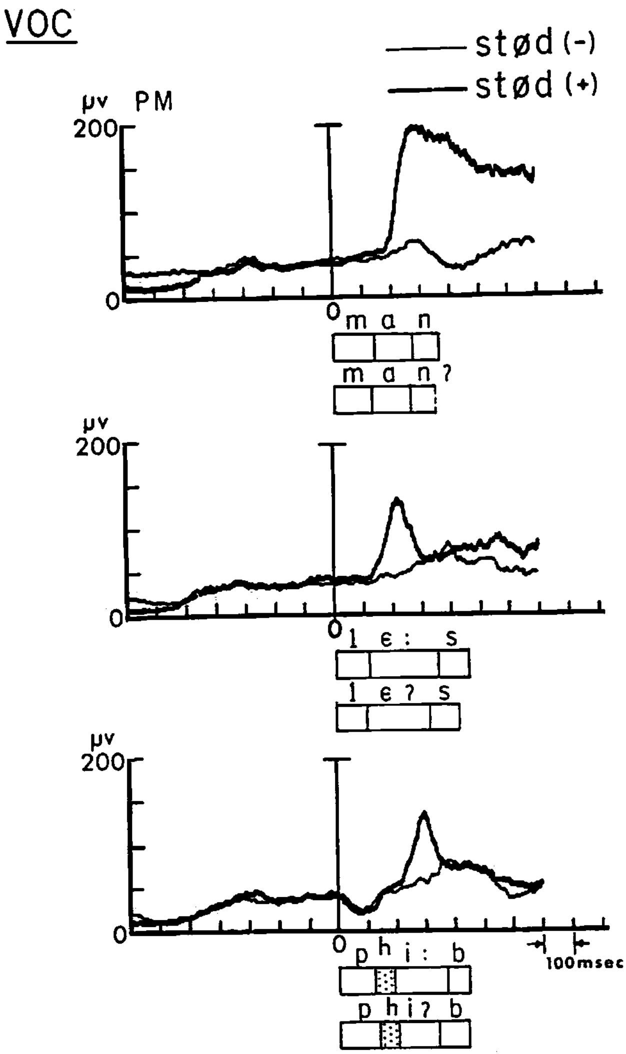

Fig. 13. VOC activity patterns comparing stød vs. non-stød contrast in Danish.

A similar type of VOC activity is also found in the case of Danish stød. In Fig. 13, we are comparing stød vs. non-stød opposition in meaningful Danish words. For the stød group, there is a sharp increase in VOC activity. Although the nature of the increasing VOC activity in these cases is still open for discussion, we do need an additional dimension independent of glottal constriction (Fischer-Jørgensen and Hirose, 1974b).

Going back to the topic of the activity patterns of the VOC and the LCA in the voicing contrast, the result of a recent EMG study on a Swedish consonants showed that these two muscles appeared to be less suppressed for the voiced cognate than for the voiceless. As can be seen in Fig. 14, both the VOC and the LCA are more clearly suppressed for short and long voiceless consonants, particularly in the middle syllable, than for their voiced counterparts. A similar tendency was also observed in our study on Danish in which VOC is more suppressed for strongly aspirated stops, namely, the so-called p, t, k group, than for less aspirated b, d, g group, even though, as mentioned previously, both groups are produced as voice less. It can also be seen in Figure 14 that CT suppression is less marked for voiceless consonants than for the voiced. As suggested by Dixit, the CT can contribute to an increase in the tension of the vocal fold which might eventually be relevant for eliminating voicing (Dixit, 1975). In this sense,

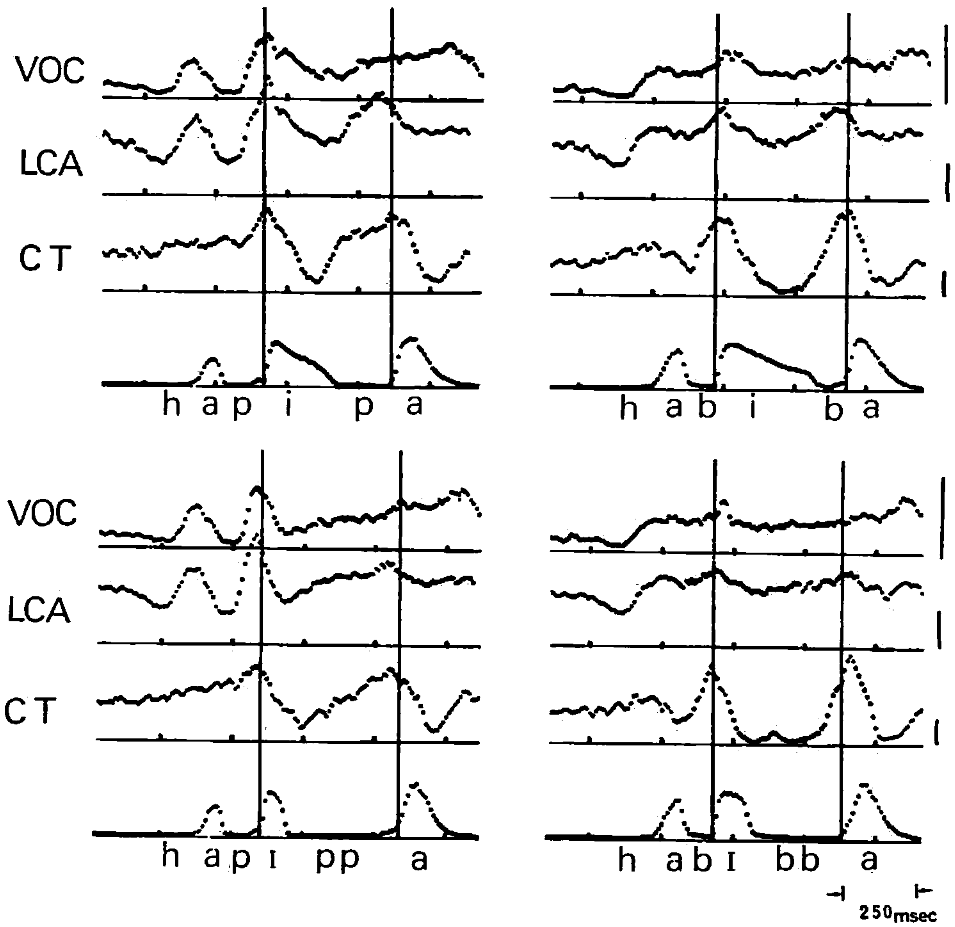

Fig. 14. Activity patterns of VOC, LCA and CT in the production of Swedish test words.

it might be plausible to consider the relatively high CT activity in the production of voiceless consonant in certain cases as one possible factor of enhancing voicelessness.

However, our recent observations on Danish consonant production revealed that a relatively high CT activity was also seen for voiced /h/, which was produced with an open glottis, where F_0 was rather low and, therefore, CT activation did not seem to be related to a pitch rise itself. Thus, the correct interpretation of the apparently higher CT activity in certain consonantal segments is still unresolved, and further investigation of the physiological and physical parameters in connection with acoustic phenomena in speech is warranted.

In summary, our EMG and fiberoptic investigations on laryngeal behavior in consonant production have revealed the following:

1. The intrinsic laryngeal muscles participate actively in laryngeal control in speech articulation.

2. A reciprocal pattern between the PCA and the adductor muscles, the INT in particular, is almost always observed in subjects of different languages and can be taken as an important physiological correlate controlling the timing and degree of the glottal opening gesture. PCA activity increases for those speech sounds produced with an open glottis, and there is a positive correlation between maximum glottal width and peak PCA activity.

3. It is suggested that there is a functional differentiation in the adductor group. In particular, the VOC can be regarded as a specific muscle working to control an additional dimension independent of glottal constriction in some specific languages.

4. The contribution of the CT in the voicing distinction seems plausible in some cases but further investigation is necessary for a definite interpretation of pattern of CT activity in speech.

References

Benguerel, A.P., Hirose, H., Sawashima, M. and Ushijima, T. (1978): Laryngeal control in French stops: A fiberoptic, acoustic electromyographic study, Folia Phoniatr. (in press).

Dixit, R. P. (1975): Neuromuscular aspects of laryngeal control: With special reference to Hindi. Ph. D. Dissertation presented to the Faculty of Graduate School of the University of Texas at Austin.

Fischer-Jørgensen, E. and Hirose, H. (1974a): A preliminary electromyographic study of labial and laryngeal muscles in Danish stop consonant production. Haskins Laboratories Status Report on Speech Research SR-39/40: 231-254.

Fischer-Jørgensen, E. and Horise, H. (1974b): A note on laryngeal activity in the Danish 'stød'. Haskins Laboratories Status Report on Speech Research, SR-39/40: 255-262.

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

Hirose, H. and Ushijima, T (1978): Laryngeal control for voicing distinction in Japanese consonant production. Phonetica (in press).

Hirose, H., Lee, C. Y. and Ushijima, T. (1974): Laryngeal control in Korean stop production. J. Phonetics 2: 145-152.

Lisker, L., Abramson, A, Cooper, F. S, and Schvey, M. H. (1969): Transillumination of the larynx in running speech, J. Acoust. Soc. Am. 45: 1544-1546.

Sawashima, M. (1970): Glottal adjustments for English obstruents, Haskins Laboratories Status Report on Speech Research SR-21/22: 187-200.

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