Ann. Bull. RILP, No. 10, 101-111 (1976)

MORE ON LARYNGEAL CONTROL FOR VOICING DISTINCTION IN JAPANESE CONSONANT PRODUCTION

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In recent years, investigation on laryngeal articulatory adjustments has been one of the important projects in speech research. The experiment to be reported here is a part of systematic studies on laryngeal control in Japanese consonant production. Previous electromyographic (EMG) and fiberoptic studies have revealed that there is a reciprocal activity pattern between the adductor and abductor groups of the intrinsic laryngeal muscles in different languages, and, in particular, the posterior cricoarytenoid (PCA) is important for active vocal fold abduction for those speech sounds produced with the open glottis.[1),2)] In the present experiment, multichannel EMG recordings were taken of a native Japanese subject and voiced/voiceless contrast was examined in various phonetic environments. The results of EMG study were then compared with those of a fiberoptic experiment.

Method

A speaker of the Tokyo dialect served as the subject and read randomized lists of test sentences sixteen times each. Each sentence embedded a test word in a frame "sorewa --- desu." (That is ---.) Table I lists the test words used in the experiment. They are all meaningful Japanese words. For the words in Group I, the accent kernel is attached to the first mora, whereas no accent kernel is attached to the words in Group II.

Group I	Group II
1. /peN/	10. /kiNpeN/
2. /beN/	11. /kiNbeN/
3. /teNki/	12. /seHteN/
4. /deNki/	13. /seHdeN/
5. /keNri/	14. /seHkeN/
6. /geNri/	15. /seHgeN/
7. /seN'i/	16. /seHseN/
8. /zeN'i/	17. /seHzeN/
9. /heN'i/	18. /seHheN/

Table I: List of test words used in the present experiment. Each word is embedded in a frame sentence: "sorewa --- desu."

Electromyographic recordings were made using hooked-wire electrodes. The electrodes were inserted into the posterior cricoarytenoid (PCA), the interarytenoid (INT), the vocalis (VOC), the lateral cricoarytenoid (LCA), and the cricothyroid (CT). The description of the insertion techniques and the methods of verification of electrode placement may be found in previous reports.[3)]

The EMG signals were recorded on a multichannel data recorder together with acoustic signals and automatic timing markers. The signals were reproduced and computer-processed to give an averaged pattern of muscle activity. The data processing system is described in more detail elsewhere.[4)]

In addition to the EMG experiment, movies of the glottis were taken during production of the same test utterance on the same subject by means of a fiberscope, at a film rate of 50 frames per second. Appropriate frame sequences for the consonant pairs were then examined by the technique of frame-by-frame analysis with special regard to the time course of glottal aperture width as measured at the vocal processes.

Results

Figures 1 and 2 show examples of activity patterns of five intrinsic laryngeal muscles for the production of paired test words embedded in the frame sentence, comparing /keNri/ vs. /geNri/ and /seHkeN/ vs. /seHgeN/, respectively. Both pairs thus compare k-g opposition in different phonetic environments.

It is apparent that the PCA and INT show reciprocal relationship regardless of the difference in phonetic environment, i.e., PCA is always active for the production of voiceless sounds, for which INT is always suppressed. The degree of PCA activation and corresponding INT suppression is, however, different depending upon the environment. Clearly, PCA activation and INT suppression are more dominant for the word initial voiceless stop than for the word medial. The environmental difference is not so remarkable in the case of voiceless fricatives as seen in Figures 3 and 4, where the comparison between /seN'i/ vs. /zeN'i/ and /seHseN/ vs. /seHzeN/ is made.

In order to further examine the ralationship between PCA and INT curves, correlation coefficient was calculated for each utterance type for the period from 500 msec before the line-up point of averaging to 500 msec after the line-up. As presented in Table II, there is consistent negati.e correlation between PCA and INT patterns, which seems to support the notion of reciprocity between the two muscles.

For the utterance samples examined in the present experiment, the relationship between the maximum glottal width measured on fiberoptic film and the peak values of averaged PCA activity was illustrated in Figure 5. As reported elsewhere [2)], the glottal width tends to be larger when the peak EMG activity becomes higher and there is a significant positive correlation between the two parameters ($r = 0.93$ at the 0.01 level of confidence).

For both VOC and LCA, muscle activity increases for initiation of each utterance, i.e., 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 voiced-voiceless distinction in the paired consonants. The activity increases again after the suppression, apparently for the nuclear vowel following the initial consonnat. In the case of VOC, muscle activity sharply increases after the voiceless consonant particularly when the accent kernel is attached to the vowel following the

Number of utterance type

1.	r = -.6514	10.	r = -.6502
2.	r = -.7709	11.	r = -.6524
3.	r = -.6888	12.	r = -.7818
4.	r = -.8469	13.	r = -.7961
5.	r = -.5995	14.	r = -.8025
6.	r = -.8138	15.	r = -.7639
7.	r = -.7552	16.	r = -.8112
8.	r = -.7977	17.	r = -.7604
9.	r = -.7587	18.	r = -.7681

Table II: Correlation coefficient between averaged EMG values of PCA and INT for each utterance type for the period from 500 msec before to 500 msec after the line-up.

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 voiced-voiceless distinction of the initial consonant.

For the consonant segment in the word medial position, VOC and LCA curves generally show the pattern of suppression after the activation for the vowel segment of the preceding mora. For both VOC and LCA, there is a reactivation for the vowel following the word medial voiceless fricative /s/, but the tendency is less remarkable after the voiceless stops.

For most voiced-voiceless pairs, the general pattern of CT activity is similar and characterized by two peaks separated apparently by suppression for the initial consonant of the test words. It is noted, however, that the degree of suppression is different depending on the voicing distinction of the initial consonant, 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.

Figure 6 compares the patterns of EMG suppression of INT, VOC, LCA and CT for the consonantal segments of the test words. For each muscle, the leftmost point indicates the value of EMG peak for the vowel segment preceding the consonant, which is unanimously taken as 100%. The EMG value * for the consonantal segment is plotted toward the right side of each figure, again taking the peak value for the preceding vowel to be 100%. The figure shows that INT suppression is consistently more marked for voiceless cognates than for the voiced if the comparison is made in the same

*When there is a definite volley for the consonantal segment in averaged EMG curve, the minimum EMG value is taken and relative value is calculated in reference to the preceding peak EMG value. If the minimum value is unclear, particularly for the word medial consonant, the EMG value at the moment when PCA shows a peak for corresponding voiceless consonant is taken for comparison.

phonetic environment. On the other hand, the degree of suppression of LCA and VOC appears to be different depending primarily on the phonetic environment and not on voicing distinction. In the same environment, suppression appears to be more marked in VOC than in LCA. Suppression of CT is not remarkable in the word medial position, whereas in the word initial position, it is generally more marked for the voiced cognates.

Comments

The present results further confirm our previous findings on the pattern of laryngeal muscular control for speech articulation in Japanese.[2),5)] In particular, reciprocal patterns in PCA and INT are clearly shown in terms of significant negative correlation, and active PCA control for voiceless consonant production in Japanese is demonstrated.

The pattern of VOC and LCA as the adductor is different from that of INT as reported elsewhere,[1)] and their activity level is apparently influenced by the phonetic environment. Both muscles are generally suppressed for consonantal segments, but the degree of suppression is much more marked in the word initial position. It would be reasonable to consider at this point that the apparent suppression of VOC and LCA in the word initial position can be related, at least in part, to the word-boundary effect in those test utterances used in the present experiment. The apparent CT suppression around the word initial consonant can also be related to the word-boundary effect of each utterance (see infra).

As for the pattern of CT activity, our previous studies did not reveal any significant difference with reference to voiced-voiceless distinction of the consonant in the test word, and the role of CT has been attributed primarily to pitch control. In the present experiment, appreciable difference in the degree of CT suppression is noted apparently with regard to the voicing distinction of the word initial consonant, in that the degree of CT suppression appears to be less remarkable in the utterance types embedding the voiceless pair. The same tendency is, however, not evident for the word medial voicing contrast. Our preliminary analysis of pitch contour of the present utterance samples of both groups reveals that there is a consistent pitch drop at the end of the carrier "sorewa.". Therefore, the suppression of CT around the word initial consonant should also be related to the pitch drop, which can be taken as one of the boundary effects. Analysis also reveals that the extent of the mean pitch drop is more marked in those sentences having the voiced consonant in the word initial position of the test word as compared with those having the voiceless pair. It thus seems conceivable that the apparent difference in the degree of CT suppression between the voiced and voiceless pairs may well be attributed to the difference in dynamic control of pitch contour between the present utterance samples.

The contribution of CT on voicing distinction was discussed by Dixit[6)] on Hindi stop production, and he postulated that CT activity contributes to the tension of the vocal folds in eliminating voicing in unvoiced stop production; our subsequent study on a different Hindi speaker, however, failed to confirm his notion on increased CT activity in unvoiced stop production.[7)] Although it is conceivable that increased longitudinal tension of the vocal fold can contribute to some extent to eliminating vocal fold vibration, a closer observation on acoustic parameters, pitch contour in particular, seems to be mandatory in interpreting the pattern of CT activity in speech.

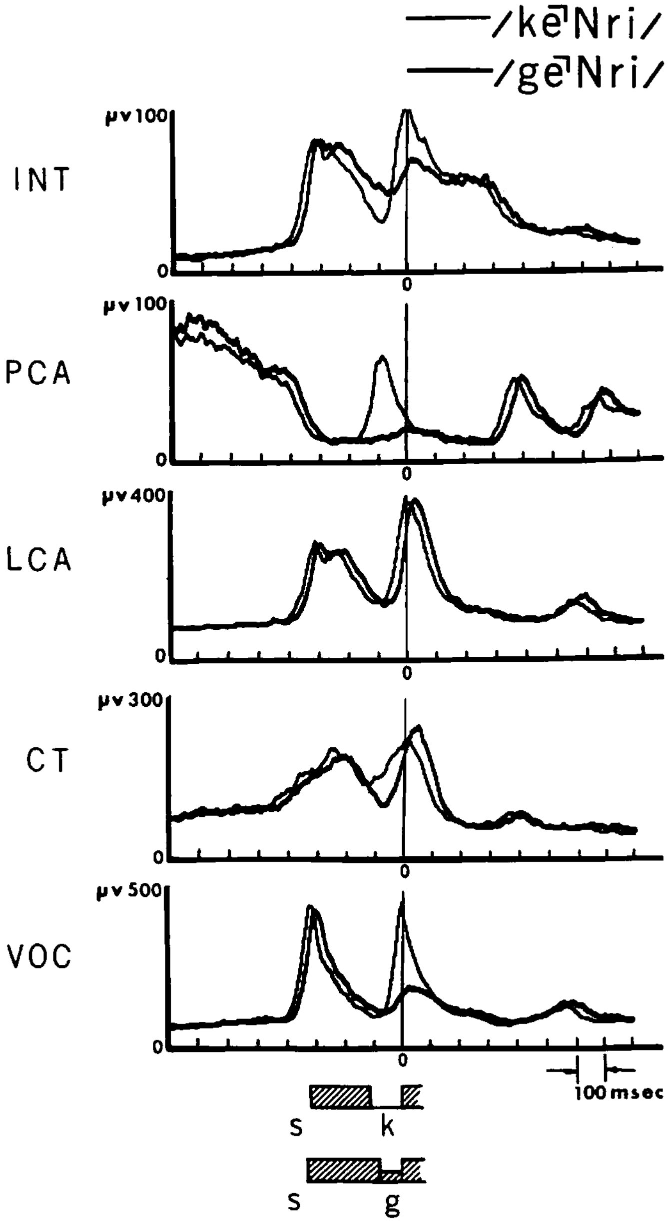

Fig. 1: Averaged EMG curves of five intrinsic laryngeal muscles for test utterances comparing the word initial /k/ vs. /g/ opposition.

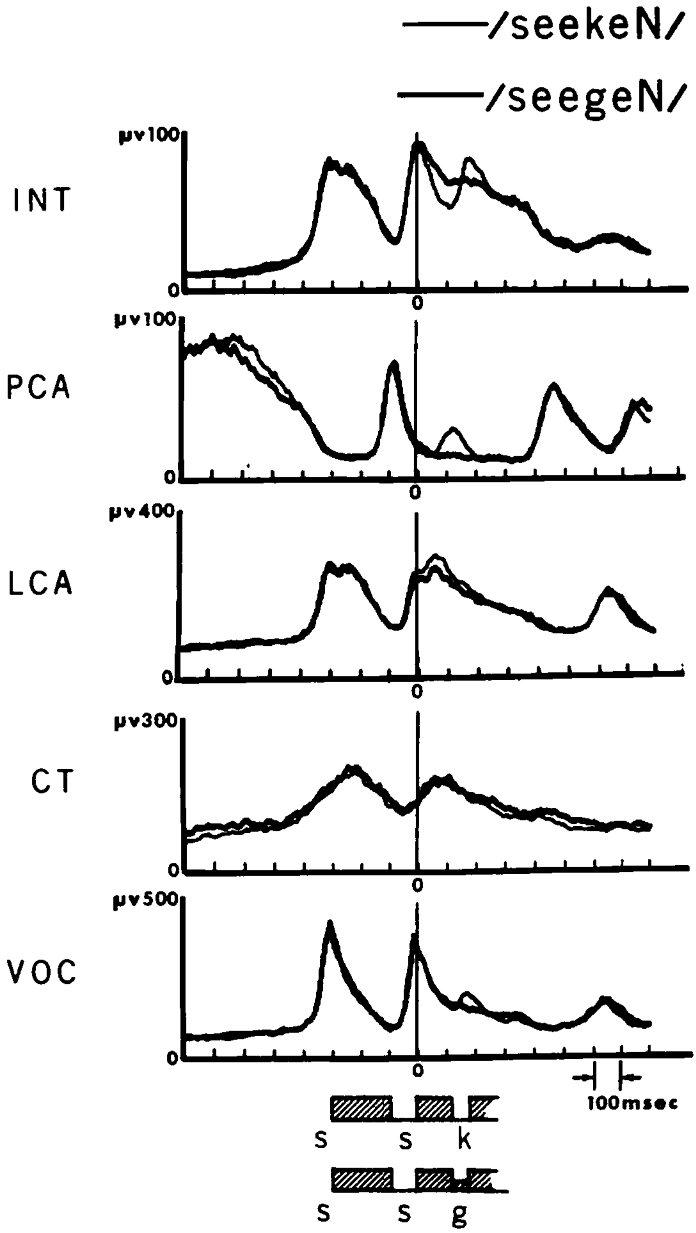

Fig. 2: Averaged EMG curves of five intrinsic laryngeal muscles for test utterances comparing the word medial /k/ vs. /g/ opposition.

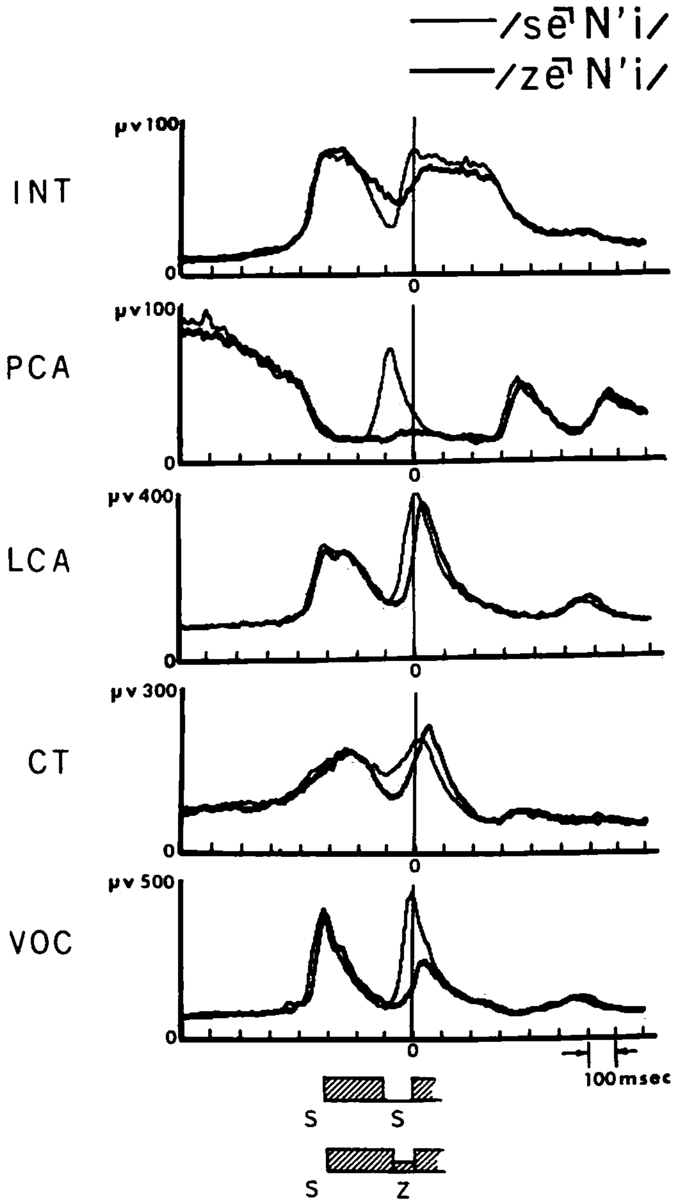

Fig. 3: Averaged EMG curves of five intrinsic laryngeal muscles for test utterances comparing the word initial /s/ vs. /z/ opposition.

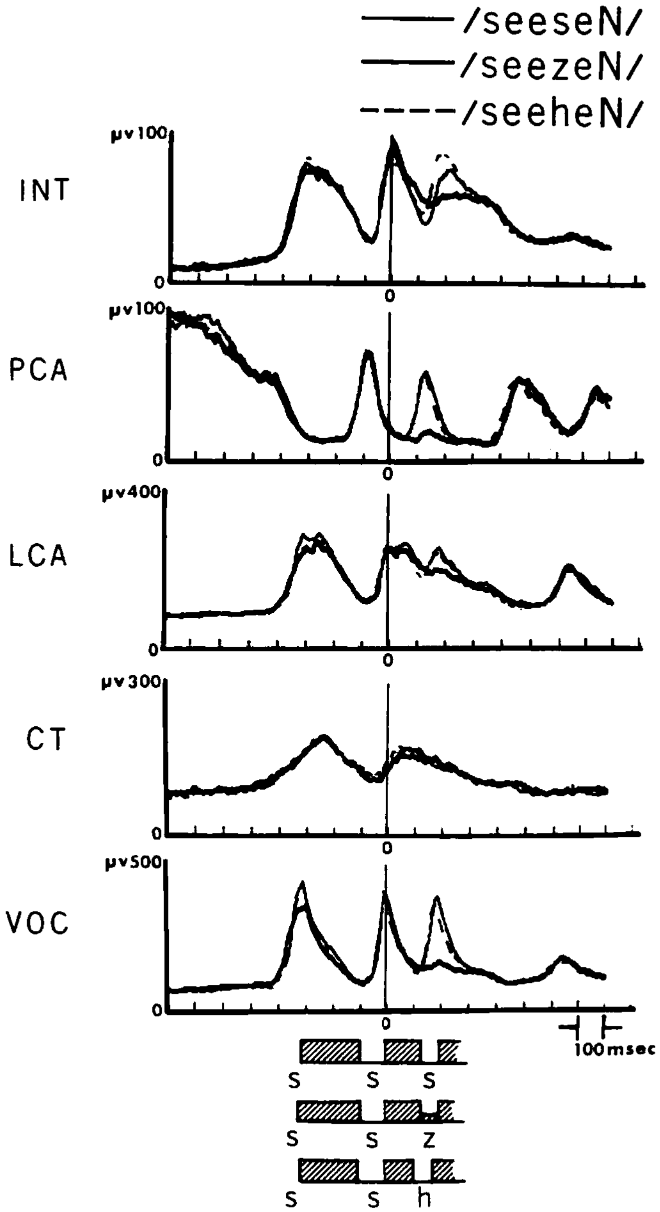

Fig. 4: Averaged EMG curves of five intrinsic laryngeal muscles for test utterances comparing the word medial /s/ vs. /z/ opposition.

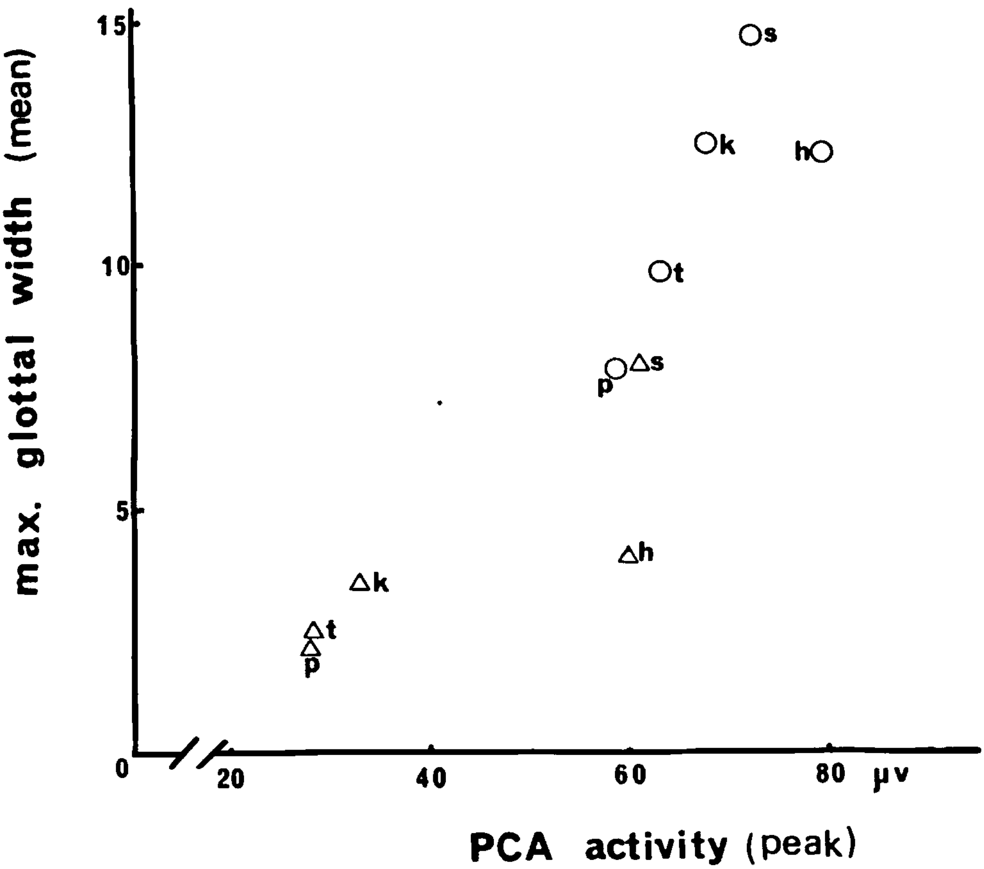

Fig. 5: Relationship between the maximum glottal width coordinate - (arbitrary scale) and peak value of averaged PCA activity (abscissa). Open circles indicate the word initial voiceless consonants; triangles indicate the word medial.

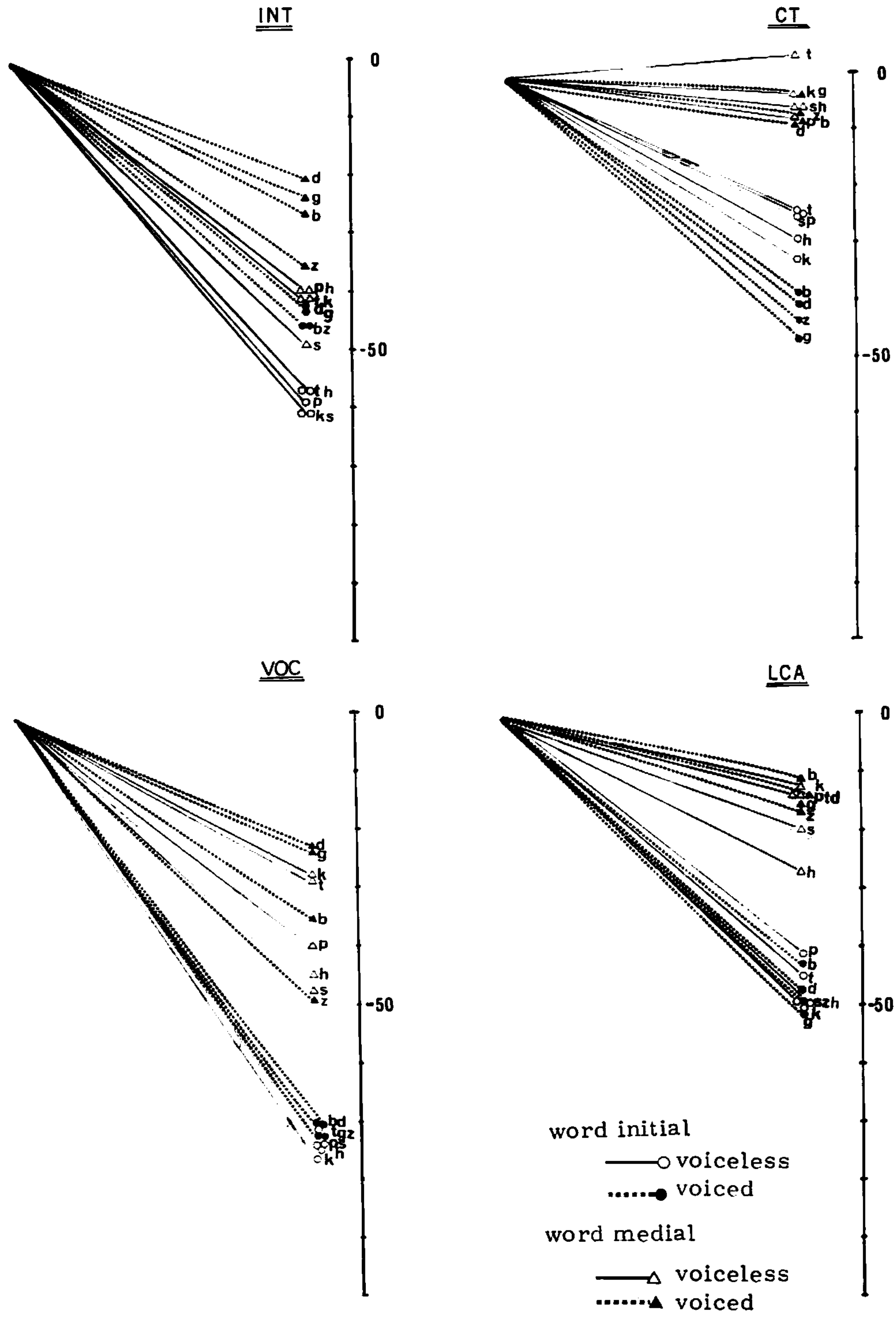

Fig. 6: The degree of suppression of averaged EMG activity of four different muscles around the obstruents in the test utterances.

Acknowledgements

The EMG data presented in the present report were obtained and processed at Haskins Laboratory, New Haven, Connecticut, U. S. A.

The authors wish to extend their gratitude to Dr. F. S. Cooper and other staff at Haskins Laboratories for the supporting grant: No. DE-01774 from the National Institute of Dental Research, National Institute of Health.

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