Phonetica
Editor: E. ZWIRNER, Münster in Westfalen
S. KARGER – BASEL/NEW YORK (Printed in Switzerland)
SEPARATUM

Phonetica *23:* 156–170 (1971)

The Activity of the Adductor Laryngeal Muscles in Respect to Vowel Devoicing in Japanese

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The aim of the present study is to examine the electromyographic activities of selected laryngeal muscles which are considered to serve as adductors of the vocal folds during speech utterances. In the experiments to be discussed here, the thyroarytenoid muscle and the lateral cricoarytenoid (lateralis) muscle were examined. Strictly speaking, the thyroarytenoid muscle consists of multiple anatomical portions. In the present study, however, the most medially situated portion (the internal thyroarytenoid or the vocalis muscle) was aimed at as the object of examination.

The vocalis muscle arise from the inner surface of the thyroid cartilage at the angle formed by the junction of the laminae, extends backward and attaches to the arytenoid cartilage mainly at the vocal process. It pulls the arytenoid cartilage forward at the point of attachment and consequently rotates the cartilage medially. For this reason, it is generally believed to have an adduction effect in addition to shortening and tensing effects on the vocal fold [NEGUS, 1962; HOLLINSHEAD, 1954].

The lateralis muscle arises from the upper border and the outer surface of the cricoid arch, extends upward and backward, attaches to the anterior surface of the muscular process of the arytenoid cartilage. When it contracts it draws the muscular process forward and downward, and this results in rotating the arytenoid cartilage in such a way that the vocal process approaches the center line of the glottis. Thus this muscle also is considered as an adductor of the vocal folds [NEGUS,

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1962; HOLLINSHEAD, 1954]. Figure 1 presents a schematic drawing of the anatomical location of the vocalis and the lateralis muscles.

Recent technical developments in electromyography have made it possible to obtain data on laryngeal muscle activity during speech and singing particularly effectively by the use of double-ended hooked wire electrodes inserted into the pertinent muscle through a percutaneous approach. In our experiments, pairs of insulated copper wires are employed as the electrodes, the outer diameter of which is approximately 80 μm. The pieces of wire are threaded through a 27 gauge hypodermic needle (0.4 mm in outer diameter and 2.0 cm in length) and the needle carrying the electrodes is inserted percutaneously either into the vocalis muscle through the cricothyroid membrane, or the lateralis muscle through the cricothyroid muscle. This technique was developed by HIRANO and OHALA [1969]. The arrows in figure 1 represent the directions of the needle insertions in obtaining access to the target muscles. When the insertion is made, the location of the pair of electrodes is tested by observing the electromyographic signals induced by gestures that have been proved pertinent for the con-

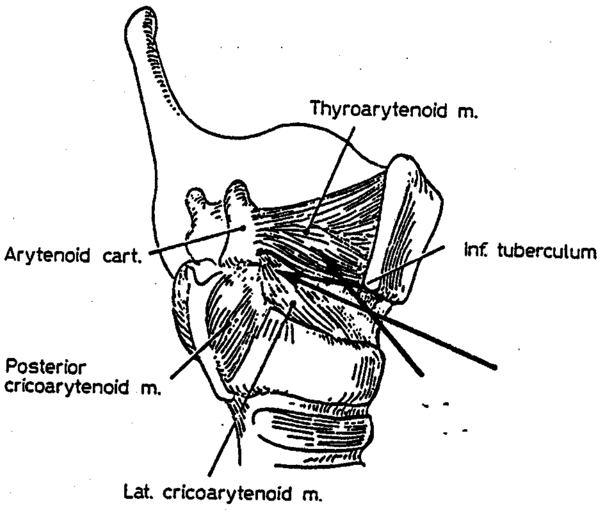

Fig. 1. A lateral view of the larynx with the right ala of the thyroid cartilage removed. Arrows indicate the direction of insertion of the needles into the vocalis muscle and into the lateral cricoarytenoid muscle, respectively. [This figure was taken from HIRANO and OHALA, 1969, with slight modifications.]

traction of the selected muscle. If the validity of location is ascertained, the needle is withdrawn, leaving the electrodes hooked into the desired portion in the muscle. Once the electrodes have been thus fixed, the subject can talk in a natural manner with practically no discomfort. After the completion of the data acquisition, the wires can be removed with a light tug.

The electromyographic and speech signals are recorded by an FM magnetic tape recorder. We employ a PDP-9 computer for processing the electromyographic data. The magnetic tape is played back and the recorded signals are fed to the computer through an A–D converter. The electromyographic signal is sampled every 250 μsec and digitized into 6-bit levels. The absolute values are taken and then integrated and smoothed over a range of 10 msec. For a selected 10 of the 15 recorded utterances for each utterance item, the integrated values as functions of time are added together with reference to the point in the time axis representing a predetermined speech event that is observed in the speech signal of the test word.

In the present study, in order to simultaneously observe the conditions of the glottis while recording the electromyographic signals, a fiberscope [SAWASHIMA, 1968] was inserted through the nose of the subject and a 16 mm motion picture was taken at a rate of 24 frames/second. Synchronizing time marks were provided both on the film and on the magnetic sound tape in the form of image-blanking DC signals with a sharp onset wave form.

Selected Japanese words as shown in table I[2] were used as the test words. The subject uttered each test word repeatedly 15 times in isolation, with a short pause between utterances.

It is known that high vowels between voiceless consonants are often devoiced in many Japanese dialects [BLOCH, 1950; HAN, 1962]. In the test words, the vowel /i/ in /sitee/, /sisee/, /sihee, /sittee/, and /sissee/ can be either voiced or devoiced. The present experiment was performed on 2 subjects, both native speakers of the Tokyo dialect. On 1 subject whose data will be discussed in this paper in some detail, the vocalis and the lateralis muscles were examined. For the 2nd subject, only the lateralis muscle was examined. The subjects were first instructed to utter the test words with and without devoicing in 2 separate series (series A and B). The subjects then uttered each of the test words as

[2] The list of utterances contains some other test words which will not be discussed here.

Table I. List of the test words used in the present experiment

sitee	(私邸)	zitee	(自邸)
sisee	(姿勢)	zisee	(時勢)
sihee	(私兵)	zihee	(時弊)
si'ee	(私営)	zi'ee	(自営)
sidee	(紫泥)		
sittee	(失邸)	zittee	(実弟)
sissee	(失政)	zissee	(実勢)

natural utterances of the word in isolation, without paying any attention to making the samples consistent in respect to the devoicing feature (series C). The recorded samples in this series were later separated into 2 subsets, voiced and devoiced, for EMG processing by visually inspecting the acoustic wave forms.

Figure 2 shows a pair of sound spectrograms of the test word /sisee/ uttered with and without devoicing of [i] in the separate series A and B, respectively. Short vertical bars under the spectrograms demarcate time intervals for the successive frames of the motion picture. The arrows at the upper corner of each spectrogram indicate the start of the blanking signal which was placed immediately after the completion of the utterance for the synchronization of the sound record and the film frames. The numbers attached indicate the frame numbers counted back from the synchronization mark and correspond to those in figure 3 (see infra). It may be mentioned that in the upper spectrogram, even though the vowel [i] is completely voiceless, we can identify rather clearly the manifestation of the vowel as a time segment with distinctly intensified F_3, F_4, and F_5 regions in contrast to (but with almost the same formant frequencies with) the adjacent fricative segments, which in turn show more concentrated components representing a higher resonance. This fact suggests that the location of

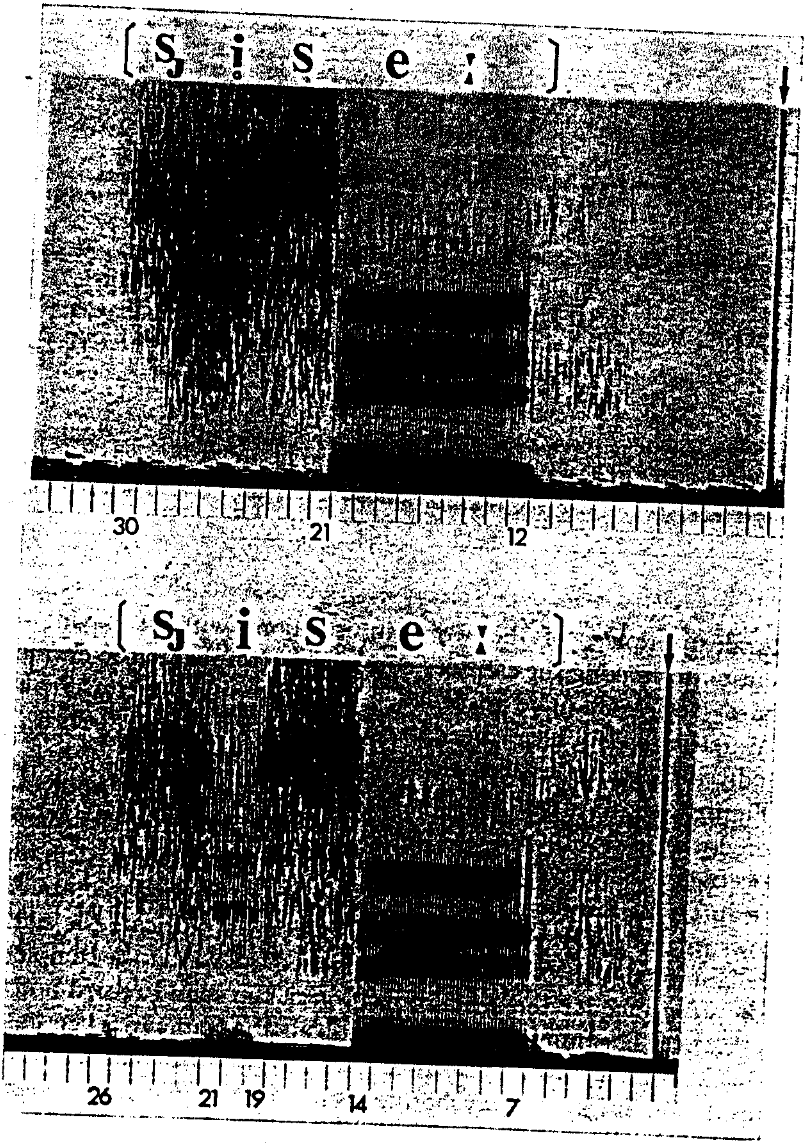

Fig. 2. A pair of sound spectrograms of the test word /sisee/ uttered with and without devoicing in the separate series. The numbers attached correspond to those in figure 3.

the turbulence source differed between the consonantal segment and the voiceless vowel segment. We may thus assume that the relative airflow impedances at the vocal tract constriction, i.e. the glottal and palatal constrictions, were appreciably different for the two segments. It would not be necessary for the interpretation of the above-mentioned acoustic observation, to assume any change in the lingual articulation, however, if it were the case that the inherent glottal gesture for the vowel segment were present and consequently the glottal constriction were narrower for the devoiced vowel segment in comparison with the adjacent fricatives. Further, devoicing of the vowel could take place simply because of some aerodynamic effect on the vocal fold vibration under this particular phonetic condition, the glottal gesture being the same as in the case of voiced [i]. In the present study, however, this hypothesis is refuted by the following evidence.

In the upper row in figure 3, successive frames for the test word /sisee/ containing the devoiced high front vowel [i̥] are presented (series A). For comparison, similar frames for the same test word in which the vowel was voiced are presented in the lower row in the same figure (series B). It is clear in the upper row that the vocal folds are set apart throughout the period from the initial [sʃ] to the end of the intervocalic [s], with no discernible effects of adduction for the vowel in between. This finding is in agreement with the photoglottographic

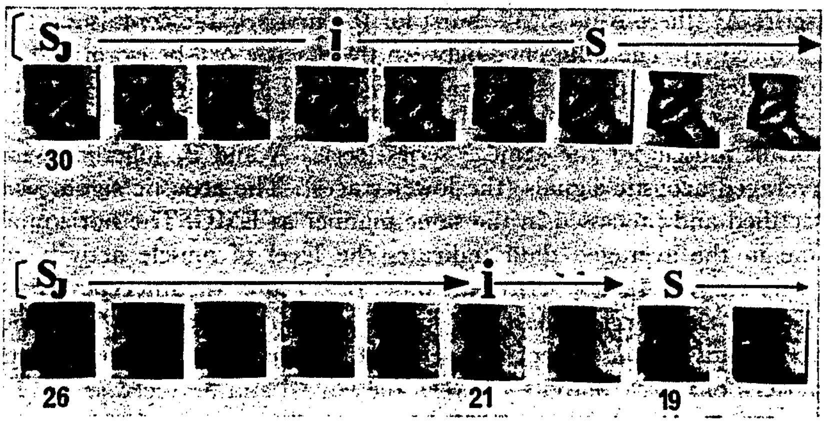

Fig. 3. Successive frames for the test word /sisee/ containing the devoiced vowel [i̥] (above) and the voiced vowel [i] (below).

data reported by SAWASHIMA [1969] who observed that the glottis stayed open for the devoiced vowel as well as for the voiceless consonants.

In contrast to the devoiced cases, the glottis is closed and the vocal folds are set into vibration for the voiced period of [i] in the case of series B (see the lower row in fig. 3). Similar results have been obtained for the voiced-devoiced contrast of high vowels in other test words. From these findings, it can be concluded that there are definitly different positions of the vocal folds for the devoiced and voiced versions of the vowel in the same phonetic environment. It might still, at this point, be argued that there might be no difference in the motor command for the laryngeal movement between voiced and devoiced [i], but depending on difference in some physical conditions near the level of the glottis, the resulting glottal state would vary as a sort of 'passive' but highly non-linear effect. This point will be refuted in what follows with evidence from the electromyographic data.

Figure 4 shows the raw electromyographic data of the vocalis muscle for the test word /sisee/ uttered with and without devoicing. In the lower sample in which the vowel [i] of the first syllable was uttered without devoicing (series B), a rapid increase in activity of the vocalis muscle is evidenced by an electromyographic burst preceding the onset of the voiced [i]. The activity then decreases and maintains a certain level until it increases again near the end of the utterance. In contrast, in the upper sample in which the vowel [i] is devoiced (series A), there is no EMG burst for the first syllable containing the devoiced [i̥]. The difference between the 2 series can be examined in more detail by appropriately processing the EMG data.

Figure 5 shows the averaged electromyographic data from the vocalis muscle for the same 2 series (series A and B) together with averaged acoustic signals (the lower traces). The acoustic signal was rectified and processed in the same manner as EMG. The horizontal line in the averaged data indicates the level of muscle activity at complete rest. In this series, the onset of [e] after the intervocalic [s] is taken as the reference point for the sample summation described above. It is obvious in the averaged data that there is a difference in the pattern of muscle activity between the voiced and devoiced series. In the series where [i] is voiced (the lower sample of fig. 5: series B), muscle activity begins to increase approximately 120 msec before the onset of voicing for [i] and rapidly forms a peak. Muscle activity then

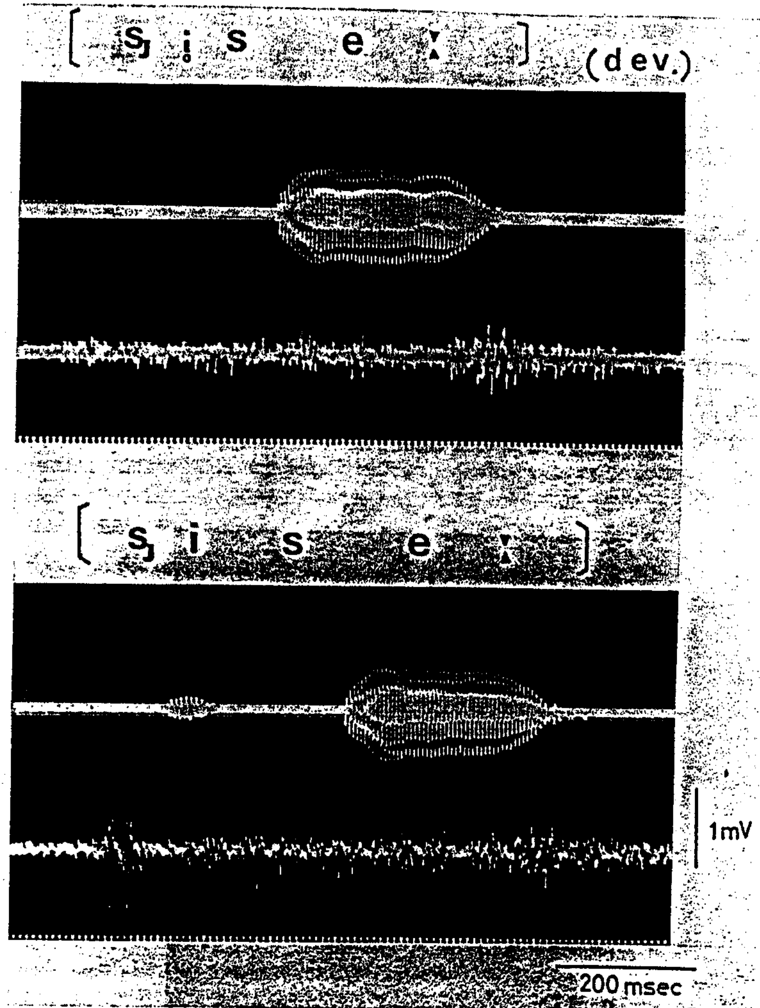

Fig. 4. Raw electromyographic data of the vocalis muscle for the test word /sisee/ uttered with (above) and without (below) devoicing. Upper traces: acoustic signal; lower traces: electromyogram.

decreases to form a dip and then recovers to a more or less stationary level until it increases again to form another large peak near the moment of the voice cessation. Corresponding to the latter peak, it has been observed by fiberscope, that the glottis was closed tightly for a period of time at the end of the utterance. In the author's opinion, the prepared repetition of the test word might cause this tight closure of the glottis, preceding a rapid abduction for a short pause between utterances.

In the series in which the vowel [i] is devoiced (the upper sample of fig. 5: series A), there is no peak in muscle activity for the syllable containing the devoiced vowel. It thus appears that the presence or absence of the phenomenon of vowel devoicing is actually caused by laryngeal motor control. It must be mentioned, however, that in the utterance in series A and B, the subject was quite conscious of making the samples consistent through the series in respect to the devoicing factor. This could well have caused some artifacts in the data in this particular point.

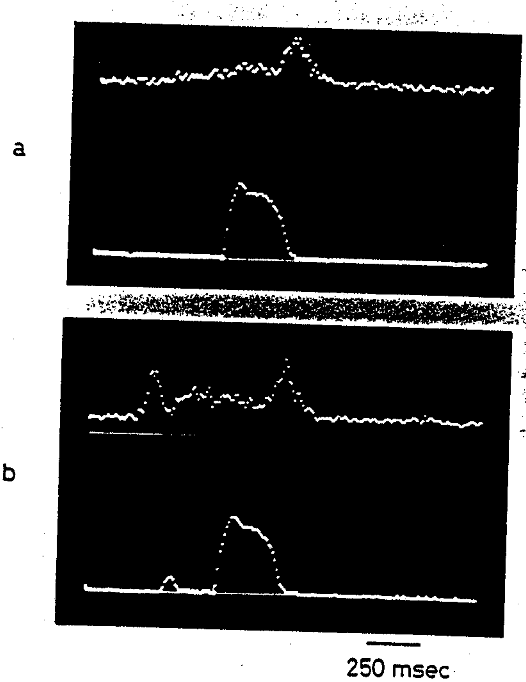

Fig. 5. Averaged electromyographic data from the vocalis muscle for the separate series of the utterances of the test word /sisee/ containing the devoiced vowel [i̥] (a), and the voiced [i] (below), together with averaged acoustic signals. Upper trace: averaged EMG; lower trace: averaged acoustic signal.

In figure 6, the averaging process was applied to the samples uttered in series C. Samples with and without devoicing occurred randomly in this series and these were separated into 2 subsets at the time of processing. The actual occurrence of devoicing was observed in about 70% of the utterances. The characteristics of the difference in the averaged electromyographic patterns between the two subsets are essentially the same as found in figure 5.

From these electromyographic results, it is now clear that the difference in the laryngeal condition in the presence or absence of devoicing depends on the inherent difference in the motor command at least for the vocalis muscle, even though the speaker does not seem

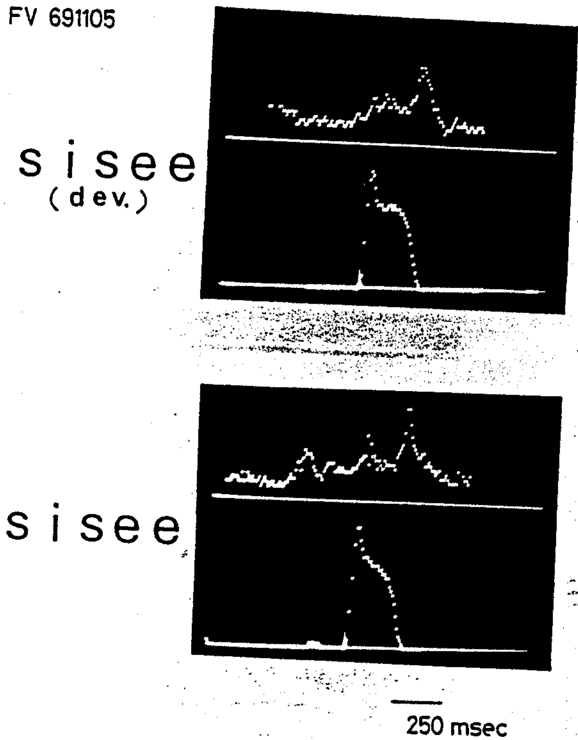

Fig. 6. Averaged electromyographic data from the vocalis muscle for the devoiced and voiced utterances. In this series, the subject uttered the test words without paying any attention to the devoicing features. Consequently, samples with and without devoicing occurred randomly. The samples were later separated into 2 subsets for processing.

to make the pertinent distinction consciously and indeed is not required to make it for any distinctive purpose in Japanese.

The devoicing of high vowel under certain phonological conditions in this language may thus be concluded to be a matter concerning the neural process that determines the motor command, rather than simply a matter of physical fluctuation. In other words, it may be said at this point (perhaps until we learn about other factors that are pertinent to the voicing-devoicing difference) that the choice between the different gestures is made as an optional application of a phonological rule. This kind of physiologically controlled free variation of speech sounds is often observed in language. Here the variation is not quite random since there is a clear bias toward devoicing.

A preliminary study was also conducted to compare the electromyographic activity of the lateralis muscle in the same subject.

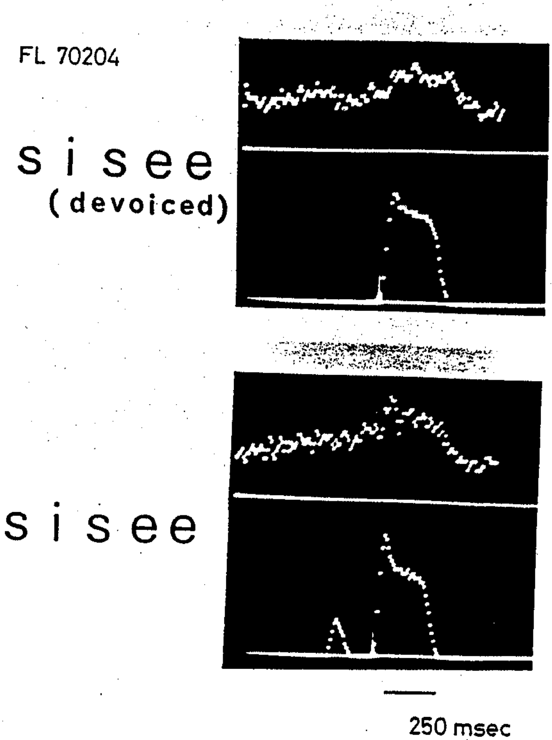

Fig. 7. Examples of the averaged electromyographic data from the lateral cricoarytenoid muscle for the test word /sisee/ uttered in the separate series.

Figure 7 shows examples of the averaged electromyographic data for the lateralis muscle of the 1st subject in the same utterance as in figure 5 (in series A and B). The general pattern of electrical activity differs considerably from that of the vocalis muscle and the distinction between voicing and devoicing is not clear.

In the 2nd subject, however, the voicing-devoicing distinction is clearly demonstrated in this muscle, too, as shown in figure 8, in which averaged electromyographic data from the lateralis muscle of the 2nd subject uttering the samples in series A and B are shown. Namely,

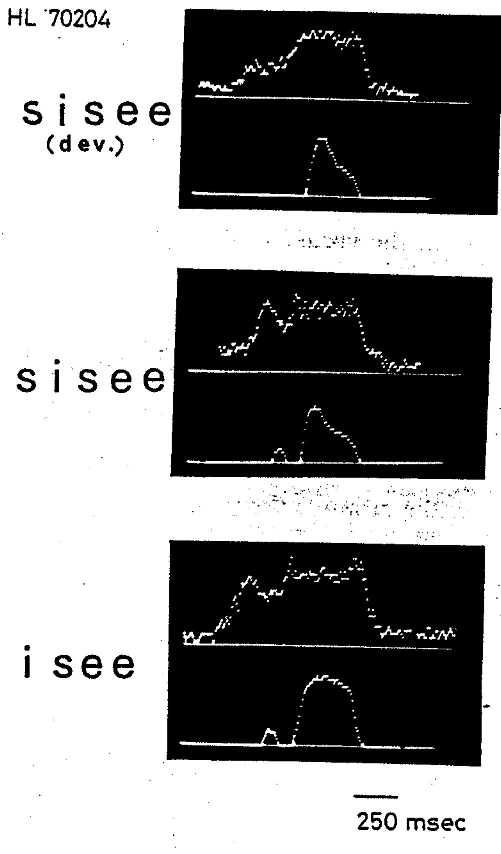

Fig. 8. Averaged electromyographic data from the lateral cricoarytenoid muscle of a 2nd subject. The test words were uttered for the 3 separate series.

there is a peak of activity corresponding to the voiced [i] for the test word /sisee/ uttered without devoicing, whereas the peak is not apparent for the same word with a devoiced [i̥]. These results are comparable to those observed for the vocalis muscle of the 1st subject, although there is, of course, a considerable difference in the EMG patterns between the vocalis muscle and the lateralis muscle in general.

It has been observed in both subjects that the activity of the lateralis muscle always starts well before the voice onset, somewhat earlier than that of the vocalis muscle, and that, even during the voiceless period of the first syllable of /sisee/ with devoicing of the 1st vowel, it stays at the certain level of activity. The activity then stays at a comparatively constant level after it has reached the level for voicing. As a result, the lateralis muscle shows more or less continuous EMG curves throughout the entire period of the utterance, appearing in a more or less trapezoidal shape in the averaged pattern. The activity of the muscle rapidly decreases near the end of utterance. In the 1st subject, the beginning of the descent appears to correspond to that of the 2nd peak in the vocalis muscle activity which was also observed near the end of the utterance.

Although it is not yet conclusive from the present data on limited numbers of subjects, it can be assumed that vocalis muscle is particularly active in voicing and has the characteristic of contracting and relaxing in a relatively fast manner, while the lateralis muscle shows relatively continuous activity during the entire period of the utterance.

The results of the present study suggest that there might be functional differentiation in the group of the so-called adductor muscles of the larynx regarding their roles in speech, although some inter-individual variations may also have to be taken into consideration in some cases.

Acknowledgement

I am deeply indebted to Prof. O. FUJIMURA (Director), Research Institute of Logopedics and Phoniatrics, Faculty of Medicine, University of Tokyo, for his invaluable support and intellectual stimulus during my work with the present paper. I wish to express my thanks to Dr. Z. SIMADA and Dr. S. KIRITANI for their assistance in the conduct of the experiment. I also want to express my sincere appreciation to Dr. K. S. HARRIS and Dr. A. S. ABRAMSON, Haskins Laboratories, for their kind advice and stimulating discussions in preparation of the manuscript.

Summary

The activity of the larynx was examined with respect to vowel devoicing in Japanese, by combining fiberoptic and electromyographic observations. The electromyographic data were obtained from the vocalis and the lateral cricoarytenoid muscles using bipolar hooked wire electrodes.

The fiberoptic observations reveal that the glottis remains open without any gesture of adduction throughout the period of vowel devoicing. The electromyographic data prove that the presence or absence of the phenomenon of vowel devoicing is accompanied by laryngeal motor activities.

Based on the experimental results, the author has concluded that the grammatically optional devoicing of high vowels under certain phonological conditions in Japanese may be a matter concerning the neural process that determines the motor commands to the larynx. The author also suggests functional differentiation in the group of the so-called adductor muscles of the larynx regarding their roles in speech.

Zusammenfassung

Die Muskeltätigkeit der Adductores des Kehlkopfes in bezug auf die Entstimmlichung japanischer Vokale

Elektromyographisch und mit Hilfe optischer Fasern wurde die Kehlkopftätigkeit in bezug auf die Entstimmlichung japanischer Vokale untersucht.

Die Beobachtungen durch optische Fasern zeigen, daß die Glottis während der ganzen Dauer der Entstimmlichung der Vokale geöffnet bleibt ohne Bewegung der Adductores. Die elektromyographischen Daten zeigen, daß das Vorhandensein oder Nichtvorhandensein des Phänomens Entstimmlichung mit motorischen Tätigkeiten des Kehlkopfes einhergeht.

Aufgrund der experimentellen Ergebnisse schließt der Autor, daß die grammatisch zugelassene Entstimmlichung hoher Vokale unter bestimmten phonologischen Bedingungen im Zusammenhang steht mit dem Nervenprozeß, der die motorischen Befehle an den Kehlkopf beherrscht. Der Autor hält es für angebracht, die Adduktormuskeln des Kehlkopfes im Hinblick auf ihre Rolle beim Sprechakt funktionell zu unterscheiden.

Résumé

L'activité des muscles adducteurs du larynx en relation avec le dévoisement de voyelles en japonais

Sur base d'observations électromyographiques et d'observations à l'aide de fibres optiques, on a étudié l'activité laryngée en relation avec le dévoisement de voyelles en japonais.

Les observations à l'aide de fibres optiques montrent que la glotte reste ouverte, sans aucun mouvement d'adduction, pendant toute la période de dévoisement vocalique. Les données électromyographiques prouvent de dévoisement vocalique. Les données électromyographiques prouvent que la présence ou l'absence du phénomène de dévoisement vocalique s'accompagne d'activités motrices du larynx.

Se fondant sur les résultats expérimentaux, l'auteur conclut que le dévoisement, grammaticalement permis, de voyelles hautes dans certaines conditions phonologiques,

pourrait être en relation avec le processus nerveux qui détermine les ordres moteurs donnés au larynx. L'auteur, en outre, suggère de différencier fonctionnellement les muscles adducteurs du larynx eu égard à leurs rôles dans l'acte de parole.

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