# THE FUNCTION OF THE LARYNGEAL MUSCLES IN RESPECT TO THE WORD ACCENT DISTINCTION*

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It has been reported that the accent distinction of Japanese words manifests itself as the difference in pitch contours. In the case of Tokyo Japanese, word accent patterns can be represented by the position (or absence) of an accent kernel mark in a phonemic transcription. The second mora of a word is generally pronounced with a higher pitch compared with the first mora, unless the accent kernel falls on the first mora, or the first syllable is a "long syllable". The pitch level drops at the mora boundary following the vowel with the accent kernel and the position of this boundary is indicated by the accent kernel mark " ˥".

For the present study, multiple-channel recordings of the electrical activities of the intrinsic and extrinsic laryngeal muscles were made with special reference to the word accent distinction, as a part of our investigations on laryngeal participation in actualizations of different phonological features. The object muscles examined in the present experiments were the lateral cricoarytenoid muscle, the cricothyroid muscle, and the sternohyoid muscle. The lateral cricoarytenoid muscle originates at the cricoid cartilage and attaches to the muscular process of the arytenoid cartilage. This muscle is considered to act as a glottal adductor (Figure 1). The cricothyroid muscle originates at the anterior central portion of the cricoid cartilage and runs upward and laterally toward the inferior border of the thyroid cartilage. A contraction of this muscle tilts the thyroid cartilage forward rotating around the cricothyroid joint, pulling the vocal cords longitudinally (Figure 2). The sternohyoid

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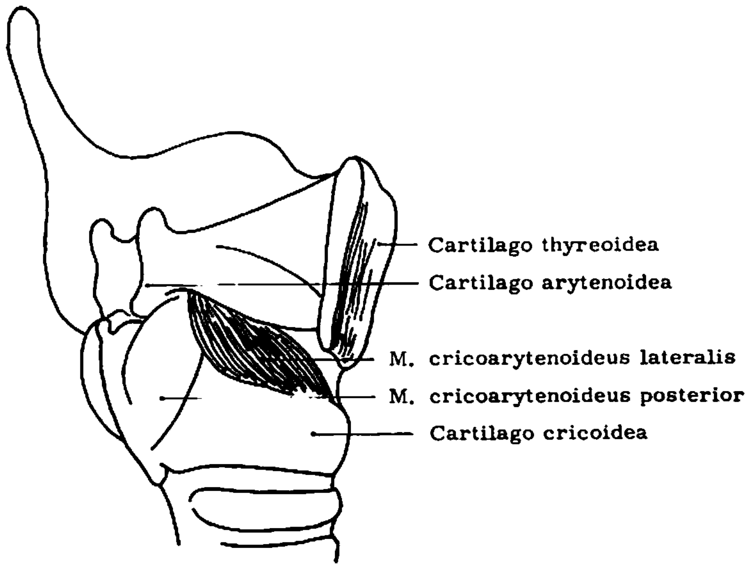


Figure 1. A side view of the lateral cricoarytenoid muscle. (From Hirano and Ohala[2], p. 38)

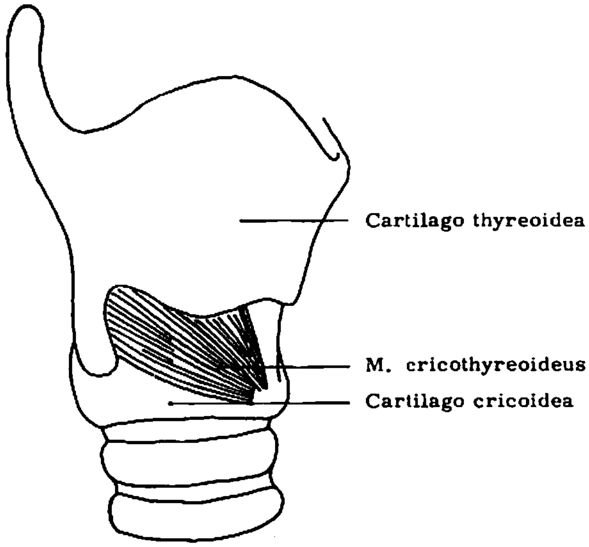


Figure 2. A side view of the cricothyroid muscle. (From Hirano and Ohala[2], p. 36)

muscle arises from the manubrium of the sternum, runs upward, and attaches to the hyoid bone. This muscle is reported by some authors to be active for lowering voice pitch (Figure 3).[5]

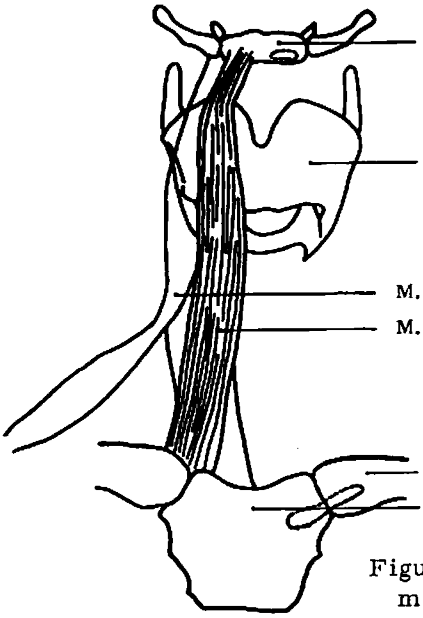


Figure 3. A front view of the sternohyoid muscle. (From Kamijo[4], p. 296)

In preparing test words, care was taken to select words for comparison with the pertinent accent distinction ceteris paribus. Table 1 (p.40) presents the list of test words in their carrier sentences. One subject, a native speaker of Tokyo Japanese, uttered each of the sentences more than ten times repeatedly, with a pause between utterances (HH701).

## EXPERIMENTAL PROCEDURES

Electromyographic recording was made using the hooked-wire electrodes described elsewhere in this issue.[3] The action potentials of the three muscles were derived simultaneously. The electromyographic and acoustic signals were recorded by a four-channel FM data recorder. For sound-spectrographic analysis, the speech signal was also recorded by an audio tape recorder. The signals reproduced from the FM tape were amplified and filtered, and were fed to the PDP-9 computer through a multiplexer and an A-D converter. The electromyographic signals were sampled every 250 μs and digitized into 6-bit levels. The absolute value was taken, and then integrated over a period of 20 ms. The time window for this integration was shifted by steps of 10 ms to give consecutive sample values. The signals thus smoothed were averaged over ten selected utterances of the same sentence.

The speech signal was also processed in the same way. An example of the results is illustrated in Figure 4. The left column shows the raw electromyographic data, the right column the averaged electromyographic signals for the utterance of /mizu'u˥mi ni 'iku/. The traces represent, from top to bottom, the lateral cricoarytenoid, the cricothyroid, and the sternohyoid muscles, and the speech signal. The reference point in the time axis for the averaging process was set at the onset of the speech signal through the visual inspection of the acoustic waveform of each

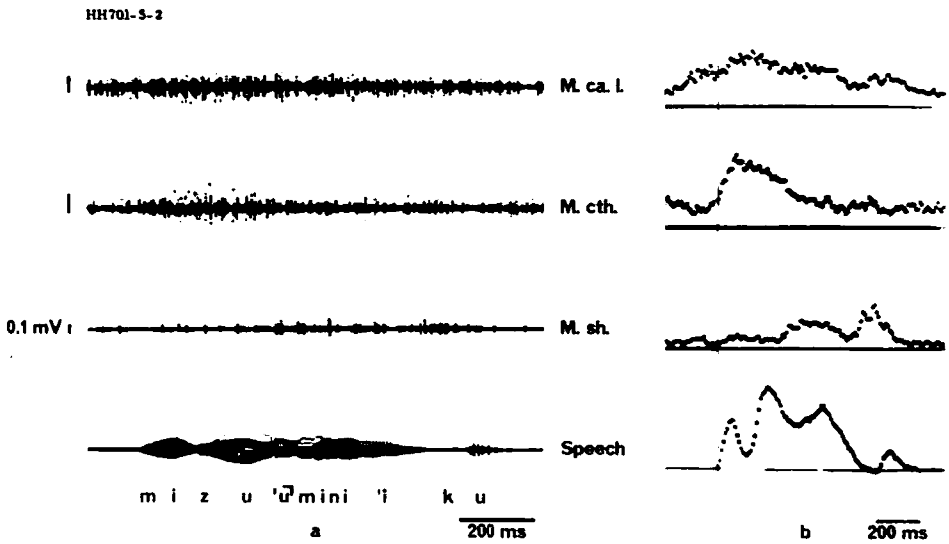


Figure 4. From top to bottom, traces represent (a) the raw EMG data and (b) the averaged EMG signals of the lateral cricoarytenoid, the cricothyroid, and the sternohyoid muscles for the utterance of /mizu'u˥mi ni 'iku/. The vertical bar indicates the reference point for the averaging process.

utterance with the aid of a thin vertical line on a display. The speed of the automatic movement of the line was controlled with a set of toggle switches on the computer. The fundamental frequency of the voiced portion was measured with the use of a narrow band sound spectrogram; the frequency of the third harmonic was measured at a number of predefined speech events of each utterance, and the mean values were calculated for these sample points.

## RESULTS AND DISCUSSION

The lateral cricoarytenoid muscle shows continuous EMG activity throughout the utterance as illustrated in Figure 5, where the words mimi˥zuku and mimizu are compared. Activity begins to increase gradually approximately 250 ms prior to the voice onset. This early activity of the lateral cricoarytenoid muscle was noted consistently in all of the utterances in connection with initiations of voicing. The activity then somewhat decreases and shows a dip approximately at the moment of the onset of the speech signal. The dip was most clearly observed for the utterances which began with a word without the accent kernel on the first mora, while it was less apparent when the accent kernel fell on the first mora of the test word (See also Figures 7, 8, 9, 10, 11, and 14b). The activity appears to increase again after the dip and shows a second and more or less flat peak, leading the pitch contour peak by 70-130 ms, and then toward the end of utterance declines gradually to the level of spontaneous activity.

The lateral cricoarytenoid muscle also participates in the articulatory gestures. The activity, for example, decreases for voiceless stops; in the utterance /mimi˥zuku ni 'yuu/, the glottis opens for the consonant [k] and closes again for the following vowel [u]. It appears that the third peak in EMG activity corresponds to the glottal closure.

The cricothyroid muscle shows the most clear-cut electromyographic feature in relation to the presence of the accent kernel. As illustrated in Figures 5, 6, 7, and 8, the cricothyroid muscle shows a relatively steep

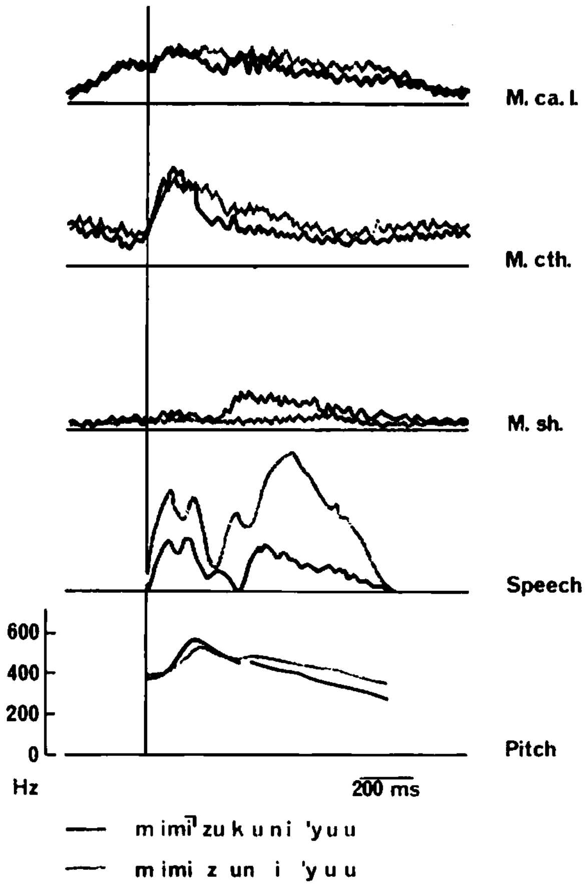


Figure 5. From top to bottom, traces represent the averaged EMG signals of the lateral cricoarytenoid, the cricothyroid, and the sternohyoid muscles, and the pitch contour for the utterances of /mimi˥zuku ni 'yuu/ and /mimizu ni 'yuu/. The vertical bar indicates the reference point for the averaging process.

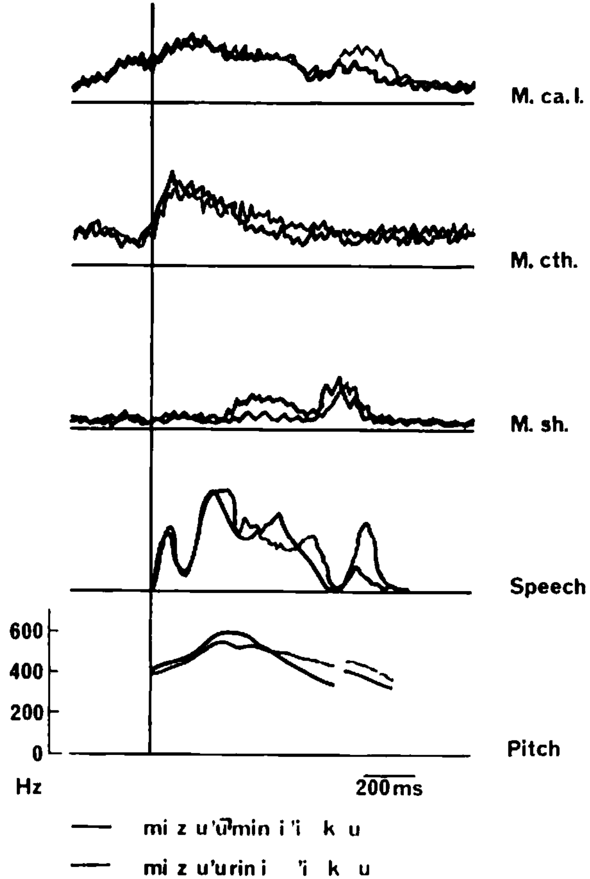


Figure 6. The same as in Figure 5, for the utterances of /mizu'u˥mi ni 'iku/ and /mizu'uri ni 'iku/.

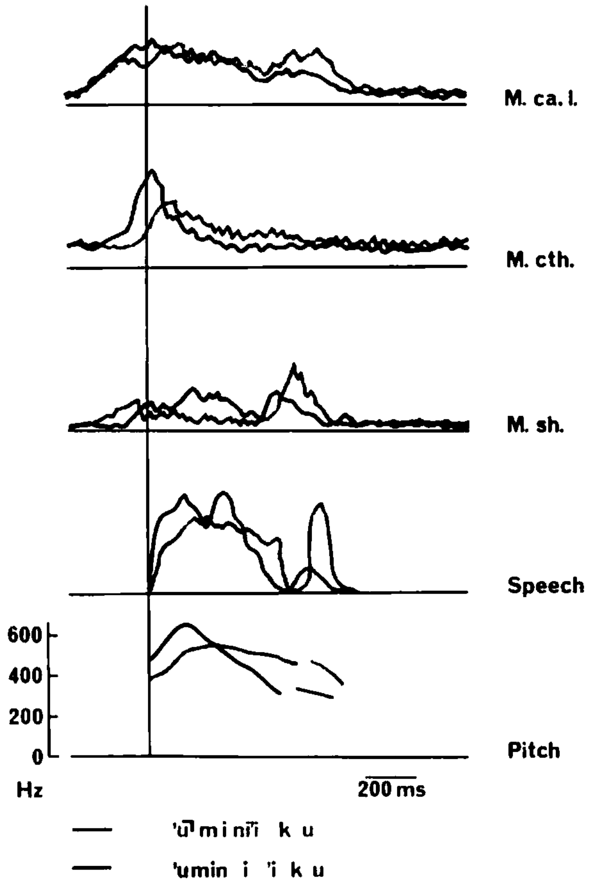


Figure 7. The same as in Figure 5, for the utterances of /'u⌉mi ni 'iku/ and /'umi ni 'iku/.

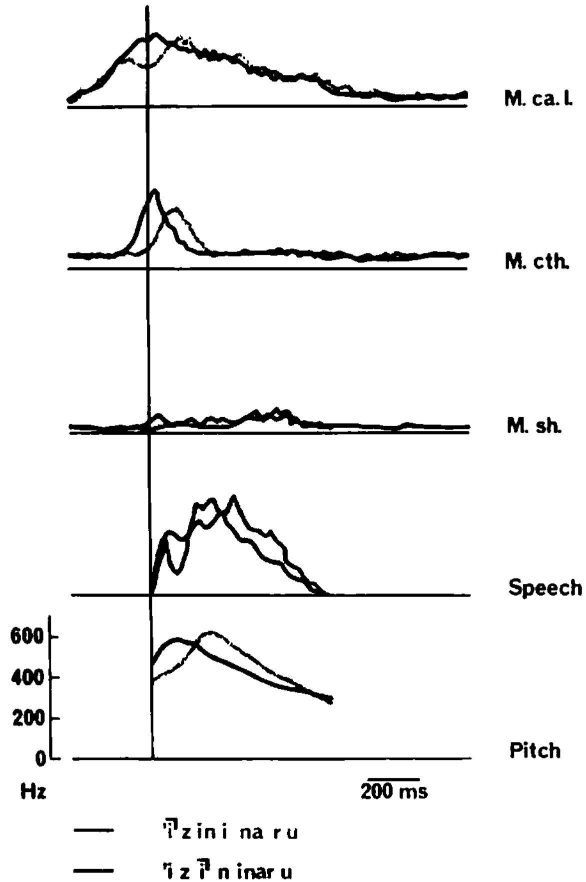


Figure 8. The same as in Figure 5, for the utterances of /'i⌉zi ni naru/ and /'izi⌉ ni naru/.

descent in its electrical activities corresponding to the accent kernel. The beginning of the steep descent seems to be correlated with the position of the accent kernel in the test word. The peak in the pitch contour also correlates well with that of the EMG curve.

Figure 7 presents an example of words with the accent kernel on the first mora. For comparison, a word without the accent kernel is also illustrated. The activity of the cricothyroid muscle begins to increase 120-180 ms before the onset of the speech signal and reaches a peak 70-80 ms prior to the corresponding peak in the pitch contour. A steep descent is observed in the EMG curve after the peak. Note that the lateral crico-arytenoid muscle does not show any dip near the voice onset. The absence of the dip may be attributed to the superimposition of the activity accompanying the rise of pitch in the first mora on the activity for the initiation of voicing.

The EMG activity of the sternohyoid muscle is complex. In cases where the accent kernel is present, as shown in Figures 5, 6, 7, and 12, some activity can be seen, apparently in correspondence to the pitch change. In Figure 5 activity begins to increase approximately 120 ms after the peak in the pitch contour. This activity might be associated with the regulation of pitch, the peak shape being affected by the presence of the consonant [k]. In this case, there is also an appreciable time interval between the decrease in activity of the cricothyroid muscle and the increase in activity of the sternohyoid muscle. The utterance /<u>mizu'u⌉mi</u> ni 'iku/ in Figure 6 seems to show no such delay of the latter. Figure 7 and 12 are also similar in this respect.

Figures 8, 9, 11, and 13 show that there is little difference in the activity of the sternohyoid muscle regardless of the presence of the accent kernel. Similarly, in Figures 14d and 14e, no remarkable activity can be seen, although Figures 14b and 14c show that there might be some increase in activity after the cricothyroid muscle becomes less active.

If we compare the averaged electromyographic curves of the cricothyroid and the lateral cricoarytenoid muscles, there is some similarity in their temporal patterns corresponding to the pitch contour. Both muscles also show a dip near the voice onset, which is then followed by an increase in activity unless there is an accent kernel on the first mora. Some consistent differences between the functions of the two muscles must be noted, however. Thus the lateral cricoarytenoid muscle always shows activity for initiation of voicing before the onset of the speech signal, while the cricothyroid muscle shows no appreciable activity for initiation of voicing unless the utterance begins with a word with the accent kernel on the first mora.

Hirano has suggested that there is an apparent synergism between the cricothyroid and the lateral cricoarytenoid muscles.[1] His interpretation of electromyographic data on the voice in singing is that one of the functions of the cricothyroid muscle is to bring the vocal cords to the paramedian position and, as a result, the vocal cords tend to be slightly abducted when the activity of the cricothyroid muscle increases for raising the pitch level. He suggested that the increasing activity of the lateral cricoarytenoid muscle accompanying the rise of pitch was to counteract the cricothyroid activity and to keep the condition of the glottis closed for phonation. The similarities of the averaged electromyographic patterns between these two muscles may possibly be based on the same mechanism.

The sternohyoid muscle is known to be active for gestures that require a lowering or fixation of the hyoid bone.[6] Thus, jaw opening, tongue lowering, and tongue retraction typically involve participation of this muscle. In our data, the vowel [a] and the consonant [k], for example, are typically associated with the activity of the sternohyoid muscle. It may be assumed that the sternohyoid muscle plays a secondary or an auxiliary role in the regulation of pitch in speech.

## ACKNOWLEDGMENTS

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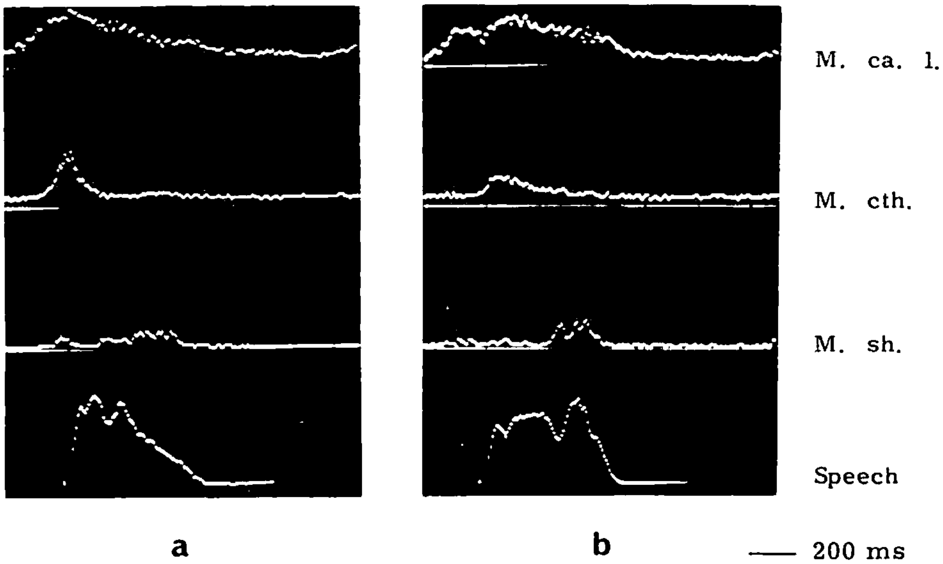


Figure 9. The averaged EMG signals for the utterances of (a) /'iꜜmi ni naru/ and (b) /'imi ni naru/. The reference point for the averaging process is the onset of the speech signal.

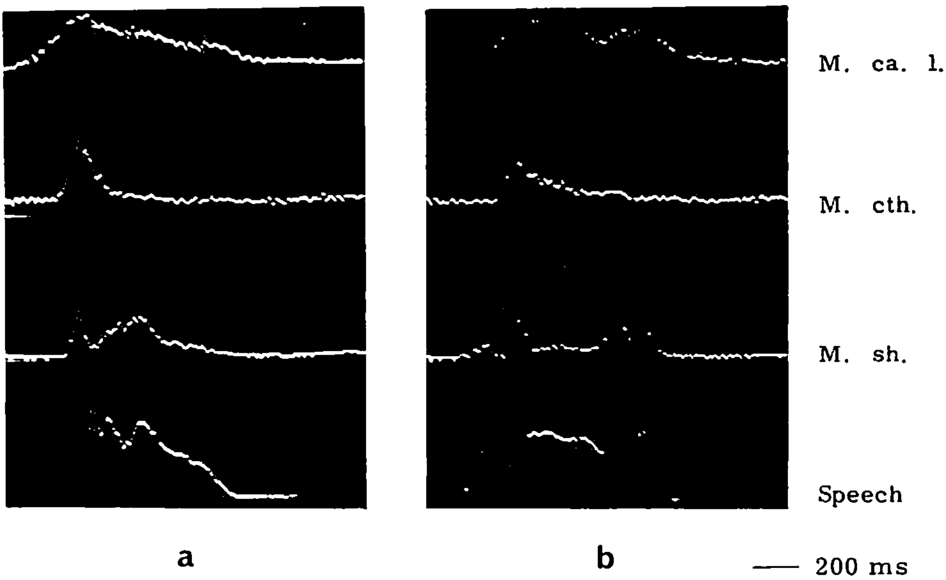


Figure 10. The same as in Figure 9, for the utterances of (a) /'uꜜri ni 'yuu/ and (b) /'uri ni 'iku/.

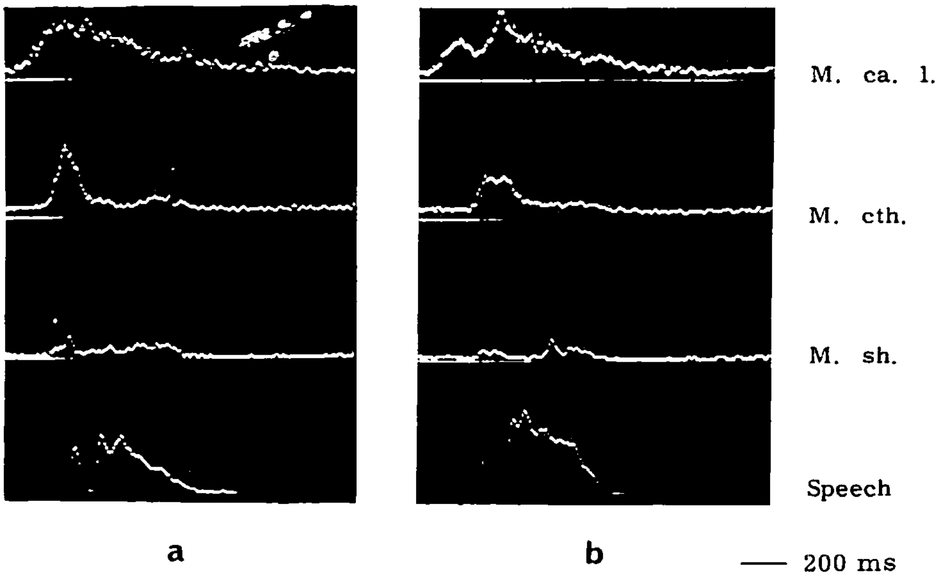


Figure 11. The same as in Figure 9, for the utterances of (a) /'iꜜsi ni naru/ and (b) /'isiꜜ ni naru/.

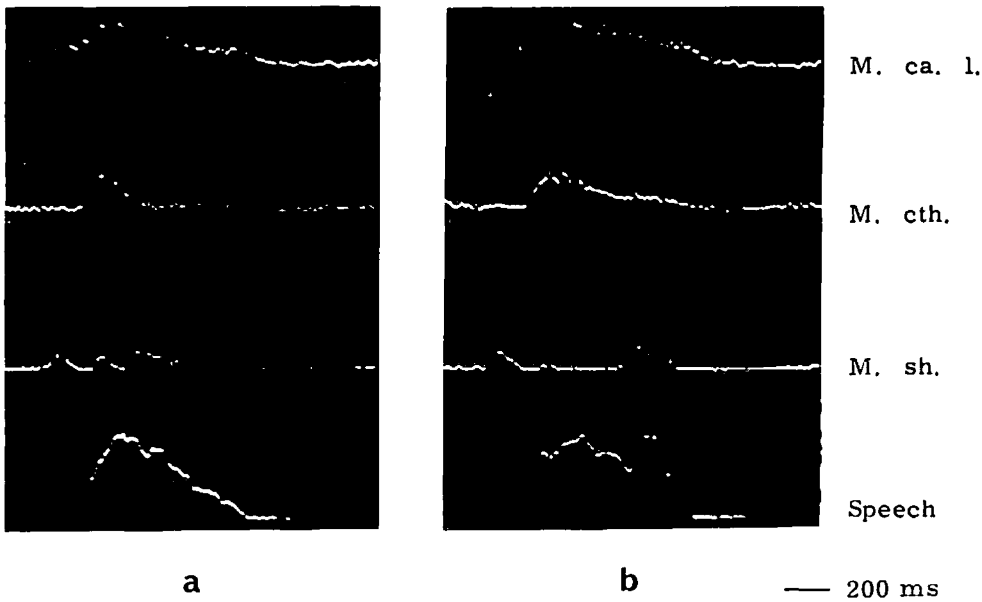


Figure 12. The same as in Figure 9, for the utterances of (a) /mu'iꜜmi ni naru/ and (b) /mu'imi ni naru/.

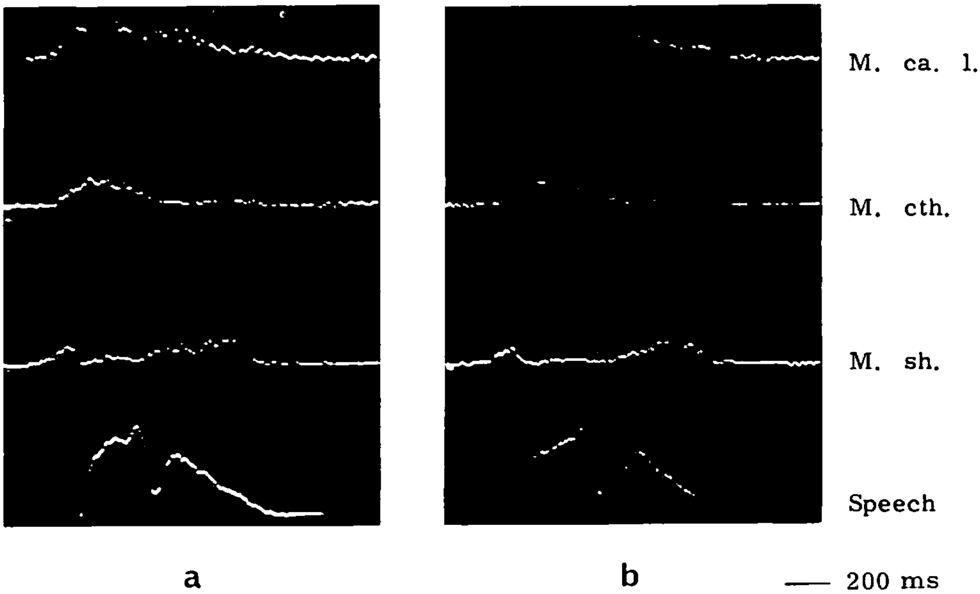


Figure 13. The same as in Figure 9, for the utterances of (a) /haN'i⌉zi ni naru/ and (b) /haN'izi⌉ ni naru/.

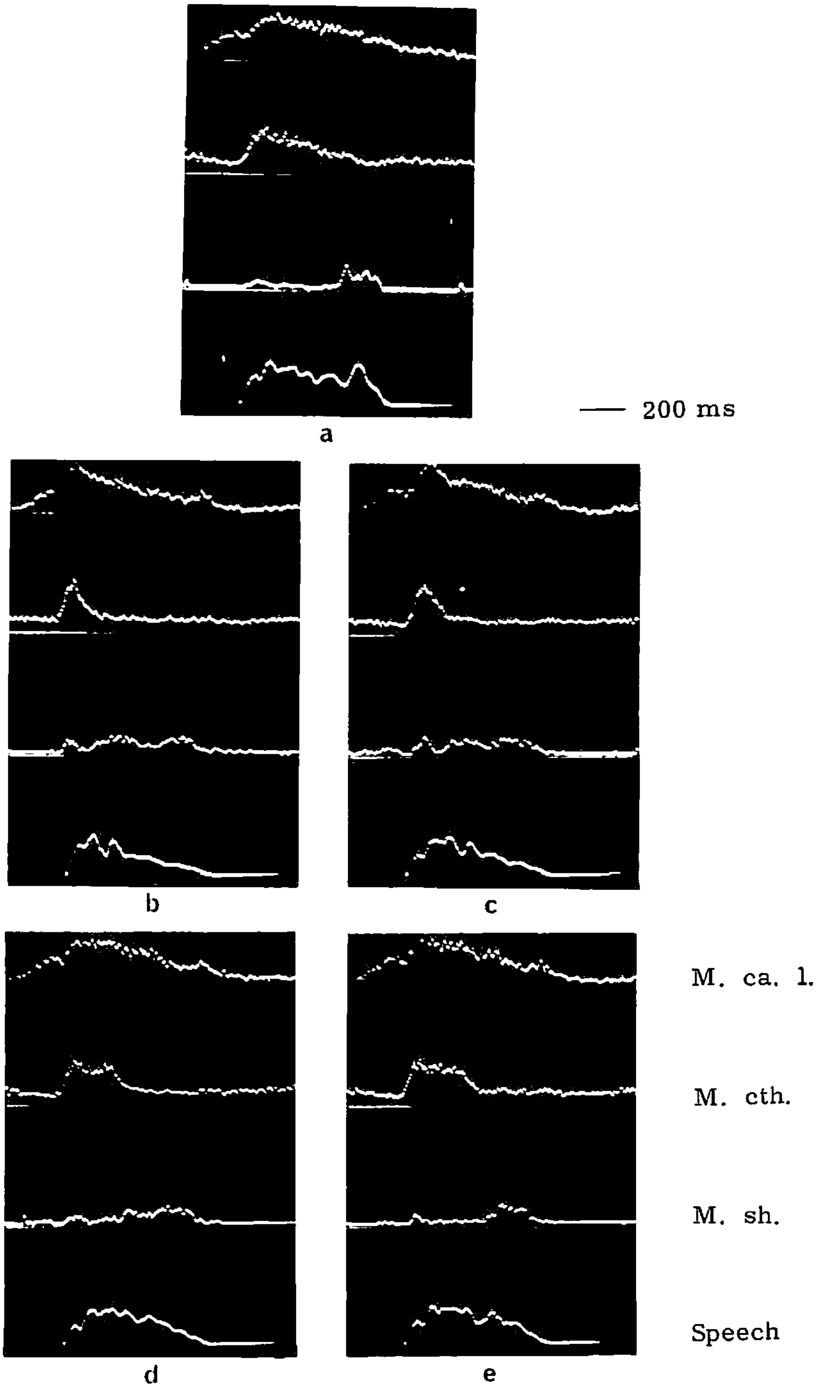


Figure 14. The same as in Figure 9, for the utterances of (a) /mirimiri ni naru/, (b) /mi˥rimiri ni naru/, (c) /miri˥miri ni naru/, (d) /mirimi˥ri ni naru/, and (e) /mirimiri˥ ni naru/.

| | |
|---|---|
| 'u⌝mi ni 'iku. | mizu'u⌝mi ni 'iku. |
| 'umi ni 'iku. | mizu'uri ni 'iku. |
| 'i⌝mi ni naru. | mu'i⌝mi ni naru. |
| 'imi ni naru. | mu'imi ni naru. |
| 'u⌝ri ni 'yuu. | haN'i⌝zi ni naru. |
| 'uri ni 'iku. | haN'izi⌝ ni naru. |
| 'i⌝zi ni naru. | mirimiri ni naru. |
| 'izi⌝ ni naru. | mi⌝rimiri ni naru. |
| 'i⌝si ni naru. | miri⌝miri ni naru. |
| 'isi⌝ ni naru. | mirimi⌝ri ni naru. |
| mimi⌝zuku ni 'yuu. | mirimiri⌝ ni naru. |
| mimizu ni 'yuu. | |

Table 1. Sentences used for the EMG investigation of Japanese word accent patterns. Test words are underlined. The last five sentences in the right column each contain a meaningless word as the test word.

## References


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