PHYSIOLOGICAL CORRELATES OF JAPANESE ACCENT PATTERNS*

Z. Simada and H. Hirose

In Japanese,** accent patterns of words can be represented by different positions (or absence) of an "accent kernel", which is often indicated by the mark "˥" placed following the pertinent vowel in phonemic transcription. The first mora of an isolated word is generally pronounced with a lower pitch compared with the second mora, unless the accent kernel falls on the first mora, or the first syllable is a "long syllable". The pitch level drops near the following mora boundary when there is an accent kernel attached to the mora. In the present study, multiple-channel recordings of the electromyographic activities of some selected intrinsic and extrinsic laryngeal muscles were examined comparing different word accent patterns.

Experimental Procedures

Two subjects, who are male native speakers of the Tokyo dialect with experience in speech studies, uttered the sentences containing a set of test words that form minimal phonological distinctions in respect to the accent pattern. The action potentials of three laryngeal muscles (the cricothyroid, the lateral cricoarytenoid, and the sternohyoid of one subject, and the cricothyroid, the sternohyoid, and the sternothyroid of the other subject) were simultaneously measured using hooked-wire electrodes*** and were recorded along with the speech wave on a four-channel data recorder. The acoustic and three electromyographic signals reproduced from the magnetic tape were amplified and high-pass-filtered, and were fed to a computer through a multiplexer and an analog-to-digital converter. Each of the signals was

* This is closely related to a paper which is going to be presented at the Seventh International Congress on Acoustics, Budapest, August, 1971.

** Here we refer to the Tokyo dialect. Many other dialects have similar accent patterns, but there are some major dialects where either additional oppositions or no accent distinction are observed.

*** We wish to express our appreciation to Prof. M. Hirano at Kurume University, who cooperated with us in deriving the EMG signals used here.

sampled every 250 μs, and the absolute value was taken and summed up over a period of 20 ms. The time window for this summation was shifted by steps of 10 ms to give consecutive sample values. The signal envelopes thus smoothed were averaged over ten selected utterances of each test sentence with reference to the point in the time axis representing a predetermined speech event, e.g., voice onset. The results were compared with pitch changes as determined by narrow-band sound spectrograms.

Results and Remarks

Figure 1 presents examples of results with one subject. The point of interest in this case relates to the presence or absence of an accent kernel in the test words (/'ŭ mi/ with an accent kernel placed on the first mora, indicated by the thick line and /'umi/ with no accent kernel, indicated by the thin line). The averaged envelope of the speech signal corresponding to each test sentence is shown in the fourth trace from the top, and the fundamental-frequency contour obtained from one of the typical utterances which were used for the averaging is shown in the bottom trace. The upper three curves from the top show the averaged EMG signals of the cricothyroid (cth), the lateral criocoarytenoid (lca), and the sternohyoid (sh). The vertical line is placed at the reference point used for the averaging. It can be seen from Figure 1 that the temporal change in the EMG curve of the cricothyroid muscle correlates well with the pitch contour of the speech signal. In the case of the test word with no accent kernel (the thin line), EMG activity begins to increase approximately at the onset of the speech signal and forms a dull peak followed by a gradual decrease toward the end of the utterance. It is assumed that this activity as a whole approximately represents a physiological actualization of the configurational feature* of the phonological phrase (in this case an entire sentence that contains one accent kernel). This feature generally manifests itself in the Tokyo dialect as a rise in pitch from the first syllable toward the second in a phonological phrase.

---

* In the sense of R. Jakobson, C. G. M. Fant, and M. Halle, Preliminaries to Speech Analysis: The Distinctive Features and their Correlates (Cambridge: The M. I. T. Press, 1963). See also O. Fujimura, "Speech of Japanese: From a Phonological Description of the Linguistic Form to the Sound Wave", in Collected Papers in Commemoration of the 20th Anniversary, NHK, Radio and Television Culture Research Institute, Ed. (Tokyo: NHK Press, 1967), pp. 363-404.

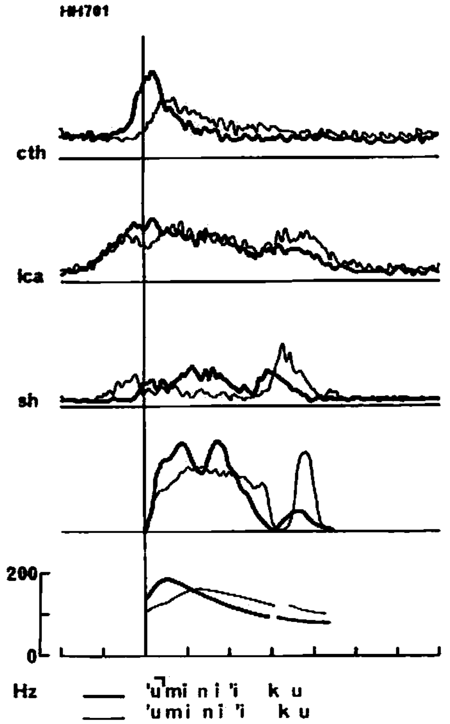

Figure 1. Averaged action potentials recorded from the cricothyroid (cth), the lateral cricoarytenoid (lca), and the sternohyoid (sh) of one subject, comparing the words /'u͞mi/ (with an accent kernel placed on the first mora, indicated by the thick line) and /'umi/ (with no accent kernel, indicated by the thin line). The fourth and fifth traces down represent the averaged envelope of the speech signal and the fundamental-frequency contour of one of the typical utterances used for the averaging. The vertical line indicates the reference point used for the averaging. Time scale is marked off every 200 ms.

When the accent kernel falls on the first mora of the test word (the thick line), the muscle shows sharply increasing activity before the voice onset which reaches a peak approximately 60-80 ms prior to the corresponding peak in the pitch contour. The muscle then rapidly becomes less acive after the EMG peak. The beginning of the decrease in activity seems to be correlated with the position of the accent kernel in the test word and thus this is assumed to display a physiological actualization of the distinctive (prosodic) feature* of the phonological phrase.

The lateral cricoarytenoid muscle seems to show EMG activity associated with the laryngeal adjustment for the general mode of utterance. Activity begins to increase approximately 250 ms prior to the voice onset and is generally observed throughout the whole utterance. This early increase in activity was noted consistently in all of the utterances in connection with the initiation of voicing. Contraction of this muscle moves the vocal process of the arytenoid cartilage medially, thus closing the glottis.

---

* ibid.

For example, the last peaks in the EMG curves clearly correspond to the glottal closure; i. e., in the word /'iku/, activity decreases for the voiceless [k] and becomes stronger again for the following voiced [u], in correspondence to the necessary glottal adjustment. It must be emphasized that the muscle is involved also in pitch-raising control. Approximately at the onset of the speech signal, a dip of the EMG curve is clearly observed for the utterance-initial test word with no accent kernel on the first mora, as seen in the phrase /'umi ni/, while it is not apparent when the accent kernel falls on the first mora of the test word. In the former case the first peak may be attributed to the initiation of voicing and the second peak to the rise in pitch. In the case of the word with an accented first mora, the single dull peak may be interpreted as the result of a collapsing of the effects of the two functions. The simultaneous occurrence of changes in one aspect of the lateral cricoarytenoid activity and the cricothyroid activity suggests that both muscles play partially cooperative roles in pitch-raising control.

The evidence available to date has not revealed in much detail the mechanism for pitch lowering. It has not been ascertained whether relaxation of the cricothyroid muscle in itself leads to a sufficient drop in pitch. Recently, the sternohyoid muscle was reported by some authors to be active for lowering pitch in speech as well as for articulatory gestures that require retraction and lowering of the tongue.* In the example in Figure 1, some increase in EMG activity of the sternohyoid muscle is observed immediately after the cricothyroid muscle becomes less active when the test word has an accent kernel. On the other hand, there is no such activity in the case of the unaccented test word. It thus seems, in these cases, that the correlation between the sternohyoid activity and the pitch lowering is supported (See infra, however). The last increase in activity seems to be necessitated by the presence of the velar stop [k] in the word /'iku/. It may be assumed that the muscle functions to lower the tongue root so that it may recover from the elevated position for the consonant [k].

* J. Ohala and M. Hirano, "Studies of Pitch Change in Speech", Working Papers in Phonetics (UCLA), No. 7, 80-84 (1967); J. Ohala and H. Hirose, "The Function of the Sternohyoid Muscle in Speech", Annual Bulletin (Research Institute of Logopedics and Phoniatrics, University of Tokyo), No. 4, 41-44 (1970).

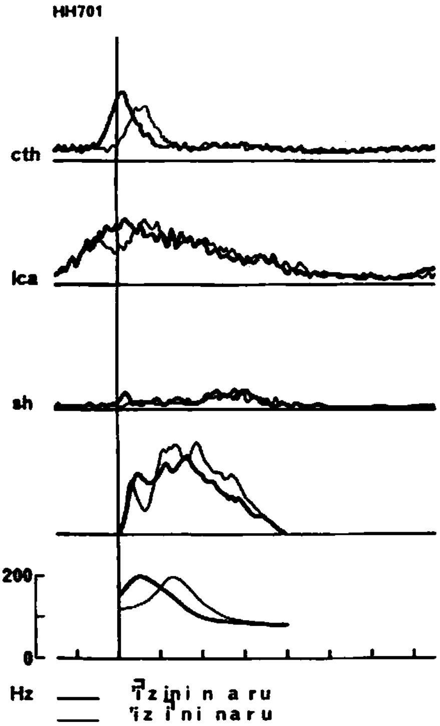

Figure 2. The same as in Figure 1 for the word /'i⌝zi/ (with an accent kernel on the first mora) and /'izi⌝/ (with an accent kernel on the second mora).

Figure 2 shows some differences in the EMG patterns when the same speaker as in Figure 1 uttered the test words /'i⌝zi/ and /'izi⌝/, which are different only in the position of the accent kernel: on the first mora for the former, and on the second mora for the latter. EMG activity of the cricothyroid muscle clearly exhibits a similar temporal pattern in the test words with an accent kernel on the first mora (cf. /'u⌝mi/ and /'i⌝zi/). When the accent kernel falls on the second mora of a word as in the word /'izi⌝/, a steep decrease in activity can be seen as an actualization of the accent kernel, while the EMG curve in the case of the unaccented word /'umi/ in Figure 1 declines gradually toward the level of spontaneous activity. It can be seen from Figures 1 and 2 that there is some temporal interval between the peak in the EMG curve of the cricothyroid muscle and that of the pitch contour of the speech signal. The former invariably precedes the latter. This is also true with the other subject.

The lateral cricoarytenoid muscle becomes less active approximately at the onset of the speech signal when the test word has no accent kernel on the first mora. When the first mora is given the accent kernel, the EMG curve is similar to the case of the same accent pattern in Figure 1.

The sternohyoid muscle in Figure 2 does not show any alternation of EMG activity between this muscle and the cricothyroid muscle; there is no increasing sternohyoid activity corresponding to the steep decrease in the cricothyroid activity which is associated with the pitch drop. Since the articulatory conditions for the test words in Figure 2 are more constant than those in Figure 1, it is suspected that in the cases of Figure 1 there was some complication in respect to the sternohyoid activity due to the tongue movements for the back vowel [u].

Figure 3 illustrates examples of results with the other subject. The EMG traces from the top indicate the cricothyroid (cth), the sternohyoid (sh), and the sternothyroid (sth). Comparison is made here between the words /mimi˥zuku/ (with an accent kernel placed on the second mora) and /mimizu/ (with no accent kernel). The EMG curves of the cricothyroid muscle begin to rise sharply approximately at the onset of the speech signal and reach their peaks at the time near the second [m] in the speech signal. It must be mentioned also that a steep decrease in EMG activity is observed after the peak in the accented test word making a clear contrast to the gradually decreasing activity in the unaccented test word.

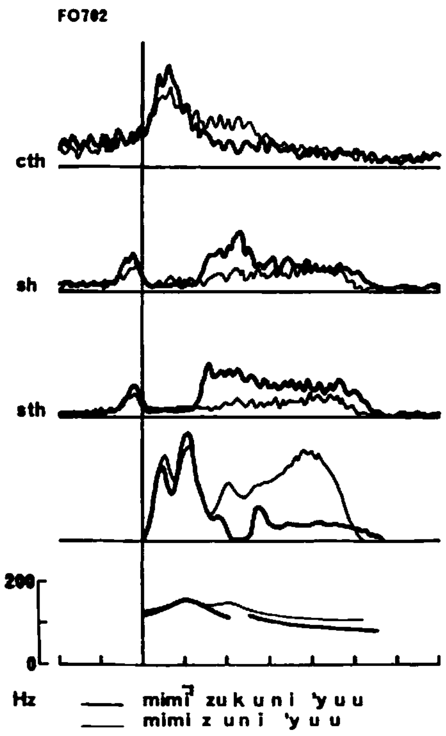

Figure 3. Results with the other subject for the words /mimi˥zuku/ (with an accent kernel placed on the second mora) and /mimizu/ (with no accent kernel). The EMG traces represent the cricothyroid (cth), the sternohyoid (sh), and the sternothyroid (sth).

The sternohyoid muscle of this subject reveals an interesting EMG pattern. Prior to the voice onset the muscle shows some increase in activity and becomes less active during the increased activity of the cricothyroid muscle. It is noted that in the case of the accented word /mimi⌝-zuku/, this muscle again shows an increase in activity immediately after the decrease in the activity of the cricothyroid muscle. This case again seems to support the hypothesis that sternohyoid activity is related to pitch lowering among other functions.

Opinions vary among authors about the function of the sternothyroid muscle in respect to pitch control.* The results of the present study clearly show that the sternothyroid muscle correlates with pitch lowering although we have investigated only one subject to date. In the case of the accented word /mimi⌝zuku/, this muscle rapidly increases its activity after the cricothyroid activity has started descending steeply after a peak, and remains active to the end of the utterance. In the case of the unaccented word /mimizu/, there is only weak activity of the sternothyroid muscle compared with the other case mentioned above. The presence of activity prior to the voice onset calls our concern to the utterance-initial pitch control of phonological phrases. This initial increase in activity was observed in other samples of test words with no accent kernel on the first mora, i. e., words starting with a lowered pitch (cf. /'izi⌝/ in Figure 4 and /'isi⌝/ in Figure 5). However, the muscle did not show such initial activity when an utterance began with a test word with an accent kernel on the first mora (cf. /'i⌝zi/ in Figure 4 and /'i⌝si/ in Figure 5). In Figure 3 it is also noted that a similarity in the EMG patterns exists between both of the extrinsic laryngeal muscles, viz., the sternohyoid and the sternothyroid.

Figure 4 shows results with another word pair uttered by the same subject as in Figure 3. The test sentences are identical with those in Figure 2: the words /'i⌝zi/ and /'izi⌝/ are compared. When we examine

---

* See, for examples, K. Faaborg-Andersen and A. Sonninen, "The Function of the Extrinsic Laryngeal Muscles at Different Pitch: An Electromyographic and Roentgenologic Investigation", *Acta oto-laryng.*, 51: 89-93 (1960) and A. Sonninen, "The External Frame Function in the Control of Pitch in the Human Voice", *Ann. N. Y. Acad. Sci.*, 155: 68-90 (1968).

the results in Figures 2 and 4, the EMG curves of the cricothyroid muscle take very similar time courses. The sternohyoid muscle in Figure 4, like in Figure 2, does not show the apparent increase in EMG activity which might be expected with the presence of an accent kernel following the assumption that the muscle participates in pitch lowering in speech.

The sternothyroid muscle clearly shows increasing EMG activity when the activity of the cricothyroid muscle decreases in association with the presence of accent kernels in the test words. As described before, the muscle does not show any activity at all before the initiation of voicing in the case of the word /'i⌉ zi/ which has an accent kernel on the first mora.

Figure 5 shows results employing a word pair containing a voiceless consonant /'i⌉ si/ and /'isi⌉ / uttered by the same subject as in Figure 3. The cricothyroid muscle here again exhibits similar EMG activity in respect to the accent pattern as with the results stated above. The first and greatest peaks in activity are attributed to the words /'i⌉ si/ and /'isi⌉ / respectively, and the second smaller ones to the word in the carrier sentences /cika⌉ i/ which has an accent kernel on the second mora. The alternation of activity is apparent between the cricothyroid muscle and the sternothyroid muscle in association with the pitch change. It is also interesting to note that the height of the respective EMG peaks of the sternothyroid muscle is greater toward the end of the utterance, in contrast to the activity of the cricothyroid muscle. The sternothyroid activity begins to increase toward the middle of the decrease in the cricothyroid activity and occurs temporally in parallel with the pitch drop. These observations lead us to hypothesize that pitch drop in speech is controlled by the relaxation of the cricothyroid muscle together with the contraction of the sternothyroid muscle.

The sternohyoid muscle shows an increase in EMG activity approximately at the voice onset with the word accented on the first mora. This activity could be a reflection of articulatory gestures of this muscle due to the specific combination of the accented front vowel [i] and the following voiceless fricative [s] and not to pitch lowering, since this activity occurs in correspondence with the increased activity of the cricothyroid muscle whereas no activity is found for the pitch drop in respect to the accent kernel in the test word /'i⌉ si/.

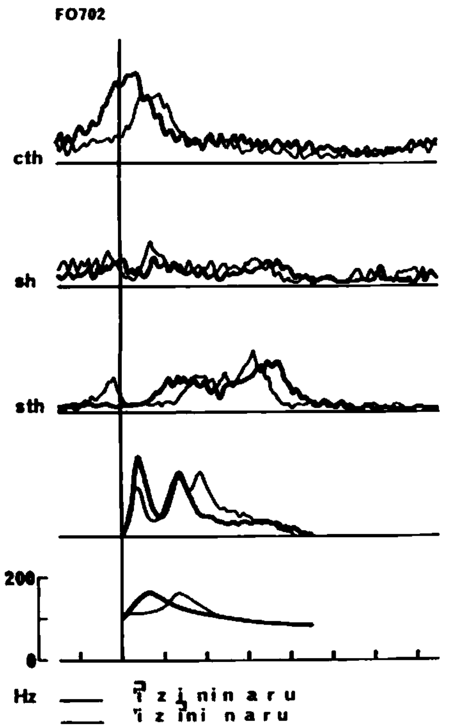

Figure 4. The same as in Figure 3 for the words /'ī zi/ (with an accent kernel on the first mora) and /'izī/ (with an accent kernel on the second mora).

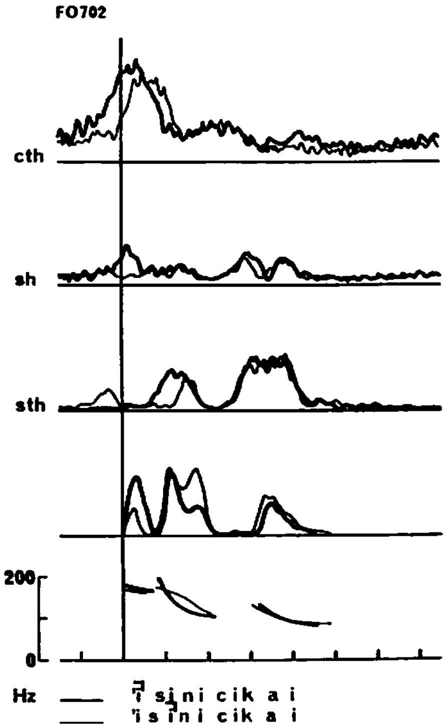

Figure 5. The same as in Figure 3 for the words /'ī si/ (with an accent kernel on the first mora) and /'isī/ (with an accent kernel on the second mora).