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# RELATIVE TIMING OF ARTICULATORY AND PHONATORY CONTROLS IN JAPANESE WORD ACCENT: A STUDY ON NONSENSE TWO-MORA WORDS

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## 1. Introduction

Japanese word accent is characterized by changes in the vocal pitch, $F_0$, which are closely linked with a time segment of the syllable or so-called "mora." Thus, laryngeal $F_0$ control should be expected to have an appropriate timing relative to supraglottic articulatory controls in the realization of Japanese word accent. Using the functional models of articulatory and phonatory controls, Fujisaki et al. 1)-3) have reported a time lag between the articulatory and accent controls in two-mora words with Kinki dialect accent types. According to their findings, the articulatory control takes place earlier than laryngeal $F_0$ control. Our own preliminary experiment with the Tokyo accent4) has also revealed a similar result. The present paper reports on our further results obtained from an experiment designed to answer the following two questions: 1) whether or not the relative timing of articulatory and phonatory controls in rising accent type may differ from that in falling accent type, and 2) whether or not the relative timing may differ according to the difference in the order of sequence of the open and closed vowels.

## 2. Experimental Procedures

An adult male speaker of the Tokyo dialect served as the subject. Test words were two-mora nonsense words /aa/, /ii/, /ai/, /ia/, /ami/, /ima/, /ama/ and /imi/. The subject pronounced the test words in isolation with both rising and falling accent types, ten times each in random order. For each of the utterances, the vowels of the test word were slightly prolonged as compared to natural speech, in order to obtain a clear steady state. In addition to the two accent types, /ai/ and /ia/ were also pronounced with flat accent type.

Simultaneous with the recording of speech waves, EMG was recorded from the cricothyroid (CT), sternohyoid (SH), anterior digastric (AD), orbiculalis oris (OO) and genioglossus (GG) muscles on a multi-channel FM tape recorder. Speech waves were also recorded on an audiotape for the use of acoustic analysis.

The acoustic analysis was made using a sound spectrograph, and the onset of articulatory events and $F_0$ changes was determined by visual examination of sound spectrogams. Pattern display with a wide-band filter was used for examining both the formant transitions of the vowel sequences and the oral closure of the /m/, while the pattern with a narrow-band filter was used for examining $F_0$ changes. Fig. 1 shows the onset of $F_0$ changes and formant transitions on the spectrograms of /ai/ and /ia/ with falling and rising accent types, respectively.

EMG signals as well as speech waves on the FM tape were integrated with a time window of 10 msec, and the values of successive windows were plotted in order to display time curves of EMG patterns, with speech envelope on the same time axis for each utterance sample. The onset of changes in EMG levels relevant to articulatory and phonatory controls was determined by visual examination of the time curves. No averaging or smoothing of EMG data was made in this procedure.

## 3. Results and Comments

### 3-1 Acoustic data

The timings of the onset of formant transition relative to the $F_0$ change for /ai/ and /ia/ in rising and falling accent types are summarized in Fig. 2. The point of 0 on the time axis indicates the $F_0$ change for each sample. Filled circles indicate onset of formant transition for the samples with falling accent type, and open circles indicate that for the samples with rising accent type. Comparing /ai/ and /ia/, it is apparent that the formant transition for /ai/ takes place earlier than for /ia/ with reference to the onset of $F_0$ change. As far as the present data are concerned, there appears to be some interaction between the vowel articulation and the $F_0$ control. In other words, the data suggest that the temporal pattern of articulatory and phonatory controls may be affected by the direction of vowel sequence, at least at the level of acoustic manifestation.

It is also noted that the formant transition tends to occur earlier in the rising accent type than in the falling accent type for each /ai/ and /ia/ sequence. This suggests that the temporal organization of articulatory and phonatory controls may also be affected by the direction of $F_0$ change.

The timing of segment /m/ relative to the onset of $F_0$ change in /ami/ and /ima/ in rising and falling accent types is shown in Fig. 3. It can be noted that both in /ami/ and /ima/ series the articulatory closure for /m/ tends to occur slightly earlier in the rising accent type than in the falling accent type with reference to $F_0$ change. The tendency appears to be consistent with that of /ai/ and /ia/ series. On the other hand, there is little difference in the relative timing of the articulatory closure for /m/ between /ami/ and /ima/ series. The data suggest that the onset timing of the consonant articulation relative to $F_0$ change is maintained more stable than that of the vowel articulation within the same accent type. It is quite probable, on the other hand, that the timing of vowel transition relative to /m/ in /ami/ is considerably different from that in /ima/, as it was revealed through observation using the X-ray microbeam system5).

Figure 4 shows the data for /ama/ and /imi/ series. Here also it is apparent that there is an earlier onset of /m/ relative to $F_0$ change in the rising accent type than in the falling accent type. Within the same accent type, there is no difference in the relative timing of /m/ between /ama/ and /imi/ series. Comparing all the items in Fig. 3 and Fig. 4, it is noted that the onset of the consonant /m/ relative to the onset of $F_0$ change is maintained fairly constant within the same accent type, regardless of the difference in vowel combination.

## 3-2 EMG data

EMG time curves for utterances of /ai/ and /ia/ in rising and falling accent types are displayed with speech envelope in Fig. 5. On each graph, vertical lines with an open triangle and an arrow indicate the onset of formant transition and $F_0$ change, respectively. In these particular displays, the time curves are smoothed by plotting running averages of the successive values with a time window of 50 msec.

Activity of CT increases for the $F_0$ rise and decreases for the $F_0$ fall. The pattern is quite consistent. An increase in the activity of GG is seen for the transition from /a/ to /i/ regardless of different accent types. This activity is considered to correspond to the tongue fronting for the vowel /i/. There is also an increase in GG activity for the second vowel of /ia/ with rising accent. This may reflect an "extra force" for the accented vowel. Activity of the anterior digastric (AD) muscle increases for the transition from /i/ to /a/. This is considered to correspond to the jaw opening. However, the activity varies to a certain extent with the difference in accent types.

The sternohyoid muscle appears to show an increase in the activity both for jaw opening and $F_0$ lowering.

For the samples with the intervocalic /m/, there is a consistent and clear EMG peak of the OO corresponding to the onset of /m/. This activity indicates the closing action of the lip for the pertinent nasal consonant.

Based on the above findings in the present experiment, reliable electromyographic events, which are uniquely related to each of the laryngeal $F_0$ control and supraglottic articulatory controls, are considered to be as follows: 1) changes in the EMG level of CT for $F_0$ changes, 2) increase in GG activity for the tongue fronting from /a/ to /i/, and 3) increase in OO activity for the lip closing for /m/.

The timing of onset of activity change in CT relative to $F_0$ change for each of the two-mora words with rising and falling accent types are plotted in Fig. 6. In the figure, point 0 on the time axis indicates the onset of $F_0$ change. Filled circles indicate utterance samples with falling accent type, and open circles indicate those with rising accent type. For almost all samples, the change in EMG level takes place earlier than the $F_0$ change. It is noted that the time lag from EMG to $F_0$ change tends to be greater for falling $F_0$ than for rising $F_0$, although there is a certain range of sample variations. The difference in the time lag may be attributed to the difference in the biomechanical characteristics between the $F_0$ rise and $F_0$ fall mechanisms.

It is also noted that within the samples with rising accent type, the time lag for /ia/ and /ima/ tends to be greater as compared to other items. A greater time lag from EMG to $F_0$ rise in these particular series may suggest that the laryngeal mechanism for the $F_0$ rise is affected by the articulatory movements from /i/ to /a/, probably by opening the jaw.

The timing of the onset of increase in GG activity relative to the onset of formant transition in /ai/ series is shown in Fig. 7. In the time axis, 0 indicates the onset of vowel transition from /a/ to /i/. Open triangles indicate data points for the utterances with flat accent type. In all the accent types, an increase in GG activity occurs 10 to 40 msec before the onset of the formant transition.

Figure 8 presents the timing of the increase in GG activity for /ai/ and /ami/ with rising and falling accent types relative to changes in CT activity. It is clear that in both /ai/ and /ami/ series with rising accent type, the increase in GG activity takes place 60 to 80 msec before the increase in CT activity. For the samples with falling accent, in contrast, the increase in GG activity takes place at or after the decrease in CT activity, the increase in GG activity for /ami/ being slightly earlier than for /ai/. The results presented here suggest that in the vowel sequence the temporal organization of tongue and laryngeal controls varies with the difference in the accent type. Also, the temporal organization for the vowel sequence is maintained for the sound sequence with the intervocalic /m/.

Here we should note that the vowel transition in /ai/ with rising accent takes place well in advance of $F_0$ rise, the relative timing being even earlier than that of the onset of /m/ in /ami/ series in rising accent (Figs. 2 and 3). Actually sound spectrograms of all of the /ami/ examples with rising accent clearly show the formant transition from /a/ to /i/ before /m/ closure, as seen in Fig. 9. But this finding does not apply to the samples with falling accent type, as is assumed by a rather small range in the time lag between the formant transition and $F_0$ change for /ai/ with falling accent.

The onset of increase in OO activity relative to the onset of /m/ in the spectrogram is summarized in Fig. 10. It is observed that the OO activity takes place approximately 80 to 100 msec before oral closure of /m/ regardless of difference in both the accent types and vowel combinations. Figure 11 shows the timing of OO activity relative to changes in CT activity for items with intervocalic /m/ with rising and falling accent types. It is clear that for all the series OO activity takes place earlier in rising accent than in falling accent with respect to changes in CT activity. The result indicates that the temporal organization of articulatory lip movement and laryngeal $F_0$ control varies with the difference in the accent type. The pattern is consistent with that of the tongue articulation for vowel sequences as mentioned above. It is also noted that the relative timing between the lip and laryngeal controls within the same accent type is maintained fairly constant regardless of the difference in the combination of vowels, although there is a certain degree of sample variation.

The results of our present study on Japanese word accent with nonsense two-mora words can be summarized as follows:

1) Relative timing of articulatory and phonatory controls varies with the difference in the accent type in both acoustic and EMG levels.
2) Articulatory control takes place earlier in the rising accent than in the falling accent with reference to phonatory $F_0$ control.
3) There appears to be some interaction between vowel articulation and phonatory control, while the timing of consonant articulation relative to phonatory control is maintained constant within the same accent type.

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5) Kiritani, S., K. Itoh, H. Hirose and M. Sawashima (1977): Coordination of the consonant and vowel articulations. Proc. 9th Int. Cong. Acoustics, Madrid 1-12.

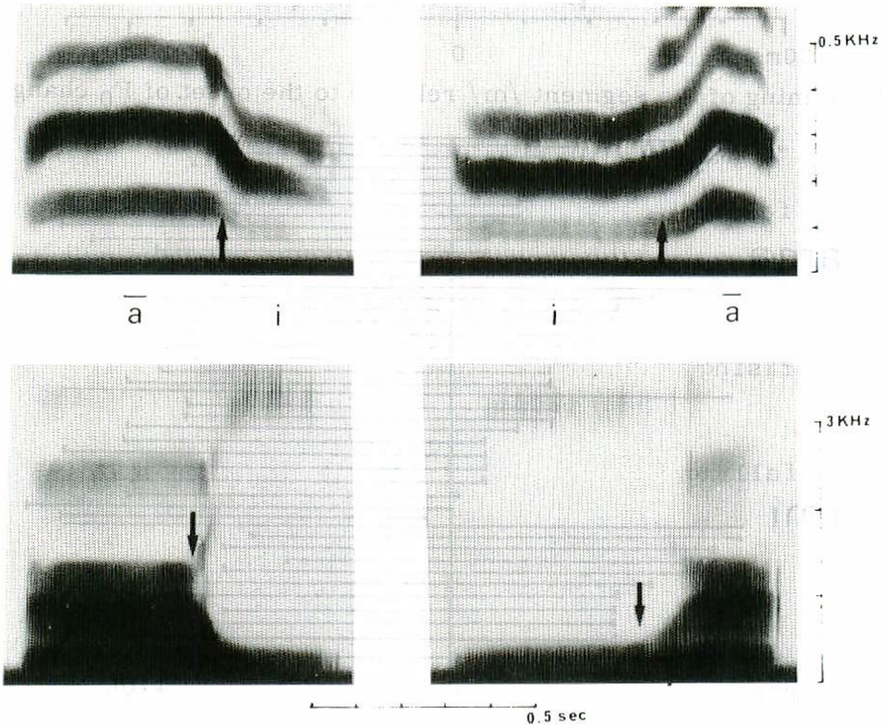

Fig. 1 Onset of $F_0$ change and formant transition determined by sound spectrograms.

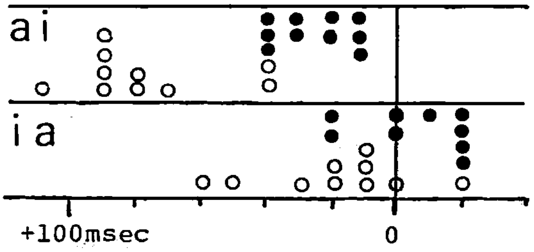

Fig. 2 Onset of vowel transition relative to that of $F_0$ change.

o: rising accent,
●: falling accent.

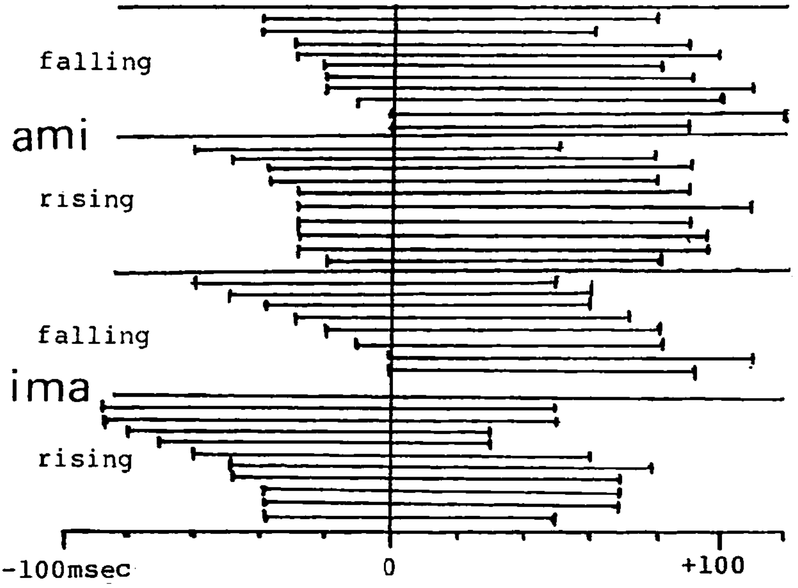

Fig. 3 Timing of the segment /m/ relative to the onset of $F_0$ change.

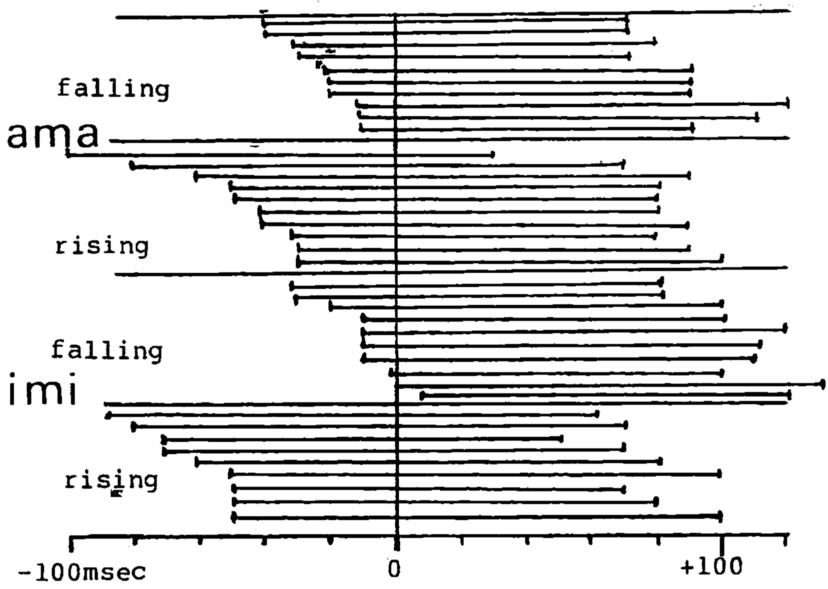

Fig. 4 Same display as Fig. 3.

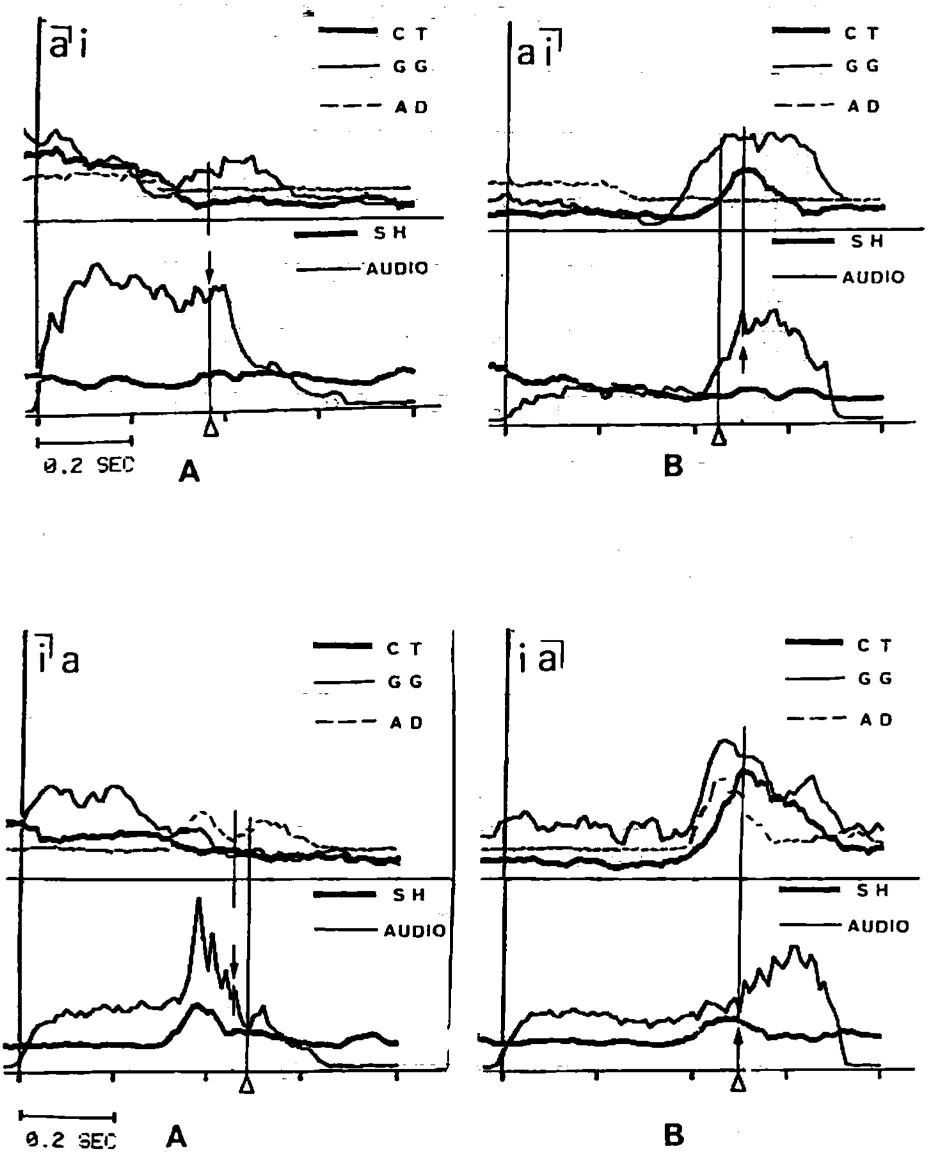

Fig. 5 Time curves of EMG and speech envelope for /ai/ and /ia/ with falling (A) and rising (B) accent types. ↓↑: onset of $F_0$ change, △: onset of formant transition.

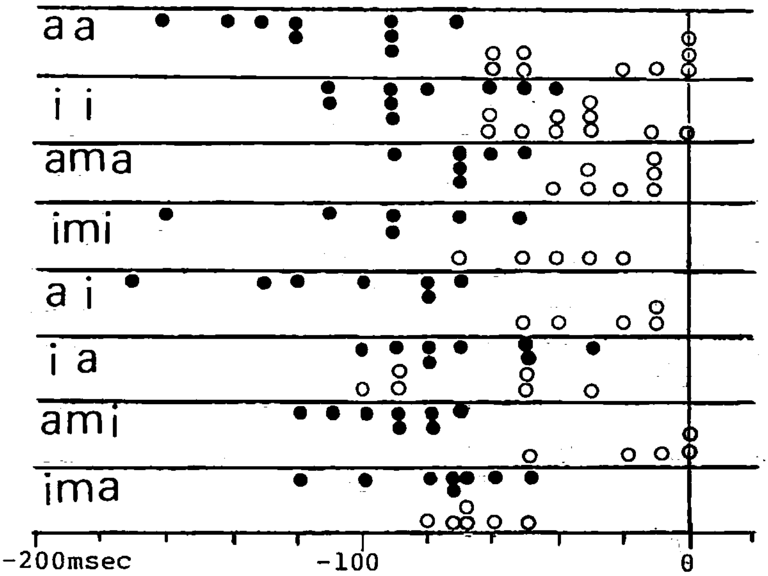

Fig. 6 Onset of change in CT activity relative to that of $F_0$ change.
○: rising accent, ●: falling accent.

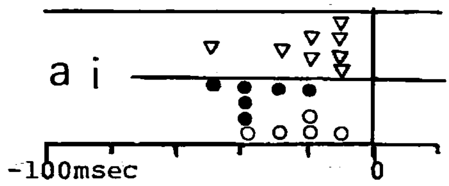

Fig. 7 Onset of increase in GG activity relative to that of formant transition. ▽: flat accent.

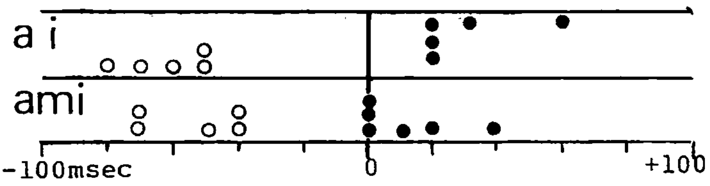

Fig. 8 Onset of increase in GG activity relative to change in CT activity.

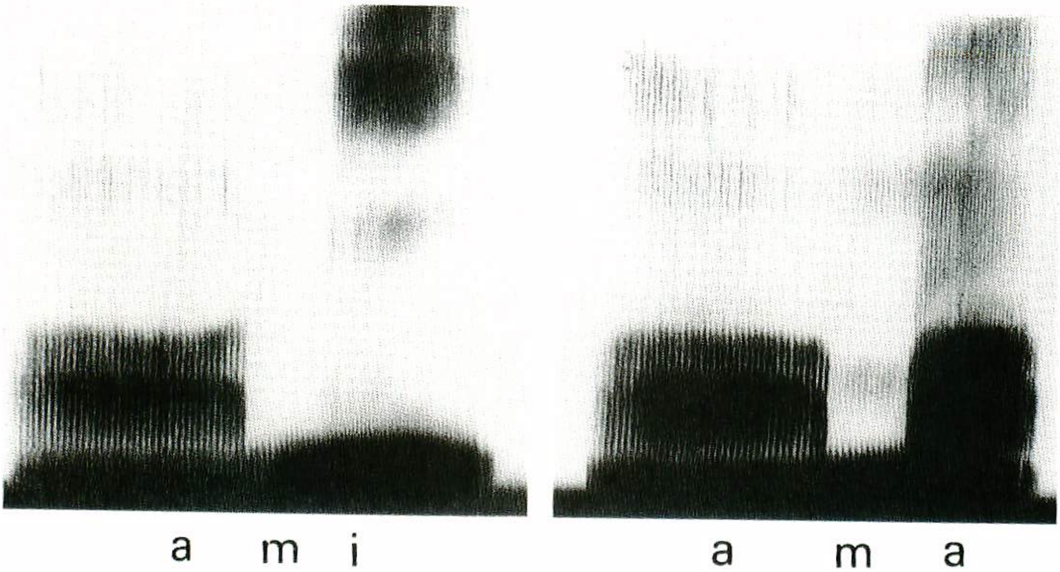

Fig. 9 Formant transition from /a/ to /i/ before /m/ in /ami/ and that from /a/ to /m/ in /ama/ in rising accent.

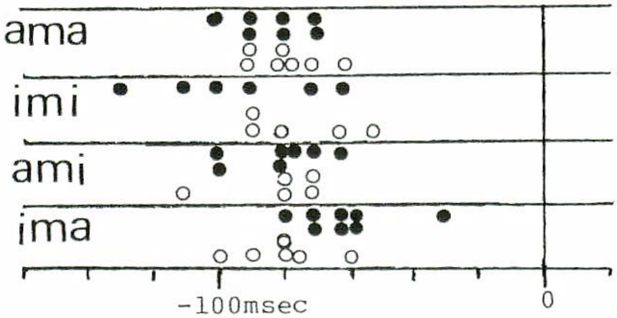

Fig. 10 Onset of increase in OO activity relative to that of /m/.

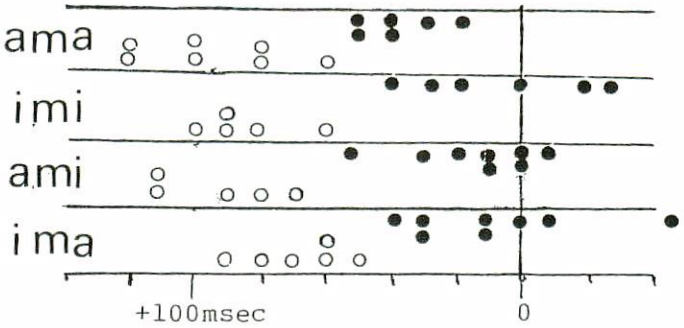

Fig. 11 Onset of increase in OO activity relative to that of change in CT activity.