AN ELECTROMYOGRAPHIC STUDY OF ARTICULATORY MOVEMENTS

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In the last issue of the Annual Bulletin, we reported on an electromyographic study of the electrical activities of the orbicularis oris and the digastric muscles in articulatory movements.[1] This report summarizes the results of further studies along the same lines using different subjects and different test words. The electromyographic recording was made using a monopolar acupuncture type needle electrode. As test words, nonsense Japanese words that contain pertinent Japanese vowels or consonants were selected to elicit the activity of the orbicularis oris and/or the digastric. The subject uttered the test word repeatedly more than ten times in isolation with a pause between utterances. The electromyographic and acoustic signals were recorded by a two-channel tape recorder.

In the series of experiments to be reported here, a PDP-9 computer was used for processing E. M. G. data. The tape was played back and recorded signals were fed to the computer through an A-D converter. The E. M. G. signal was sampled every 100 μsec. and digitized into 6-bit levels. The absolute value was taken and then integrated over a range of 10 msec. The smoothed signals as functions of time for an appropriate number of selected utterances were added together with reference to the time moment of a predifined speech event in the given test word.

Fig. 1 shows an example of the summed E. M. G. signals of the orbicularis oris for articulation of the word [kaetori]. The test word was uttered 24 times with an intermediate speed. The three oscillographic displays compare results of summation taking as the reference point for summation three different speech events preceding the central portion of the vowel [o]: (a) the voice onset of the test word, (b) the implosion of [t] and (c) the explosion of [t] (see the triangle below each display). No significant difference is noted among the three different conditions in processing in this case.

Fig. 2 shows examples of averaged E. M. G. of another subject. In this series, samples with different speeds of utterance are compared. There is

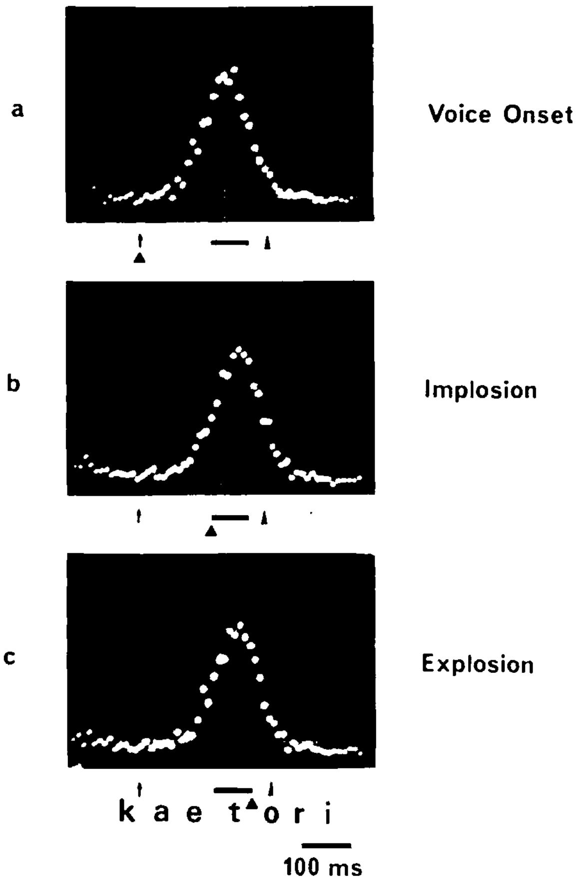


Fig. 1 - Summed E. M. G. data with reference to particular acoustic events. The reference time moment for the summation process is selected at:

a. onset of the speech signal
b. implosion into the stop
c. explosion of the stop

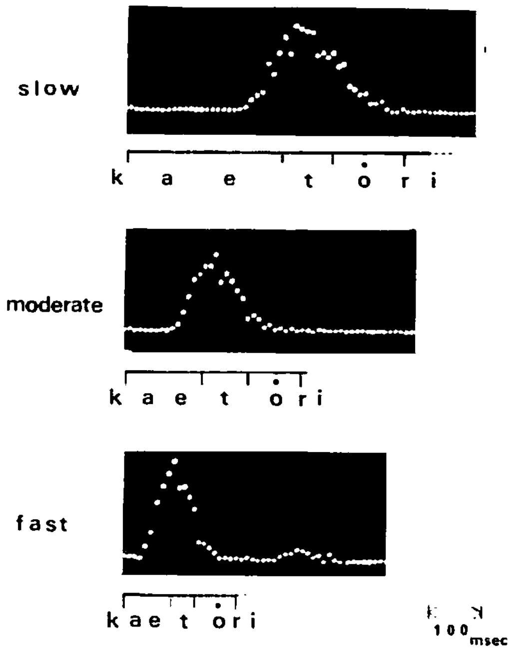


Fig. 2 - Summed E. M. G. data of another subject.

a comparatively constant time interval, irrespective of the speed of utterance, of approximately 110 msec. between the peak of the E. M. G. signal as the center of the formant curves and indicated by a dot in the scale underneath. This compares well with the result of the previous report.[1)]

Fig. 3 demonstrates the effect of varying the speed of utterance for another experimental condition. In this series, the subject repeatedly uttered the test word at random rates with a pause between utterances. The recorded data were then classified into six groups according to the length between the voice onset and the flap of the [r], and the summation of the curves was performed in each of the six groups (top to bottom of the figure). Each group contained nine utterances having approximately the same length. It is noted here again that the time relation between the peak of the E. M. G. activity and the center of the corresponding acoustic event of the vowel [o] (as indicated by the thin traiangle) is comparatively constant, estimated approximately at 90 msec. This figure also compares the two different acoustic events, the implosion and explosion of [t], taken as the reference point for the summation. Little consistent difference is observed in this case, too, except that in some occasions one case rather than the other gives a more neatly defined peak for the E. M. G. curve.

Fig. 4 shows some results of simultaneous recording of the orbicularis oris and the digastric. In articulating test words [irori] and [ioi], both

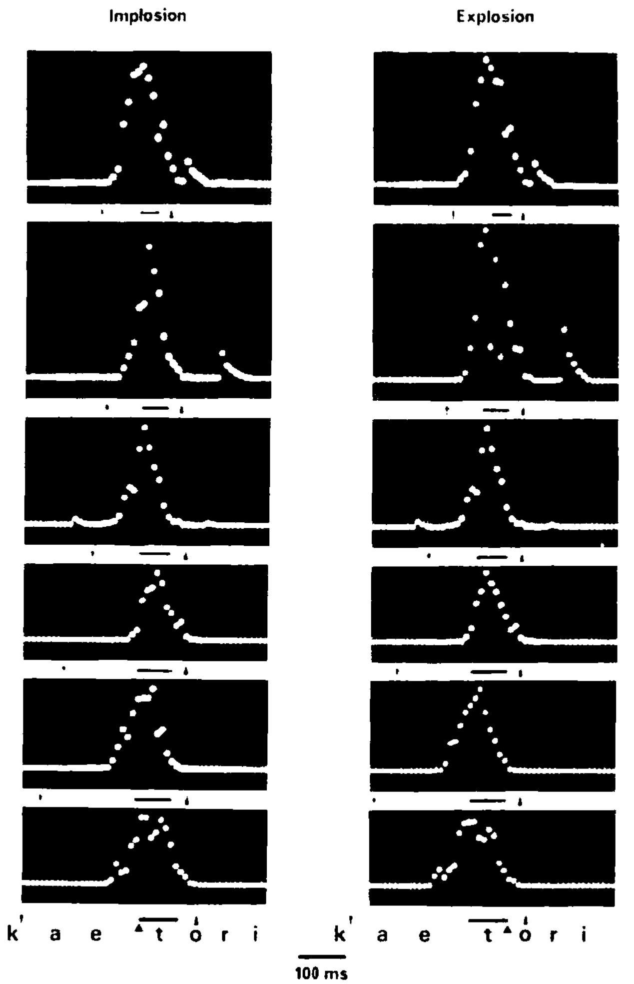


Fig. 3 - Summed E. M. G. data of the orbicularis oris muscle. In this series, speed of utterance is classified into six subsets according to the length of the recorded test words (bottom to top in the increasing order of speed). In the left column, the reference time moment for summation is set at the implosion into the stop, while the explosion of the stop is used for the reference in the right column.

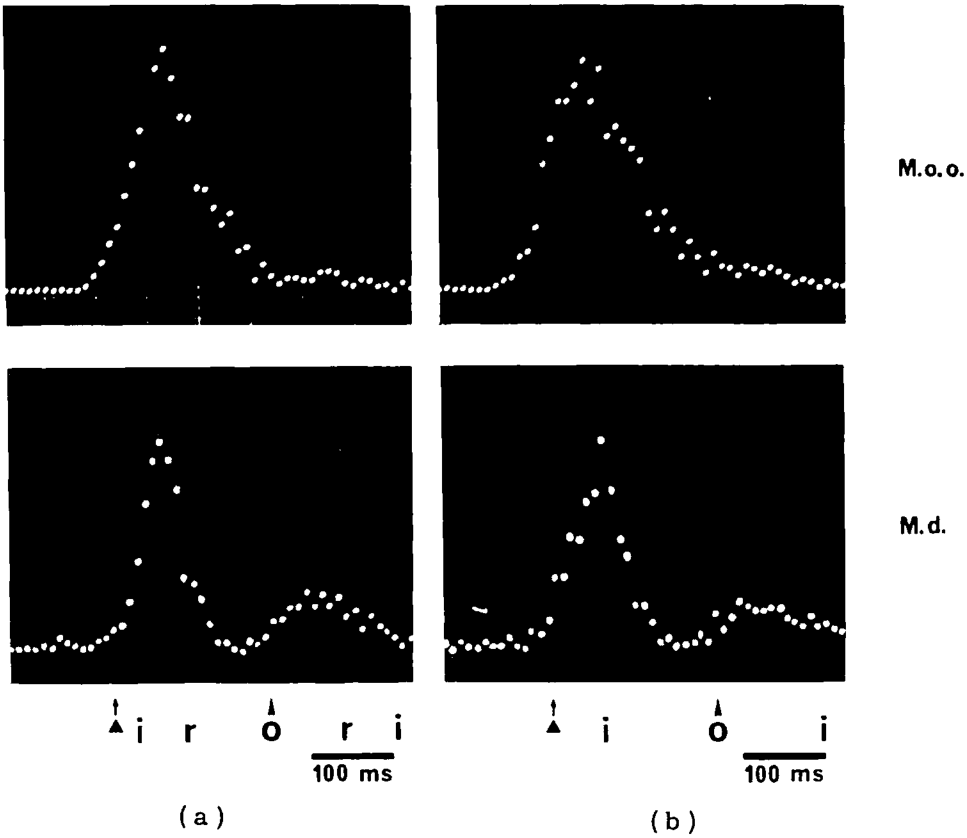


Fig. 4 - Summed E. M. G. signals of the orbicularis oris and the digastric recorded simultaneously, for utterances of (a) [irori] and (b) [ioi].

muscles are expected to show activity for the vowel [o] in each of the test words. As shown in these figures, in which the upper and lower curves are aligned in time for direct comparison, the peak of E. M. G. appears roughly at the same time in both muscles. This may suggest the possibility that the orbicularis oris and the digastric are activated synergistically in pronouncing the vowel [o]. In this series, the interval between the E. M. G. peak and the maximal manifestation of the phonetic value is approximately 120 msec.

Fig. 5 shows another example of simultaneous recording of the orbicularis oris and the digastric. These samples show a nonsense word [apa] uttered at three separate speeds. In pronouncing the word, the orbicularis oris is expected to show activity in executing the consonant [p], while the digastric will be active for the occurence of the vowel [a]. Reciprocal activities are actually observed in the data of the two muscles. It is also noted that the interval between the peak of E. M. G. activity of the orbicularis oris and the center of the closure period of the bilabial stop is approximately 80 msec., somewhat less than in the case of the vowel [o].

These results are in agreement with those of the previous report[1] in that the E. M. G. signal always precedes the pertinent acoustic event with a comparatively constant time interval regardless of the speed of utterance. However, the value of the interval slightly varies depending on the subject and on the phonetic structure of the test utterance.

Acoustic characteristics such as the change of formant frequencies or the implosion (or the center of the closure period) of a stop consonant are not always reliable measures of the timing of the articulatory events that result from muscle contraction.[2, 3] In order to provide more direct measures of the movements of the lips in relation to the muscle activities, we employed the technique of stroboscopic photography. The face of the subject was illuminated fifty times per second with a stroboscopic light source and the lateral view was taken continuously with a long-recording camera during pronunciation of the test word [kaetori]. The E. M. G. signal of the orbicularis oris was recorded simultaneously. The stroboscopic light was powered by a train of pulsive square waveforms, which was also recorded by a pen-recorder simultaneously with the speech signal in order to relate in time the frames to the speech signal.

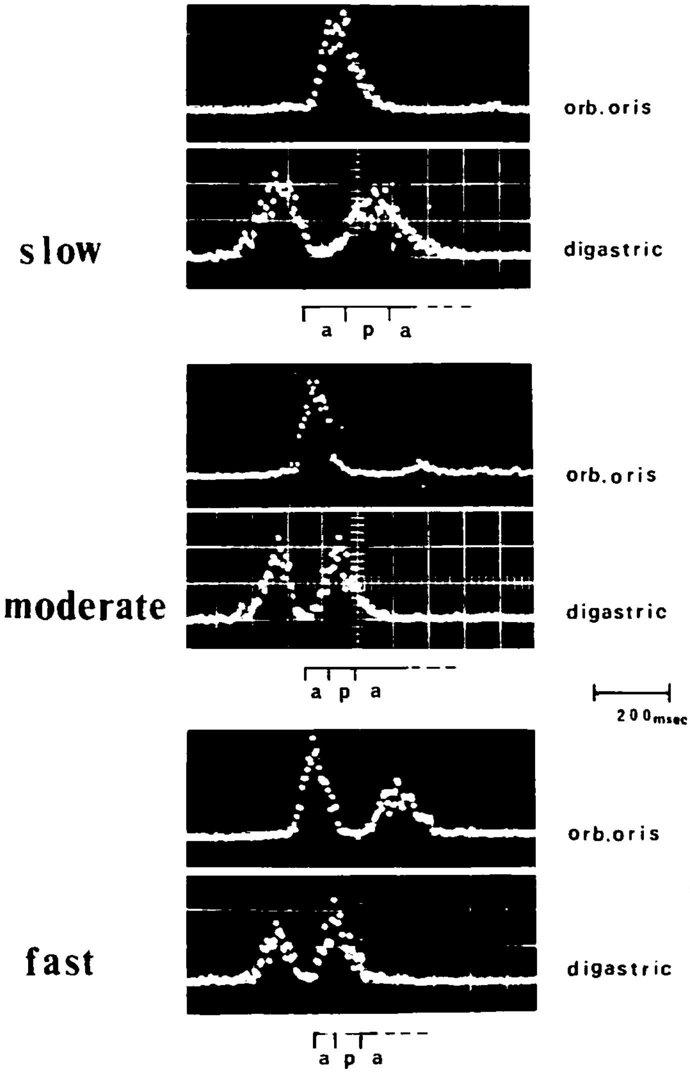


Fig. 5 - Summed E. M. G. signals of the orbicularis oris and the digastric recorded simultaneously, for utterances of [apa] .

A rigid but light bar with a hook was firmly attached to the forehead of the subject. A headrest was used for fixing the head of the subject. The upper lip region of the subject was stained black and multiple white spots were marked on the black portion. The degree of protrusion of the upper lip during the articulatory movements was measured referring to the displacement of a pertinent white spot relative to the fixed bar.

The subject set three different speeds of utterance designated as slow, moderate, and fast. For each speed, the test word was repeated with a pause ten times in series.

Fig 6 shows a series of stroboscopic frames. For estimating the lip

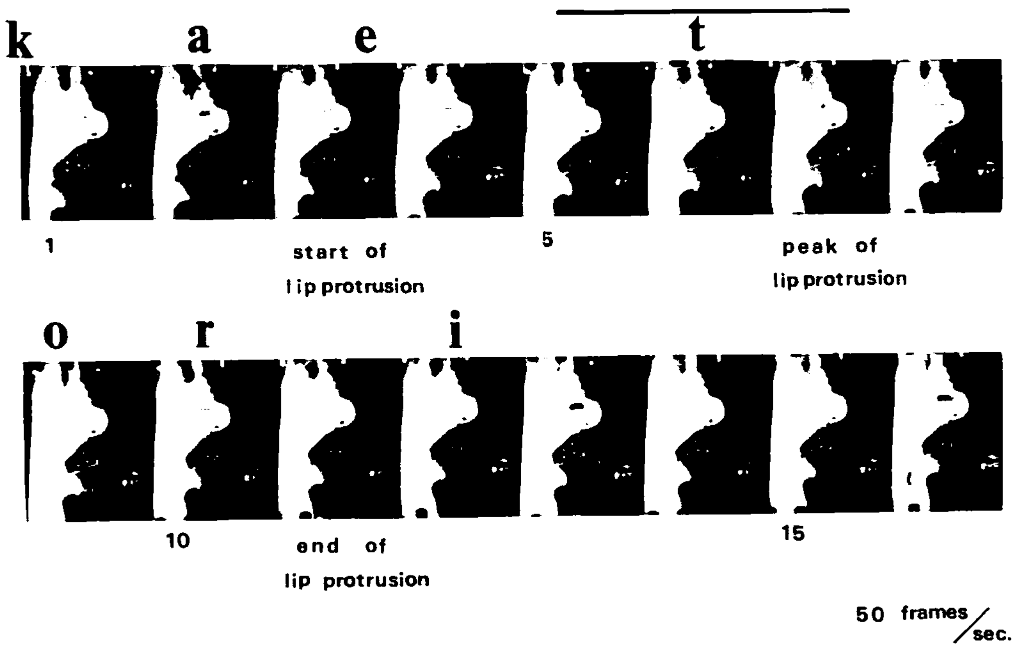


Fig. 6 - Stroboscopic frames for the word [kaetori] uttered at the fast rate.

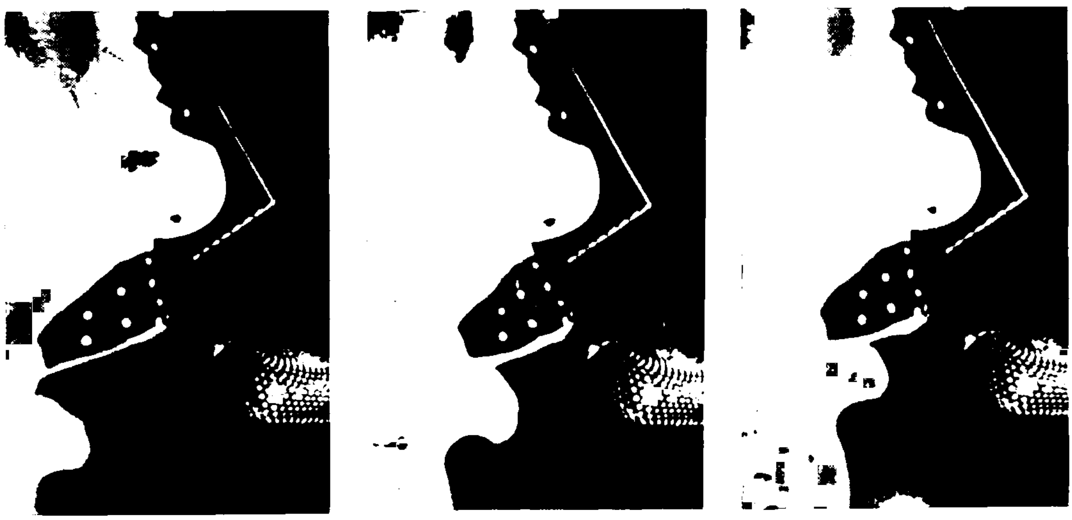
position frame by frame, each frame was projected on a screen and the lateral outline of the upper lip region as well as the bar and the white spots were traced on paper. By superposing the traces of all the frames of each series of articulation, displacement of the lip represented by a selected white spot was determined as function of time.

In Fig. 7, examples of stroboscopic frames and the superposed traces are illustrated.

Fig. 8 shows an example of the entire course of the white spot closest to the margin of the lip during a single utterance. The spot roughly follows an elliptic trajectory. For simplicity in the measurement, a line perpendicular to the longer axis of the ellipse was drawn from the pertinent white spot and displacement projected onto the long axis was estimated relative to the hooked point of the bar.

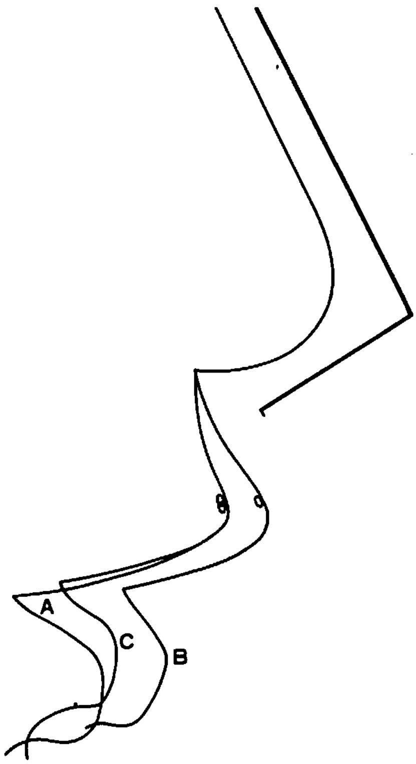
In Fig. 9, the movement of the upper lip is plotted in comparison with the crucial time moments observed in the speech signal and the peak position of the E. M. G. signal for the orbicularis oris (closed triangle).
It is shown in this figure that the peak position of the E. M. G. signal precedes the time moment of the maximum displacement of the lip. This delay of the movement of the articulator relative to the electrical activity can be explained by the fact that when the muscle with some mass contracts, a certain time interval is required between the electrical excitation of the muscle fibers and the mechanical displacement of the system. Physiologically, the delay should also contain in short time for the excitation-contraction coupling.

In voluntary movement, many motor units in one muscle are activated asynchronously to develop smooth contraction of the muscle as a whole. Considering a single utterance, the peak of the E. M. G. signal might be regarded as representing the time moment when the number of motor units being activated reach the maximum and the frequency of discharge of a unit also reaches its maximum, since the maximum in the two senses generally occur simultaneously. It is possible, however, that the E. M. G. signal for a single utterance can only reflect the activity of a limited portion of the muscle detected by a needle electrode. Through the averaging process employed in our experimental procedure, we probably obtain in effect the contraction activity of the muscle as a whole. The peak position of the



A **B** **C**

(a)

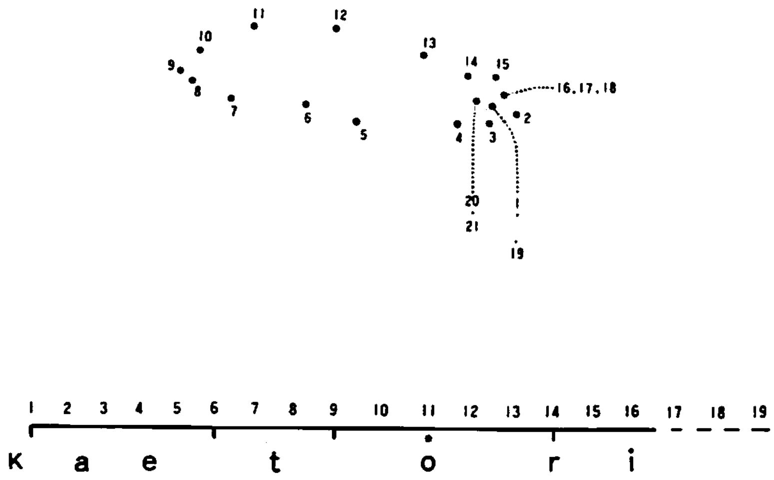


(b)

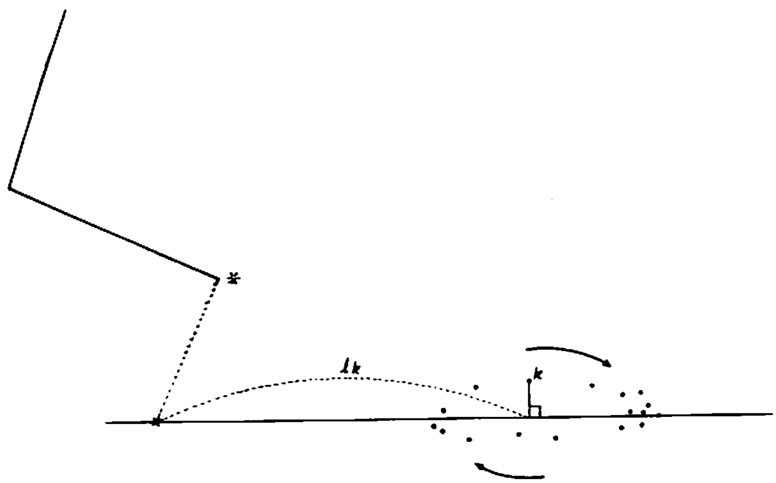
Fig. 7 -

(a) Representative stroboscopic frames
- A. start of lip protrusion
- B. peak of lip protrusion
- C. end of lip protrusion

(b) Superposed traces of the three frames.
Small open circles represent the position of the selected white spot on the lip region.



(a)



(b)

Fig. 8

a) An example of the trajectory of the selected white spot during a single utterance. In this case, the test word is uttered at the moderate rate. The protrusion here is in the opposite direction to that shown in Fig. 7.

b) For measurement of displacement of the selected spot, a line is drawn from every point in the trajectory to the hypothetic long axis of the elliptic trajectory and a point of intersection is obtained. A reference point for measurement is defined on the same axis by drawing a line from the tip of the angled bar (*) parallel to the longitudinal portion of the bar. The distance between the reference point (x) and the point of intersection is measured for each point.

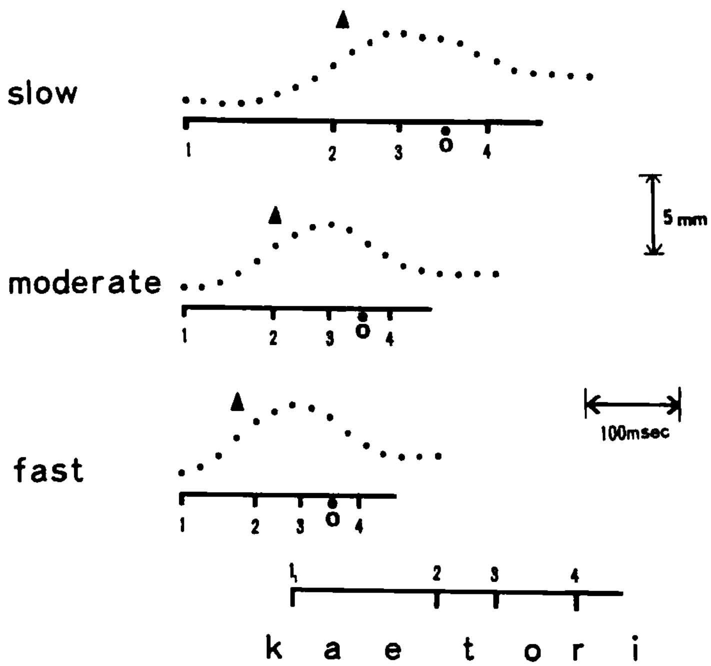


Fig. 9 - Time course of the lip protrusion with reference to the acoustic event. The peak position of E. M. G. is indicated by the triangle.

summed E. M. G. should then represent the time moment for the maximum activation of the entire muscle and, therefore, may coincide with the time when the rate of tension development of the muscle is at its maximum, i. e., when the second derivative of the positional parameter of an articulator is at its peak. In reality, however, the movement and deformation of the lip are three dimensional, and there is some interdependence between positions in different dimensions when it deforms. The curve plotted in Fig. 9 illustrates only one dimensional displacement of the lip protrusion. Presumably in any case, if we could obtain information on the actual development of tension in the muscle, the time relation between the peak of the E. M. G. signal and the executed movement of the articulator would be much more straightforward.

There is an apparent discrepancy between the time moment for the maximum lip protrusion and the center of the vowel [o], defined by the extreme of the F_2 curve, as shown in Fig. 9. This finding suggests that the protrusion of the lip does not entirely characterize the acoustic manifestation of the vowel [o] as a function of time. It may be presumed that the other principal articulator, the tongue, plays a more determining role in characterizing the phonetic value of the vowel in this case.

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