Ann.Bull.RILP(1986)No.20, 33-46

INFLUENCES OF INCREASE IN SPEAKING RATE ON JAW AND TONGUE POSITIONS FOR VOWELS IN THE PRODUCTION OF VOWEL SEQUENCE WORDS

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1. INTRODUCTION

In previous research, we have observed the movements of the jaw for vowel sequence words and analyzed the changes in the jaw positions for vowels caused by the increase in speaking rate [1]. Results obtained in the study showed that jaw positions for open vowels /a/ and /e/ at the fast speaking rate were higher than those at the slow speaking rate. These phenomena were explained by the combination of the under-shoot of jaw movements and the change in the target position of the jaw for the vowel. However, the change in the tongue shape for the vowel caused by the increase in speaking rate has not been investigated although the tongue plays as important a roll as the jaw in vowel production. The characteristics of change in the tongue position should be analyzed and compared with those of the jaw. The purpose of this paper is to determine if changes in the positions of the jaw and tongue for vowels caused by the increase in speaking rate can be explained by the under-shoot of articulatory movements.

In order to collect a large amount of data on articulatory movements, non-invasive techniques should be adopted. In this study, the technique of ultrasonic tomography was used to observe the movements of the tongue [2]-[3]. Jaw position can be observed by a video camera. These techniques were combined to compose a simultaneous observation system for the positions of the jaw and tongue.

2. DATA COLLECTION

Figure 1 shows a block diagram of the measuring system. Two dot marks were placed on the surface of the subject's face to monitor the movement of the head. Another two dot marks were placed on the solid wire attached to the lower front tooth to monitor the jaw position. In addition, two dot marks were placed on the probe of the ultrasonic tomograph. These marks were monitored by a video camera and recorded by a video tape recorder (VTR-1).

The probe of the ultrasonic tomograph (3.5 MHz, electrical sector scan type) was held beneath the subject's submandiblar triangle. The image of the tongue shape obtained from the ultrasonic tomograph was recorded by another video tape recorder (VTR-2) with superimposed frame numbers generated by a code generator. Timing pulses generated by the code generator were also recorded by VTR-1 to identify the simultaneous video frame recorded by VTR-2. Speech sound and the timing pulses were

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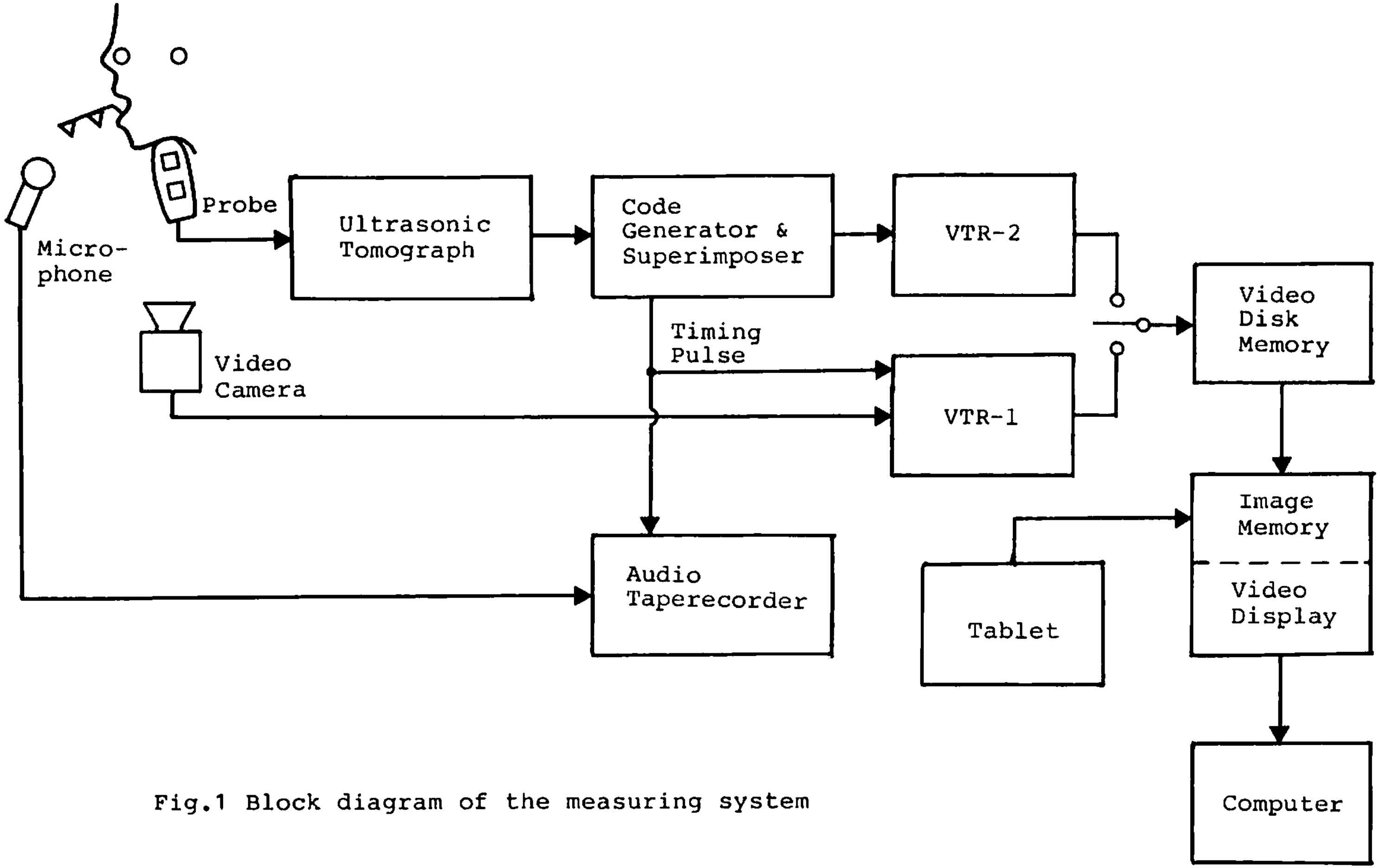

Fig.1 Block diagram of the measuring system

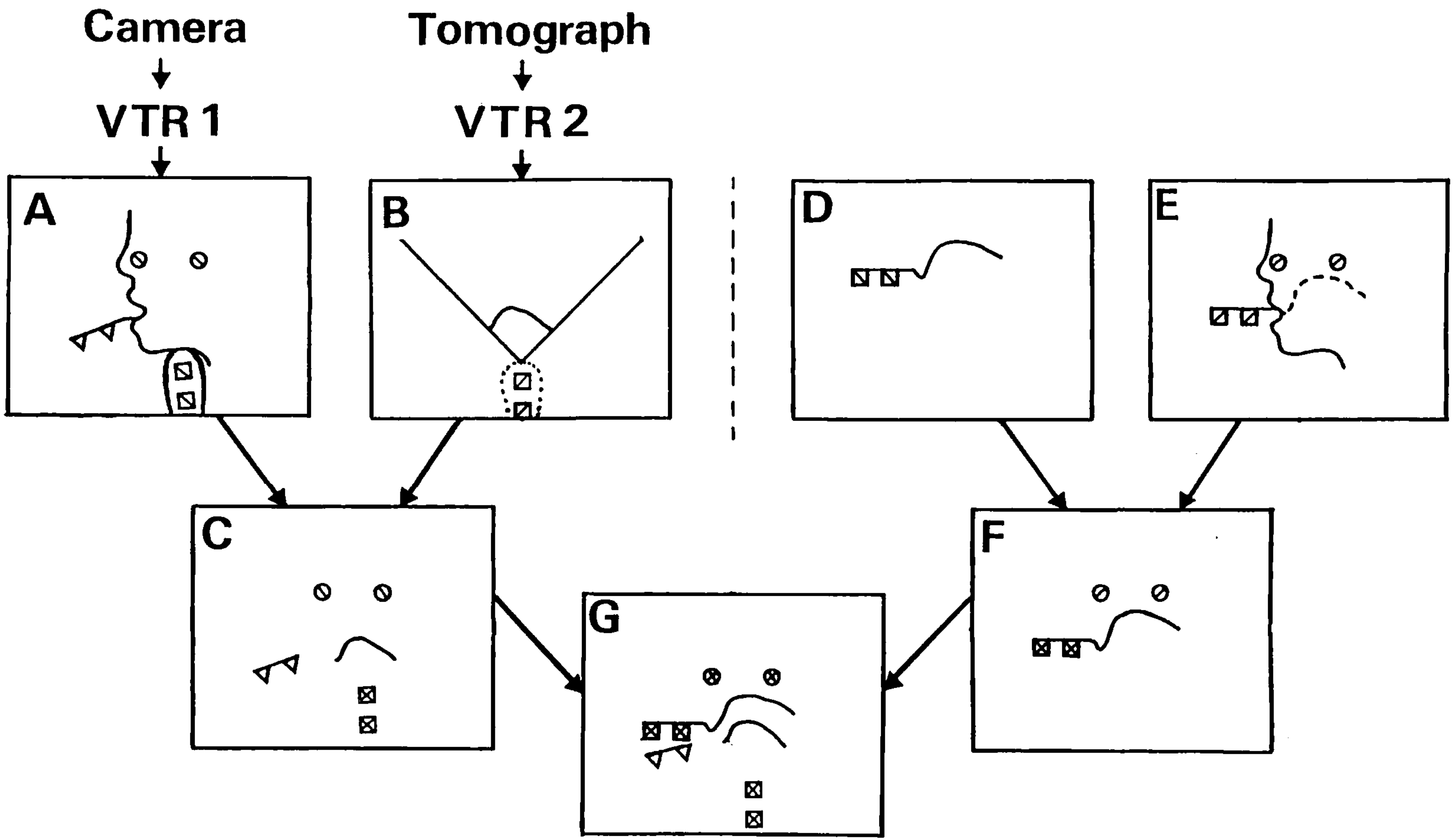

Fig.2 Method used to obtain the positions of the jaw and tongue relative to the palate.
Refer to section 3 for detailed explanation.

recorded on a separate channel of the audio tape by a two-channel audio tape recorder.

After the data collection, the coordinate values of the six marks recorded in the VTR-1 and those of the tongue shape recorded in the VTR-2 were evaluated. Images recorded in VTRs were stored into a magnetic video disk memory and then an image of a certain frame was displayed on the video display. A cross mark, which move according to the movement of a cursor on the tablet, was also displayed on the same display. In order to evaluate the coordinate value for each data point, the button on the cursor was pushed. The evaluated coordinate values were stored into the computer. The positions of the jaw and tongue relative to the palate were obtained based on the evaluated coordinate values by means of the method outlined in the following section.

3. METHOD USED TO OBTAIN THE POSITIONS OF THE JAW AND TONGUE RELATIVE TO THE PALATE

Figure 2 illustrates the method used to obtain the positions of the jaw and tongue relative to the palate.

[A]: An image monitored by a video camera. Circles (⦸), triangles (△) and boxes (⧅), represent the two marks on the surface of the subject's face to monitor the movement of the head, two marks on the solid wire attached to the lower front tooth to monitor the jaw position and two marks attached to the probe of the ultrasonic tomograph to monitor the probe position, respectively.

[B]: An image obtained from the ultrasonic tomograph. The curved line represents the image of the tongue shape.

[C]: A superimposed image of [A] and [B] showing the positions of the jaw and tongue relative to the marks on the surface of the subject's face (⦸). In order to obtain this figure, [B] was superimposed on [A] with boxes (⧄) in [B] placed on boxes (⧅) in [A].

[D]: A figure of a palatal prosthesis which replicates the palatal shape on the midsagittal plane. The solid wire with marks represented by boxes (⧅) which is protruded through the lips was attached to the prosthesis so as to monitor the spatial relationship between the prosthesis and the marks on the subject's face.

[E]: A figure showing the spatial relationship between the marks on the surface of the subject's face and those attached to the palatal prosthesis. This relationship was monitored before or after data collection.

[F]: A figure showing the spatial relationship between the marks on the surface of subject's face and the palatal prosthesis. In order to obtain this figure, [D] was superimposed on [E] with boxes (⧅) in [D] placed on boxes (⧄) in [E].

[G]: A figure showing the positions of marks attached to the lower jaw and tongue shape relative to the palate. In order to obtain this figure, [C] was superimposed on [F] with circles (⊗) in [C] placed on circles (⊘) in [F].

4. SPEECH SAMPLES

Speech samples are four meaningless four-mora words, in which the open vowels /a/ or /e/ and the close vowel /i/ appear alternatively; /aiai/, /iaia/, /eiei/ and /ieie/. These words were uttered at slow and fast speaking rates.

For the slow speaking rate, test words were uttered within the carrier sentence / desu/. In order to fix the speaking rate, click sounds, whose intervals were 714 ms, were presented to the subject. The subject was instructed to utter each mora of a test word so as to correspond to the interval of click sounds. When the subject got used to uttering speech samples at this speaking rate, the subject uttered them without hearing the click sounds. The data uttered without hearing click sounds were sampled for the analysis.

For the fast speaking rate, three sentences were uttered in succession. In this utterance, /aiai/ and /iaia/, or /eiei/ and /ieie/ were uttered alternatively. For the test word /aiai/, for example, the subject uttered /iaia desu, aiai desu, iaia desu/. Data from the second sentence in the utterance was analyzed. In this case, the click sounds at intervals of 150 ms were presented to the subject.

The subjects were two adult males with Tôkyo dialect. For each test word, five utterance data were obtained for subject 1 and ten for subject 2.

In this paper, the positions of the jaw and tongue will be discussed for the second vowels in four-mora vowel sequence words such as /i/ in /aiai/, /a/ in /iaia/, /i/ in /eiei/ and /e/ in /ieie/. The moments at which the positions of these articulators were measured were determined as follows. Figure 3 shows examples of the sonagrams of speech sounds for /aiai desu/ at both slow and fast speaking rates along with the timing pulses generated by the code generator to identify the simultaneous frame of VTR-1 and VTR-2. For the slow speaking rate, the stationary portion for each vowel was clearly visible in the time function of formant frequencies. At the middle of this portion, the positions of the jaw and tongue were measured. For the fast speaking rate, the peak for each vowel was seen. At the moment of this peak, the positions of the jaw and tongue were measured. Vertical arrows represent the moments at which the positions of these articulators for vowels were measured.

5. RESULTS

5-1. Influences of increase in speaking rate on positions of articulators for vowels

Figures 4 and 5 show the comparison of positions of articulators for vowels between slow and fast speaking rates for

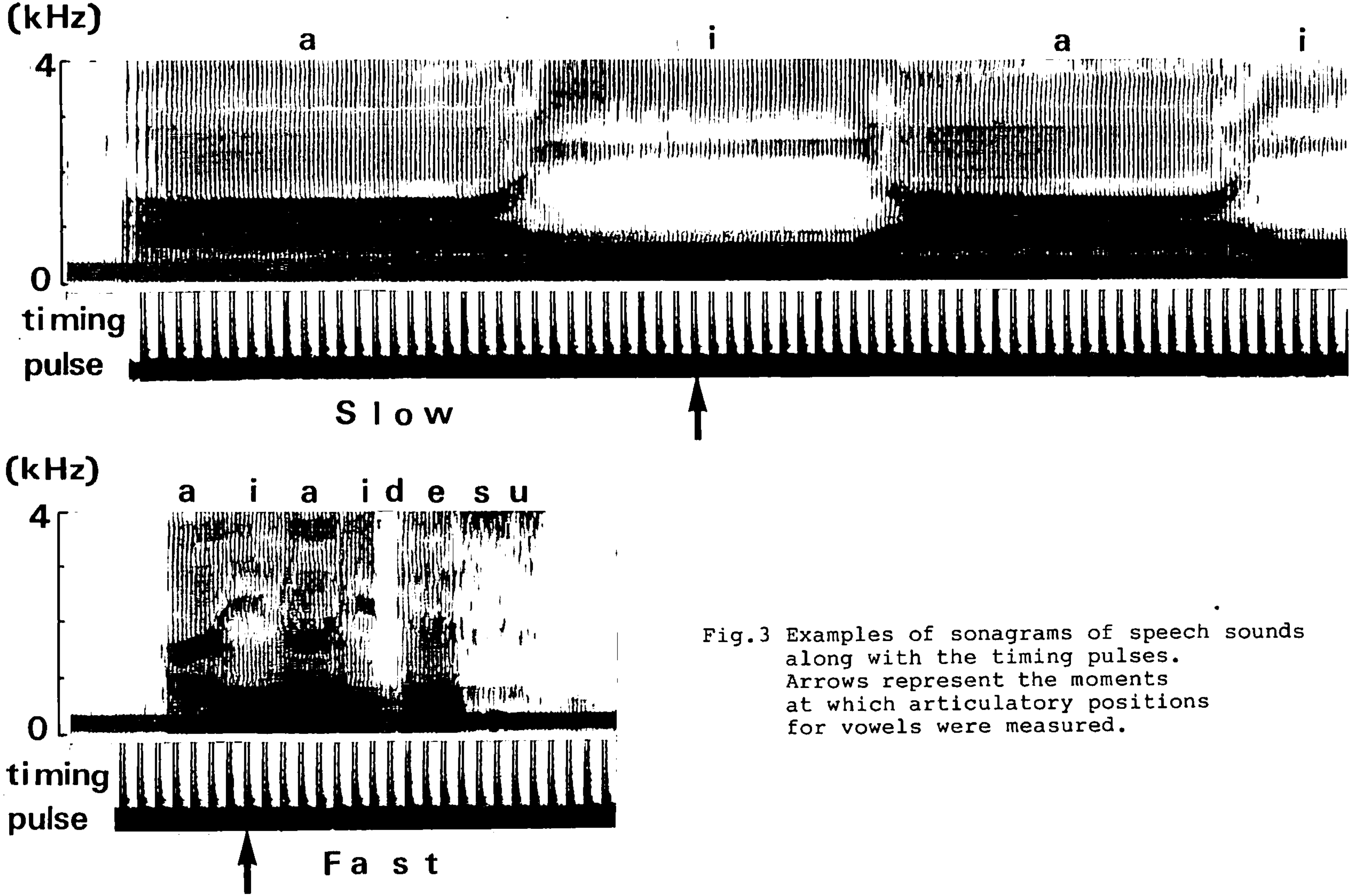

Fig.3 Examples of sonagrams of speech sounds along with the timing pulses. Arrows represent the moments at which articulatory positions for vowels were measured.

subjects 1 and 2, respectively. In these figures, jaw position is represented by the connected line between the marks on the solid wire attached to the front tooth. Position and shape of the tongue are represented by lines connecting sampled data points from the line image of the tongue obtained from the ultrasonic tomograph. Solid and broken lines represent the results for slow and fast speaking rates, respectively. In each figure, all data for each speech sample at both slow and fast speaking rates were superimposed.

5-1-1. Results for subject 1

For the second vowel /i/ in /aiai/, as shown in Fig.4 (a), jaw positions at the fast speaking rate are lower than those at the slow speaking rate. Positions of the anterior part of the tongue at the fast speaking rate were lower than those at the slow speaking rate. Positions of the posterior part of the tongue at the fast speaking rate were posterior to those at the slow speaking rate.

For the second vowel /a/ in /iaia/, as shown in Fig.4 (b), jaw positions at the fast speaking rate were higher than those at the slow speaking rate. Positions of the anterior part of the tongue at the fast speaking rate were higher than those at the slow speaking rate. Positions of the posterior part of the tongue at the fast speaking rate were anterior to those at the slow speaking rate.

For the second vowel /i/ in /eiei/, as shown in Fig.4 (c), jaw positions at the fast speaking rate were higher than those at the slow speaking rate. Positions of the tongue at the fast speaking rate were almost the same as those at the slow speaking rate.

For the second vowel /e/ in /ieie/, as shown in Fig.4 (d), jaw positions at the fast speaking rate were higher than those at the slow speaking rate. Tongue positions at the fast speaking rate were almost the same as those at the slow speaking rate.

5-1-2. Results for subject 2

For the second vowel /i/ in /aiai/, as shown in Fig.5 (a), jaw positions at the fast speaking rate were lower than those at the slow speaking rate. Positions of the anterior part of the tongue at the fast speaking rate were lower than those at the slow speaking rate. Positions of the posterior part of the tongue at the fast speaking rate were posterior to those at the slow speaking rate.

For the second vowel /a/ in /iaia/, as shown in Fig.5 (b), jaw positions at the fast speaking rate were higher than those at the slow speaking rate. Positions of the tongue at the fast speaking rate were higher than those at the slow speaking rate.

For the second vowel /i/ in /eiei/, as shown in Fig.5 (c), jaw positions at the fast speaking rate were almost the same as those at the slow speaking rate. Positions of the anterior part of the tongue at the fast speaking rate were slightly lower than those at the slow speaking rate. Positions of the posterior part of the tongue at the fast speaking rate were posterior to those

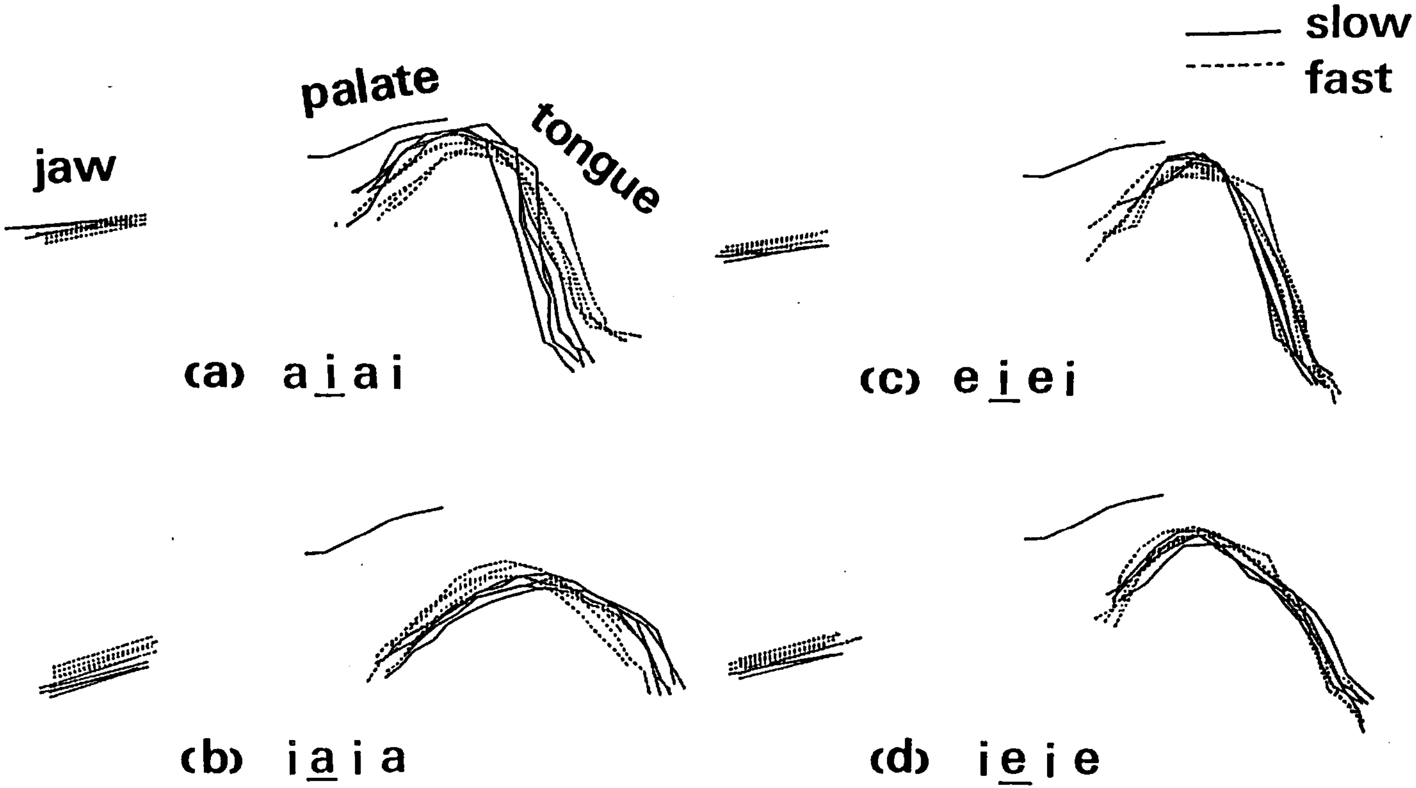

Fig.4 Positions of jaw and tongue for each vowel
at both slow and fast speaking rates for subject 1

(a): second vowel /i/ in /aiai/
(b): second vowel /a/ in /iaia/
(c): second vowel /i/ in /eiei/
(d): second vowel /e/ in /ieie/

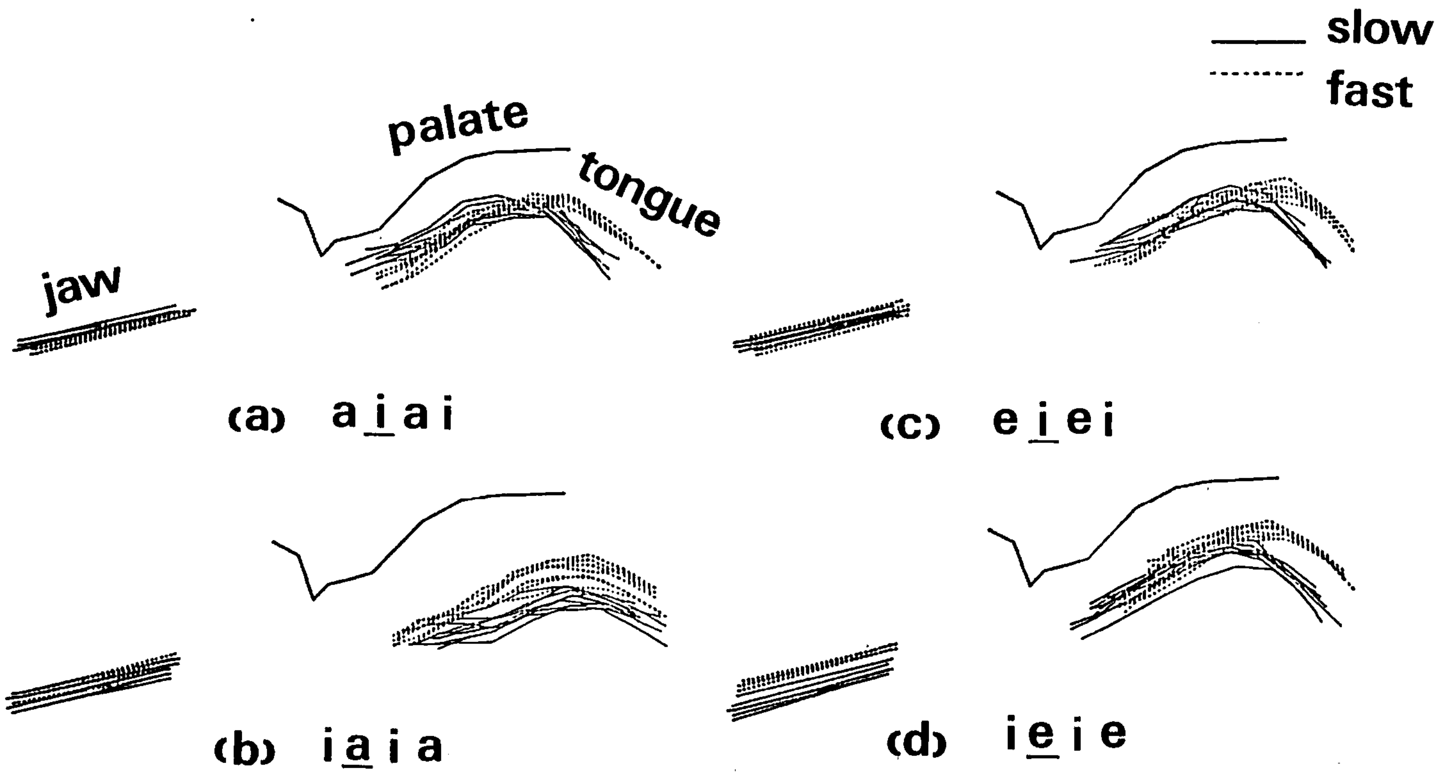

Fig.5 Positions of jaw and tongue for each vowel
at both slow and fast speaking rates for subject 2

(a): second vowel /i/ in /aiai/
(b): second vowel /a/ in /iaia/
(c): second vowel /i/ in /eiei/
(d): second vowel /e/ in /ieie/

at the slow speaking rate.

For the second vowel /e/ in /ieie/, as shown in Fig.5 (d), jaw positions at the fast speaking rate were higher than those at the slow speaking rate. Positions of the tongue at the fast speaking rate were higher than those at the slow speaking rate.

5-2. Under-shoot of articulatory movement

If the changes in positions of articulators for the vowel in the production of alternative vowel sequences of open and close vowels caused by the increase in speaking rate were explained by the simple under-shoot of the articulatory movements, the positions of the articulators for open and close vowels at the fast speaking rate would change in the direction toward those for close and open vowels at the slow speaking rate, respectively. In other words, the positions of the articulators for open and close vowels at the fast speaking rate should be between those at the slow speaking rate. The positions of the jaw and tongue were examined to observe the probable accounts of these phenomena.

Superimposed figures of the positions of the articulators for both the second vowel /i/ in /aiai/ and the second vowel /a/ in /iaia/ at slow and fast speaking rates are shown in Fig.6 (a) and Fig.7 (a) for subjects 1 and 2, respectively. Superimposed figures of the positions of the articulators for both the second vowel /i/ in /eiei/ and the second vowel /e/ in /ieie/ at slow and fast speaking rates are shown in Fig.6 (b) and Fig.7 (b) for subjects 1 and 2, respectively. Data shown in Figs.6 and 7 are rearranged from the data in Figs.4 and 5. For example, Fig.6 (a) is the superimposition of Figs.4 (a) and (b).

5-2-1. Results for subject 1

In Fig.6 (a), the positions of the jaw and tongue for /i/ and /a/ at the fast speaking rate were between those at the slow speaking rate. However, the positions of these articulators for /i/ were distinct from those for /a/ at the fast speaking rate.

In Fig.6 (b), the positions of the jaw at the fast speaking rate were higher than those at the slow speaking rate for both /i/ and /e/. As a result, the positions of the jaw for /i/ were distinct from those for /e/ at the fast speaking rate. As shown in Figs.4 (a) and (b), positions of the tongue for /i/ and /e/ at the fast speaking rate were almost the same as those at the slow speaking rate, respectively. Consequently, positions for /i/ were distinct from those for /e/ at the fast speaking rate.

5-2-2. Results for subject 2

In Fig.7 (a), the positions of the jaw for /i/ and /a/ at the fast speaking rate were between those at the slow speaking rate. As a result, the positions of the jaw for /i/ were not distinct from those for /a/. On the other hand, the positions of the tongue for /i/ were distinct from those for /a/ at the fast speaking rate. However, these positions were not between those for /i/ and /a/ at the slow speaking rate. The positions of the tongue for both /i/ and /a/ changed globally in a posterior direction with the influence of the increase in speaking rate.

In Fig.7 (b), jaw positions for /i/ at the fast speaking rate were almost the same as those at the slow speaking rate. At the same time, jaw positions for /e/ at the fast speaking rate were higher than those at the slow speaking rate. Consequently, the positions of the jaw for /i/ were not distinct from those for /e/ at the fast speaking rate. The positions of the tongue for /i/ were also not distinct from those for /e/ at the fast speaking rate. However, these positions were not between those for /i/ and /e/ at the slow speaking rate. The positions of the tongue changed globally in a posterior direction with the influence of the increase in speaking rate.

6. COMMENTS

The positions of the jaw and tongue were measured for a vowel in the production of four-mora words in which open vowels /a/ or /e/ and close vowel /i/ appear alternatively at slow and fast speaking rates.

Some of the results can be explained by the under-shoot of articulatory movements. For subject 1, positions of the jaw and tongue for /i/ and /a/ at the fast speaking rate were between those at the slow speaking rate. For subject 2, positions of the jaw for /i/ and /a/ at the fast speaking rate were between those at the slow speaking rate.

However, there were some phenomena which can not be explained by the under-shoot of articulatory movements. Results for subject 2 suggest global change in the tongue position in a posterior direction caused by increase in speaking rate. It should be confirmed if there are any effects of these variations in positions of the articulators on the variations in the formant frequencies. For example, there is a question if the change in the tongue position in a posterior direction lessens the influence of the under-shoot of articulatory movement on the under-shoot in the movements of formant frequencies at the fast speaking rate.

In addition to changes in positions in the articulators caused by an increase in speaking rate, the following phenomena were observed. As shown in Fig.7 (a), tongue shapes for /a/ and those for /i/ were distinct from each other at the fast speaking rate. However, as shown in Fig.7 (b), tongue shapes for /e/ overlapped with those for /i/ at the fast speaking rate. These phenomena may be caused by the following mechanism.

In the production of sequence of vowels /i/ and /a/, the increase in speaking rate involves the under-shoot of the articulatory movements. Consequently, the positions of articulators for /i/ and /a/ at the fast speaking rate changes in the direction toward those for /a/ and /i/ at the slow speaking rate, respectively. However, the positions of the articulators for /i/ and /a/ at the fast speaking rate are distinct from each other since the difference in the averaged positions of articulators between /i/ and /a/ are larger than the range of the positions of articulators for /i/ and /a/.

However, in the production of sequence of vowels /i/ and

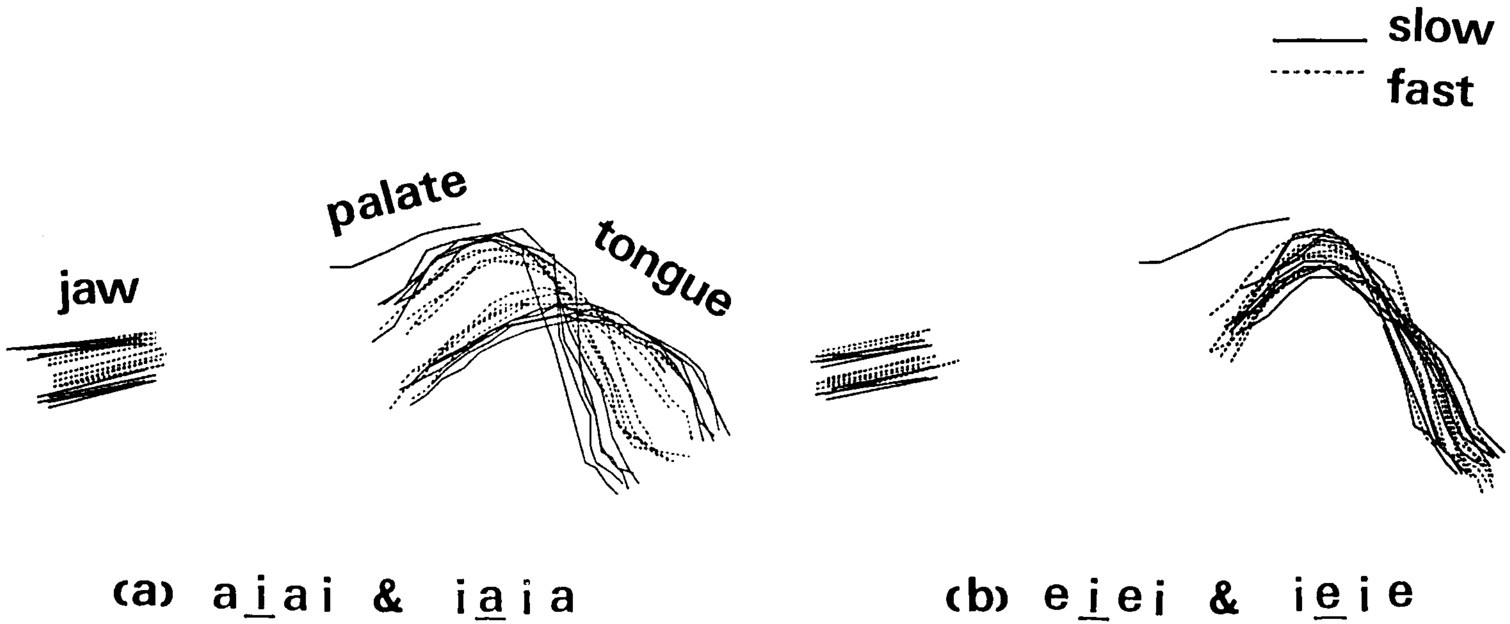

Fig.6 Positions of jaw and tongue for vowels
at both slow and fast speaking rates for subject 1

(a): second vowels /i/ in /aiai/ and /a/ in /iaia/
(b): second vowels /i/ in /eiei/ and /e/ in /ieie/

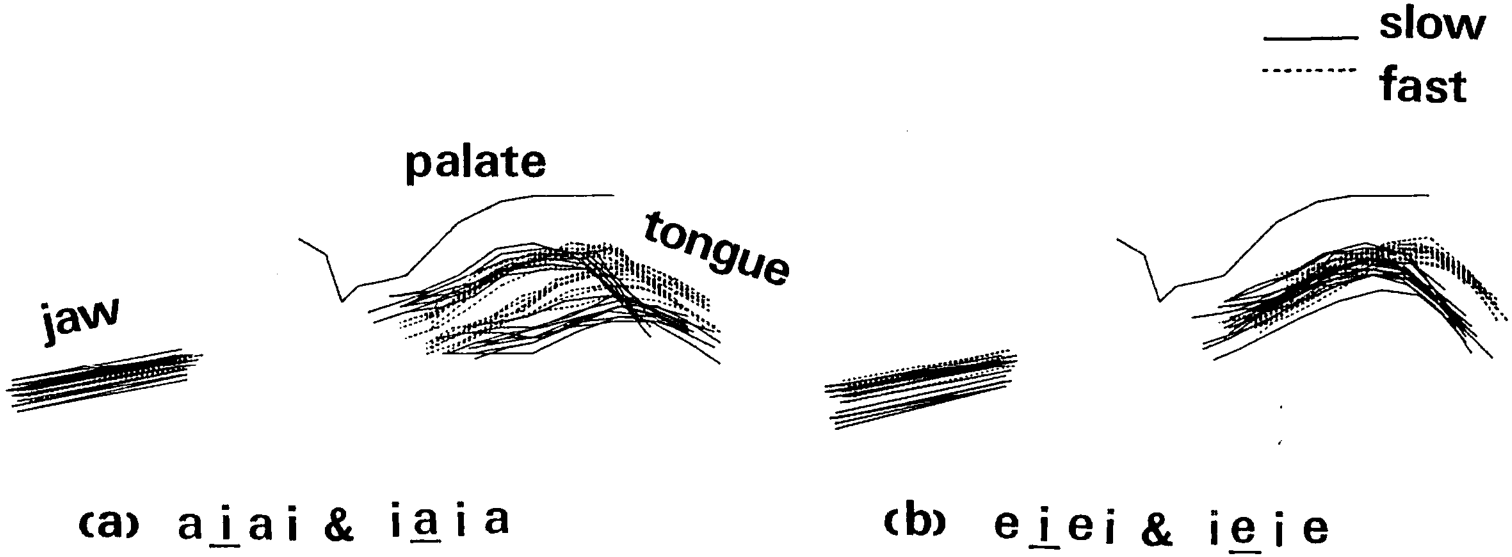

Fig.7 Positions of jaw and tongue for vowels at both slow and fast speaking rates for subject 2

(a): second vowels /i/ in /aiai/ and /a/ in /iaia/
(b): second vowels /i/ in /eiei/ and /e/ in /ieie/

/e/, the difference in the positions of articulators between /i/ and /e/ at the slow speaking rate is originally small. Therefore, if the degree of the under-shoot and the range of positions of articulators for each vowel in the sequence of /i/ and /e/ are the same as those in the sequence of /i/ and /a/, the range of the positions of the articulators for /e/ overlaps with that for /i/.

However, there is another possibility. That is, the degree of the under-shoot for /a/ in the sequence of /i/ and /a/ is smaller than that for /e/ in the sequence of /i/ and /e/ to avoid the overlap of the positions of articulators and the confusion of the acoustic outputs between /a/ and /e/. In future research, examination of whether the degree of the under-shoot for each vowel in the sequence of /i/ and /a/ is the same as that in the sequence of /i/ and /e/ is necessary.

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