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COORDINATION OF THE CONSONANT AND VOWEL ARTICULATIONS — X-RAY MICROBEAM STUDY ON JAPANESE AND ENGLISH — *

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Introduction

In the present paper, several characteristics of coarticulation between the consonant and the vowel in Japanese will be reported. Movements of the tongue in the production of the vowel-consonant-vowel sequences and the consonant-vowel-consonant sequences were observed by the x-ray microbeam system. Perturbations on the articulations of the consonant and vowel by the adjacent vowels or consonants were investigated.

Experimental Procedures

The speech materials used in this study are shown in Table 1. In the first experiment, the test word contained a set of CVC sequences, where the consonant was one of the four: /m, t, k, s/. The vowel was one of the five Japanese vowels: /i, e, a, o, u/. For these test words, variations in the vowel articulations due to the differences in C_1 and C_2 were examined.

EXP I	EXP II
CVC-SEQUENCE	VCV-SEQUENCE
/$C_1 V C_2$ i desu/	/m V_1 C V_2 e desu/
(80 WORDS)	(100 WORDS)

V = i, e, a, o, u
C = m, t, k, s

Table 1: Speech materials.

The number of test words in this experiment was 80. Experiment II was designed to observe the articulations of V_1CV_2 sequence. Vowels and consonants in the test words were the same as in Experiment I. In this case the number of test words totalled 100. Variations in the consonant articulations by the vowel context were examined. Test words were uttered in a sentence, which consisted of a test word and the copula desu. The sentences

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were pronounced in succession without pause in between. The speaking rate was considerably fast.

Movements of the tongue were observed by the x-ray microbeam method. [1][2] By this method, it is possible to collect a large set of utterance samples such as shown in Table 1. Several metal pellets were attached to the articulatory organs and their movements were tracked by the x-ray microbeam. Deflection of the x-ray beam was controlled by an on-line computer to automatically track the moving pellets. The block diagram of the x-ray microbeam system is shown in Fig. 1.

Four pellets were attached to the tongue (Fig. 1). Pellet No. 4 was located at about 1 cm back from the tongue tip. The distance between each pellet on the tongue was about 3 cm. In order to observe the movements of the jaw and the lip, the pellets were also attached to the lower incisor and lower lip. The movements of the pellets were recorded at a rate of 130 frames/second, and their coordinate values were stored in the computer.

An example of the pellet trajectories is also shown in Fig. 1. The utterance is a sequence of Japanese five vowels /i, e, a, o, u/.

Pellet No. 3 on the tongue is located at about the highest point of the tongue for vowel /i/. Starting from the high frontal position for /i/, it moves downward for vowel /e/, then goes backward for low back vowels /a/ and /o/. The displacement of the back-most pellet (pellet No. 1) is essentially horizontal, mainly representing front-back movements of the tongue.

Results and Comments

Experiment I

An example of the pellet movements including the consonant gestures is shown in Fig. 2. The test word is /takai/. Pellet trajectories are plotted for the time interval between initial /t/ and second /a/. Pellet No. 2 on the tongue, for example, first moves downward and backward from /t/ to /a/. Then, the direction of the movement changes upward for the articulation of consonant /k/. Then, it moves downward for the second vowel /a/. The pellet then moves forward for vowel /i/.

The tongue positions for the first and second vowel /a/ are shown by connecting the pellets with solid lines. The dashed line shows tongue position for /k/. There is a considerable difference in the tongue positions between first and second vowels. The tongue position for the first vowel which is placed between the consonants /t/ and /k/, is higher compared to that of the second vowel.

The patterns of variations of individual vowels in C_1VC_2 sequences are shown in Fig. 3. Pellet positions at the middle of the time period between the two consonant peaks were sampled for representing tongue configurations of the vowels. Each figure shows pellet positions in nine different consonant contexts. The pellets on the tongue are connected by the straight lines.

In the case of the front vowels /i/ and /e/, variations in the positions of the tongue tip pellet are smaller than for the back vowel. The variations mainly result from the vertical displacement for the /k/-articulation. The pellet positions for vowel /e/ accompanied by /k/ tend to be high. Thus, there is a considerable overlap in the positions of pellets No. 1 and 2 for vowel /i/ and /e/. However, there is a clear difference in the positions of the pellet No. 3 between /i/ and /e/.

For the back vowels, compared to the front vowels, there is a larger variation in the positions of tongue tip pellet. This is mainly due to the articulation of consonant /t/. At the same time, the upper surface of the tongue is stretched out and becomes flat because of /t/. Due to this effect, the difference in the tongue shapes for the different vowels tends to decrease. For high vowel /u/, this effect also causes a lowering of pellet positions. On the other hand, there are upward shifts of the low vowels /a/ and /o/ by the consonant /k/. Consequently, there is a large overlap in the range of tongue configurations among the back vowels, /u/, /a/ and /o/.

As for the front-back distinction, the horizontal position of the back-most pellet (pellet No. 1) is consistently different between the groups of front and back vowels. Front-back distinction appears to be consistently maintained against context variations in vowel articulations.

It is observed that the difference in the jaw and the lip positions among the back vowels are more consistent as shown in Fig. 4. The figure compares the positions of the jaw and lip pellets for back vowels /u/, /a/ and /o/. The pellet positions in the various context are plotted on an x-y plane. It is seen that the data points for vowels /u/ and /a/ are clearly separated. The difference in the jaw position is approximately 4 mm on the average. As for the vowels /a/ and /o/, jaw position is almost the same. However, for this vowel pair, there is a consistent difference in the position of lip pellet.

As far as the tongue configuration is concerned in this study, perturbations due to the neighboring consonants introduce the confusion among back vowels. The distinction in these cases is consistently achieved by the lip and jaw controlling the oral end of the vocal tract.

Figure 5 shows magnitudes of variations in the position of pellet No. 3 for the middle vowels in consonant-vowel-consonant sequences. Effects of the preceding consonant C_1 and the following consonant C_2 are compared. For each vowel, standard deviation of the pellet coordinate is calculated for two different sets of the test words, as is explained in the upper and lower formula in the figure. In the upper formula a particular pair of the middle vowel and the second consonant C_2 is preceded by three different consonants. The variation for these three words is estimated and then, averaged over the different C_2. This gives a measure of perturbation by C_1. Perturbation by C_2 is calculated in a similar way as indicated in the lower formula of the figure. The result is shown in the lower part of Fig. 5. It is seen that the perturbation by the first consonant is two times greater than that by the second consonant in terms of standard deviation. This is true regardless of the type of the vowels. This result shows that the effect of the neighboring consonant on vowel articulation is asymmetric with regard to time axis.

Experiment II

For the VCV sequences in the experiment II, variations in the middle consonants due to the difference in the vowel context were examined. The pellet coordinates were sampled at the time moment of consonant peaks. The measure of the perturbation was obtained by a similar procedure to that described in Experiment I, where the variation of the middle vowel in CVC sequences due to the neighboring consonants was estimated.

It is seen that the variations due to the following vowel are greater than that by the preceding vowel (Fig. 6). This result agrees with the general idea that the consonant and the following vowel constitute a syllable in Japanese.

For the middle consonant /a/, tongue configurations at the time of the consonant peak were examined in more detail. For this purpose, patterns of pellet positions were represented by a linear sum of the articulatory components as seen in Fig. 7. The method and the validity of this approximation have been reported elsewhere.[3][4][5] It has been demonstrated that, for the vowels in Japanese, pellet positions can be specified by using two major components, J-component and T-component. The J-component corresponds to so-called high-low movement and the T-component to the front-back movement of the tongue.

In Figure 8, the articulatory components for the middle /m/ in various V_1 - V_2 context are plotted on an x-y plane, using two parameters: J and T_1 as the coordinate axis. The thick dots in the dashed area represent the five vowels in the test words such as /mamae/, /mimie/,/mumue/ and so on.

It is noted that the data points for the middle /m/ tend to be clustered around the particular vowels. For example, for the vowel pair /a/ and /i/, the data points for /ami/ and /ima/ are both located close to the vowel /i/. This tendency of bias is indicated by the arrows between the pairs of vowels. For the vowel pair of /a/ and /e/, this relationship appears to be symmetrical.

The characteristics of this phenomena can be interpreted as shown in Fig. 9. The figure shows time functions of the articulatory parameters mentioned above. Tongue movements for the test words /mamae/, /mimie/, /mamie/ and /mimae/ are compared. The curves at the top show the lip movements for /m/. The curves in the middle represent front-back movements for the tongue. Within four curves, the upper one corresponds to /mimi/ and the lower one to /mama/. The other two curves crossing in the middle correspond to /mami/ and /mima/. It is observed that, with regard to the peak of the middle consonant /m/, /i/ to /a/ transsition in /mima/ is more delayed than /a/ to /i/ transition in/mami/. In other words, the degree of vowel transition from /i/ to /a/ is less than from /a/ to /i/. Consequently, in both words, tongue configuration at the middle /m/ is close to /i/. A similar tendency was observed for other pairs of vowels which conforms to the observed bias in the tongue configuration for middle /m/ which is shown in Fig. 8.

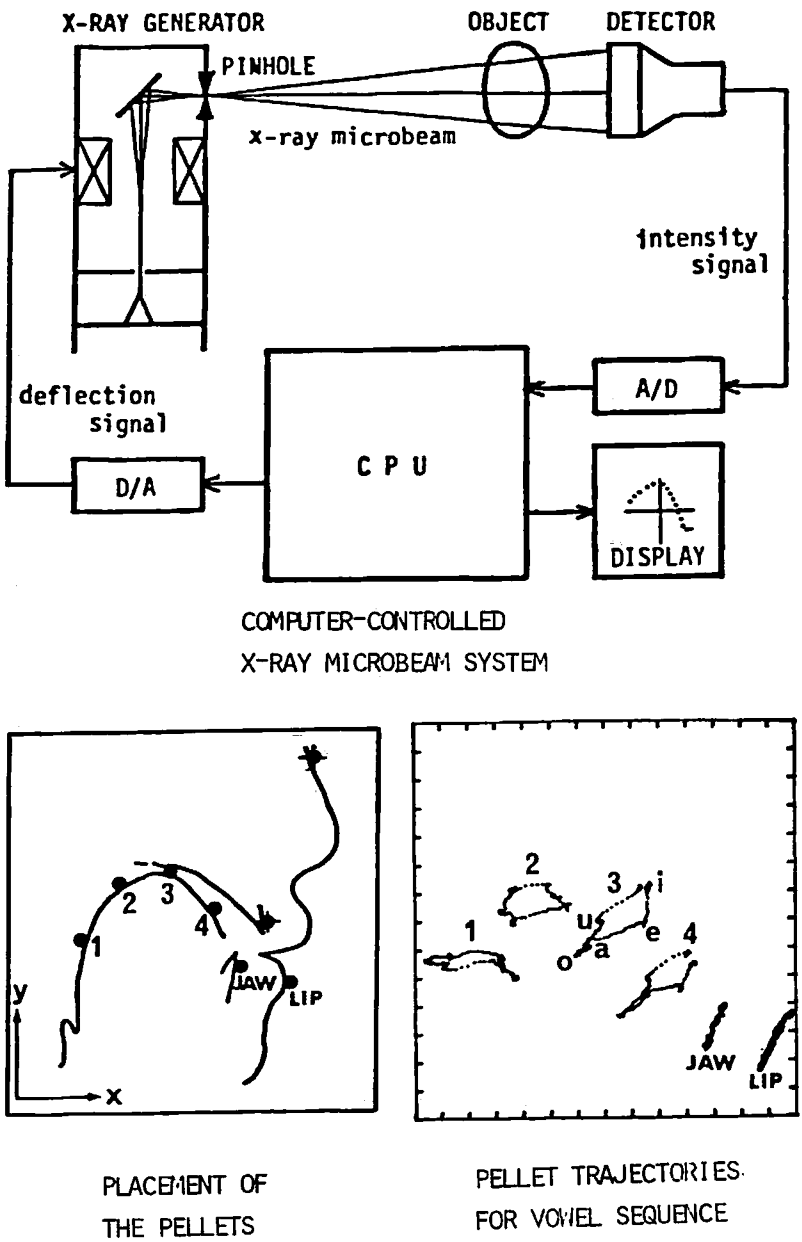

Fig. 1: Pellet tracking by computer-controlled x-ray microbeam system.

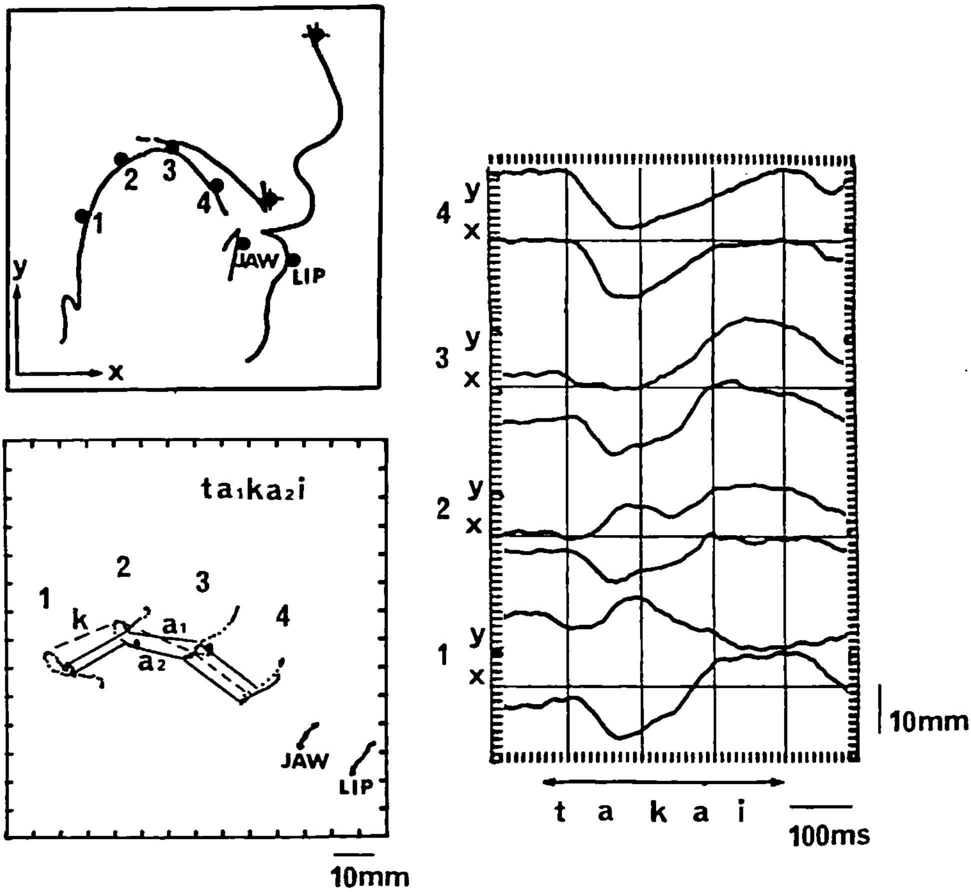

Fig. 2: Pellet movements for /takai/.

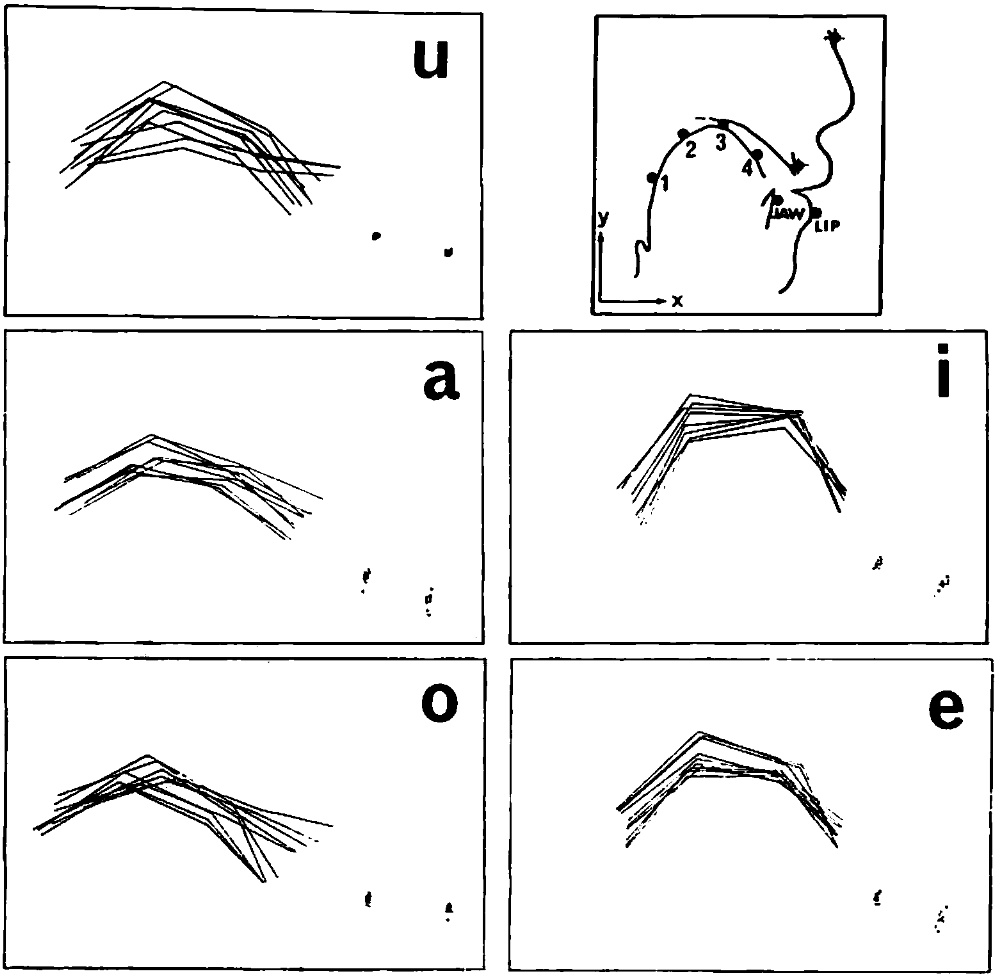

Fig. 3: Pellet positions for V in C_1VC_2 (C_1, C_2 = m, t, k).

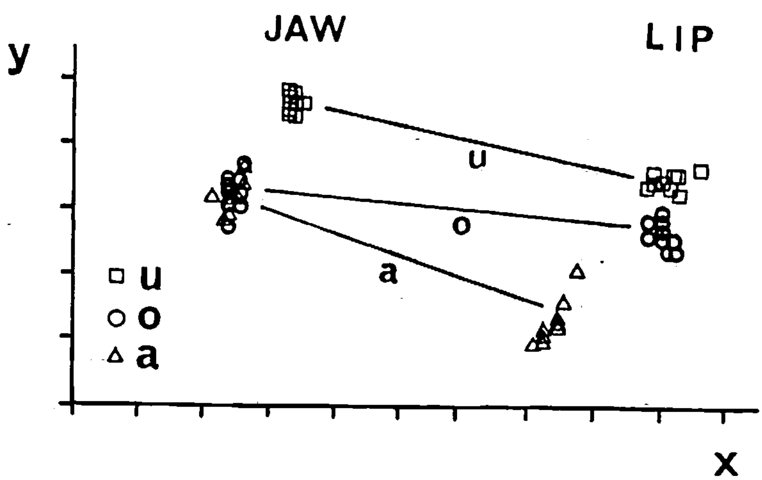

Fig. 4: Position of jaw and lip pellets in back vowels.

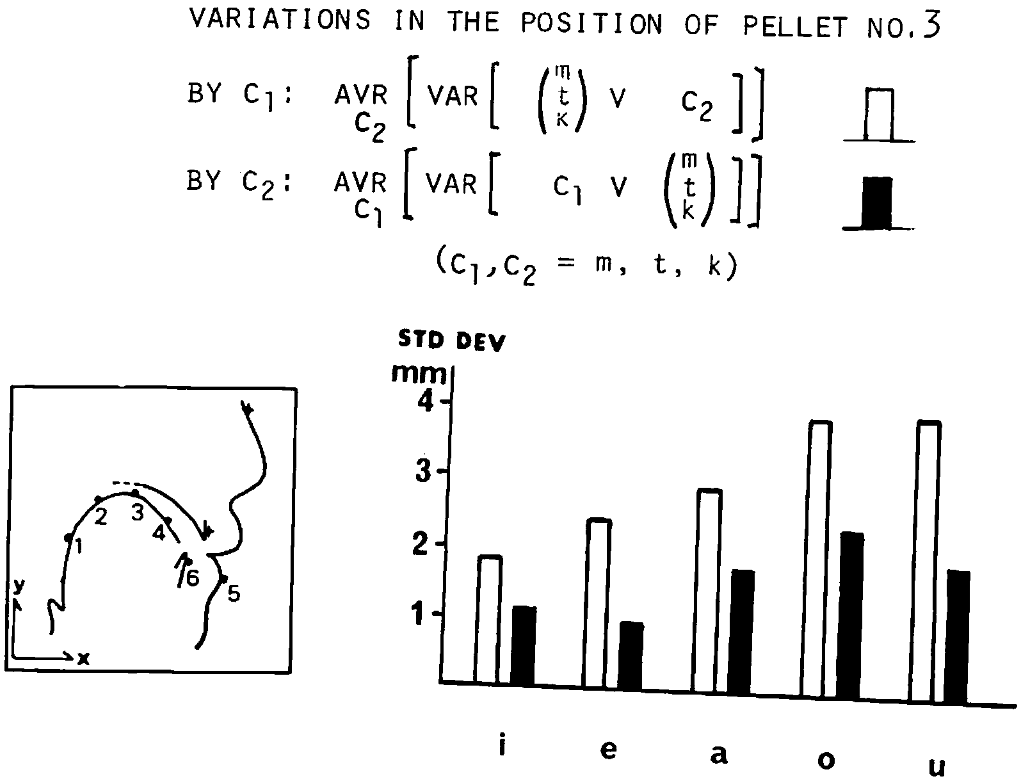

Fig. 5: Variations of V-articulation in C_1VC_2 (C_1, C_2 = m, t, k)

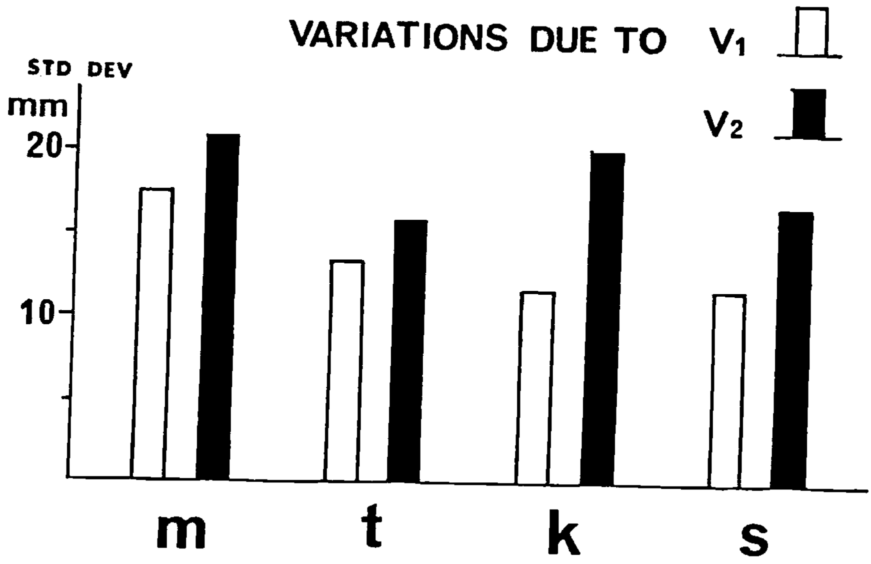

Fig. 6: Variations of C-articulation in V_1CV_2 (V_1, V_2 = i, e, a, o, u).

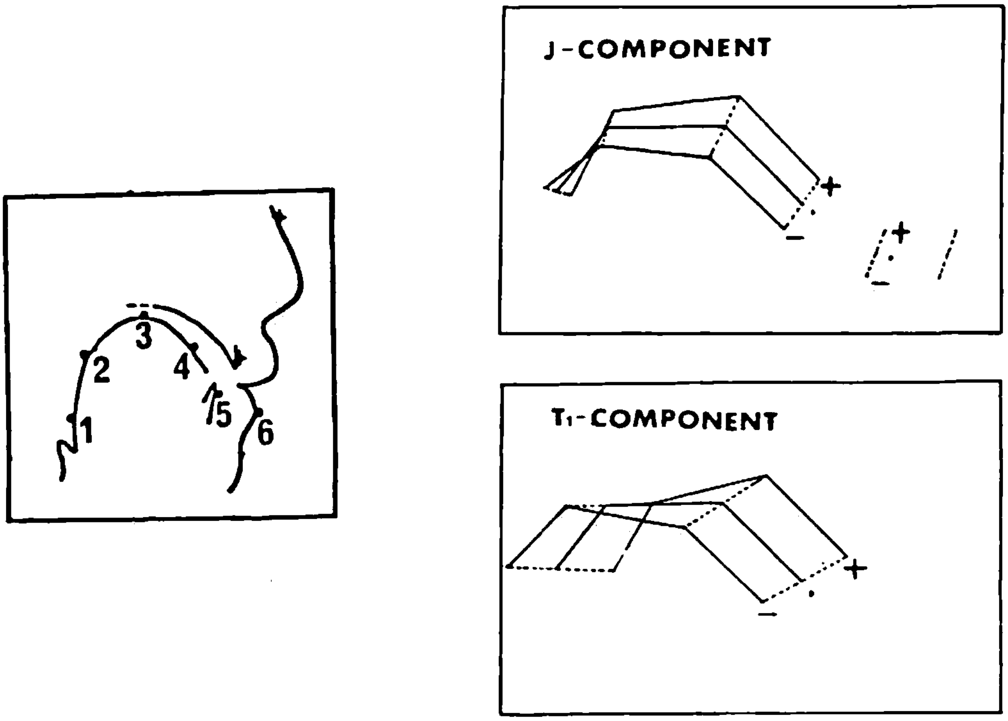

Fig. 7: Two major articulatory components

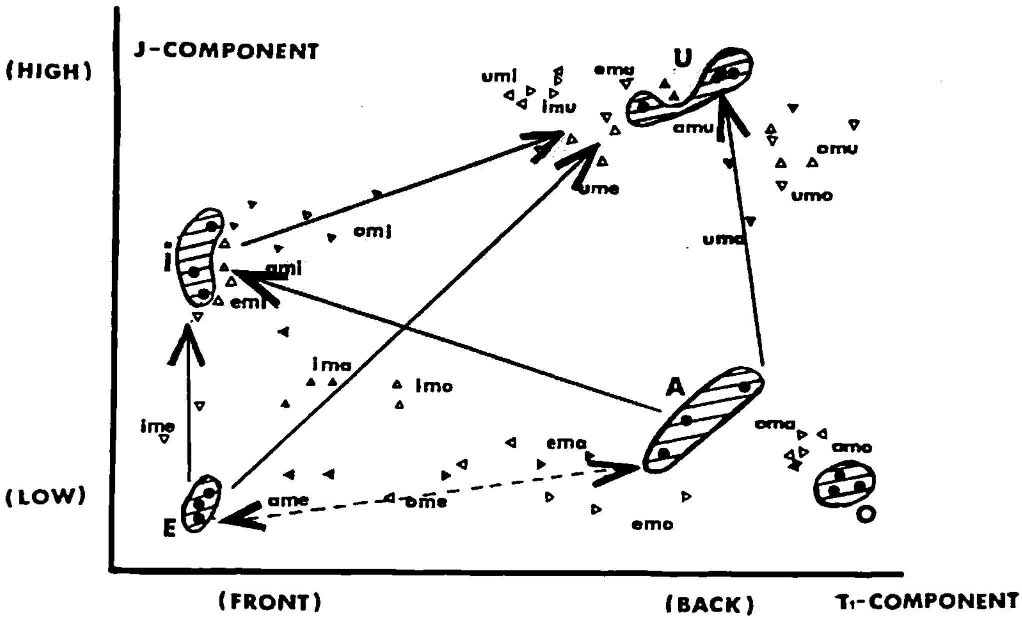

Fig. 8: Tongue positions for /m/ in /V_1 mV_2/ (V_1, V_2 = i, e, a, o, u).

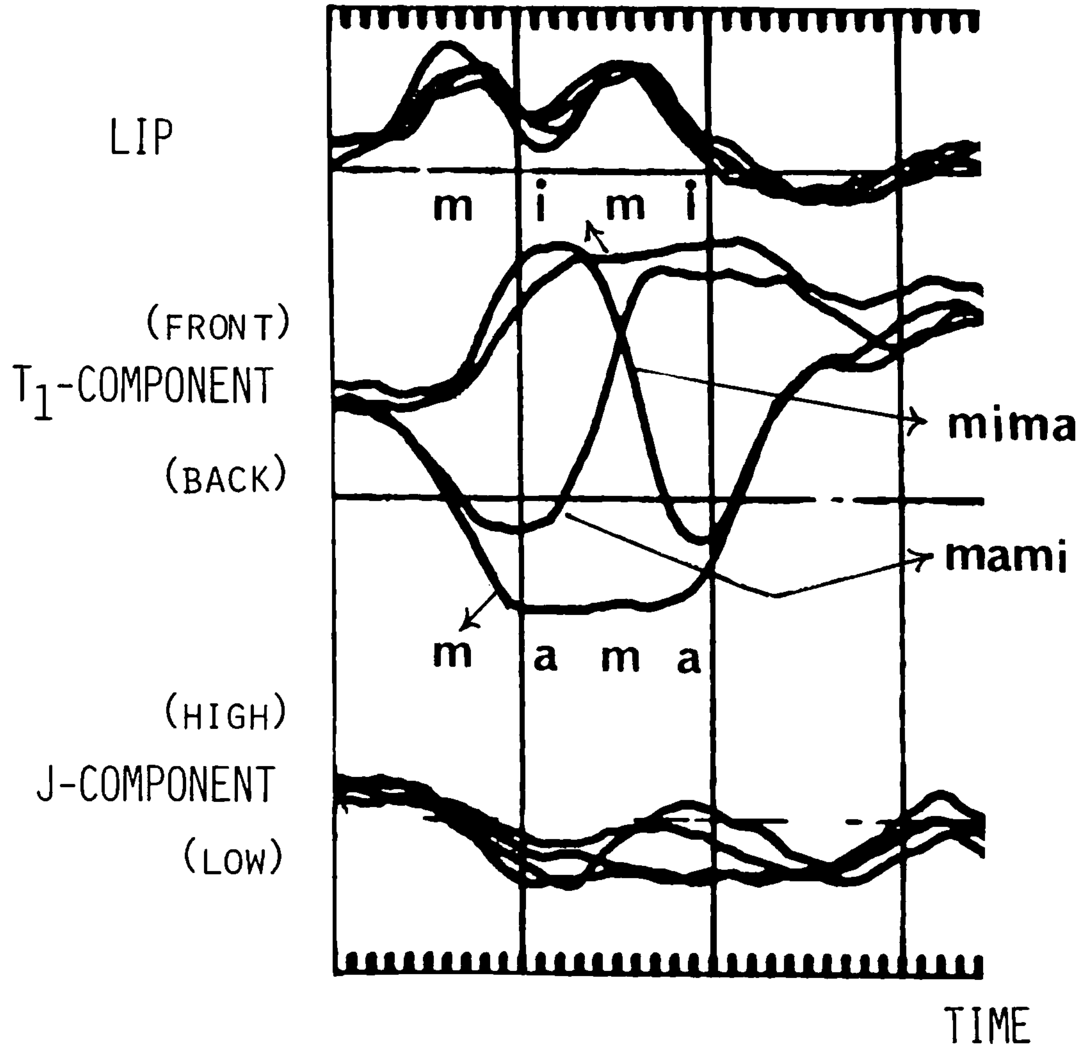

Fig. 9: Tongue movements in /mama/, /mimi/, /mami/, and /mima/.

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