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ANALYSIS OF TONGUE POINT MOVEMENTS BY A LINEAR SECOND-ORDER SYSTEM MODEL

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Recently, new techniques for the observation of articulatory movements have been developed, one using highly sensitive magnetometer systems,[1] the other consisting of a computer-controlled x-ray microbeam system.[2] The techniques have made it possible to collect a substantial amount of systematic data, thereby providing remarkably effective means for the study of the dynamic characteristics of speech production processes. The present paper describes certain preliminary results of data analysis in which observed movements of the tongue points were approximated as step responses of a linear second order system.

Data Gathering **

Tongue movements were observed using a set of magnetometer sensors. Figure 1 shows the positioning of the two sensors and of a small permanent magnetic rod which was attached with a quick adhesive at a selected position on the tongue. For this experiment, the magnet was attached to a point on the mid-saggital plane, approximately 30 mm back from the tongue tip.

Pronunciation of the test words, which consisted of three contiguous vowels, was examined. The test words were of the type /e V e/, where the middle vowels consisted of one of the four Japanese vowels /a, i, u, o/. Randomized lists of these words were read by one subject at normal and slow speaking rate, three times for each test word.

Output signals of the two sensors S_H and S_V, which represent the horizontal and vertical components of the movement of the magnet, were recorded simultansously with acoustic speech signals. These two signals and the envelope of speech signal were sampled at intervals of 5 msec and stored in the computer. Figure 2 shows an example of the data obtained by this method during the utterance of /e a e / at normal speaking rate.

Analysis Method

As a preliminary step in analyzing dynamic characteristics of the tongue movements, movements of the tongue point were approximated by output responses of a second-order linear system of hypothetical stepwise commands for successive vowels represented as

$$C(S) = \frac{B^2}{S^2 + 2\alpha\beta S + \beta^2}$$

where α is the damping factor and β is the characteristic frequency. The values of α and β which minimize the entire mean-squared error over a

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** The data here analyzed is part of a larger body of data, reported on elsewhere by one of the present authors (Sonoda). [3), 4)] time interval of vowel-to-vowel transition were estimated using a gradient-climbing method.

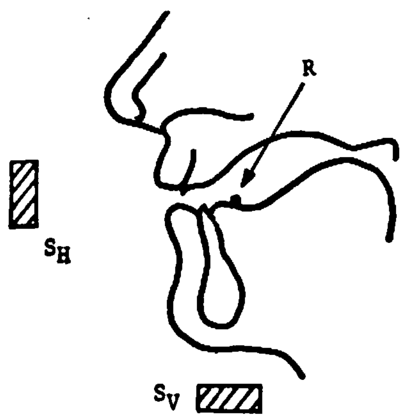
Results

An example of approximated movements as compared with observed tongue point movements is shown in Figure 3. Solid curves indicate observed movements and the dotted curves, their best approximations by the model over the time interval between T_1 and T_2. The dotted curves marked as 'ERROR' show the deviation between the two curves.

In general, fairly close approximation can be obtained by adjusting parameters of the second-order system as seen in this figure.

Figure 4 shows the estimated values of the parameters α and β for the horizontal transitions from /e/ to middle vowel and middle vowel to /e/ in the utterances at normal speaking rate. It might be noted in passing that there was little vertical movement for /e u e/ and /e o e/; parameter values for these words are therefore not included in this figure. In this case, overshoot behavior was observed in the tongue point movement, i. e., the tongue point, moving from the position for the first vowel, moved beyond the steady-state position for the following vowel. The values of parameter α were clustered in the range of approximately 0.6 to 0.8, except in the case of /u/ - /e/. The values of β, in contrast, varied over a wide range, depending on the middle vowel in /e V e/.

In order to see the characteristics of these variations, the relations between parameter β and the travelling distances during transitions are plotted in Figure 5. It can be seen that the value of parameter β is inversely related to the magnitude of displacement from one vowel to another.



S_H : Magnetometer sensor for measuring horizontal movements of the tongue.

S_V : Magnetometer sensor for measuring vertical movements of the tongue.

R : Permanent magnetic rod.

Fig. 1. Positioning of sensors and pellet (permanent magnetic rod).

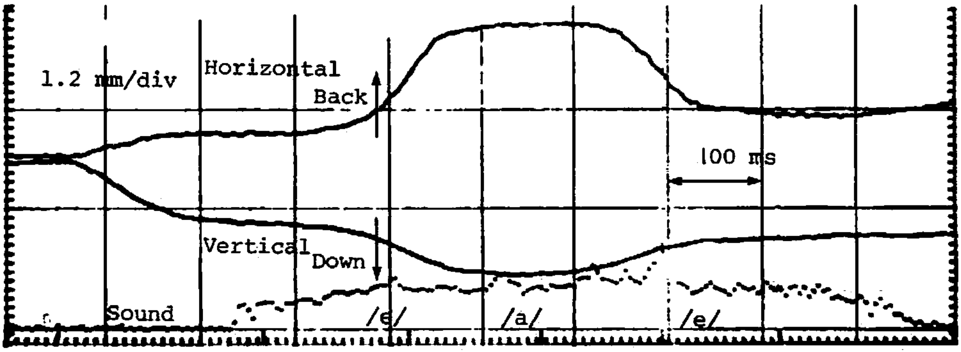


Fig. 2. Tongue point movement (30 mm from the tongue tip) during the utterance of /e a e/ at normal speaking rate.

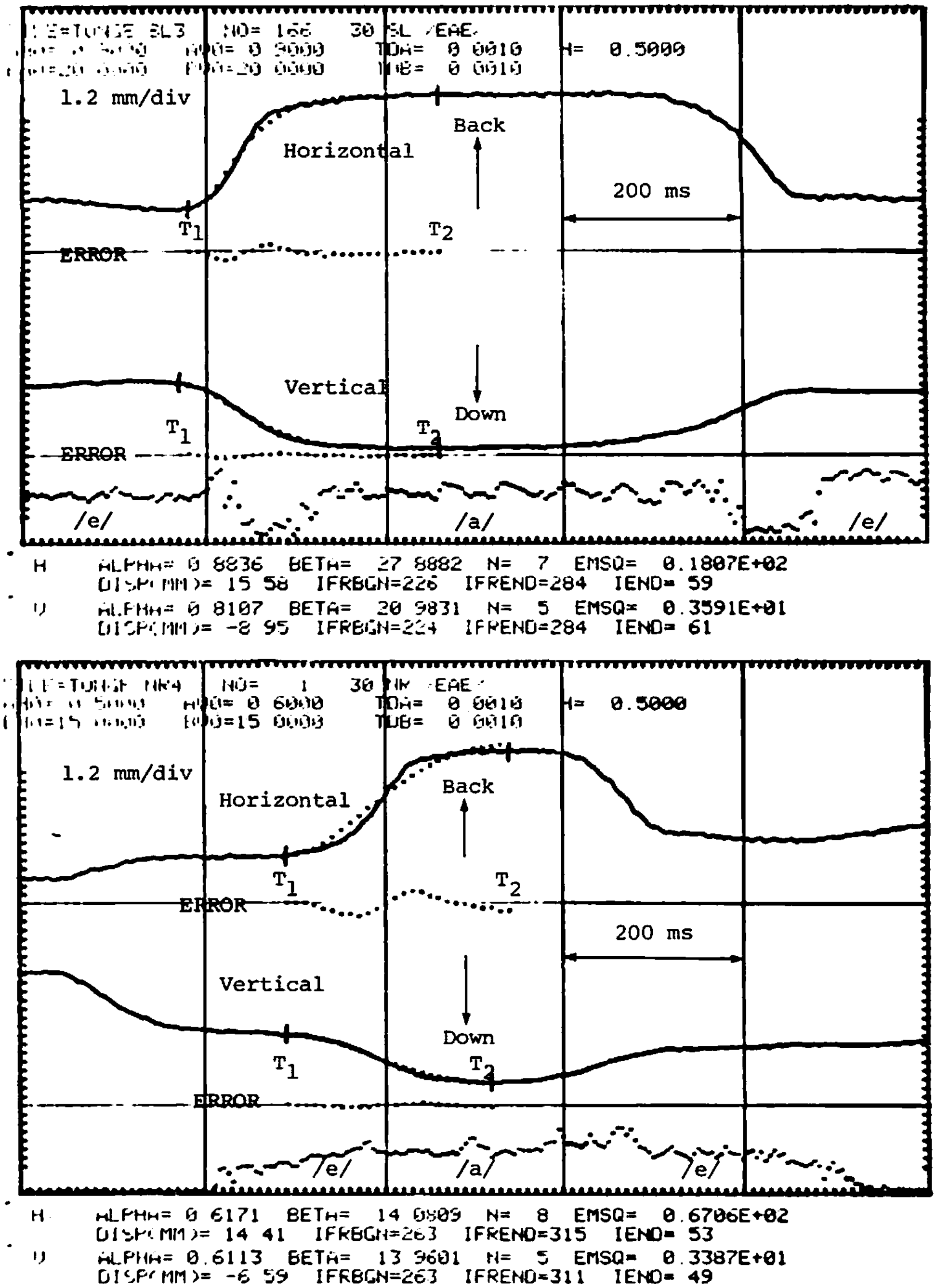


Fig. 3. Observed tongue point movements (solid curves) and their best approximations by the second-order system (dotted curves) in the transition of /e/ to /a/ in /e a e/ (the point 30 mm from the tongue tip).

(a) Slow speaking rate.
Estimated value: [H] α =0.88, β =27.89. [V] α =0.81, β =20.98.

(b) Normal speaking rate.
Estimated value: [H] α=0.62, β =14.08. [V] α =0.61, β =13.96.

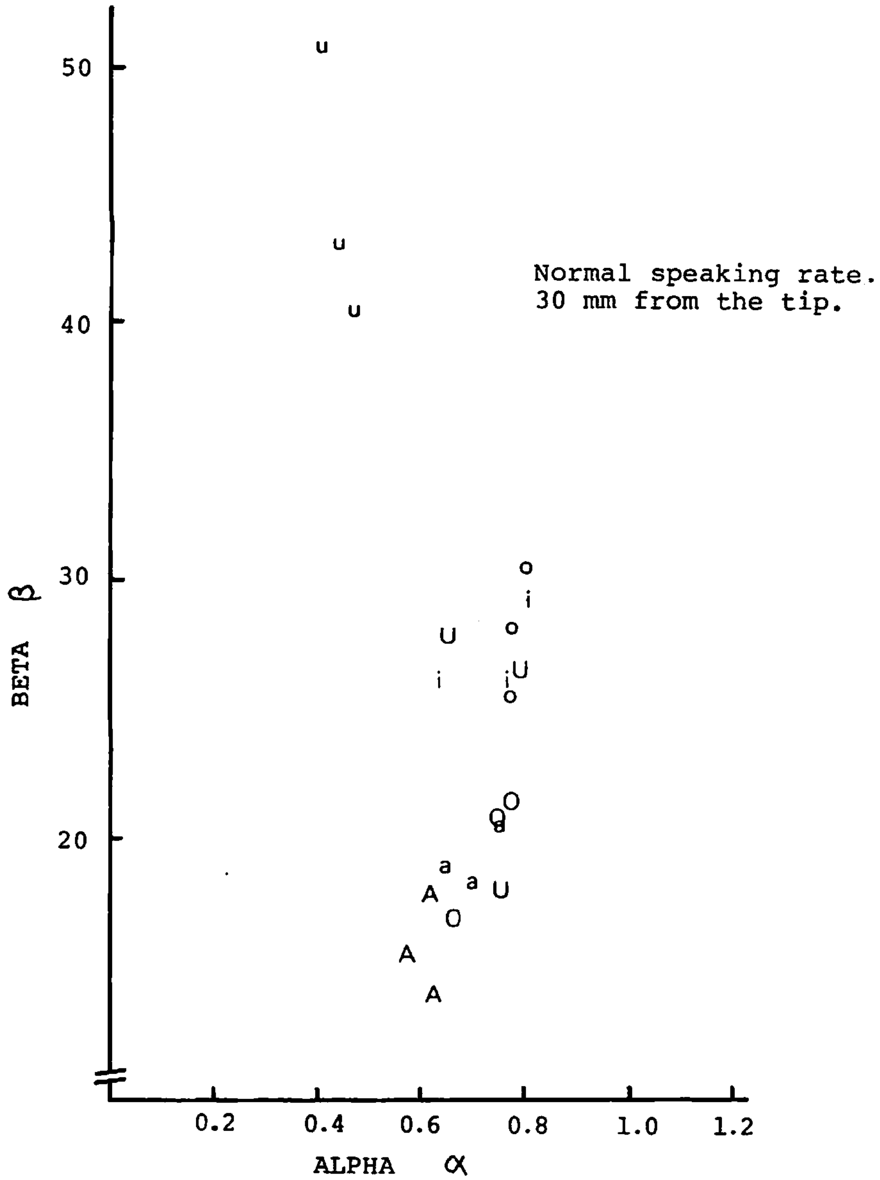


Fig. 4. Relations between parameters α and β during the utterance of /e V e/. The capital and small letters correspond to the transitions of /e/ to /V/ and /V/ to /e/, respectively. (U; /e/ to /u/ and u; /u/ to /e/ in /e u e/. etc.)

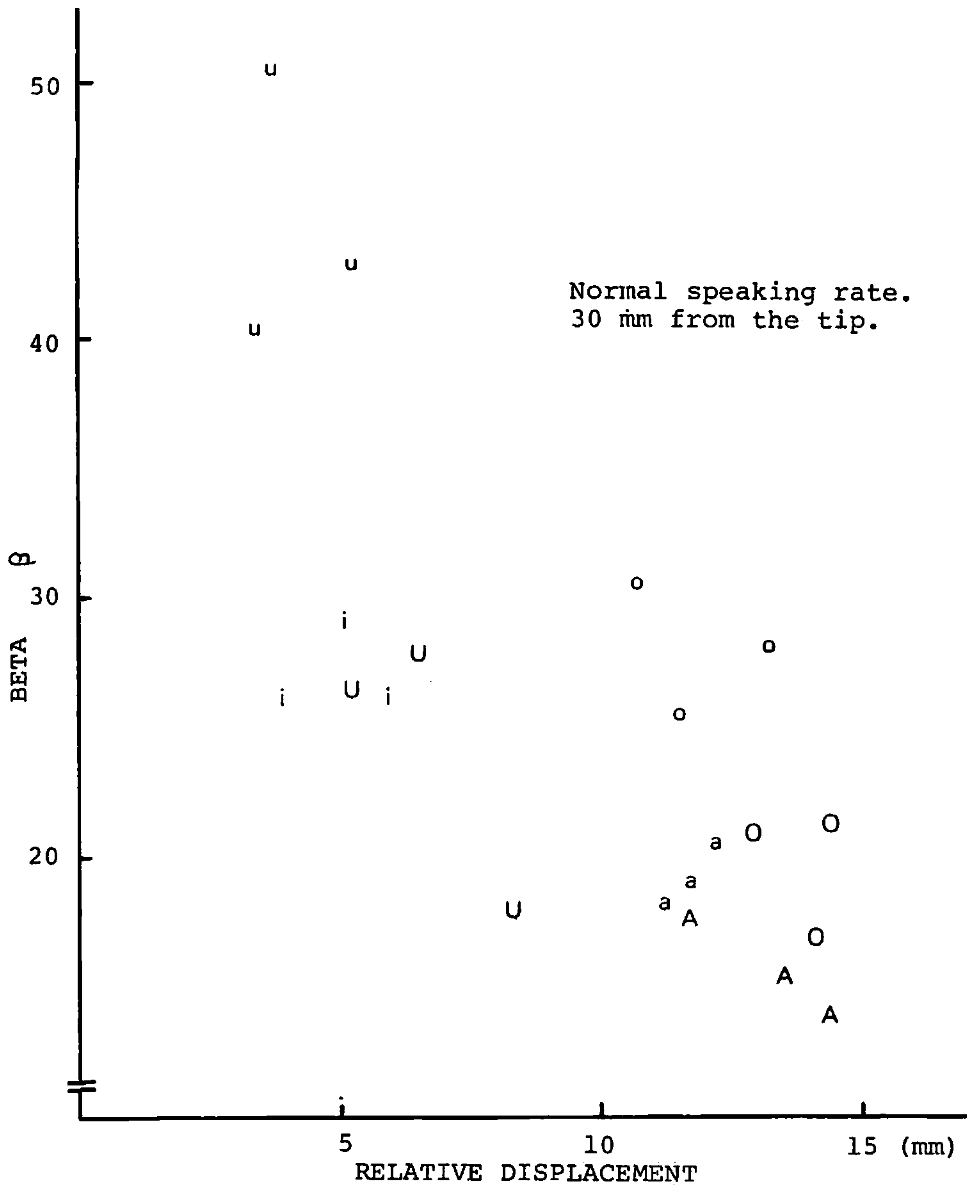


Fig. 5. Relations between relative displacement and β . Symbols (A, a, U, u, etc.) are used in the same manner as in Figure 4.

References

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