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A CORRELATION ANALYSIS OF VELAR MOVEMENT AND THE EMG ACTIVITY OF THE LEVATOR PALATINI MUSCLE DURING SPEECH

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Introduction

In the study of the dynamic aspects of speech production, it is ultimately necessary to investigate the pattern of motor control signals from the central nervous system and the dynamic characteristics of the speech organ which acts in response to the control signals. Although the pattern of motor control signals has usually been observed in the form of electromyographic (EMG) potentials, the quantitative analysis of the relationship between EMG activity and articulatory movements has not been fully accomplished.

The present study was an attempt to analyze the dynamic characteristics of velar movements recorded by means of an x-ray microbeam system simultaneously with the EMG recording of levator palatini muscle activity.[1),2)] The articulatory movement of the velum can be regarded as being one-dimensional for the sake of approximation and is known to be controlled almost solely by the activation or suppression of its principal mover — the levator palatini muscle. Velar movement is relatively independent of the movement of the other articulators and, thus, the analysis of the relationship between the displacement of the velum and the EMG patterns of the levator palatini muscle is considered to be relatively straightforward.

Data Recording

An adult male speaker of the Tokyo dialect served as the subject of the present study. The subject read a list of test words (presented in Table I) at both normal and fast rates of speech. Each test word was embedded in a frame "sorewa ____ desu" (that is ____).

Velar movement was recorded by means of an x-ray microbeam system. The description of the computer-controlled x-ray system and the strategy for the automatic tracking of a pellet on a moving articulator, such as the velum, has been reported elsewhere.[1)] In the present study, a strip of thin plastic film with a lead pellet attached to its end was passed through a nostril, placing the pellet on the nasal surface of the velum. The location of the pellet was examined and adjusted under anterior as well as posterior rhinoscopy and then the front end of the strip was secured by a piece of adhesive tape to the skin anterior to the nostril. The pellet movement was recorded with a frame rate of approximately 190 frames/sec.

Conventional hooked-wire electrodes were inserted into the levator palatini muscle perorally. The EMG signals were recorded on an FM tape recorder together with the speech signals and timing pulses which were generated from the computer for each frame of the x-ray tracking. The EMG signals were then digitized through an A/D converter with a sampling rate of 8 kHz. Absolute values were taken and integrated over 5.83 msec, the value of which corresponds to the interval between successive timing pulses.

Table I : Utterance list.

DATA SET

#1

bemee, beNmee, beN'ee, beemee

memee, meNmee, meN'ee, meemee

#2 Slow

bemee, beNmee, beN'ee, beemee

#3 Fast

bemee, beNmee, beN'ee, beemee

Data Analysis

The Y-coordinate of the pellet on the velum was selected to represent the movement of the velum, and the relationship between the time function of the coordinate value and the EMG signals was examined. EMG activity is associated with the generation of muscle force and, therefore, can be related to such variables as the displacement, velocity and acceleration of the movement of the pertinent articulator. Thus, the present analysis aimed at obtaining a quantitative estimation of the relationship between these variables and the EMG signal.

It was assumed that EMG activity (E) of the lavator palatini at a given instant can be expressed as the sum of the three components dependent on the displacement (y), velocity ($\dot{y}$) and acceleration ($\ddot{y}$) of the movement of the velum, as given in equation (1):

$$\widehat{E}_i = c_o + c_1 \cdot y_i + c_2 \cdot y_i + c_3 \cdot \ddot{y}_3 \qquad (1)$$

The suffix i denotes the i-th time sample. The above equation indicates that velar movement is realized as a response of a linear second order system to the EMG signal which is given as input. The coefficients which give the best approximation were estimated by the least square error method. That is, for every time sample of EMG signal E_i, an estimate $\widehat{E}_i$ in the equation (1) was formed by using the observed coordinate value. The coefficients, C_is were determined by minimizing the value of Err in the equation (2) :

$$\text{Err} = \sum_i (E_i - \widehat{E}_i)^2 \qquad (2)$$

Here, summation extends over all of the time samples in a given data set.

In the above procedure, it was necessary to introduce a temporal smoothing of the observed coordinate value. Without smoothing, the noise components in the calculated velocity and acceleration were so dominant that virtually no effective correlation could be observed between these variables and the EMG. To reduce the noise effect, temporal variation of the coordinate value within a short time window was approximated by the parabolic function of time as given in equation (3) :

$$y_{i+k} = \alpha + \beta\cdot(t_{i+k} - t_i) + \delta\cdot(t_{i+k} - t_i)^2 \quad (k = -N, N) \qquad (3)$$

where 2 N+1 is the width of the time window. The coefficients were determined by the least square error method. Then, the displacement, velocity and acceleration at sampling time "i" were calculated as:

$$y_i = \alpha$$
$$y_i = \beta \qquad (4)$$
$$y_i = 2\cdot\delta$$

These values were substituted into equation (1) to obtain an estimate of the EMG signal.

The coefficients in equation (1) were calculated separately for the three data sets in Table I. Fig. 1 shows the magnitude of the error as a function of the width of the time window. The abscissa indicates the error per time sample divided by the mean amplitude of the EMG. It can be seen

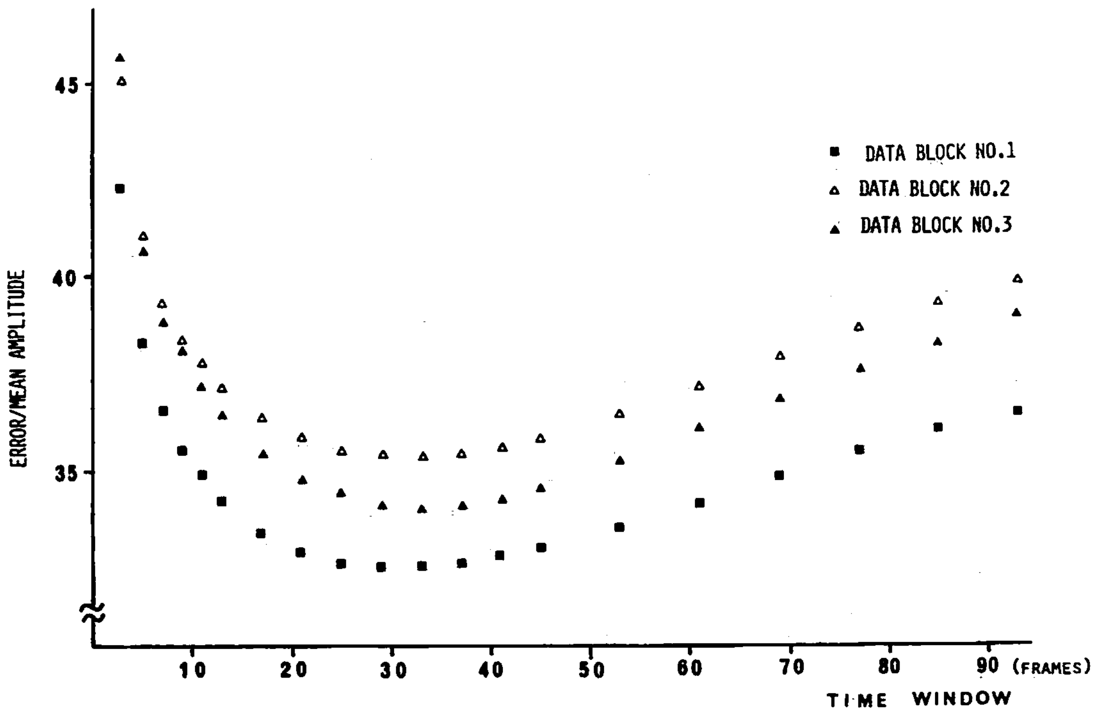

Fig. 1 : Estimation error in EMG signal versus time window width.

that when the time window was smaller than 30 frames, the error decreased with an incrdase in the width of the time window. This is considered to be due to a suppression of the noise effect. With a larger time window, however, the error increased with an increase in the width of the time window, because the fitting of the parabolic function to the observed time curve of the coordinate value became less accurate. Thus, the error was minimal for a time window of about 30 frames. In the present analysis, the values calculated for this time window width were considered to be the best estimates of the coefficients.

Results

Table II presents the characteristic constants of the linear second order system which were calculated from the estimated values of the coefficients in equation (1). It appears that the results obtained for the three different data sets are essentially identical. The value of the damping factor is close to 1, which implies that the second order system is critically damped. The characteristic time constant for each set is approximately 80 msec, and the difference in the rate of utterance does not appear to affect the time constant value.

Table II : Estimated Values of System Parameters

Data Set	Damping Factor	Angular Freq.	Time Const.
# 1	1.07	0.012	81
# 2	1.03	0.013	75
# 3	1.00	0.013	78
		(msec)	(msec)

Figure 2 shows examples of estimated EMG curves calculated by using equation (1). These curves correspond to the three different types of velar movements in the test words /bemee/, /beNmee/ and /beN'ee/, where /N/ represents the syllable final nasal element in Japanese. The sequence of nasal segments /Nm/ is generally uttered as a geminate nasal consonant. For each test word, the curve at the top shows the estimated EMG. The remaining three curves are the displacement-, velocity- and acceleration-dependent components of the EMG, and the addition of these three curves will give the uppermost curve.

Among the three components, the displacement- and velocity-dependent components have nearly the same amplitude of variation. Compared to these two components, the acceleration-dependent component appears to have a smaller contribution, i. e., its amplitude of variation is about one-third of that of the other two components. Consequently, the moment of the negative peak for EMG suppression associated with velum lowering generally coincides with that of the negative peak of the downward velocity.

It has been reported that there are characteristic differences in the temporal patterns of velar movements for these three utterance types types. [3), 4)] As seen in Fig. 2, the patterns of the velar movement for /N/

and /m/ differ in that the velocity of velar elevation is more rapid for /N/ than for /m/ The EMG curve for /N/ shows a rapid suppression and re-activation of EMG activity, and its shape is nearly symmetrical near the moment of maximum suppression. On the other hand, the EMG curve for /m/ is characterized by the fact that when the EMG activity increases after the negative peak of suppression, the rate of increase is temporally depressed before it reaches the maximum level. This tendency is more clearly observed for /Nm/ as a kind of plateau in the EMG curve.

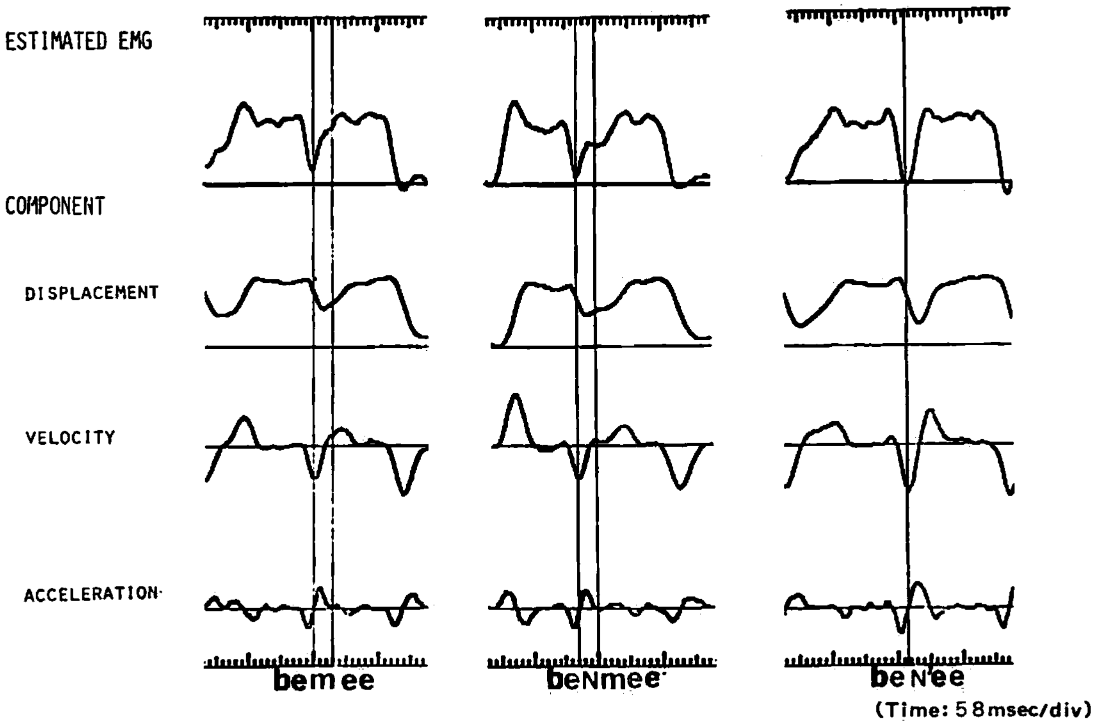

Fig. 2. : Estimated curves of EMG for three different utterance types: "Sorewa bemee desu', 'Sorewa beNmee desu' and 'Sorewa beN'ee desu'. Addition of the three components (displacement, velocity and acceleration dependent components) give the uppermost curves.

These results suggest that, as far as the second order linear relationship between the EMG and velar movement is concerned, the patterns of the velar movement for /m/ and /Nm/ cannot be accounted for by a constant increase in the EMG activity after suppression. Rather, an intermediate stage of EMG control is necessary during the phase of re-activation.

Raw EMG curves in Fig. 3 appear to confirm the above observations. In the figure, the time functions of the velar movements and EMG for the same test utterances given in Fig. 2 are shown. It can be seen that the EMG activity for /N/ shows a step-like suppression and re-activation. In the case of /m/ and /Nm/, there appears to be a short period of an intermediate level of EMG activity following an almost complete suppression.

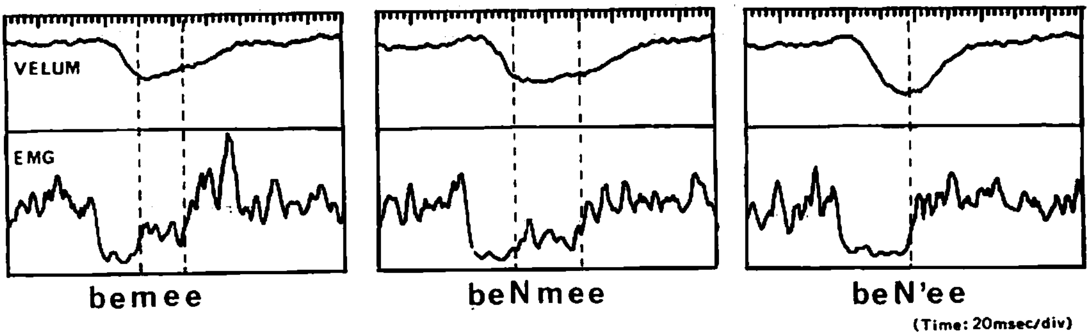

Fig. 3 : Raw EMG curves and vertical movement of the pellet on the velum for the utterance types shown in Fig. 2.

A comparison of the estimated EMG curves with the raw EMG data reveals the following:

First, in the estimated EMG, the level of the maximum suppression is lower for /N/ than for /m/. This difference is considered to be due to the fact that the downward velocity in velum lowering is greater for /N/ than for /m/. However, in the raw EMG curves in Figure 3, the level of EMG suppression is nearly the same for /N/ and /m/. Thus, the observed raw EMG curves do not reflect the difference in the velocity of velum lowering for these two nasal sounds. The discrepancy between the estimated and raw EMG's may reflect the possibility that, in the production of /N/, another articulator, i. e., the tongue, is also participating in the enhancement of the lowering of the velum. In fact, a backward and upward movement of the tongue dorsum in the production of /N/ was observed. Thus, it may be the case that the muscles responsible for this tongue movement can enhance the downward movement of the velum in the production of /N/.

Secondly, an inspection of the raw EMG curves reveals that the suppression and the re-activation of EMG activity are very rapid in some cases where the transition in the activity level appears to take place within a time period as short as 30 msec. However, it appears that, at least in the present analysis, such rapid changes in activity level are not sufficiently reflected in the estimated EMG. The effect of time smearing must be taken into account when explaining this apparent discrepancy, and further attempts should be made to minimize this effect for a better quantitative analysis of the relationship between the EMG and articulatory movements.

References

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