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RESPONSE CHARACTERISTICS OF THE VELAR MOVEMENT TO THE ACTIVITY OF THE LEVATOR PALATINI MUSCLE

Shigeru Kiritani, Hajime Hirose, Viktor Sorokin
Hiroshi Imagawa and Shinobu Masaki

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 signal. Although the pattern of the motor control signal has generally been registered in the form of electromyographic (EMG) potentials, the quantitative analysis of the relationship between EMG activity and articulatory gesture has remained difficult.

The present study is an attempt to analyze the dynamic characteristics of the movements of the velum recorded by means of our X-ray microbeam system, simultaneous with EMG recording of the activity of the levator palatini muscle, which has been known to be exclusively responsible for velum elevation. Since velar movement is relatively independent of the movement of the other articulators, the relationship between the displacement of the velum and the EMG patterns of the levator palatini can be considered to be relatively straightforward.

Procedures

One of the present authors (VS) served as the subject. The subject attempted several kinds of simple step-like movements of the velum, including the production of sustained /ʃ/, vowels /a/ and /i/, and blowing. All gestures were preceded and followed by deep inspiration through the nose. Although additional recordings were also made for the production of monosyllables and nonsense words, the results of the latter part of the experiment will not be included in the present report.

For recording velar movement, a strip of thin plastic film with a lead pellet attached to its end was passed through the nasal cavity, with the pellet coming to rest on the nasal surface of the velum. The pellet movement was registered by means of our X-ray microbeam system with a frame rate of 232.6 frames/sec.

For EMG recordings, specially designed hooked-wire electrode pairs were inserted into the levator palatini muscle perorally. The EMG signals were recorded on an FM tape recorder together with the speech signals and the timing pulses which were generated from a PDP 11/34 computer for each frame of the X-ray tracking. The EMG signals were first rectified and integrated over 4.3 msec, the value of which corresponds to the interval between successive timing pulses. The signals were then fed to the computer through an A/D converter.

Results

1) Relationship between velar height and EMG activity

It was generally observed that the velum started to elevate in response to the onset of activation of the levator palatini muscle, and to descend at the cessation of its activity. A pattern of overshoot was observed in EMG values in most cases of velum elevation.

Figure 1 shows examples of time curves of the integrated EMG of the levator palatini muscle and the Y-coordinate of the velar pellet. In the examples shown here, the velum is highest for the production of /ʃ/ and next highest for /i/ gesture. In the case of /a/ production, there was a tendency toward nasalization of the audiosignal in the present series. As for velar movement in /a/ production, the velum appears to reach the highest peak at the onset of phonation, and then become slightly lower and stay at that level afterwards. The EMG level also appears to be lower than that for the other speech samples.

A comparison was made between the velar height at the steady-state after elevation and the corresponding EMG value of the levator muscle. Data for the preparatory gesture in each recording session in which sustained /i/ was produced was also included as a part of speech materials.

A steady-state period of approximately 1 second was selected by inspection for each sample, and the relationship between the integrated EMG and the Y-coordinate value during that period was examined. As shown in Figure 2, there was a linear relationship between the two parameters. In this figure, the relationship was also plotted for the values obtained for the period of deep inspiration where the levator muscle was completely inactivated.

2) Frequency response characteristics in step-like movements

In order to further analyze the relationship between input (EMG) and output (velar height) signals, frequency response characteristics were calculated for the step-like movements consisting of sequences such as inspiration-/ʃ/-inspiration. Since there is a possible difference between the elevation and lowering of the velum, calculation was made separately for the two conditions.

The procedure of calculation was as follows:
A finite period of 256 frames (approximately 1 sec.) was chosen to include the transition of either elevation or lowering. At the same time, the steady-states preceding and following the transient were also included in the finite period as well. The EMG and velar height signals over the period thus selected will be denoted as $f_E(t)$ and $f_V(t)$ $(0 \leq t \leq T)$. Then, calculation of frequency response characteristics was made using the function $g_E(t)$ and $g_V(t)$ derived from the original signals:

$$g_E(t) = \begin{cases} f_E(t) \\ C_E - f_E(t-T) \end{cases} \qquad g_V(t) = \begin{cases} f_V(t) & 0 \leq t \leq T \\ C_V - f_V(t-T) & T \leq t \leq 2T \end{cases}$$

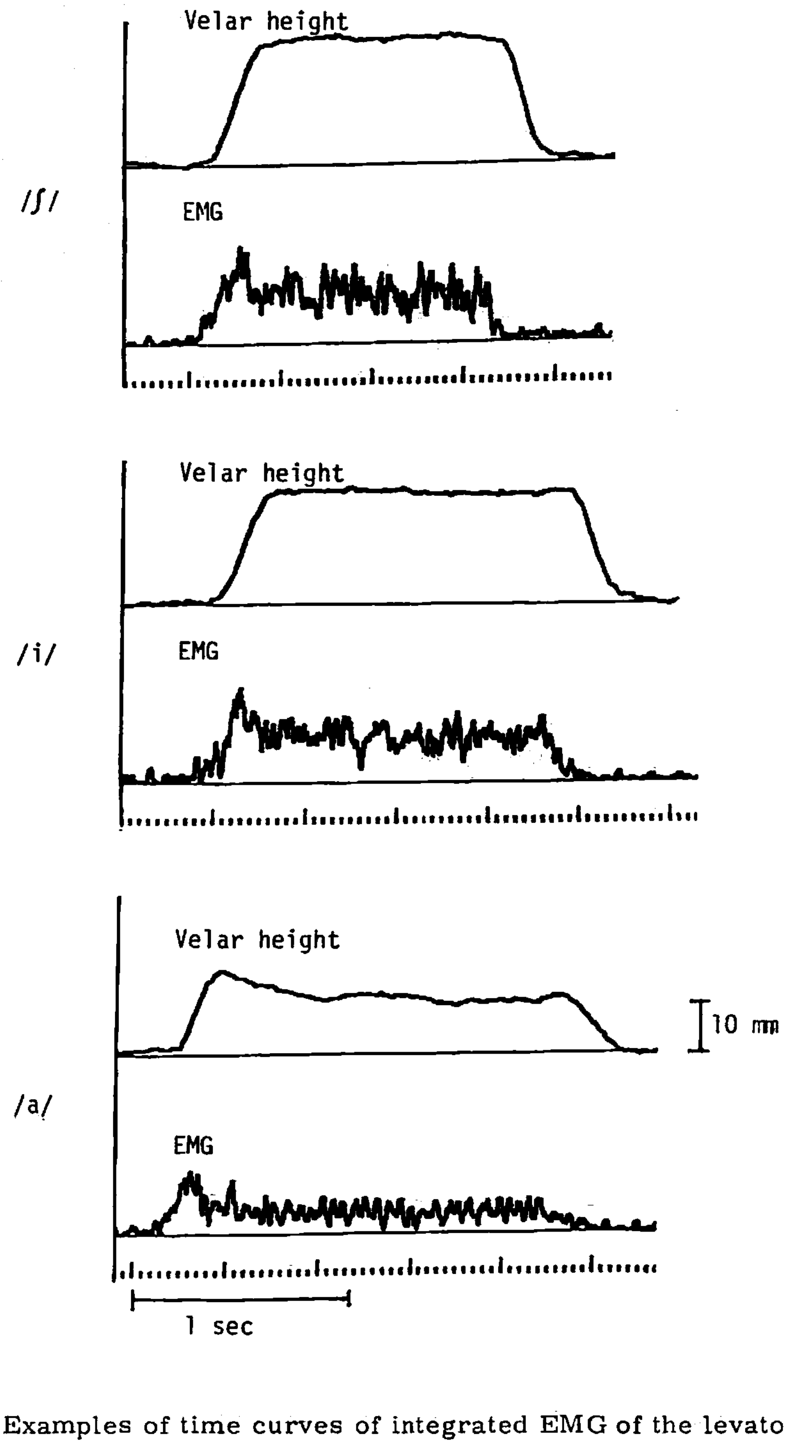

Fig. 1 Examples of time curves of integrated EMG of the levator palatini muscle and the Y-coordinate of the velar pellet.

where C_E and C_V are the means of the steady-state values before and after the transition.

The power spectrum was obtained for each of the two parameters, and the ratio between the two was then calculated to obtain the frequency response characteristics of the system in question.

Figure 3 shows examples of the results obtained for the sequences including /ʃ/ and /i/. In this figure, the spectrum of EMG signals, the spectrum of velar (pellet) movements and the frequency response characteristics are illustrated for both velar elevation (solid line) and velar lowering (dotted line). In the cases of both sequences /ʃ/ and /i/, it is apparent that the bandwidth of frequency response characteristics is wider for velum lowering than for velum elevation. The bandwidth was estimated as 2Hz for 6dB down of gain in the case of velum elevation, whereas in velum lowering it appeared to be flat up to 3Hz.

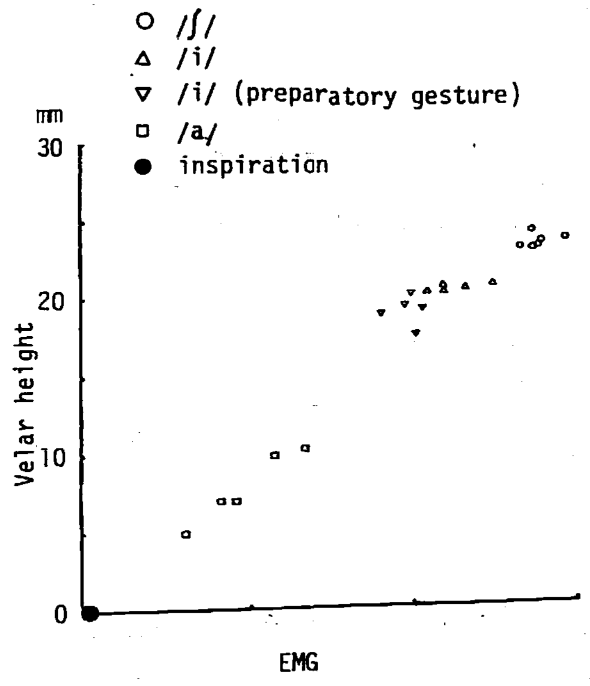

Fig. 2 The relationship between the integrated EMG and velar height (Y-coordinate) for steady-state condition.

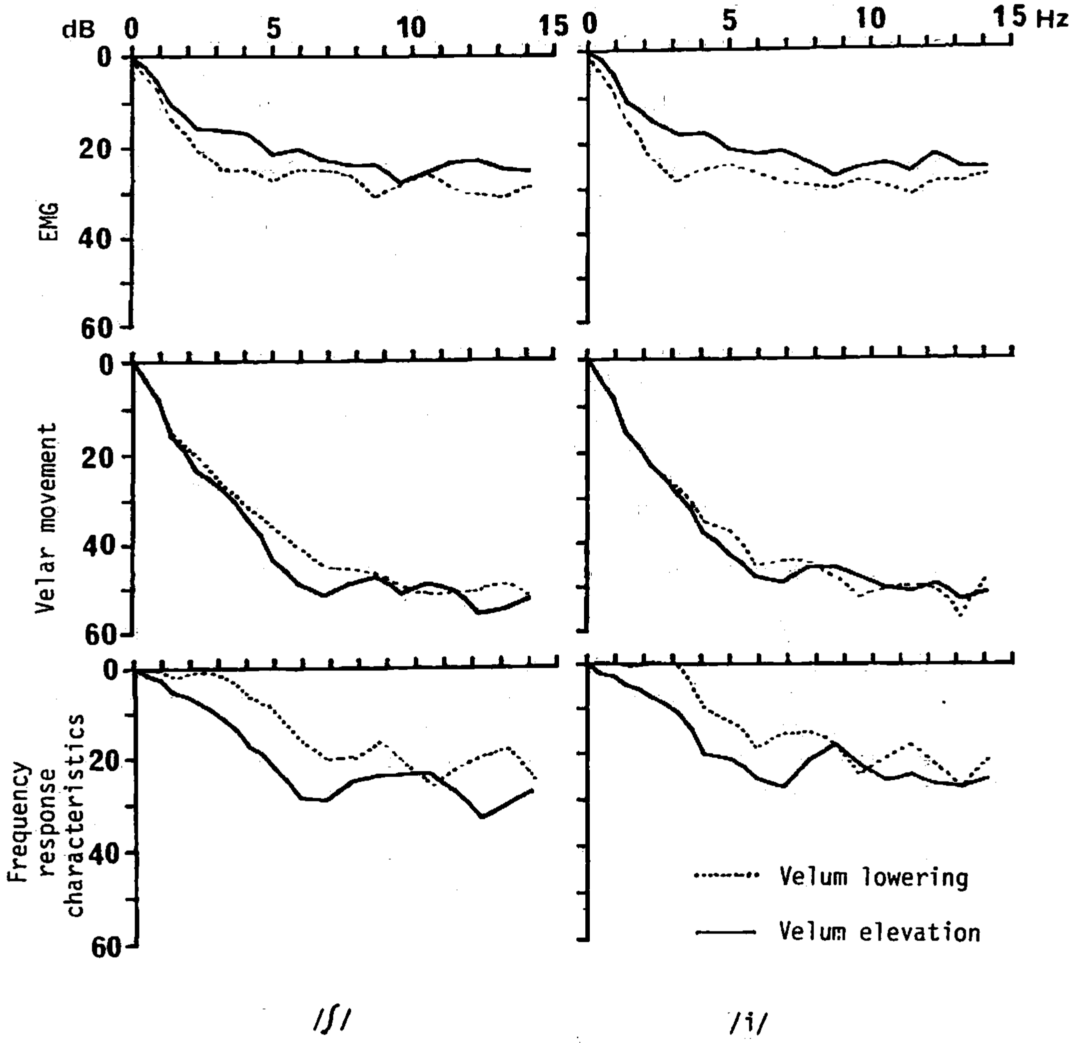

Fig. 3 Spectra of the integrated EMG (top) and velar movement (middle) for the production of /ʃ/ and /i/, and calculated frequency response characteristics (bottom).

Discussion

It seems reasonable to consider that the basic components relevant to velum movement are the muscle force of the levator palatini and the passive elastic force of the tissues attached to the structure of the velum. In equilibrium state under complete relaxation of the levator muscle, the velum is fully lowered as in the condition of deep inspiration. Thus the tissue elastic force is considered to be effective only toward the direction of velum lowering.

Before the onset of velum lowering, the levator palatini muscle is fully contracting and the attached tissues are also maximally tensed. In that particular condition, it is plausible that stiffness of both muscle and attached tissues is increasing and, as a result, the response to a change in input force must be relatively fast. It is assumed that the increasing stiffness of the system is a direct cause of the wider spectrum bandwidth in frequency response characteristics for velum lowering than for velum elevation.

In the interpretation mentioned above, two factors have to be taken into consideration. First, increasing stiffness of the system associated with muscle activation is considered not only to exist at the initial state of velum lowering but also to be maintained throughout the transient period of velum lowering. In other words, the time constant of stiffness change must be larger than that of velar movement.

Second, the above result on the response characteristics of velum lowering was obtained by analyzing exclusively the sequences of sustained phonation where /ʃ/ or /i/ was sustained for more than 1 second. It may be true that the apparently rapid response of the system in velum lowering is realized only when the contraction of the levator muscle is maintained for a relatively long period before the onset of lowering.

These two factors can be related to the temporal characteristics of stiffness change with reference to the state of muscle activity. In order to clarify the effect of duration of muscle contraction, analyses of the speech materials containing shorter steady-state condition between alternative velum elevation and lowering are in progress.

Acknowledgment

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