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SIMULTANEOUS X-RAY MICROBEAM AND EMG STUDY OF VELUM MOVEMENT FOR JAPANESE NASAL SOUNDS

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Our previous studies on the movement of the velum by means of fiber-optic observation[1] and X-ray microbeam observation[2] revealed that there were characteristic differences in the temporal pattern of the velum movement among the different types of nasal sounds in Japanese. Electromyographic study[3] of the levator palatini, which is exclusively responsible for velum elevation, also revealed some characteristic patterns of motor control related to the pattern of the velum movement. The present study is an attempt to obtain more detailed information on the pattern of this muscle activity and its relationship to velar movement by simultaneously recording the velum movement and the EMG activity of the levator palatini muscle.

Data recording

Two male speakers of the Tokyo dialect, MS and HH, served as the subjects in the present study. The subjects read a list of the following test words:

1) bemee, beemee, beN'ee, beNmee
2) memee, meemee, meN'ee, meNmee
3) beNpee, beNbee

The test words were embedded in a carrier phrase

/sorewa _____ desu/ (That is _____)

In the above list, /N/ represents the syllable-final nasal element in Japanese. The sequence /Nm/ is pronounced as the geminate consonant [mm].

For recording velum movements, a strip of thin plastic film with a lead pellet attached to its end was passed through the nostril, placing the pellet on the nasal surface of the velum. The movement of the lead pellet was tracked and recorded by means of the X-ray microbeam system. Another pellet was attached to the lower lip and its movement was tracked simultaneously in order to record lip gestures. The frame rate for the pellet tracking was 170 frames /second for subject MS, and 180 frames/sec for subject HH.

Specially designed hooked-wire electrodes were inserted into the levator palatini muscle, and the EMG signal was recorded on a data recorder together with the speech signal and the timing pulses which were generated from a computer for each frame of pellet tracking. The EMG signal was rectified and integrated over the time interval between successive timing pulses. The period of EMG integration was 5.8 and 5.5 msec for subjects MS and HH, respectively. The values of the integrated EMG were sampled and stored in the computer and compared with their corresponding pattern of velum movement. In the following, the time function of the Y-coordinate of the pellet was taken as representing an up-down movement of the velum.

Results and Comments

/m/, /N/ and /Nm/

Figure 1 compares the temporal pattern of EMG activity and the movement of the velum for /m/, /N/ and /Nm/ in the two subjects. The movement of the lower lip (Y-coordinate of the pellet on the lower lip) and the envelope of the speech signal are also shown.

For /bemee/, in subject MS (Fig. 1-a), the EMG curve shows the period of nearly complete suppression associated with velum lowering for /m/. In the case of subject MS, this period of suppression is followed by a burst-like reactivation of levator EMG, and the velum turns from downward to upward. However, EMG activity falls almost to zero level once again. Thus, the velum does not exhibit a pattern of continuous ascent after /m/. Rather, after a slight upward movement, the velum stays at a relatively low position during the period of the vowel following /m/. After that, EMG activity increases again and the velum moves upward rapidly to reach the fully elevated position for the production of /d/ in the carrier phrase /--desu/.

For /beemee/ in the same subject, a similar pattern of velum movement is observed. However, the decrease in EMG activity for /m/ is more gradual in /beemee/ as compared to /bemee/. This is considered to be due to the fact that the first syllable in /beemee/ is longer than that in /bemee/ and more time is allowed for lowering the velum for /m/.

In the case of subject HH (Fig. 1-b), the tendency toward burst-like EMG reactivation following /m/ is also observed for /bemee/, but this is not so distinct as in subject MS. For /beemee/, an increase in EMG activity is rather continuous up to the level for /d/. A more gradual decrease in EMG activity for /beemee/ than for /bemee/ is observed also in this subject.

The pattern of levator activity for /N/ in /beN'ee/ is characterized by a simple step-like suppression. After the suppression, EMG activity recovers sharply up to a certain level. This pattern of EMG activity explains a more rapid elevation of the velum after /N/, as compared to a more gradual or staggered elevation after /m/. It appears that for the speech samples shown here, the period of EMG suppression is longer for /N/ than for /m/ and, correspondingly, the velar position at the moment of maximum lowering is lower for /N/ than for /m/.

These differences between /N/ and /m/ in the patterns of velar movement and levator activity generally agree with the results of previous studies by Ushijima and Sawashima[1], and Ushijima and Hirose[3].

In the case of a geminate consonant /Nm/, it is observed that a nearly complete suppression is followed by a period of an intermediate level of levator activity. This activity level is observed during the period of lip closure and precedes the reactivation for the following vowel, the onset of which is approximately synchronized with an opening movement of the lip. Although the entire period from the onset of EMG suppression to the moment of reactivation for the following vowel in /beNmee/ is longer than the suppression period for /N/, the intermediate activity observed for /Nm/ appears to prevent an extreme lowering of the velum. In the case of subject HH the duration of the complete suppression for /Nm/ is shorter than for

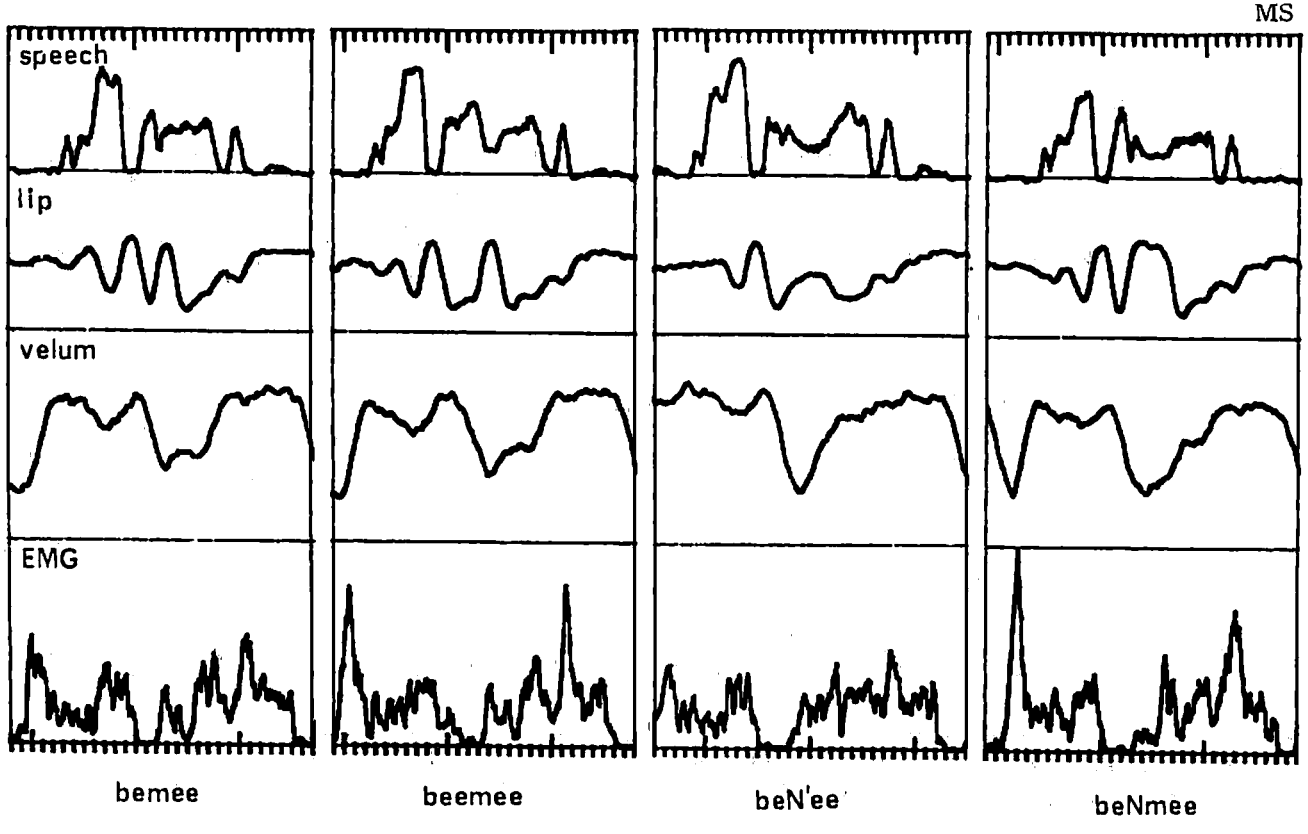

Fig. 1(a) /bemee/, /beemee/, /beN'ee/ and /beNmee/ for subject MS.

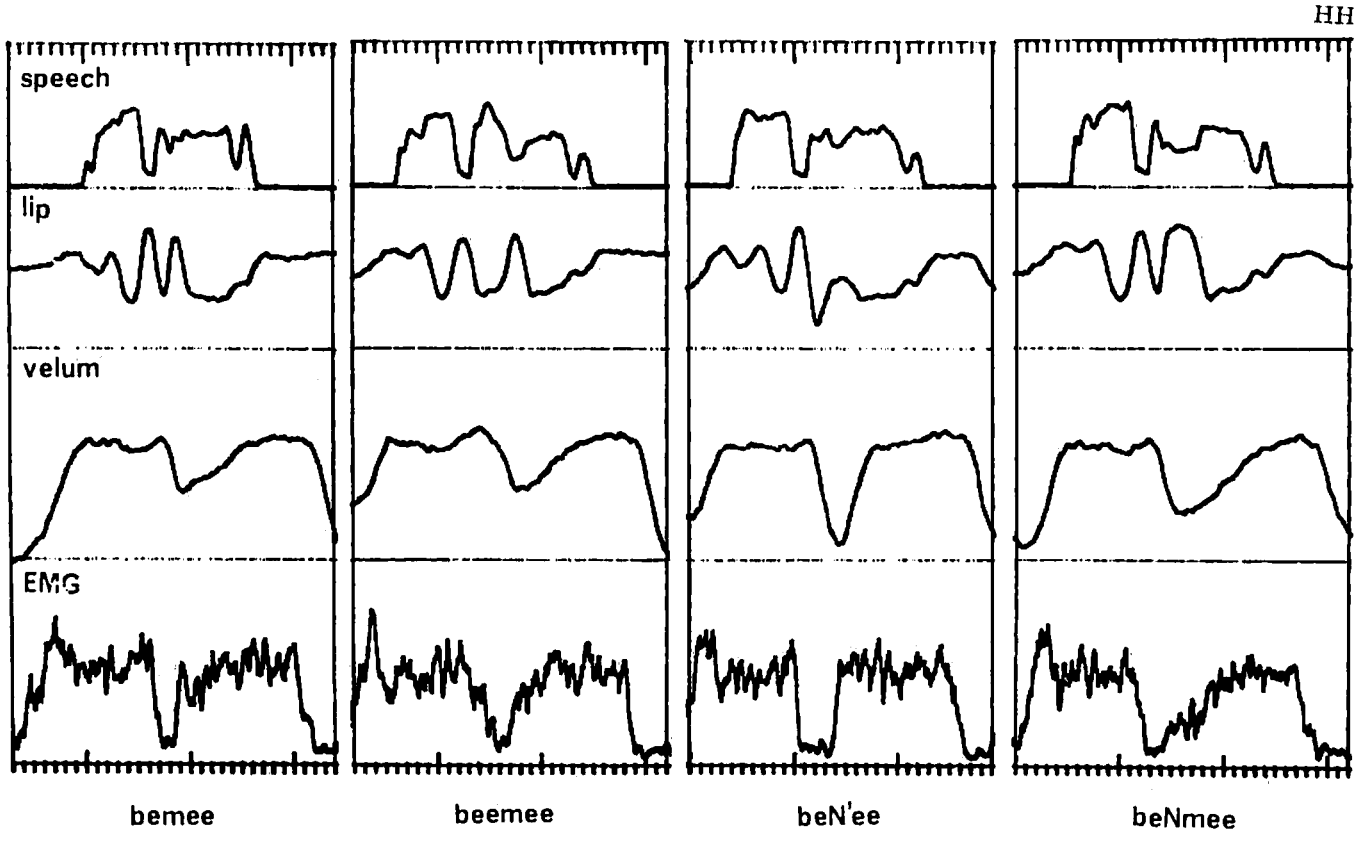

Fig. 1(b) /bemee/, /beemee/, /beN'ee/ and /beNmee/ for subject HH.

/N/, and the velum position for /Nm/ at the moment of maximum lowering is higher than for /N/ and nearly the same as for /m/. For subject MS, the duration of the suppression period for /Nm/ is almost the same as that for /N/, and the velar height is also nearly the same.

The results of analysis of the utterance samples shown in Figure 1 seem to indicate that there is a correlation between the velar height and the duration of suppression of EMG activity. The relationship between these two parameters is plotted in Figure 2. The abscissa represents the duration of the suppression period and the ordinate represents the velar height relative to the maximally lowered position during the pause between utterances. It can be seen from this figure that the velar height is generally lowest for /N/ and highest for /m/. It appears that the difference in velar height is correlated with the duration of the suppression period of levator activity. In subject HH, the difference in the duration of suppression period among the three test words is greater than in the case of subject MS and, correspondingly, the difference in the velar height is greater.

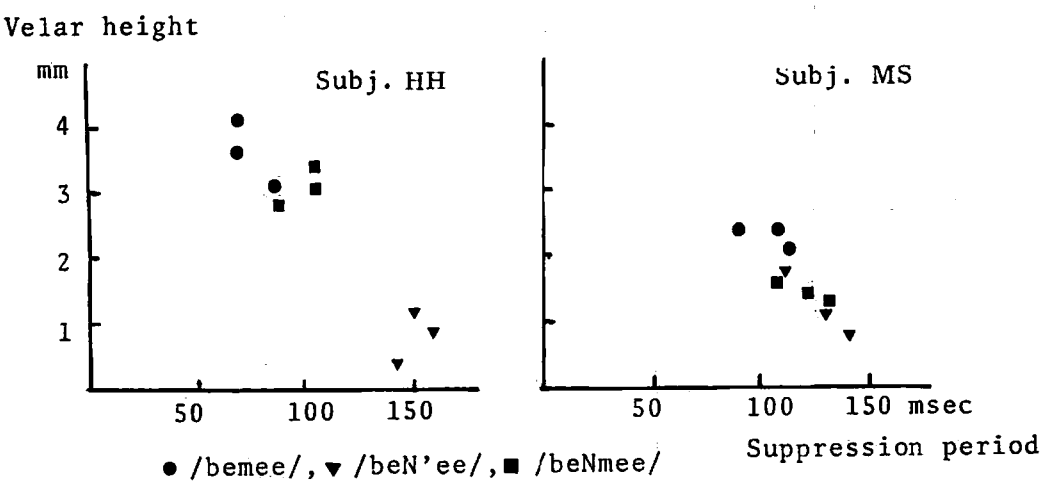

Fig. 2 Relationship between the duration of the suppression period and velar height for /m/, /N/ and /Nm/.

/m/-vowel-/m/

Figure 3 shows examples of utterances containing /memee/, /meemee/, /meN'ee/ and /meNmee/. In these utterances the vowel /e/ in the first syllable is preceded and followed by /m/, and the velum appears to stay at a lowered position for this vowel. As for EMG activity, however, it is observed that in all of these utterances, there is a clear reactivation of the levator muscle at the period between the two /m/'s in the first and second syllables.

In the case of /memee/, the velum turns upward after a downward movement for the word-initial /m/ by EMG activation for the vowel /e/. The EMG activation is followed by a suppression for the word-medial /m/,

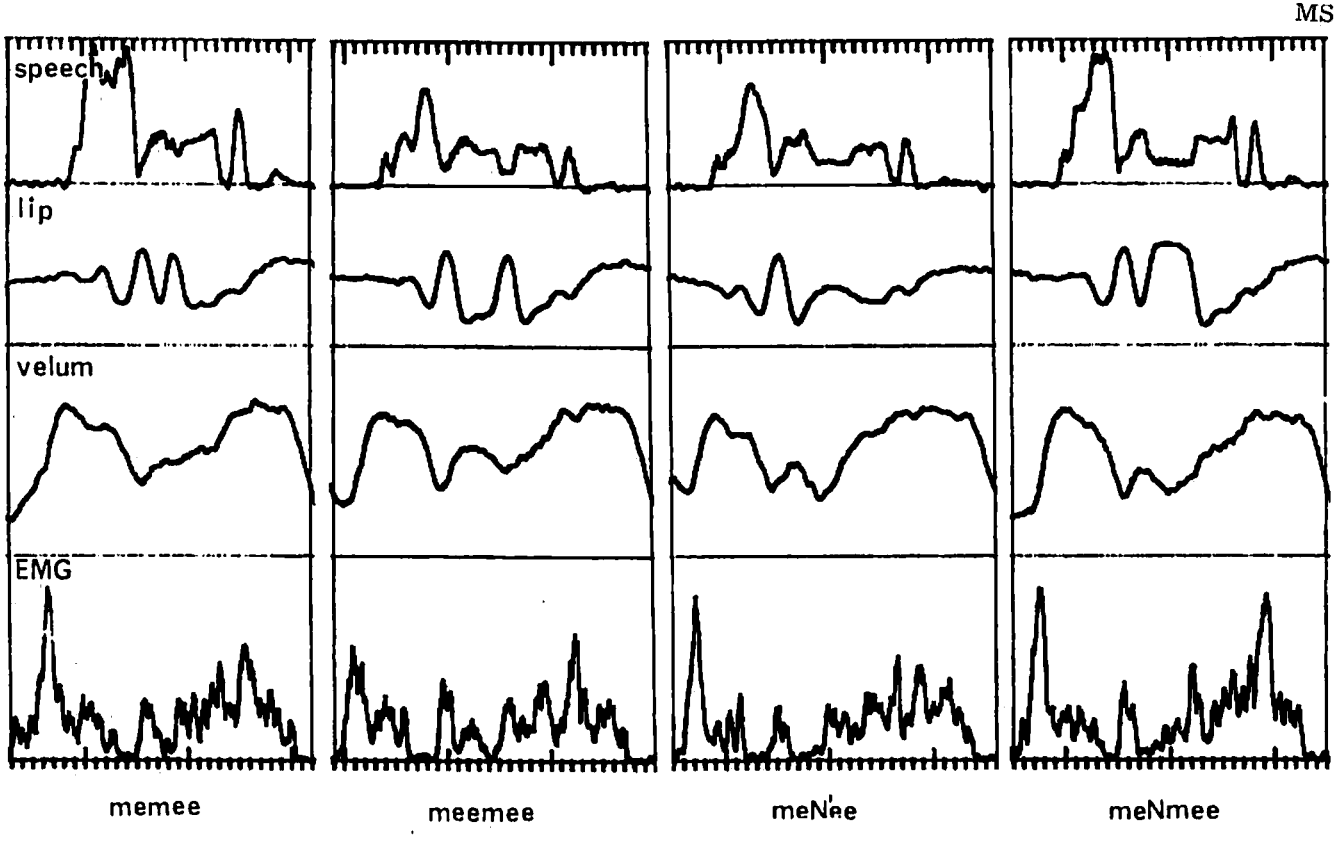

Fig. 3(a) /memee/, /meemee/, /meN'ee/ and /meNmee/ for subject MS.

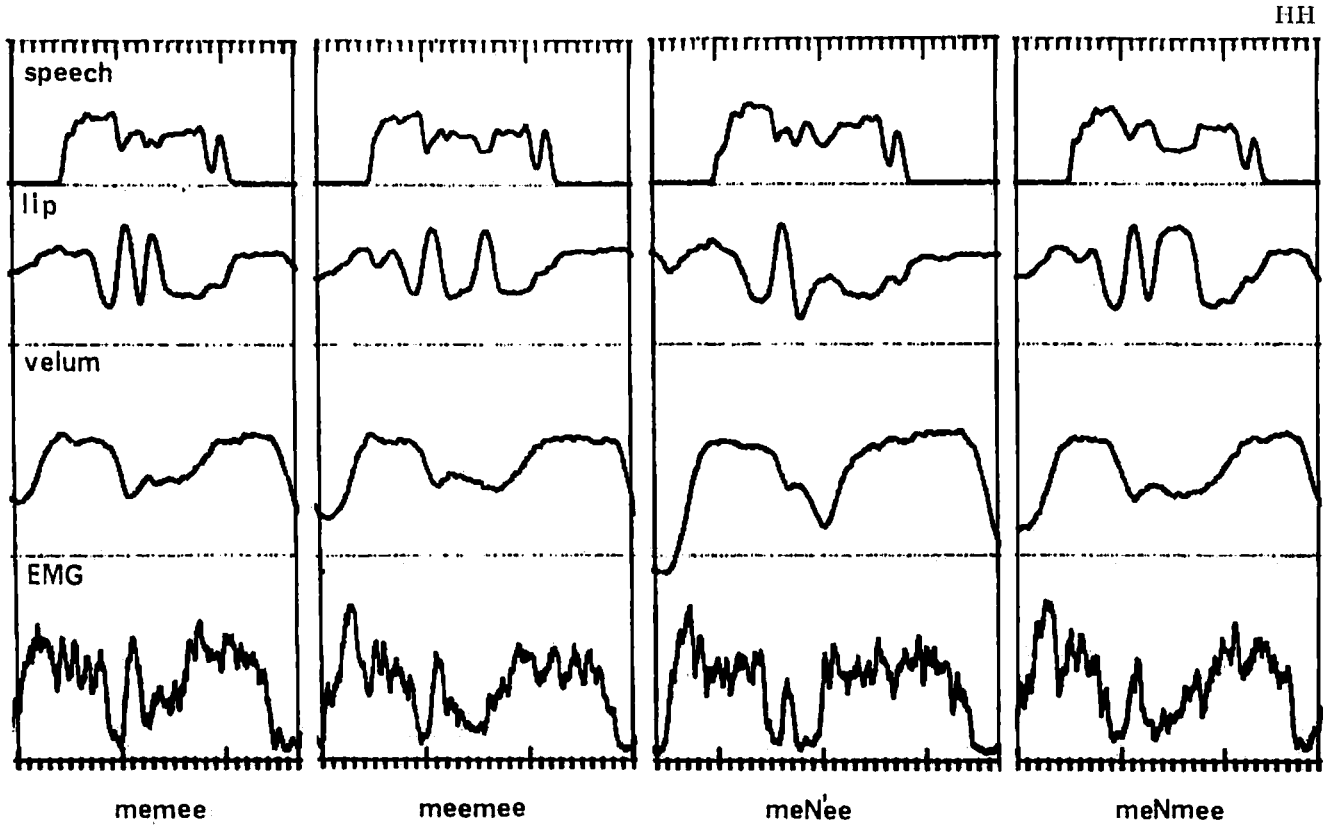

Fig. 3(b) /memee/, /meemee/, /meN'ee/ and /meNmee/ for subject HH.

and the velum is seen to stay at the lowered position. For /meemee/, the period of EMG suppression for the word-medial /m/ is clearer than for /memee/, possibly because of the longer duration of the first syllable. Correspondingly, the velum exhibits a slight downward movement again for the second /m/ after the upward movement for the vowel /e/.

In /memee/ and /meemee/, EMG suppression for the word-medial /m/ is not so clear as that for the word-initial /m/. In the case of /meN'ee/, EMG suppression for /N/ is nearly complete and a further lowering after vowel /e/ can be seen. As observed in Fig. 2, subject HH shows a remarkable difference in velar height between /m/ and /N/. The difference is also reflected in velum movement for /meN'ee/, in which there is a further marked downward movement after velum lowering for the initial /m/. In subject MS, the difference in velar height for /m/ and /N/ is relatively small, even in the case of /meN'ee/. For /Nm/ in /meNmee/, it is observed again that the period of complete suppression of EMG activity is followed by an intermediate level of activity as observed for /beNmee/ in Figure 1. Thus, for subject HH, velar height for /Nm/ in /meNmee/ is clearly higher than that for /N/ in /meN'ee/, although the duration of the nasal sound appears to be longer for the former.

/Np/ and /Nb/

Figure 4 compares utterances /beNpee/ and /beNbee/. In Japanese, the sequences /Np/ and /Nb/ are phonetically realized as [mp] and [mb]. It is considered that for the production of a stop consonant, a full elevation of the velum is required and velum raising following /m/ should be performed quickly. The pattern of EMG activity in these cases is characterized by a transient overshoot with high peak value.

Fujimura et al. reported[4] that, for the syllable-final consonant cluster with nasal element in American English, the timing of velum raising with regard to tongue movement tends to be earlier when the final consonant is tense. A similar tendency is also observed for [mp] and [mb] sequences shown here, although the effect appears to be less remarkable than in the case of American English. Namely, with regard to the closing movement of the lip, the timing of velum raising is earlier for [mp] than for [mb]. For the utterance samples in Figure 4, the duration of lip closure is about 200 msec and the timing difference in the velum elevation between [mp] and [mb] is about 50 msec. Correspondingly, there are consistent differences in the pattern of EMG activity for [mp] and [mb].

Thus, for [mp], the onset of EMG activation is earlier, the increase in activity is more rapid, and the peak activity is greater than for [mb]. All these factors can contribute to the earlier timing of velum raising. It is confirmed in these data that there is a positive control at the level of levator activity to achieve a more complete elevation of the velum for /p/ than for /b/.

Summary

In the present report, the correspondence between the pattern of velum movement and the EMG pattern of the levator palatini in individual utterance

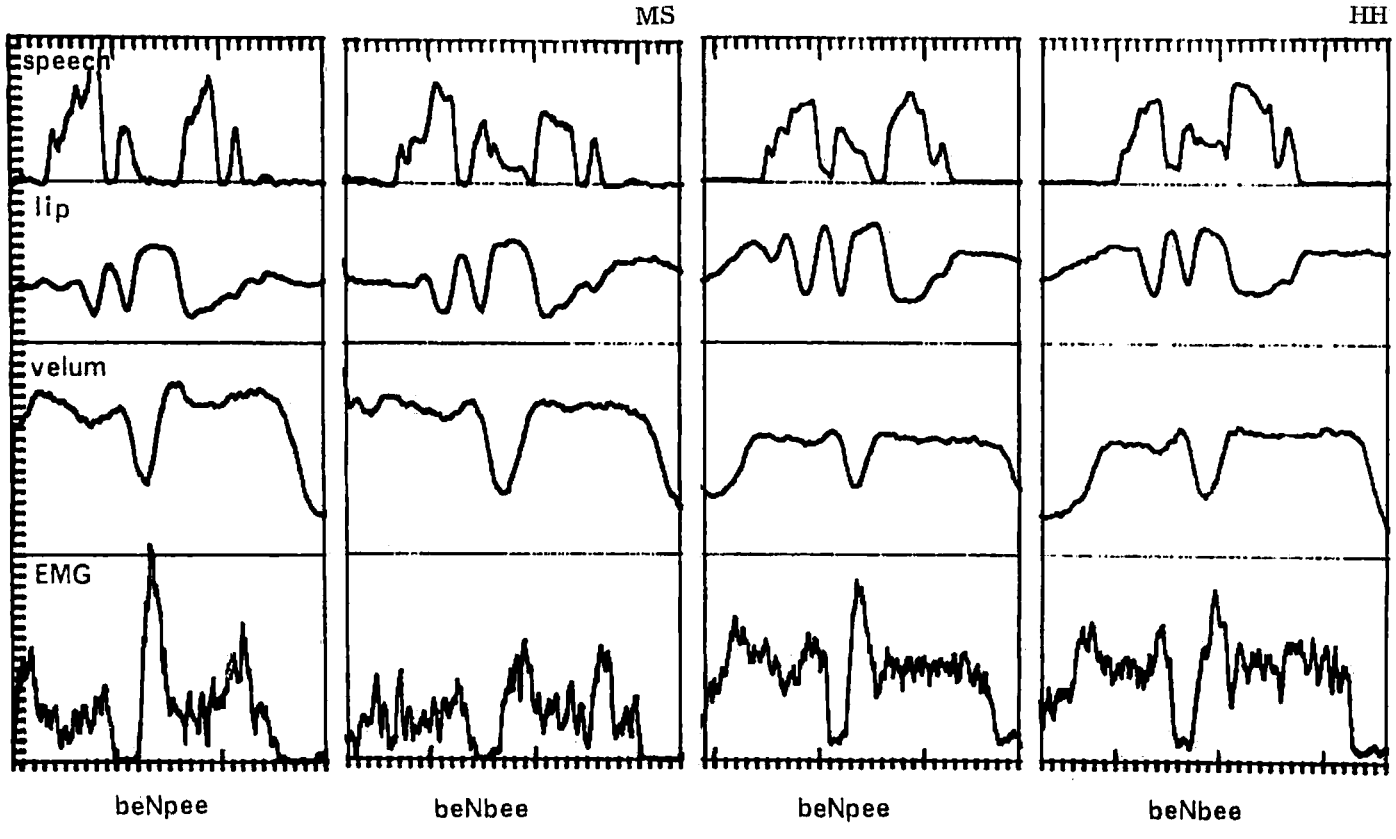

Fig. 4 /beNpee/ and /beNbee/ for subjects MS and HH.

samples was examined. It is observed that the pattern of EMG curve for each utterance sample corresponds well to the pattern of the velum movement for that utterance. The difference in the pattern of the velum movement for the different types of nasal sounds is explained by the observed difference in the EMG patterns. The different patterns of velum movements between speakers are also explained by the differences in the EMG patterns. It is considered that the observations of the detailed characteristics of the EMG patterns such as in /beNmee/ and /memee/ are made possible through the examination of the EMG curves for the individual utterances without averaging over repeated utterances.

The present study confirms that there are characteristic differences between the syllable-initial /m/ and syllable-final /N/, as reported in previous studies[1)2)3)]. The present study reveals that at least in /bemee/ and /beN'ee/, the EMG suppression is nearly complete both for /m/ and /N/ and there is no apparent difference in the level of suppression. It is found that the difference in their velar heights is correlated with the difference in the duration of the suppression period.

Another finding in this study is that there is clear activation of the levator for the vowel positioned between the nasal sounds, such as vowel /e/ in /memee/ and /meN'ee/. Although it is observed that the velum stays at a low position during the vowel, this nasalization is considered to be due to mechanical smoothing of the movement and not due to nasalization at the level of the motor command.

It should be noted here that the levator activity for the stop consonants in /Np/ and /Nb/ is characterized by a remarkably higher peak value compared to that in non-nasal environment. Apparently, for these consonants, there are context-dependent adjustments of the motor command to achieve the full elevation of the velum. In contrast, there appears to be no such adjustment of the motor command for the vowel, and the position of the velum varies depending on the context.

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