

Electromyographic study of the velum during speech

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Abstract:

Electromyographic recordings of the levator palatini were obtained to investigate the relationship between velar movement and its motor command. Two Japanese subjects read a list of meaningful disyllabic test words. There was no systematic difference in EMG level between either voiced and voiceless or stop and fricative consonants. Rather, the activity level for a given nonnasal consonant varies with its phonetic environment. Electromyographically, anticipatory nasal coarticulation generally followed the so-called look-ahead mechanism, although in some examples there seemed to be a restriction of the anticipatory effect. On the other hand, carry-over nasal coarticulation was not as pervasive as the anticipatory effect, as the carry-over effect was present for vowel segments following syllable-initial nasals, while it was absent for vowel segments following syllable-final nasals.

Introduction

In a previous study, direct viewing of the velum by use of a fiberoptic system revealed several interesting findings on the velopharyngeal mechanism during speech articulation (Ushijima & Sawashima, 1972). Our interest was then directed to an investigation of the relationship between the actual movements of the velum and their motor commands during speech. For this purpose an electromyographic (EMG) study of velar movements was undertaken, using test words similar to those used in the earlier fiberoptic study. This procedure was intended to offer EMG data comparable with those of velar movements.

In this report we will discuss EMG activity of the levator palatini in relation to the results of the earlier fiberoptic experiment. The levator palatini has been generally considered to be the principal muscle of velopharyngeal closure. The aim in this study was, therefore, to investigate the possible correlation between levator activity and apparent velar height, especially for nasal coarticulation.

Procedure

Two Japanese speakers (HH and TU), both of Tokyo dialect, served as subjects for this EMG experiment. They had not served as subjects in the earlier fiberoptic experiment. The subjects read a randomized list of 28 utterance types 16 times (Table I). In this table a syllable-final nasal is indicated as /N/, while a syllable-initial nasal is shown as /n/.¹ The

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¹In Japanese the syllable-final nasal /N/ is characterized by some special features. The phoneme /N/ has a duration equal to that of one mora. The specification of the articulation of this segment seems entirely dependent on that of the following phoneme.

test words, consisting of meaningful disyllabic words, were included in a carrier sentence of /-----desu/ (it is-----). None of the test words contain any accent kernel. The subjects were required to read the sentences at a conversational rate, which proved to be nearly identical for the two different experiments.

Conventional hooked-wire electrodes were inserted into the levator muscle perorally (Hirose, 1971). The EMG signals were computer-averaged with reference to a line-up point on the time axis. A more detailed description of the computer-processing system used is reported elsewhere (Kewley-Port, 1973a).

Table I List of test words

	For EMG (meaningful words)	For filming (meaningful words)	(nonsense words)
1.	/see'ee/	/see'ee/	/aiueoaiueoa/ /tetetete/
2.	/seesee/		/sesesese/
3.	/seetee/		/dededede/
4.	/seezee/		/zezezeze/
5.	/teetee/		/nenenene/
6.	/zeesee/	/see'eN/	/teNteNteNteN/
7.	/see'eN/		
8.	/seeseN/		
9.	/tee'eN/		
10.	/teeteN/		
11.	/teedeN/		
12.	/teezeN/		
13.	/teenee/		
14.	/deence/	/deenee/	
15.	/seN'ee/	/seN'ee/	
16.	/seNsee/	/seNsee/	
17.	/teNtee/		
18.	/zeNsee/	/zeNsee/	
19.	/deNsee/		
20.	/neNsee/	/neNsee/	
21.	/seeneN/	/seeneN/	
22.	/teeneN/		
23.	/seN'eN/	/seN'eN/	
24.	/seNseeN/		
25.	/teNteN/		
26.	/seNneeN/	/seNneeN/	
27.	/teNneeN/		
28.	/neNneeN/	/teNseeN/ /deNseeN/ /heNseeN/ /seNteN/ /'eNseeN/ /seNdeN/ /'eNsee/	

Results and Discussion

Vowel and nonnasal consonant

Figure 1 shows three examples of averaged EMG curves for the two subjects. The thin line represents a /CVV'VV/ sequence, /see'ee/, with a syllable boundary occurring within the

four successive vowel phonemes.² The thick line represents a /CVVCVV/ sequence, /seeese/. The dashed line represents a /CVVCVN/ sequence, /seeeseN/, with a syllable-final nasal at the end of the second syllable. Zero on the time axis is the voice onset of /e/ after the initial /s/, which was obtained from the audio signal and which served as the line-up point for averaging. It is clear that the level of EMG activity for the vowel /e/ is much lower than that for /s/.

Kewley-Port (1973b) described the results of an experiment with multiple electrode insertions to different locations in the levator palatini muscle. She commented that consistent patterns of averaged EMG curves, with high correlations for each of several different electrode locations, were obtained regardless of different amplitudes of the maximum

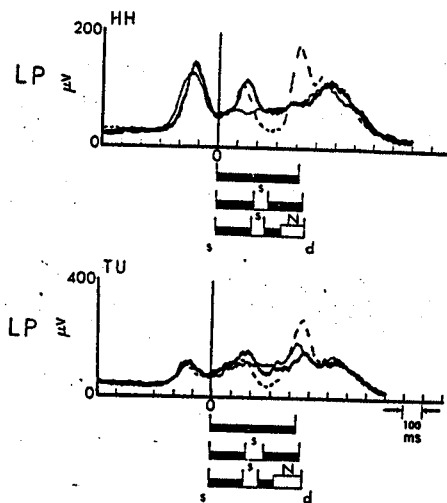


Figure 1

Superimposed averaged EMG curves for three utterance types: /see'e#desu/ (—), /seeese#desu/ (---) and /seeeseN#desu/ (· · · · ·). “· · · · ·”, “#”, and “N” represent a syllable boundary, a word boundary and a syllable-final nasal, respectively.

scale values among them. Therefore, the activity pattern picked up from one location should represent the overall change in the motor command to this particular muscle. In this sense, the different levels of activity between /s/ and /e/, shown in Fig. 1, lead us to assume that there are quantitatively different neural commands for movements of the velum for consonant and vowel production.

Even if nasality may be considered as a “one muscle-one parameter” system, a decrease in levator activity for the vowel /e/ should not necessarily be interpreted as indicating a proportional decrease in absolute velar height. Instead, the amount of EMG activity is known to be proportional to the mechanical work required to approximate the required articulatory configuration (MacNeilage, 1972).

Bell-Berti & Hirose (1972a) pointed out a similar moderate difference in EMG potentials, between /i/ and /b/, and stated that such a difference may not be sufficient to result in a considerable shift in velar height, while the far greater increase in EMG activity for an oral consonant following a nasal will be sufficient to cause a considerable shift in velar height.

²According to Hattori (1961), “· · · · ·” represents a sort of consonant phoneme which has no manifest articulatory characterization except that it may indicate a syllable boundary.

In our earlier fiberoptic data, all the /see'ee/ samples [an example is shown in Fig. 2 (a)] indicate that the velum stays at an utmost constant height throughout the test word, or shows only a very slight decrease corresponding to the vowel portion of the test word. Thus, the activity level for /e/ in Fig. 1 seems sufficient to maintain the velar height after having once reached the height for /s/.

In Fig. 1, Subject HH shows a higher peak value for the initial /s/ than for the intervocalic /s/, while Subject TU does otherwise.³ This fact would suggest that the neural commands necessary for the velopharyngeal closure for the two /s/'s appear to differ in degree between the two subjects.

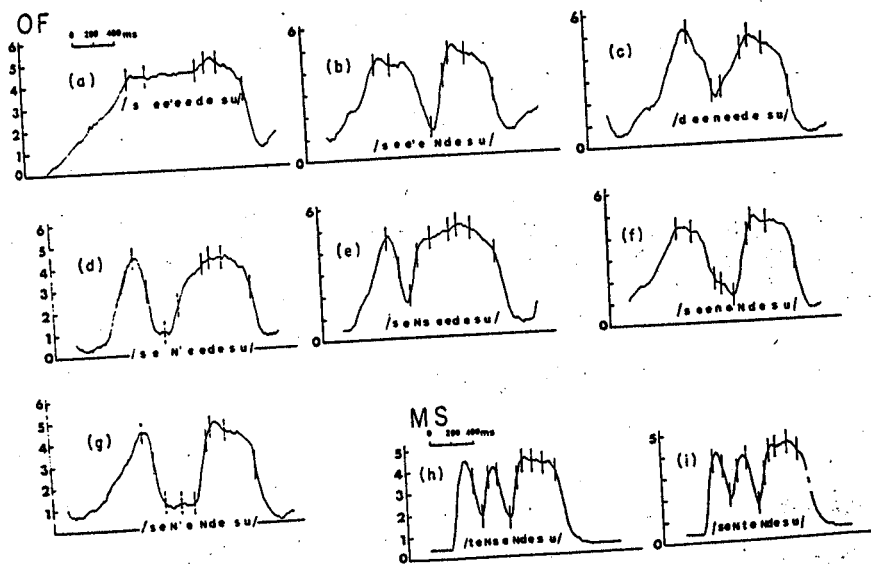


Figure 2

Selected examples of the velum height obtained from the previous fiberoptic study; (a) /see'ee/, (b) /see'eN/, (c) /deenee/, (d) /seN'ee/, (e) /seNsee/, (f) /seeneN/ and (g) /seN'eN/ from subject OF, (h) /teNsen/ and (i) /seNteN/ from Subject MS. The ordinate is an arbitrary linear scale. The subjects (Subject OF and MS) were different from those who served in the present EMG study.

If we assume that velar height is generally constant during the repetition of CV syllables, the difference in muscle activity seen between word-initial and intervocalic /s/ in Fig. 1 is considered not to be transformed into a clear difference in absolute velar height. In other words, subtle variance in the neural input to the velum is more directly reflected in the time course of the averaged EMG activity than in the time course of the actual velar movement. The averaged EMG may be substantially influenced by other factors. Some suprasegmental factors such as the existence of an accent kernel or stress, for example, may well affect the

³Immediately preceding each utterance the subjects were required to inspire through the nose. Therefore, the flat portion of the averaged EMG curves before the peak for the initial /s/ is considered to correspond to the resting state of the velum. Thus, both subjects do not seem to have any "speech ready" position for the velum, i.e. the velum appears to move smoothly from the resting position to the position for the initial velopharyngeal closure.

EMG level, even though such factors might not be completely realized in velar height.

For /N/, levator activity falls to a level observed for the resting state.

We may infer from our EMG data that the neural signal to the velum is not controlled by a simple dichotomy, such as an on-off mechanism. Instead, the absolute activity level for a given nonnasal phoneme may vary with the phonetic environment.

Differences among four nonnasal consonants

Figure 3 compares averaged levator EMG activity for the consonants /t/, /s/, /d/ and /z/. Although the material does not cover all possible combinations of the four consonants, the two nasal consonants, and the vowel /e/, we can evaluate the peak values for each oral consonant in comparable phonetic environments. The consonant pairs are selected as follows:

- (1) /teenee/ vs. /deenee/
/teeteN/ vs. /teedeN/ for /t/-/d/ comparison
- (2) /seesee/ vs. /zeesee/
/seNsee/ vs. /zeNsee/
/seesee/ vs. /seezee/ for /s/-/z/ comparison
- (3) /tee'eN/ vs. /see'eN/
/teeneN/ vs. /seeneN/
/teNneN/ vs. /seNneN/
/see'tee/ vs. /see'zee/ for /t/-/s/ comparison
- (4) /deNsee/ vs. /zeNsee/
/teedeN/ vs. /teezeN/ for /d/-/z/ comparison

In the figure, the consonant pairs are connected with solid lines for Subject HH and with dotted lines for Subject TU, and all the comparisons are shown pairwise regardless of the difference in the position of the consonants in the test words.

It is obvious that even in the same subject there is no consistent difference in peak activity between either voiced-voiceless or stop-fricative pairs. This holds true even when the consonant position is taken into consideration, though the detail of that is not shown in the figure.

Bell-Berti & Hirose (1972*b*) found differences in levator activity associated with stop consonant voicing for two out of three subjects. For their subjects, the presence or absence

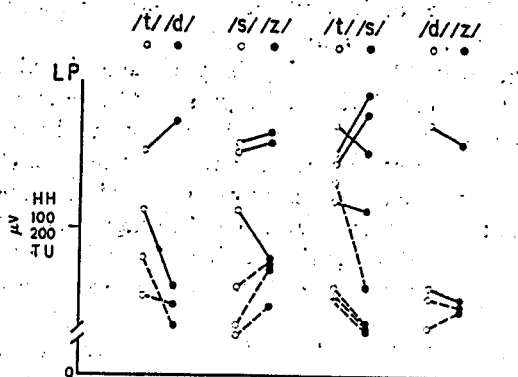


Figure 3

Comparison of levator activity for nonnasal consonant pairs (1).
○—●, Subject HH; ○----●, Subject TU.

of differences in levator activity could be explained on the basis of intersubject differences in strategy for velopharyngeal enlargement to maintain voicing. Since data were obtained only from the levator in the present study, it is impossible to decide whether the two Japanese subjects use a cavity enlargement strategy that does not involve the levator, or alternatively, whether there is a difference between Japanese and English. The lack of difference between peak height for stops and fricatives was also observed in the earlier fiberoptic study.

The wide variation in peak values in Fig. 3 may be due to the effect of a difference in phonetic environment. The effect is further investigated in Fig. 4, where utterances are classified into seven groups according to the contextual construction, indicated as $/C_1ee---$, $/C_2eN---$, $/C_3een---$, $|-eC_4ee/$, $|-eC_5eN/$, $|-NC_6ee/$, and $|-NC_7eN/$. Open circles (Subject HH) and filled circles (Subject TU) indicate the peak values for the $/C/s$. The mean of those values within each group is shown by a short horizontal line (the solid line for Subject HH and dotted line for Subject TU).

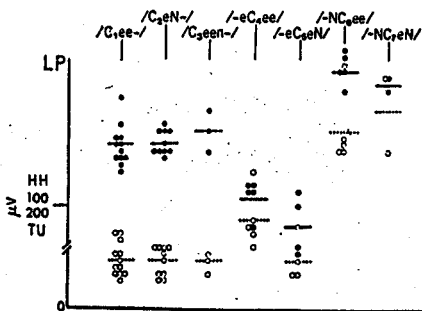


Figure 4

Comparison of levator activity for nonnasal consonant pairs (2).
 —●, Subject HH; —○, Subject TU.

For both subjects, consonants in absolute initial position show the same peak height, whether there is a following nasal consonant of either type. The subjects differ in that for TU consonant position change has no effect, while for HH it does have an effect. Although such individual differences in EMG peak value for consonants may not be directly related to the difference in velar height, it is interesting to note that the two subjects show the rather different patterns described above.

The second finding worthy of note is that the peak values for C_6 and C_7 are far greater than those for the other groups. This would suggest that the neural command is organized so that the muscle activity is greatly increased for elevating the velum immediately after it has been lowered for the preceding $/N/$ segment. Bell-Berti & Hirose (1972a) asserted that there is a strong correlation between the magnitude of the increase in EMG potential and the magnitude of the change in velar height. The increased EMG potential after $/N/$ in these cases may be reasonably explained as being essential for the longest excursion of the velum from the position near the resting state to the elevated position for the succeeding stop consonants.

In this respect, our earlier film analysis of the velum indicates that velar height for the consonants after $/N/$ is no greater than that for the word-initial consonants in the test words [Fig. 2 (e, h, and i)]. In light of this finding, then, the increased EMG for C_6 and C_7 is considered to indicate neither greater maximum elevation of the velum nor, presumably,

tighter velopharyngeal closure, but instead to indicate the contraction strength necessary to achieve velopharyngeal closure for the oral consonants following nasals.

Difference between /N/ and /n/

The earlier data, from velar movement analysis, implying an inherent difference between /n/ and /N/, with greater nasalization for the latter in Japanese (Figs 2 and 5), were compared with the EMG results obtained in the present study.

Figure 6 shows superimposed EMG curves for /teenee/ and /seN'ee/, each containing one nasal segment in intervocalic position. The downward slope of the EMG curves after the peak for the word-initial consonant is apparently steeper for /N/ than for /n/. This may be regarded as indicating greater speed of velar lowering for /N/ than for /n/. However, the

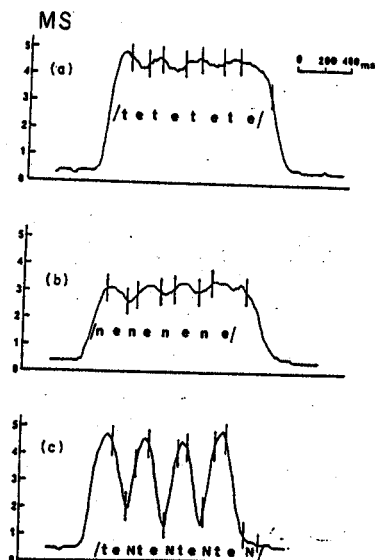


Figure 5

The velum height for three nonsense syllables observed in Subject MS (cf. Fig. 2); (a) /tetetete/, (b) /nenenene/ and (c) /teNteNteN/. The ordinate is an arbitrary linear scale.

apparently greater slope for /N/ might also be explained by the fact that the duration of the prenasal vowel segment is shorter before /N/. In any event, the minimum EMG activity preceding the nasal sounds is slightly lower for /N/ than for /n/ for both subjects. The question of whether or not the slight difference in activity level between /N/ and /n/ indicates a difference in actual velar height can be answered by combining EMG recordings with fiberoptic observation on the same subject, a process that is now in progress.

The segmental duration of /N/ is clearly longer than that of /n/ (Fig. 6). The nasal segment duration may have some relationship to the observed differences in velar height. Ohala (1971) stated that the palate lowers more for word-final nasal consonants than for word-initial nasals, but he did not comment on the difference in the duration of nasal segments. Further studies, using different speaking rates and measurements of nasal segment duration in various phonetic positions, seem to be needed. We also see in Fig. 6 that levator activity remains suppressed after /n/ but not after /N/, a fact that will be further discussed below.

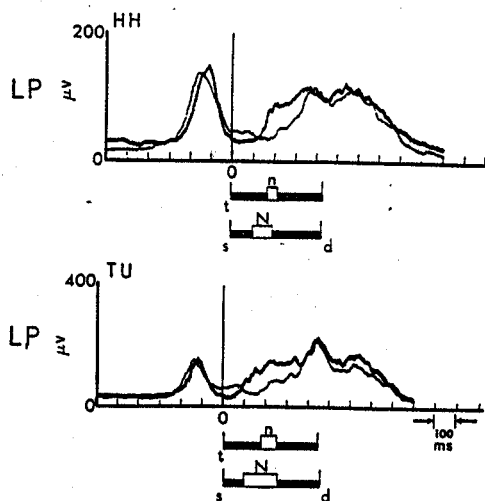


Figure 6 Superimposed averaged EMG curves for two utterance types; /teenee#desu/ (—) and /seN'ee#desu/ (---).

Coarticulatory movements of the velum

Many authors have described the coarticulation of nasality, based on cineradiographic observations of velar movement, on aerodynamic studies, and on acoustic analysis of speech. If coarticulation is interpreted as "the influence of one speech segment upon another speech segment" (Daniloff & Hammarberg, 1973), we might expect to observe such effects at the level of the motor command, or electromyographically. Dixit & MacNeilage's (1972) EMG and aerodynamic studies of Hindi on the extent of coarticulatory effects are so unique as to lead to the following conclusions:

- (1) The effect of coarticulation can stretch across four segments.
- (2) Carry-over effects (left-to-right effects) are as extensive as anticipatory effects (right-to-left effects).
- (3) The temporal scope of coarticulatory effects is unrestricted by syllable or word boundaries.

Our data on Japanese are not entirely consistent with their results.

Carry-over coarticulation. EMG activity for the underlined vowel segments of the second syllable in /seN'ee/ (Fig. 7) does not reveal any carry-over suppression from the preceding /N/. Rather, it shows a far greater increase than the EMG level necessary for the underlined vowel sounds in /see'ee/. If the carry-over effect represents a change in the time course of the neural command, as indicated by Dixit & MacNeilage's (1972) EMG data on Hindi, we should expect decreased activity for the underlined segments in /seN'ee/. But this is not the case. Phonemically there is no contrastive nasality in Japanese vowels, so presumably, there are no restrictive influences against velar lowering. At the level of the neural command to the velum the carry-over effect, if it is observed at all, is not realized as decreased muscle activity. In this case, carry-over coarticulation does not seem to extend beyond the syllable boundary between the two syllables of the test words.

On the other hand, comparison of the /see'ee/-/teenee/ pair in Fig. 8 shows a clear carry-over effect of a syllable-initial /n/ on the following vowel segments in the second syllable. Specifically, the activity for the /ee/ after /n/ in /teenee/ never surpasses the level for /'ee/

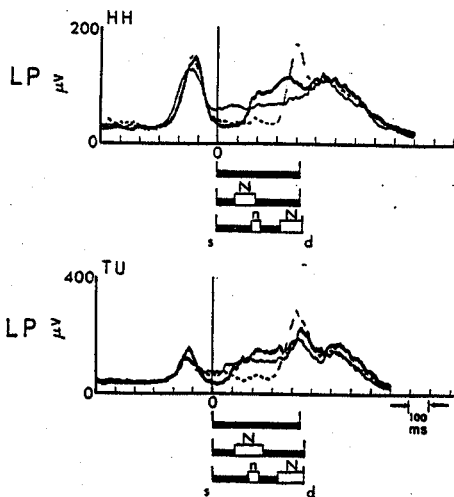


Figure 7

Superimposed averaged EMG curves for three utterance types; /see'ee#desu/ (—), /seN'ee#desu/ (---) and /seeneN#desu/ (-----).

in /see'ee/. This is also evident in the difference in activity level for the post-/n/ vowel segments shown in Fig. 6. A possible explanation for this difference is that the vowel segments after a syllable-final /N/ may have to be oralized to prevent listener confusion. Further comment will be made below on the restrictions on coarticulation.

Although the carry-over effect does not appear to be present in the case of a /CeN'ee/ sequence at the motor command level, the earlier fiberoptic study showed a lower velar height for the vowel segments following /N/ than for vowel segments in oral environments. It should be reasonable to assume, therefore, that realization of the carry-over effect in the form of velar movement in those cases may be due to some inherent mechanical response characteristics of the velum. At present, we would agree with the speculation (Daniloff &

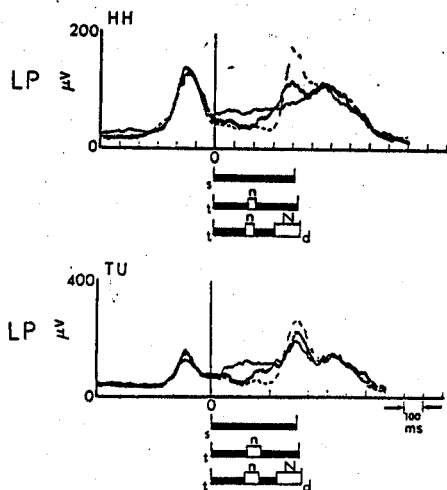


Figure 8

Superimposed averaged EMG curves for three utterance types; /see'ee#desu/ (—), /teenee#desu/ (---) and /teeneN#desu/ (-----).

Hammarberg, 1973) that carry-over coarticulation is partly due to mechano-inertial limitations on the articulators as a physical system.

Anticipatory coarticulation. EMG evidence supports the existence of anticipatory nasal coarticulation in vowel production. Figure 7 compares three utterance types, /see'ee/, /seN'ee/ and /seeneN/. Unless EMG activity for /e/ after /s/ is influenced by anticipatory effects from /N/ in /seN'ee/ or from /n/ in /seeneN/, the three curves should show the same level of activity, at least for the short period following the peak for the initial /s/. In this respect, however, there is a clear difference among the examples in Fig. 7, where the curve for /see'ee/ shows a higher EMG level before the line-up than the other curves for Subject HH. Subject TU shows a similar tendency between /see'ee/ and /seN'e/.

Another example indicating the anticipatory effect in the vowel segment before /N/ is shown in the /seesee/-/seeseN/ comparison in Fig. 1. The effect appears to manifest itself as about a 25 ms difference in timing of initiation of EMG suppression after the peak for the intervocalic /s/, which is significant even when the difference in timing of postconsonantal vowel onset is taken into consideration. It seems reasonable, then, to conclude that the neural commands for vowels followed by nasals are reorganized by the anticipatory effect.

As far as we have surveyed the collected data, the anticipatory effect and the carry-over effect have different characteristics at the EMG level. The anticipatory effect manifests itself as some kind of reorganization of the neural command following the so-called "look-ahead" principle or future scanning mechanism, to which we will refer later. The carry-over effect manifests itself as some kind of reorganization of the time course of the neural command for vowels following some nasal segments. After syllable-final /N/, there is no carry-over effect at the EMG level. In this sense, the carry-over effect is less pervasive than the anticipatory effect. In such cases, realization of the carry-over effect as actual velar lowering is due, in part, to some mechanical response characteristics of the velum.

Restriction of coarticulation. In the examples such as /teenee/, /deenee/, /seeneN/, and /teeneN/, the syllable boundary before /n/ does not restrict the anticipatory coarticulation from /n/ in the second syllable. Figure 8 compares the /teenee/-/teeneN/ pair with /see'ee/. In the figure, after the peak for the initial consonant, activity for the underlined /ee/ in each case with a syllable-initial nasal is somewhat more suppressed than in the case of /see'ee/. The higher degree of suppression or greater decrease in EMG level begins as early as about 50 ms before the line-up point for Subject HH, and about 50 ms after the line-up point for Subject TU. Many authors now agree with the opinion that anticipatory nasal coarticulation extends across syllable boundaries, and our present results are partly consistent with that opinion.

The next important finding in this study is evidence of a restriction of the anticipatory effect of velar lowering. Moll & Daniloff (1971) have suggested, following Henke (1966, quoted in Moll & Daniloff, 1971), that anticipatory coarticulation operates on a "look-ahead" principle. A feature is articulated in a speech string as soon as it can be. Thus, if the vowels are presumed to be neutral with respect to nasalization, velar lowering for a terminal nasal should occur at the beginning of a preceding vowel string. The length of the vowel string should be irrelevant.

This hypothesis was tested by comparing three speech strings. Figure 9 shows three examples of averaged EMG curves for the two subjects. The thin line represents a /CVV'VV/ sequence, /see'ee/. The thick line represents a /CVV'VN/ sequence, /see'eN/, with a syllable-final nasal at the end of the second syllable. The dashed line represents a /CVN'VV/ sequence, /seN'ee/, with an /N/ at the end of the first syllable. About 150 ms before the line-up, there is always a peak for the high velum consonant /s/. Immediately

after the peak, there is suppression of EMG activity in /seN'ee/ (the dashed line), indicating, of course, decreased activity for the syllable-final nasal. By contrast, in /see'eN/ (the thick line) the activity for the initial vowel segment after /s/ has the same level as the vowel in the utterance without the nasal. The activity begins to fall about 100 to 150 ms after the line-up.

If Moll & Daniloff's hypothesis of "unspecified" velar position for the vowel is applicable to Japanese vowels, the EMG signal for the vowel segment after /s/ in /see'eN/ should show the same decrease as for the underlined /e/ in /seN'ee/. However, the present data suggest that there is a restriction on anticipatory velar lowering. These results are consistent with the finding of a delayed onset of velar lowering shown in Fig. 2(b).

In summarizing the results obtained so far from both direct viewing and EMG of the velum, there seems to be no anticipatory lowering of the velum during the first portion of

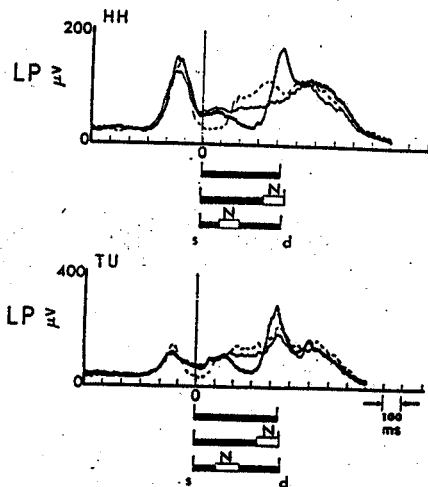


Figure 9

Superimposed averaged EMG curves for three utterance types; /see'ee#desu/ (---), /see'eN#desu/ (—) and /seN'ee#desu/ (—).

the vowel segment in the /CVV'VN/ environment containing a syllable boundary (Figs 2 and 9). The results do not support Moll & Daniloff's (1971) proposal, although, to be sure, the languages tested are different. Since our disyllabic test words do not contain any obvious acoustic pause, we cannot explain this delayed onset of velar lowering by the existence of a prosodically marked grammatical boundary. This delayed onset of coarticulation might be due to a high-level reorganization of the input commands to the velum (McClellan, 1973). Then, the presence of a syllable boundary within the vowel string and/or the number of the interposed vowel segments may well have some effect on anticipatory velar lowering.

Another possible explanation of this phenomenon might be the following. The specification of velar position for the elongation of Japanese vowels may not be neutral. Instead, the elongation of the vowel can be regarded as positively specified in terms of denasalization. Thus, coarticulation may not occur beyond the boundary, as in /see'eN/.

Summary and Conclusion

EMG recordings from the levator palatini muscle of two Japanese subjects lead us to summarize as follows:

- (1) From the viewpoint of the motor command level the velum is not controlled by a simple dichotomy such as an on-off mechanism.
- (2) There is no systematic segmental difference between either voiced and voiceless or stop and fricative consonants. However, the absolute activity level for a given nonnasal phoneme may not be predicted, but varies according to its context.
- (3) The different degree of nasalization for /n/ and /N/ seems to be realized electromyographically in the form of greater suppression of EMG activity for /N/.
- (4) There are different mechanisms for anticipatory and carry-over effects of coarticulation at the level of the motor command. The anticipatory effect is some kind of reorganization of the neural commands following the "look-ahead" principle. On the other hand, the carry-over effect is less pervasive than the other in the sense that for the vowel segment after a syllable-final nasal there is no carry-over suppression of EMG activity.
- (5) There seems to be no anticipatory lowering of the velum during the vowel segments before a syllable boundary in the /CVV'VN/ environment. This phenomenon, which does not appear to support Moll & Daniloff's (1971) proposal, suggests that the elongation of vowels in Japanese might be regarded as positively specified in terms of denasalization.

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