Preliminary Investigation of a New Concept of Velar Activity During Speech

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Among the reported results of investigations of the velopharyngeal mechanism are observations that the velum assumes a variety of positions during speech. For example, it has been consistently observed (*6*, *7*, *10*, *13*, *18*) that velar elevation varies with tongue height, being greater on high vowels than on low vowels. In addition, it has been reported that on nasal consonants the velum does not descend completely but assumes a position which is intermediate between rest and complete closure (*5*, *13*).

A number of possible explanations for observed variations in velar position during speech might be considered. First, it is possible that the different positions reflect changes in the muscular forces applied to this structure. The speaker may 'adjust' such forces in relation to the speech unit being produced, possibly in relation to the degree of velopharyngeal closure required for a particular unit. For example, high vowels may exhibit greater elevation because a small degree of velopharyngeal opening affects the quality of high vowels more extensively than the quality of low vowels (*9*). The labeling of the intermediate velar position on nasal consonants as the ready position (*5*, *13*) also implies an adjustment by the speaker: the velum presumably is held ready by muscle activity in anticipation of rising on the subsequent non-nasal sound.

Recent studies by Lindblom (*11*) and by Stevens and House (*17*) suggest another explanation for variations in velar positions. They propose that the variations in articulatory positions which are observed for productions of the same speech unit in different contexts do not necessarily imply similar variations in activity at higher physiological levels. For example, the neural control signals and/or the muscular forces applied to the articulatory structure may be invariant in magnitude and pattern for all occurrences of a particular speech unit. At the articulatory level, however, the position assumed by the structure may vary, due to the mechanical con-

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straints of the articulatory system and to the relative timing of the control signals and forces. Thus, even when the same muscular forces are applied, the position that an articulator reaches during a speech unit will depend on the timing of the force application and on the mechanical properties of the articulatory mechanism.

If velar activity is considered in terms of such an articulatory model, it appears plausible that many of the variations in velar positions may not result, necessarily, from varying muscular activity. Some support for this hypothesis is found in the electromyographic data of Harris, Schvey, and Lysaught (*8*) who observed that activity of the velar muscles was essentially the same for all non-nasal sounds which they studied. During nasal consonants they observed only a very low level of activity in the velum and found no activity of inferior palatal muscles which was related to velar lowering. On the basis of such observations and on the basis of the articulatory model of Lindblom (*11*) and Stevens and House (*17*), the simplest hypothesis that might be proposed is that there are only two modes of muscular activity in the velum during speech. For discussion purposes, these modes might be labeled as 'on' and 'off'. Intermediate positions of the velum would then be due to varying mechanical restraints on velar movements and to the relative timing of the muscular signals, rather than to changes in the muscular forces applied to the velum. In other words, the velum may not be lowered or raised completely at a given point in time *only* because it is restrained from doing so or because it has not had time enough to do so.

The purpose of the present study was to make a preliminary test of this hypothesized model of velar activity during speech. It is an indirect test, since velar positions and movements rather than muscular activity were observed. If the model is appropriate, however, velar positions should vary as the relative timing of speech units is changed. For example, the velum should assume lower and lower positions on a nasal consonant as the time for lowering is increased. An attempt was made to see if such variations do occur.

Procedure

Subjects and Phonation Conditions. Two adult males, both of whom were judged to be normal speakers, served as subjects in this study. Each subject produced the following utterances:

a) sustained production of /n/, /m/, /u/, and /ɑ/,

b) production of /ʌn/, /ʌm/, /mu/ and /mɑ/ with the final sound sustained, and

c) production of /tʌ/, /mu/ and /mɑ/ at rates of one, two and four syllables per second.

The vowels, the consonant /t/, and the syllables made up of these sounds were chosen to represent hypothesized 'velum-on' conditions. Vowel sounds also were selected on the basis of tongue height. The nasal consonants and the breaks between utterances constituted hypothesized 'velum-off' units. Syllables were varied in rate to investigate the effect of sound unit duration on velar movements.

Each subject was instructed to produce the speech samples at his usual pitch and vocal effort level. Syllable rates were controlled with the aid of a metronome and the subjects were given practice in controlling rate prior to the actual cinefluorographic filming. The phonation conditions were randomized for each subject; however, the syllables were produced at the three production rates successively.

In addition to the conditions described above, cinefluorographic pictures also were taken of each subject during 'physiologic rest'. For this condition, the subject was instructed to sit quietly, to not swallow, and to breathe normally through the nasal cavities.

CINEFLUOROGRAPHIC PROCEDURES. The basic cinefluorographic and head positioning equipment utilized in this study have been described previously (*12*). Lateral cinefluorographic pictures were taken at 24 frames per second and a synchronized, optical sound track was made directly on the film.

FILM ANALYSIS. The cinefluorographic films obtained were analyzed by tracing selected movie frames and making measurements from the tracings. For tracing, the film was enlarged by projection to life-size. For sustained sound productions, a number of frames prior to the beginning of phonation and every frame during the sound were analyzed. For the syllable productions, successive frames from the end of one syllable through two complete syllables to the beginning of the third were analyzed.

A drawing of the structures traced on each frame is shown in Figure 1. This drawing also represents a tracing of the physiologic rest position for one subject. The rest position was used as a template and all other tracings were placed upon it so that the incisors and the pterygomaxillary fissure coincided. A reference line for measurement was determined by selecting successive tracings from a syllable on which velopharyngeal closure was obtained. From these tracings a composite tracing was made which depicted velar movement from maximum opening to complete closure. The reference line A-A′, shown in Figure 1, was then drawn through the high points (levator eminence) of the velum. This line thus approximated the direction of velar movement for the particular subject.

The following measurements were made from the tracings to the nearest 0.25 mm (Figure 1):

a) Velar elevation (VE): the position of the highest point of the velum as measured from the physiologic rest position (point R) along line A-A′.

b) Velum-pharynx distance (V-P): the shortest distance between the posterior surface of the velum and the posterior pharyngeal wall.

To evaluate the accuracy of the measurements, fifty cinefluorographic frames were selected randomly and were retraced and remeasured by one investigator. Pearson product-moment correlation coefficients for the measures V-P and VE were .94 and .96, respectively. Absolute mean dis-

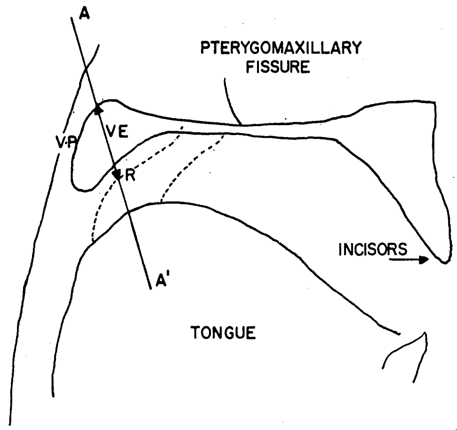


FIGURE 1. Line drawing of a cinefluorographic frame showing the position of the velum at rest (dotted line) and the measurements made: V-P, velum-pharynx distance; VE, velar elevation.

crepancies were 0.49 and 0.56 mm. These values are consistent with data previously reported (*13*).

Results

SUSTAINED SOUNDS. The amount of velar elevation prior to and during the sustained /n/ sound is plotted in Figure 2 for both subjects. The results for the sustained /m/ were similar and are not shown. It can be noted that the velum is elevated approximately 7.0 mm just prior to the beginning of the nasal sound and then descends as phonation begins. It does not return, however, to a physiologic rest position (represented by the baseline 0 on the graph), but assumes a position for the /n/ which is approximately 2.5 to 3.0 mm higher. During sustained /m/ sounds the average position assumed was 4.0 mm for subject A and 5.0 mm for subject B. Although almost continuous variation in velar elevation can be observed from Figure 2, even during the sustained sound, the velum appears to vary around the average levels stated above.

For the sustained vowels /ɑ/ and /u/, complete closure of the velopha-

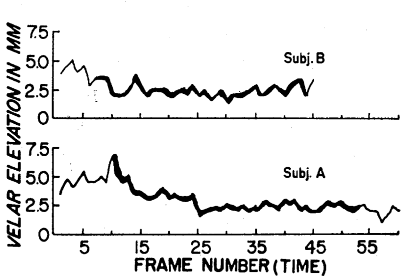


FIGURE 2. Velar elevation for subjects A and B during a sustained /n/ sound. The duration of sound track modulation for the /n/ is shown by the darker line.

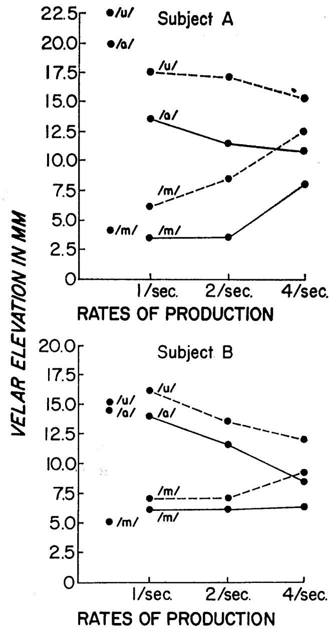


FIGURE 3. Lowest velar elevation achieved on /m/ and the highest achieved on the vowel in the syllables /mu/ (broken lines) and /mɑ/ (solid lines) produced at different utterance rates. Average velar elevations for /m/, /u/, and /ɑ/ sustained in isolation are indicated by the isolated data points at the left.

ryngeal port was observed for both subjects. As might be predicted from previous research (13), greater velar elevation occurred during /u/ than during /ɑ/. The average levels assumed during these sounds are shown in Figure 3.

NASAL-CONSONANT-VOWEL SYLLABLES. Data for the nasal consonant-vowel syllables are summarized in Figure 3. Maximum velar elevation on the vowel and minimum velar elevation on the nasal consonant are shown for each of three syllable rates. The average velar elevation for sustained isolated productions of /m/, /u/, and /ɑ/ also are shown for comparison. The effect of rate of production on velar position is apparent from these data and is relatively consistent for both subjects. As rate increases, elevation on the nasal consonant becomes greater while that for the vowel becomes less. As a result, the velar 'swing' (the distance moved by the velum between consonant and vowel) decreases consistently with increasing rate. There appear to be some differences in the findings depending on the identity of the vowel sound in the syllable. Elevation on /m/ is affected by rate more for the syllable /mu/ than for /mɑ/. In addition, it can be noted that the general level of velar elevation is lower for /mɑ/ than for /mu/.

For productions of /ʌn/, /ʌm/, /mu/ and /mɑ/ with the final sound sustained, it was observed that velar elevation on the final sound approx-

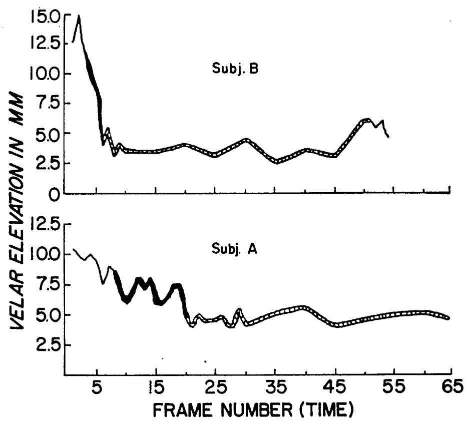


FIGURE 4. Velar elevation for /ʌn/ produced with the final sound sustained. Sound track modulation for /ʌ/ is indicated by the darker solid line and for /n/ by the double-barred line.

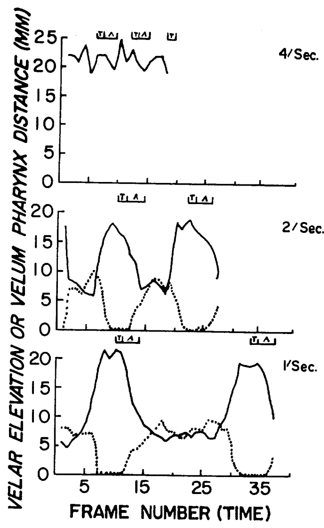
imated that observed for the sound sustained in isolation. A sample data graph for the syllable /ʌn/ is shown in Figure 4. One subject also produced the disyllable /unu/, sustaining the consonant for varying periods of time. Again, as the /n/ became longer the velum descended to the position observed for an isolated /n/. It thus appears that variation in the duration of nasal consonants and vowels in context, whether produced by sustaining the sounds or by varying syllable rate, affects the position attained by the velum.

Consonant-Vowel Syllables. The data in Figure 5 demonstrate that rate of syllable production also affects velar movement on syllables consisting of non-nasal consonants and vowels. For /tʌ/ syllables produced at rates of one and two syllables per second, the velopharyngeal port alternately opens and closes (broken line in Figure 5), opening for the pause between syllables and closing for the syllable productions. At a rate of four per second, however, the port is closed throughout the sequence of syllables. This change also is reflected in the measure of velar elevation. The amount which the velum 'swings' from syllable production to utterance break decreases consistently as rate of production increases (Figure 6).

Discussion

The hypothesis from which this investigation was developed was that velar positions during speech may be explained by assuming only two modes of muscular activity (labeled as 'on' and 'off', and by considering the relative timing with which the two modes are applied to the velum and the varying mechanical restraints on velar movement. The observations reported in the previous section will be discussed in relation to this theoretical model of velar activity.

The 'Off' Mode. If the muscular forces causing velar elevation are



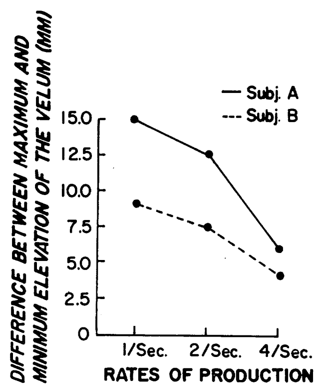


FIGURE 5. Velar elevation (solid line) and velum-pharynx distance (broken line) for /tʌ/ produced at different syllabic rates. Duration of sound track modulation for each sound is shown at the top of each graph.

FIGURE 6. Differences between maximum velar elevation during the syllable and the minimum elevation during the pause between syllables for /tʌ/ produced at different syllabic rates.

truly 'off' during nasal consonants and breaks in utterance, it might be expected that the velum would return to that position assumed during physiologic rest if enough time were available for it to do so. It has been noted that this did not occur; the velum remained two to five millimeters above the rest position even during a sustained nasal sound. It was observed from the films that the velum also assumed this position slightly above rest when the subjects were instructed to phonate, long before the utterance actually began, and remained at this position long after the utterance ended. These findings might have been predicted from the electromyographic data of Harris, Schvey, and Lysaught (*8*) which indicate that, although velar muscle activity decreases markedly during nasal consonants, there is some low level of activity present. Such a level also appears to be observable in their data before an utterance begins. It might be hypothesized that this low level of muscular activity, which elevates the velum slightly from the physiologic rest position, is due to a general tensing of structures in anticipation of speech production and that this is the *base* position from which the velum elevates or to which it descends during an utterance. This position would then correspond to what has been labeled here as the 'velum-off' mode, although obviously there is some muscular activity present. That the velum does not return to rest during a nasal consonant is not surprising since it is generally in contact with the tongue at rest so that the oral cavity is blocked posteriorly. The nasal consonants obviously could not be produced in such a situation since the resonance characteristics of the oral side-branch are important to their production (*3*).

The fact that muscle activity in the velum may not be completely 'off' during nasal consonants and during breaks in utterance does not mean necessarily that the original hypothesis concerning only two modes of muscle activity during speech is untenable. However, the hypothesis must be revised to describe the two modes as two levels of muscular activity during speech productions: That is, a low level which raises the velum slightly from the rest position and a much higher level which elevates the velum as completely as possible.

Effect of Utterance Rate. The most consistent finding of this investigation is that the velar position attained on a nasal consonant or on a vowel adjacent to a nasal is influenced by the durational characteristics of the speech sample. As the sound units and the breaks between syllables become shorter, the time available for raising or lowering the velum decreases and, using the terminology of Lindblom (*11*) and Stevens and House (*17*), the velum 'undershoots' the position that it would attain if enough time were available. These observations suggest that the intermediate 'ready' position of the velum on nasal consonants (*5*, *13*) can be explained without assuming that some intermediate degree of muscle activity is being applied to maintain the velum in a higher and thus more advantageous position for elevating on the subsequent vowel than would be the case if it were lowered to the base position. The 'ready' position may be due only to the fact that the velum does not have time to descend farther before the muscles again contract to raise it for the next sound. This conclusion is supported by the observation that, as the nasal consonant in /unu/ is increased in duration, the velum approaches the base position found on a sustained nasal sound. There is no evidence that the speaker adjusts the velum to a 'ready' position in anticipation of producing the final vowel sound. The same reasoning can be applied in explaining velar positions on vowels in nasal contexts: the 'assimilated' velopharyngeal opening on such vowels (*13*) can be explained simply on the basis of the time available for velar elevation.

Effect of Tongue Position. The model of velar activity which was hypothesized also suggests that mechanical restraints on velar movement, as well as durational characteristics, affect velar positions. Because of the attachments between the tongue and soft palate (palatoglossus muscles), it would be expected that tongue positioning would affect velar elevation. The fact that palate elevation is greater on high vowels than on those with low tongue positions has been reported previously (*7*, *8*, *11*, *14*, *19*). In the present study, palatal elevation was greater on a sustained /u/ than on /ɑ/. In addition, on nasal consonant-vowel syllables the average level of velar elevation was higher for syllables containing /u/ than for those containing the low vowel /ɑ/. It seems more reasonable to attribute the differences in velar elevation between high and low vowels to changes in the degree of restriction on velar movement by tongue position (*1*, *7*, *13*) than to contend that the speaker adjustes velar muscle activity to achieve the degree of velopharyngeal closure required for producing a given vowel without nasal quality.

It also is possible that other mechanical factors besides tongue position may affect velar elevation. For example, Ackerman (*1*) and Podvinec (*15*) suggest that movements of the pharynx and larynx may be important in determining velar position, since the velum is attached to both of these structures by the palatopharyngeus muscles. Velar position also may be affected by variations in intraoral breath pressure during speech; the pressures built up in the oral cavity during fricative and stop sounds might tend to force the velum somewhat higher. It has been reported (*15*) that velar elevation becomes greater during blowing tasks as the pressure produced is increased. However, there are other factors besides intraoral pressure changes (such as variations in physiological effort) which could account for this observation.

VELAR MOVEMENT AS A PREPARATORY ACTIVITY. One of the observations made in this investigation which is not predictable from the hypothesized model is that the velum starts to elevate before the beginning of a sustained nasal sound and then descends for the sound. This finding parallels that of Fritzell (*4*) who observed electromyographic activity in the velar muscles preceding an utterance, even when the first sound in the utterance was a nasal consonant. These observations suggest that the velum elevates before the beginning of an utterance regardless of the first sound to be produced. If the first sound is a nasal, the velum may not elevate enough to obtain complete velopharyngeal closure before the muscular activity is changed to the opposite mode for the nasal sound. It might be hypothesized that velar elevation represents part of a preparatory activity for utterance which occurs prior to the beginning of any phonation. This hypothesis would explain why velar activity precedes the beginning of phonation and also precedes the movement of the tongue into position for the first sound (*2*, *12*).

A marked change in velar activity which was observed as the rate of production of /tʌ/ was increased from two to four syllables per second; the opening and closing movements of the velum which were noted at slower rates disappeared. If elevation of the velum is a preparatory activity for utterance, this observation may reflect the fact that each syllable is not considered as a separate utterance at high production rates; that is, velar muscle activity is not changed to the 'non-elevation mode' between each syllable because there is no utterance break. An alternative hypothesis is that not enough time is available for the velum to descend appreciably at the fast production rate before the next syllable starts. It is interesting to note, however, that the present findings on velar activity parallel those of Stetson and Hudgins (*16*) for abdominal muscle activity. They observed that separate abdominal pulses no longer preceded each syllable when rate of production exceeded two syllables per second. Instead, abdominal muscle activity was observed before groups of syllables. Stetson and Hudgins interpreted the abdominal pulses as representing a preparatory activity.

The observations discussed above suggest that elevation of the velum, activity of the abdominal muscles, and possibly other activities, such as laryngeal adjustments, may be involved in preparing the mechanism for utterance. Such a concept would explain why the velum elevates before an utterance, even if the first sound is a nasal. It also suggests that the velum may not be an 'articulatory' structure in the same sense as the tongue, jaw, and lips. The muscles elevating the velum may be turned 'on' for utterance and remain contracted unless a nasal consonant or a pause in utterance occurs; that is, the velum may not be activated separately for each sound or syllable unit at higher production rates. Any variation in velar positions during speech, except for nasal consonants or utterance breaks, would then be due to movements of the tongue or to the effects of other mechanical factors.

STATUS OF THE MODEL. On the basis of the findings of this study, it appears that the model of velar activity during speech which was hypothesized in the study can be utilized to explain variations in velar movements which are observed. The results of this preliminary investigation do not demonstrate the validity of the model. Further investigations are needed to apply the model to velar movements in other English speech samples and to other languages, to relate observations of velar muscle activity to velar movements, and to identify mechanical and other variables which affect velar positions. With information obtained from such investigations it may be possible to derive a mathematical model to predict velar positions and to construct a mechanical model of the system which can be used for experimentally varying different parameters.

Throughout this discussion it has been assumed that the proposed binary operation of the velar mechanism applies at the muscular-contraction level. It is possible, of course, that this two-mode mechanism may function at a higher physiological level; that is, in the peripheral or central nervous system. Such a possibility does not refute the proposed model, however, since the basic notion that only two velar positions are 'specified' during speech still would be valid. The only change necessary in the model would be to consider the properties of both the structural and muscular systems in accounting for variations in actual velar positions.

It is recognized that the observations on velar movements reported in this study might be interpreted differently. The observation that velar positions on adjacent vowels and nasal consonants vary with utterance rate could be interpreted as reflecting muscular adjustments by the speaker to adapt to such rates. The point to be made, however, is that it is possible to explain variations in velar positions, at least in the limited speech sample utilized in this study, on a much simpler basis, assuming a small number of different modes of muscular activity, possibly only two, and by considering the timing with which these modes are applied and various mechanical restraints on velar movement. As the work of Lindblom (*11*) and Stevens and House (*17*) has demonstrated, it should not merely be assumed that variations in structural positions and in the acoustic signal during speech must necessarily reflect an almost infinite number of complex adjustments and adaptations by the speaker. Such variations may be explainable on the basis of much simpler models. The theoretical model proposed in this study represents only a first attempt to obtain a simpler explanation of velar activity during speech than heretofore has been available.

Summary

This study was designed to provide a preliminary test of a new concept of velar activity during speech production. It was hypothesized that velar positions during speech might be explained by assuming only two modes of velar activity at the muscular level. In terms of this hypothesis, one muscular contraction mode would be applied to elevate the velum and close the velopharyngeal port during all non-nasal sounds and the second mode, resulting in little velar elevation, would be applied during such units as nasal consonants or utterance breaks. The intermediate velar positions which are observed in speech may then be accounted for by considering the timing with which the two modes are applied and the inherent restraints of the mechanical system on which the muscular contractions are acting.

The results of this study indicate that, as predicted from the hypothesized model, the position of the velum during various speech units depends on the durational characteristics of the units and, to some extent, on the position of the tongue. It is also suggested that velar elevation may represent a portion of a preparatory activity for utterance. Thus, in general, the results indicate that the hypothesized model of velar movements during speech appears tenable and that it serves to integrate and explain data of previous investigations.

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