A Cineradiographic and Electromyographic Investigation of Velar Positioning In Non-Nasal Speech

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Simultaneous cineradiographic and *electromyographic* analyses were made of the speech of three male and three female normal speaking adults. Each subject produced a series of symmetrical non-nasal CVC syllables embedded in a carrier phrase in a normal manner and also at increased rate and effort levels. A model of velar control was formulated and tested in relationship to changes in velar height resulting from forces provided by tongue positioning and contraction of *levator veli palatini*, *palatoglossus*, and *palatopharyngeus* muscles.

Two patterns of levator activity were observed in the six subjects. Palatopharyngeus activity appeared to be important in producing adjustments in exact velar position when the velum was in an elevated state. Palatoglossus activity appeared to be related to elevation of the posterior portion of the tongue. The time differences between changes in muscle activity and velar positioning were determined.

The results provide additional normative data regarding velar activity and serve to illustrate the need to view the velum as a complex mechanical system.

Review of Literature

The velum can be viewed as a mechanical structure responding to a number of potential force vectors pulling in different directions. This view suggests a need for the simultaneous study of electromyographic activity in the velopharyngeal muscles and associated velar movement. Previous studies investigating velar dynamics and their neuromotor control have either failed to monitor both the muscular and movement (Moll, 1962; Moll and Shriner, 1967; Fritzell and Lindquist, 1970; Kent et al. 1974; Bell-Berti, 1976; Kuehn, 1976; Benguerel *et al.*, 1977) or have not monitored a substantial number of muscles (at least levator, palatoglossus, and palatopharyngeus) at the same time in a given subject while monitoring movement (Lubker, 1968; Fritzell, 1969).

The purpose of this study was to investigate the effects on velar positioning of the forces provided by tongue positioning and contraction of the levator, palatoglossus, and palatopharyngeus muscles. A number of variables to be described below were utilized to manipulate these potential forces.

Method

Subjects. Three female and three male normal speaking young adults were used as subjects in this investigation. All of the subjects used the English dialect typical of the Midwest, and none had a history of orofacial anomalies.

Speech Sample. Symmetrical non-nasal consonant-vowel-consonant (CVC) syllables were constructed by using the vowels /i, I, æ, ʌ, u, ʊ, ɑ/ with the consonant /p/, and the consonants /p, b, s, ʃ, k/ with the vowel /ʌ/. These speech sounds were selected to assess the influence of tongue positioning (high, low, front, back) and articulatory tension (tense, lax) features of the vowels and the place (front-to-back) and voicing (voiced, voiceless) features of the consonants on velar position-

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ing. Each CVC syllable was produced in the carrier phrase "Say *CVC* again". Each syllable and its carrier phrase were produced twice. The entire set was produced in random order.

The effects of changes in rate and effort of production on velar positioning were assessed by utilizing symmetrical CVC syllables consisting of the consonants /p,k/ and the vowels /i,u/ in the carrier phrase. Each subject produced the utterances in a normal manner followed by either a fast rate or a double effort. The fast rate was described as being as fast as possible while maintaining intelligibility. Each subject was allowed to establish his or her own double effort level. In this study, double effort was equated with an increase in loudness. A pre-experiment practice session was used to monitor each subject's ability to maintain a consistent double effort (using a standard VU meter) and increased speaking rate.

Cineradiography. High speed (100 frames-per-second) cineradiographic analyses of lingual and velar movements were made of each subject. The equipment utilized has been described previously (Kent and Moll, 1969). The total radiation dosage per subject was less than 3R and was coned to the region below the lens of the eye and above the thyroid gland.

Prior to filming, three hemispherical radiopaque markers (approximately 3mm in diameter) were attached to the midline of the tongue in three locations (tip, blade, and dorsum) using the dental adhesive Durelon (Carboxylate cement). Figure 1 shows the placement of the three markers on the tongue of one subject. Each subject was allowed to practice the experimental utterances to facilitate adaptation to the markers. Only the tongue dorsum marker was utilized in subsequent analyses.

The frame-by-frame positioning of the tongue (tongue point markers) was determined by reading the instantaneous x-y position of each marker to the nearest half-millimeter from a template derived for each subject (Kuehn, 1976). Figure 1 shows an example of a template for one subject. Remeasurement of 50 film frames resulted in a standard error of measurement of less than one millimeter for each tongue marker for all but two subjects. In both of these subjects the blade marker had a standard error of measurement

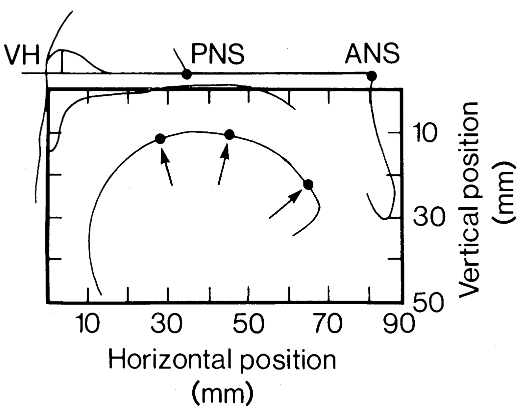

FIGURE 1. Tracing of cineradiograph for one subject. Velar height (VH) is measured along the line perpendicular to ANS-through-PNS line. Arrows indicate the fleshpoint tongue markers. The instantaneous x-y position of each marker was determined using the coordinate system drawn for this subject.

of less than two millimeters.

Velar height was measured frame-by-frame for each subject using a procedure similar to that described by Moll (1965) (Figure 1). Fifty frames were remeasured, and standard errors of measurement of less than one millimeter were found for all but one subject (SEM = 1.1 mm). The velar height measures were then graphed as a function of time (frame-by-frame) and smoothed by eye.

Selected points in time of various articulatory movements during the CVC syllables were determined for each subject. The frame numbers and corresponding time values were determined.

Electromyography. Three sets of hooked wire electrodes similar to those described by Hirose (1971) were inserted into the palatal levator, palatoglossus, and palatopharyngeus muscles. Each electrode was connected to a preamplifier set for a frequency response of 10 to 10,000 Hz and a gain of 1000. The preamplifiers were connected to driver amplifiers, which were coupled to separate channels of an FM tape recorder (recording speed of 30 inches-per-second). Also, the output from a Binary-Coded-Decimal (BCD) time code generator and a directional microphone were recorded on separate channels of the FM recorder.

The electrode insertion sites were prepared by using the topical anesthetic Cetacain. A ground electrode was placed on each subject's ear lobe using a standard electrode paste.

The insertion and verification procedure for levator and palatopharyngeus were the same as those reported by Bell-Berti (1976). Verification of electrode placement in palatoglossus was established if marked EMG activity was noted during the elevation of the tongue in the syllables /gɑ/ and /kɑ/. For both palatoglossus and palatopharyngeus, the electrodes were inserted in a caudal direction in the midline of each faucial pillar on the subject's right side.

Each channel of muscle activity was prepared for analysis by full-wave rectification and RC smoothing (time constant of smoothing = 20 msec). The output from the integrator and the time code generator were recorded on paper using a Visicorder (oscillographic recorder).

Data Reduction. The rectified and smoothed EMG recordings for each muscle and the velar and tongue displacement graphs for each utterance were aligned in time for each subject. These composite graphs were inspected to obtain information about the general patterning and levels of activity for the three muscles. Also, these data plots were used to obtain information about the relationships among velar height, muscle activity, and tongue height and the time latencies involved in the movements of the velum.

A model of velar positioning was formulated based on the anatomical relationships among the muscles, the tongue, and the velum (Figure 2). The direction of force generated by the active contractile elements of the musculature and the downward movement of the tongue are represented by the arrows. The exact angles of muscle courses and the potential magnitudes of force are not represented in this model. This simplified model was not intended to be complete. Rather, it was formulated to provide a framework within which to make predictions concerning the effects of tongue positioning and muscle activity on velar positioning.

Changes in muscle activity and tongue positioning were considered as independent variables in studying the dependent variable of velar height changes. Each muscle and the tongue dorsum were assumed to be capable of three changes in activity: increasing, decreasing or plateauing. Because the CVC syllables were nonasal, there was always some activity in levator when its activity plateaued. The plateau points for platoglossus and palatopharyngeus sometimes coincided with moments when activity had returned to a baseline resting level.

The velar height graphs were inspected for those points in time when movements equal to or greater than one millimeter were initiated. Next, the time location of the nearest inflection point (activity change) in the muscles and tongue movement graphs preceding the velar height inflection points were noted (Figure 3).

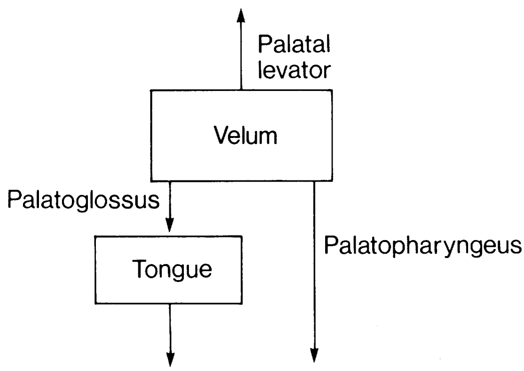

FIGURE 2. Schematic representation of the anatomical relationships among the velar musculature, the tongue, and the velum. Arrows represent the direction of force generated by a contraction of the musculature and the downward movement of the tongue.

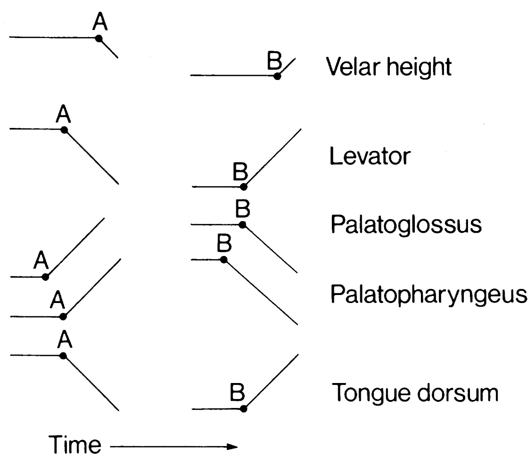

FIGURE 3. Schematic representation of rectified and smoothed EMG recordings and velar and tongue height graphs for an example of changes in the various measurements with a decrease in velar height (point A) and with an increase in velar height (point B). Velar height change is the dependent variable, and the others are independent variables.

The inflection points for the muscle activity and tongue height changes were used to determine percentages representing the number of velar height changes correctly predicted by the independent variables under study. The activity in one of the independent variables was considered to correctly predict the velar height change if that activity was consistent with the velar model. For instance, if levator increased in activity prior to a velar height increase, then its activity was thought to correctly predict the velar height change. Similarly, if the activity in one of the inferiorly positioned muscles increased prior to a decrease in velar height, this activity was thought to be consistent with the observed change in velar height. Also, a decrease in tongue height was considered to be consistent with a decrease in velar height because of the anatomical linkage between the tongue and the velum.

The points where the slopes of the muscle activity curves changed also had to be considered. If a rising slope in levator activity increased prior to an increase in velar height, then it was considered to be consistent with the proposed model in that this point represented a time when the lifting force provided by the levator presumably increased relative to the activity immediately preceding. If an increase in a rising slope in palatoglossus or palatopharyngeus activity was observed prior to a decrease in velar height, then this point was considered to predict a velar height decrease in that it represented a point when the force pulling down on the velum increased. The inflection point data were used also to determine the time latencies between the changes in tongue and muscle activity and velar height.

Results

GENERAL PATTERNS OF MUSCLE ACTIVITY. Two general patterns of levator activity were observed. In five subjects, levator activity continued to increase from its pre phonation onset to reach a maximum level during the CVC syllable, followed by a major decrease in activity generally after the production of the stressed CVC syllable (Figure 4). In one subject, the maximum level was observed after the CVC syllable. Some examples were observed of a pre-syllable build-up in levator activity followed by a leveling through the syllable. In the one subject exhibiting a different general pattern, levator activity was observed consistently to build to a peak prior to the production of the test syllable. From this peak, the activity then decreased continually throughout the rest of the utterance (Figure 5).

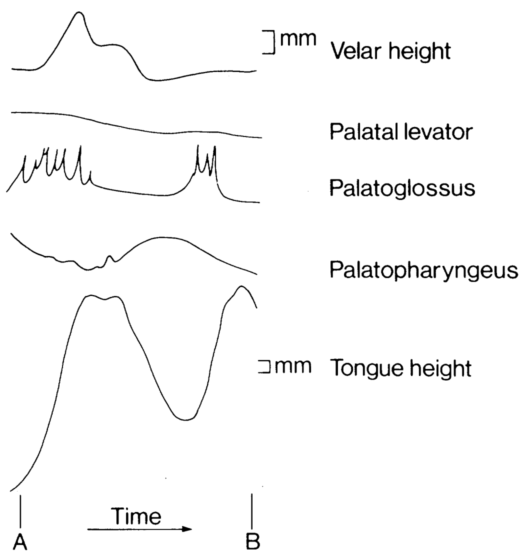

FIGURE 4. Example of velar and tongue height graphs and rectified and smoothed EMG recordings for Subject 1. Data obtained for the utterance "Say /kʌk/ again." Points A and B represent the articulatory approach and release of the initial and final consonants respectively in /kʌk/.

The activity in palatopharyngeus tended to parallel that of levator. This was also true of the one subject whose levator activity decreased throughout the utterance. Some examples of where palatopharyngeus activity remained fairly level during the utterance also were noted in this subject. Palatopharyngeus was sometimes observed to peak in activity long after the production of the CVC syllable near the end of the production of the carrier phrase in some of the subjects.

A general patterning of palatoglossus activity could be discerned in four of the six subjects. In two other subjects, little or no activity was observed in this muscle or the activity was often contaminated by artifacts created by electrode contact. For the four subjects, palatoglossus generally was active during the elevation gestures of the tongue (Figures 4 and 5), although not consistently for three of these subjects. A strong burst was often noted near the end of the CVC syllables in all four subjects, possibly for the /g/ consonant in the word "again". In one subject, two peaks of palatoglossus activity were observed for all syllables except those containing the /k/ consonant. The first peak usually was observed around the midpoint of the CVC syllable. The second and more prominent peak occurred just prior to the /g/ in the carrier phrase. In three subjects the CVC syllables containing /k/ consonants had three peaks in activity apparently associated with the production of the /k/ consonants and the /g/ in the last word of the carrier phrase.

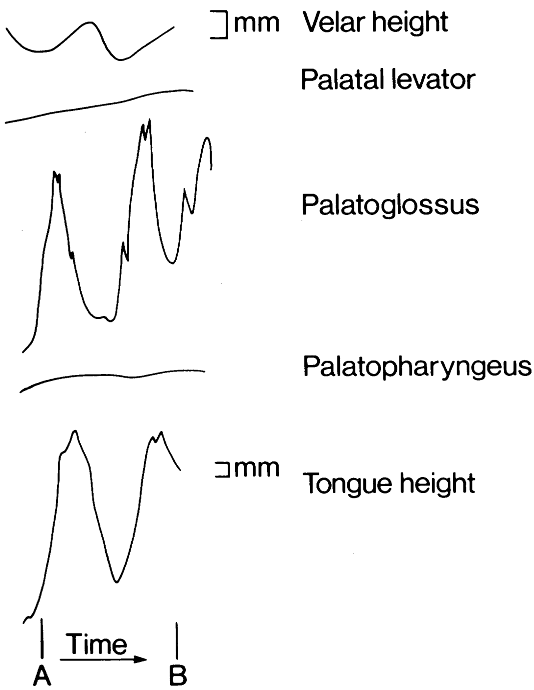

FIGURE 5. Example of velar and tongue height graphs and rectified and smoothed EMG recordings for Subject 4. Data obtained for the utterance "Say /kʌk/ again." Points A and B represent the articulatory approach and release of the initial and final consonants respectively in /kʌk/.

PHONETIC FEATURE EFFECTS ON VELAR HEIGHT AND MUSCLE ACTIVITY. Consistent differences in velar height were observed only for the comparison of high and low vowels (Table 1). The high vowels were associated with greater velar height in all six subjects. Considerable intersubject variation was observed in velar height for the other vowel feature comparisons (front/back, tense/lax) for the comparisons between the consonants /b, s, ʃ, k/ and the vowels /i, I, ɑ, u, ʊ, æ/ and the other consonant features (Table 2). Many of the differences were less than one millimeter.

Considerable intersubject variation was observed in the effects of the vowel features on the activity in the muscles. The most consistent findings were for the high/low feature. It was observed that this feature appeared to interact with the front-back positioning of the tongue. When differences were found, the high vowel syllables were associated with greater levels of activity in levator and palatoglossus. This was especially evident for comparisons of the back vowels. Differences in palatopharyngeus activity appeared to be related primarily to the high/low feature. When differences were observed, greater levels of activity were most often found in low vowel syllables. As was the case with other musculature, these differences were not observed in all subjects.

Although some differences in the patterning and levels of activity in the muscles could be found for the different consonant features, they were not present for all subjects, and there was often intersubject variation. The

TABLE 1. Means and Standard Deviations for the Cineradiographic Measurements (in Millimeters) of Velar Height for Each Subject for the Vowel Features.

Subject	*Front*		*Back*		*High*		*Low*		*Tense*		*Lax*	
	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*
1	5.2	2.8	5.2	1.2	6.4	0.9	3.7	1.9	5.9	0.7	6.8	0.9
2	2.7	1.1	3.2	0.8	3.4	0.5	1.9	0.8	3.6	0.6	3.3	0.3
3	3.9	0.7	4.2	1.0	4.4	0.6	3.7	0.6	4.4	0.7	4.5	0.6
4	2.3	0.4	2.2	0.7	2.3	0.6	2.2	0.6	2.2	0.8	2.3	0.4
5	17.6	1.4	16.5	1.8	17.4	1.7	16.1	1.5	17.8	1.5	17.1	2.0
6	4.2	0.4	4.0	1.0	4.4	0.5	3.4	0.5	4.2	0.6	4.7	0.3

TABLE 2. Means and Standard Deviations for the Cineradiographic Measurements (in Millimeters) of Velar Height for Each Subject for the Consonant Features, All Vowels Combined, and All Consonants Combined.

Subject	Vowels		Consonants		Voiced		Voice-Less		Labial		Lingual		/S/		/ʃ/		/k/	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
1	5.2	1.9	5.7	1.1	5.6	0.7	6.7	1.3	6.0	1.2	5.7	1.2	4.9	1.5	6.1	0.9	6.0	1.1
2	2.9	1.0	3.5	0.6	3.3	0.6	3.1	0.4	3.2	0.5	3.6	0.5	3.6	0.4	3.8	0.3	3.4	0.8
3	4.0	0.8	3.6	0.8	4.5	0.7	3.9	0.6	3.9	0.6	3.5	0.8	3.2	0.7	3.6	1.1	3.6	0.5
4	2.2	0.6	2.6	0.9	2.6	0.2	2.5	0.5	2.5	0.4	2.6	1.0	2.3	0.8	2.5	1.3	2.9	1.1
5	17.0	1.7	16.6	1.6	17.6	2.2	16.4	1.1	17.0	1.7	16.2	1.2	15.9	1.8	16.3	1.2	16.4	0.9
6	4.1	0.7	3.6	0.4	3.8	0.2	3.7	0.5	3.7	0.3	3.6	0.5	3.2	0.6	3.8	0.2	3.6	0.4

major finding for levator was greater levels of activity in the voiceless consonant /p/ syllables in two subjects. The place feature had very little or no effect on this muscle. The activity in palatoglossus appeared to have more pronounced changes and greater levels of activity in syllables containing such velar consonants as /k/. Palatopharyngeus appeared to be affected by both the voicing and place features in some subjects. The voiced consonant /b/ syllables generally exhibited activity which was constant and lower in level than the voiceless consonant /p/ syllables. The activity for the velar consonant /k/ syllables, when different, was higher in magnitude than for the more anterior lingual /s, ʃ/ consonants.

NONPHONETIC EFFECTS ON VELAR HEIGHTS AND MUSCLE ACTIVITY. The velum was found to be positioned higher for the velar consonant /k/ and those vowels produced adjacent to velar consonants in the fast rate condition. The velum was also found to be positioned higher for the increased effort condition for all but the vowels produced in the environment of the labial consonant /p/. The effort condition syllables (both normal and double effort) were associated with greater velar height than the rate condition syllables (both normal and fast rates).

Very few consistent differences were found in the patterning and levels of muscle activity for the rate and effort conditions. The general patterning of the fast rate utterances was not always the same as for the normal rate utterances, thereby not supporting the idea that the neuromotor signals to the velum undergo only a time reorganization during fast speaking rates (Moll and Shriner, 1967; Kent et al., 1974). Also, it should be pointed out that an increase in effort was not always accompanied by an increase in muscle activity.

VELAR HEIGHT PREDICTIONS. It should be emphasized that all of the velar height changes to be described in this section occurred when the velum was in an *elevated* position, that is, during the production of non-nasal speech. Consequently, most of the changes in velar position were relatively small, approximately one to six millimeters. Approximately 36% of the velar height changes could be accounted for by changes in levator activity only regardless of the activity in the inferiorly positioned independent variables (palatoglossus, palatopharnyngeus, and the tongue dorsum) (Table 3). The values for increases and decreases in velar height were quite similar (32% and 39% respectively). It also can be observed in Table 3 that considerable intersubject variation was obtained with values ranging from 19% for Subject 6 to 49% for Subject 3.

Table 4 contains the percentages of velar height changes predicted when all of the independent variables of the velar model were used in the analysis. Only 35% of the velar height changes could be accounted for by any of the variables under study when the activity in the remaining variables was not in violation of the predictions made by the model. Again, considerable intersubject variation was observed.

At least one of the four independent variables was in violation of the predictions made by the velar model for almost one half (89/214, 42%) of all the velar height changes observed. Of these 89 occurrences, 79% (70/89) involved violations in only one of the four independent variables. Of these 70, 60% (42/70) exhibited activity in more than one of the remaining three variables, which was consistent with the predictions made by the velar control model. Levator and tongue height were involved in 36% of the violations. Approximately 30% of the violations involved palatoglossus, and the lowest number of violations involved palatopharyngeus (26%).

Sex Effects. An analysis of the relative contribution of each of the inferiorly positioned variables in the predictions resulted in a sex related difference. In the male subjects, tongue height was involved in more of the velar height changes. For the female subjects, palatopharyngeus was found to be the most consistent inferiorly positioned variable in the predictions of velar height change. In both sexes, the palatoglossus muscle was the least accurate predictor.

TABLE 3. Percentages (%) and Ratios of Velar Height Changes Correctly Predicted by Changes in Palatal Levator Muscle Activity.

Subject	*Velar Height Changes*				*Total*	
	Increases		*Decreases*			
	Ratio	%	*Ratio*	%	*Ratio*	%
1	(12/28)	43	(14/33)	42	(26/61)	43
2	(2/12)	17	(6/11)	55	(9/23)	39
3	(7/16)	44	(12/23)	52	(19/39)	49
4	(2/13)	15	(4/16)	25	(6/29)	21
5	(7/18)	39	(5/13)	38	(12/31)	39
6	(3/15)	20	(3/16)	19	(6/31)	19
Mean	(33/102)	32	(44/112)	39	(77/214)	36

TABLE 4. Percentages (%) and Ratios of Velar Height Changes Correctly Predicted by the Model of Velar Functioning When the Activity in the Inferiorly and Superiorly Positioned Variables Was Not in Violation of the Predictions Made by the Velar Model (i.e., Number of Changes in Which at Least One Variable Was Correct with no Violations in the Others.

Subject	*Velar Height Changes*				*Total*	
	Increases		*Decreases*			
	Ratio	%	*Ratio*	%	*Ratio*	%
1	(14/28)	50	(9/33)	27	(23/61)	38
2	(1/12)	8	(4/11)	36	(5/23)	22
3	(6/16)	38	(11/23)	48	(17/39)	44
4	(3/13)	23	(3/16)	19	(6/29)	21
5	(3/18)	17	(5/13)	38	(8/31)	26
6	(8/15)	53	(7/16)	44	(15/31)	48
Mean	(35/102)	34	(39/112)	35	(74/214)	35

The number of velar height changes appeared to be affected by the sex factor. A large number of changes in velar height was observed in the female subjects. It was also observed that the number of decreases was larger than the number of increases in velar height in the female subjects.

Time Latencies. Average time latencies (onset of levator activity to change in velar height) were measured for those velar height changes correctly accounted for by levator only. Latencies of 56 msec for velar height increases and 27 msec for velar height decreases were observed. Some of the velar height changes were predicted by both levator and one or more of the inferiorly positioned variables. When these velar height changes were included in the analysis, average latencies of 32.4 msec and 40 msec were obtained for the increases and decreases respectively.

Time latencies were determined for each of the inferiorly positioned variables working independently and each in combination with one or more of the other variables. All three of the inferiorly positioned variables had average latencies (onset of muscle activity to change in velar height) in the 30 to 60 msec range. With the exception of the tongue height variable, the latencies established when a variable was working in combination with the others were longer than those for which the muscles accounted for the velar height changes independently. With the exception of palatopharyngeus, smaller latencies were obtained for the inferiorly positioned variables when levator also accounted for the velar height changes.

Discussion

PATTERNING OF MUSCLE ACTIVITY. *Levator Activity*: The results from this study indicate the levator tends to respond with maximum activity during the production of the stressed element (CVC syllable) of the phrase for most of the subjects. Therefore, the greatest magnitude of velar movement (i.e., velar elevation for the /s/ sound in the first word of the carrier phrase) was not found to be associated with maximum levator activity. One possible explanation of this finding is that the production of a stressed element in a phrase or sentence may be associated with a change in the neuromotor programming of levator. Harris (1971) found the genioglossus activity to be greater for vowels produced in stressed syllables. While the present investigation failed to find any consistent differences in levator activity associated with normal production and increased effort (loudness) of production, it may be that an increase in loudness does not involve the same neuromotor programming as the production of linguistic stress.

An alternative explanation involves the recruitment of motor units during voluntary motor acts. Sussman et al. (1977) have demonstrated that for certain speech activities larger motor units tend to be recruited after the smaller units in the anterior belly of the digastric muscle. The greater amplitude in levator activity during the middle of the phrase may represent the activation of larger motor units. This could be a response to increased demands to maintain velopharyngeal closure provided by changes in activity in the tongue and the inferiorly positioned velar musculature.

One of the subjects in this study demonstrated levator activity that decreased continually from a pre-syllable maximum. The velopharyngeal port was closed during the production of all utterances with the exception of two syllables, both containing the low vowel /ɑ/. Therefore, despite the continued decrease in levator activity, it would appear that sufficient activity was maintained to facilitate velopharyngeal closure for most of the oral speech sounds in this subject.

A number of investigators have attempted to relate the differences in velar height for the high and low vowels to differences in levator activity (Lubker, 1968; Fritzell, 1969; Bell-Berti, 1976). While the high vowels used in this study were associated with slightly greater velar height values than the low vowels, this difference was not always related to differences in levator activity in all subjects. Therefore, it would appear that the reported differences in levator activity for the high and low vowels may not be apparent when single productions of each vowel are compared. No consistent differences in levator activity could be found for the other vowel and consonant features. For the front/back vowel features, this result appears consistent with the findings of Fritzell (1969).

Fant (1973, p. 156) has described tenseness in vowels as being ". . . associated with a more extreme articulation and with a greater time spent in an extreme atticulatory position." The existance of what Fant called ". . . a more extreme articulation . . ." was not found at either the muscular or movement levels for the tense vowel syllables used in this study. In fact, the velum was found to be positioned higher for the lax vowels in three of the six subjects. Therefore, it would appear from the results of the present investigation that the tense/lax features of the vowel sounds do not consistently influence the positioning or control of the velum.

Bell-Berti (1973) found the differences in levator activity for voiced and voiceless stops to vary depending on the phonetic context. Only two subjects in the present investigation exhibited differences in levator activity for the voiced and voiceless consonant syllables. Although the voiceless consonant syllables had higher levels of activity in both subjects, the average velar heights for the voiced and voiceless consonants were the same. Because of the findings from these two studies, it would appear that further research is needed to investigate the influences of utterance construct on levator activity and velar positioning for voiced and voiceless consonants. It may be that these differences are simply a result of idiosyncratic behavior.

The finding of no consistent differences in levator activity between the labial and lingual consonants probably reflects the fact that all of these consonants require levator to respond by simply elevating the velum to provide an adequate velopharangeal seal. The lack of consistent differences between the various lingual consonants would tend to indicate that levator was not forced to exert a different level of effort in response to the place of articulation moving closer to the mechanical interconnection between the tongue and the palate.

Palatopharyngeus Activity: The finding indicating that palatopharyngeus activity parallels levator activity is consistent with the results of Bell-Berti (1976). In the present study, however, the onsets, offsets, and major peaks in palatopharyngeus activity were often located later in time than the corresponding levator activity. If the activity in palatopharyngeus is considered to be associated with a narrowing of the pharynx for vowel production and/or an adjustment of the larynx for the first voiced sound in the utterance, then these delays in the onset of palatopharyngeus activity must be accounted for by a response to the production of the vowel /eI/ in the word "say."

The increase in palatopharyngeus activity near the end of the production of the carrier phrase in some subjects is consistent with the findings of Fritzell (1969). Since no swallowing behavior was observed following the production of the test utterances in these examples, it is tempting to conclude that this activity might be associated with the velar lowering gesture for the /n/ in the word "again" and perhaps further velar lowering at the end of the utterance. However, other investigators (Fritzell *et al.,* 1974; Bell-Berti, 1976) have failed to find a relationship between increases in palatopharyngeus activity and the nasalization of speech. Because nasalized speech was not investigated in the present study, it is not clear at this time whether this activity is related to velar lowering or to some laryngeal and/or pharyngeal changes associated with the cessation of phonation.

A number of investigators (Fritzell, 1969; Fritzell *et al.*, 1974; Bell-Berti, 1976) have found greater levels of palatopharyngeus activity in the production of low vowels. In the present study only one subject demonstrated this relationship. Therefore, both inter- and intrasubject variability may exist in this muscle's involvement in the production of high and low vowels when the subject's productions are analyzed on an utterance-by-utterance basis.

Bell-Berti (1973) reported finding intersubject variation in the differences in palatopharyngeus activity for the production of voiced and voiceless stops. She related these findings to the control of pharyngeal cavity size to maintain the transglottic pressure differential necessary for the production of voiced stops. A "passive" expansion of the pharyngeal cavity was described as being characterized by an outward movement of the pharyngeal walls and could be expected to be associated with less palatopharyngeus muscle activity during the production of voiced stops. In the present investigation, three subjects demonstrated palatopharyngeus activity which was consistent with Bell-Berti's hypothesis, while a fourth was in violation. Although three subjects in the present study had palatopharyngeus activity consistent with Bell-Berti's predictions, her hypothesis would need to be tested using both the electromyographic analysis of the palatopharyngeus fibers contained within the pharyngeal wall and observations of changes in the size of the pharynx.

In three subjects, palatopharyngeus was observed to increase in activity as the place of articulation of the lingual consonants moved posteriorly. The reason for this finding is not clear at this time. It may be that this increase in activity is a response necessary to narrow the faucial isthmus to provide an adequate oral cavity seal for the pressure consonants or represents some type of laryngeal or pharyngeal adjustments associated with the production of back consonants.

Finally, palatopharyngeus appeared to be involved frequently in changes in velar height when the velum was in the elevated position. Therefore, it appears that the function of this muscle may be in making subtle adjustments of the velar mechanism in the elevated state.

Palatoglossus Activity: In general, palatoglossus activity was found to be consistent with that reported by other investigators (Fritzell, 1969; Lubker and May, 1973; Bell-Berti, 1976) in that it appeared to be related to the elevation of the posterior portion of the tongue. However, this patterning of activity was not always consistent in three of the four subjects for whom data could be analyzed, especially during the production of vowels.

SEX EFFECTS. Some differences were noted in velar activity in relation to the factor of sex in the present study. McKerns and Bzoch (1970) reported consistent differences between males and females in the configuration and positioning of the velum during speech. They hypothesized that the differences in the configuration of the velum during velopharyngeal closure may have been due to differences in the insertion sites of palatoglossus and palatopharyngeus relative to levator. The more obtuse angle in females was thought to be a result of palatopharyngeus and levator having similar velar insertion sites. It was hypothesized that the more acute angle found in males might be the result of a palatoglossus insertion site in the velum which is posterior to that of levator. Further analyses by the present investigators of previously reported data by Kuehn and Azzam (1978) revealed that palatoglossus had an insertion site in the same region as levator in three male subjects, a result not consistent with the McKerns and Bzoch hypothesis (See Figure 3A, Kuehn and Azzam, 1978). In an additional three male subjects and in all three female subjects, palatoglossus was found to insert into the velum posterior to the levator insertion. This finding also is in violation of the predictions made by the hypothesis for the female subjects. It would appear that continued investigation of the possible differences in the velopharyngeal mechanisms of male and female subjects is needed.

VELAR CONTROL MODEL. Considerable intersubject variation was observed in the prediction percentages obtained using the velar control model. This variation might be explained by a number of factors. For example, muscles other than those investigated in this study have the potential for affecting velar positioning. The involvement of these forces in altering the position of the velum may be subject specific. Therefore, this could alter the relative contribution of each muscle in the changes in velar positioning for a given subject. The elastic properties of both contractile and noncontractile tissue also may have the potential to affect velar positioning. It is not clear at this time how these components may have contributed to the observed intersubject variation. It is possible that some of the velar height changes not accounted for by the present model may have been a result of these factors.

A number of changes in muscle activity were actually in violation of the model. That is, an increase or decrease in velar height sometimes was accompanied by an inappropriate increase or decrease in muscle activity. It is assumed, logically, that other forces were sufficiently great to compensate for the force opposing the movement. However, until further biomechanical data are obtained, it is not possible to assign weights to the various forces acting on the velum.

The inability of this model to account for all of the velar height changes also may be related to the procedure used for analysis. An attempt was made to simplify the design of this study by excluding nasal consonants and studing the effects of major forces in positioning the *elevated* velum. The adjustments in velar height observed were relatively small, on the order of one to six millimeters. It may be desirable in future investigations involving models of velar control to increase the dynamic range of velar movements by including nasalized speech sounds. Moreover, the decisions about what constituted a change in muscle activity were subjective and could have been influenced by using different RC time constants in smoothing the raw EMG data.

Previous investigators have attempted to relate differences in velar positioning during the production of non-nasal speech either to the mechanical interconnection between the tongue and velum (Moll, 1962; Moll and Shriner, 1967) or to differences in levator activity (Lubker, 1968; Fritzell, 1969; Bell-Berti, 1976). The data from this investigation suggest that changes in velar positioning during the production of non-nasal speech are a result of the interaction of a number of variables operating simultaneously. Any attempt to relate only one of these variables to the activity of the velum may represent an oversimplification of this complex mechanical system. This study analyzed only four of the variables that have the potential to affect velar positioning. Other variables having a similar potential should be investigated. In this regard, the simultaneous observation of velopharyngeal movements and the associated muscle activity will be most efficacious. When such data are obtained in combination with other biomechanical properties such as tissue mass and elasticity, a more complete model of velar control can be formulated.

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