An Electromyographic-Cinefluorographic Investigation of Velar Function During Normal Speech Production

JAMES F. LUBKER, Ph.D.
Iowa City, Iowa

Impetus for this study was provided by a concept of palatal function described by Moll and Shriner (*23*) which suggests that, although palatal movement and position during the production of non-nasal sounds varies predictably in relation to such factors as phone type, duration, and consonantal context, the underlying neuromuscular activity is essentially invariant. More specifically, two levels of palatal muscular contraction are hypothesized: a) a relatively high level for the production of all non-nasal phones which require complete or nearly complete velopharyngeal closure, and 2) a relatively low level presumed to be characteristic of the production of nasal sounds and phrasing breaks when the velopharyngeal port is relatively open. In the case of prolonged vowels the variations in palatal position that occur in predictable association with differences in tongue height are attributed to constraints on palatal movement due to anatomical interconnection (for example, connections to the tongue via the palatoglossus muscle). Reduced palatal elevation in rapidly repeated nasal consonant-vowel syllables (which require alternate opening and closing of the velopharyngeal port) is explained as the inevitable result of the inertia of the palate which dictates that full elevation of the palate cannot be attained unless a certain minimum time is available. The data showing that palatal elevation may vary depending on the contextually adjacent consonants, or whether the vowel stands alone without preceding or following consonants, are also explained as a mechanico-inertial effect. This hypothesis is based upon more generalized theories of articulation which have been suggested by such investigators as Liberman, Cooper, Harris, and MacNeilage (*14*), Lindblom (*15, 16*), and Stevens and House (*27*). Although the import of these earlier theories is recognized, the present investigation will be concerned only with Moll and Shriner's applications of them to palatal function.

The significant point is that, according to the Moll and Shriner concept, none of these variations in palatal movement which have been observed for

Dr. Lubker is Research Assistant Professor, Department of Otolaryngology and Maxillofacial Surgery, University Hospitals, The University of Iowa. This paper was presented at the 72nd meeting of the Acoustical Society of America, November, 1966, and is based upon a dissertation completed under the direction of James F. Curtis, Ph.D., The University of Iowa. The study was supported in part by PHS Research Grant DE-00853, National Institute of Dental Research.

non-nasal sounds is considered to be the result of a corresponding variation in the underlying neuromuscular events. Stated somewhat differently, insofar as the basic neuromuscular events are concerned, the theory holds that palatal elevation and retraction for non-nasal sounds and the absence of palatal elevation in nasal sounds is considered to be a binary distinctive feature having only two significant states. This is held to be true despite the variability of positions and movements actually observed, since this variability is presumed to be a function of peripheral conditions that are incidental to the basic feature.

In their report, Moll and Shriner discuss data which appear to be consistent with the previously stated hypothesis, at least in the sense that their data are not contradictory to it and, to some extent, may be predicted by the hypothesis. However, their data are derived entirely from cinefluorographic observations and provide no information about the neuromuscular events of the palate which accompanied their speech utterances. Since the binary assumption is not the only possible one which would fit their cinefluorographic data, further testing of the assumption appears warranted.

The present study is an attempt to provide information about the neuromuscular events associated with palatal movements during speech, and to provide an additional test of the binary assumption discussed by Moll and Shriner.

Procedures

Subject and Speech Sample. Simultaneous electromyographic and cinefluorographic records were obtained from five normal speaking adults, three male and two female. The speech sample used in this research, shown in Figure 1, was selected to provide several possibilities for variations in palatal activity. To sample the effects of tongue position, four vowels (/i, u, æ, ɑ/) selected to represent the extremes of high, low, front, and back tongue positions were produced by each subject in the sustained, isolated

SPEECH SAMPLE

I. To Sample Tongue/Palate Position on Sustained Phone Types
High Front /i/ High Back /u/ Nasal /m/
Low Front /æ/ Low Back /ɑ/

II. To Sample Effects of Duration
Long duration /i/, /æ/ and /m/, approx. 1.0 sec.
Short duration /i/, /æ/ and /m/, approx. 0.25 sec.

III. To Sample Variation in Phonetic Context – CV Syllables
/pi/, /bi/, /ti/, /di/, /mi/
/pæ/, /bæ/, /tæ/, /dæ/, /mæ/

FIGURE 1. Speech sample.

state. In addition, the nasal consonant /m/ was sustained in isolation to provide a sample of an open velopharyngeal port. To sample the effects of changes in duration, subjects were required to produce the vowels /i/ and /æ/ and the nasal consonant /m/ at both relatively long durations (approximately 1.0 sec) and at relatively short durations (approximately .25 sec). To sample phonetic context variations, consonant-vowel (CV) syllables were formed, consisting of all possible pairings of the vowels /i/ and /æ/ with the consonants /b, p, d, t, m/. The order of the utterances comprising the speech sample was randomized for each subject. Because of the inherent variability of electromyographic data each utterance type (that is, each sustained, isolated sound, or each syllable) was repeated 20 times during each experimental run. Electromyographic records were taken during all 20 repetitions of each utterance type. To minimize radiation exposure of the subjects, cinefluorographic films were exposed only during the middle three of the 20 repetitions.

In order to provide a baseline for evaluation of both cinefluorographic measurements and EMG signals, a condition of "physiologic rest" was included: prior to the production of the speech sample the subject sat quietly at rest for several seconds and breathed lightly through the nose with the lips closed. (EMG recordings and cineflurographic films were obtained throughout the physiologic rest condition.)

Apparatus. A block diagram of the instrumentation is shown in Figure 2. The cinefluorographic unit has been described in detail elsewhere (*19, 20*). It includes a Philips nine-inch intensifier and an Auricon 16 mm

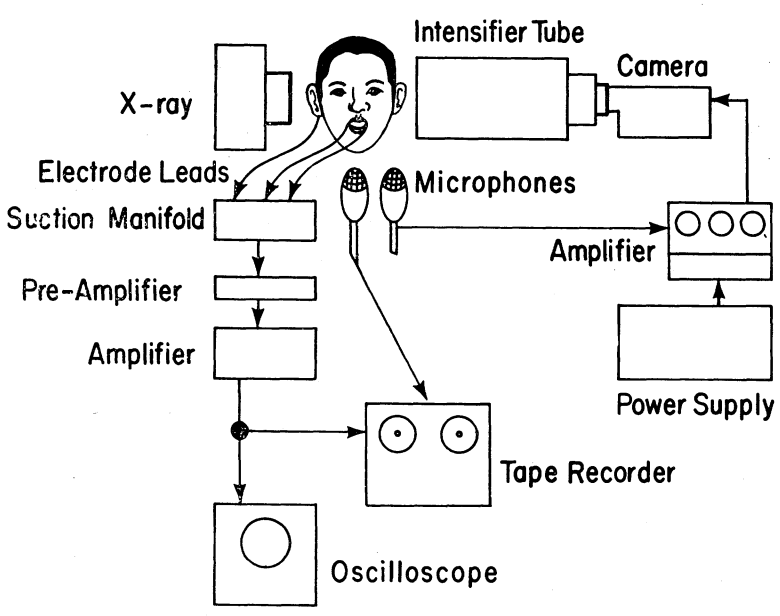

FIGURE 2. Block diagram of instrumentation.

sound-on-film motion picture camera. The camera operated at a film speed of 24 frames per second.

The primary electromyographic equipment consisted of a surface suction electrode system (*10*), a custom made pre-amplifier and amplifier having very low noise and excellent frequency response characteristics[1], a Magnacord (Model 728) two-channel tape recorder, and a Tektronix Type 503 oscilloscope which was used for continuous visual monitoring of the EMG signal. The amplified EMG signal was recorded on one channel of the magnetic tape while the speech signal was simultaneously recorded on the second channel. The overall frequency response of the system (including both record and playback) is flat, ±2 dB, from 50 to 10,000 Hz.

DATA COLLECTION. A bipolar electrode system was used on the palate, with a third (ground) electrode attached to the ear lobe. The active and reference electrodes were placed side by side in the middle third of the soft palate, at the approximate level of the palatal levator dimple. The specific placement of the electrodes was based upon previous research which indicates: a) that the muscles used to elevate the palate apparently function as a unit, each performing in essentially the same manner (*6*, *25*), and b) that surface electrodes placed at a variety of locations on the superior and inferior surfaces of the palate record 'essentially the same picture of activity at all palatal locations' (*11*). Therefore, in the present study, the electrodes were placed in a relatively accessible position which also demonstrated considerable muscular (primarily levator) function. The placement of the electrodes and tubing was such that contact between the subject's tongue and the tubing was minimized.

A short rest period followed placement of the electrodes to allow them to achieve maximal attachment. A medical suction apparatus was used to remove saliva so that it was unnecessary for the subject to swallow, thus making it possible for the tongue and palate to be held essentially immobile during the rest period. Prior to starting the experimental run, the subject produced the entire speech sample in order a) to determine the adequacy of the electrode attachment, b) to provide a final check on the entire system, for example, gain settings and noise levels, and c) to allow the subject to adapt to the presence of the electrodes.

DATA REDUCTION.

Cinefluorographic Films. The technique used in this study to obtain speech articulation measurements from cinefluorographic films has been described in detail by Moll (*21*). Briefly, the procedure involves the frame-by-frame projection of a life-size image of selected frames of cinefluorographic film. The structures of interest are traced for each of the selected frames and measurements are made to the nearest 0.5 mm. Nine measurements of structural positioning were made from each selected frame of cinefluorographic film. The nine measurements are shown by a sample

[1] Schematic diagrams and operating characteristics of these components may be obtained from the author.

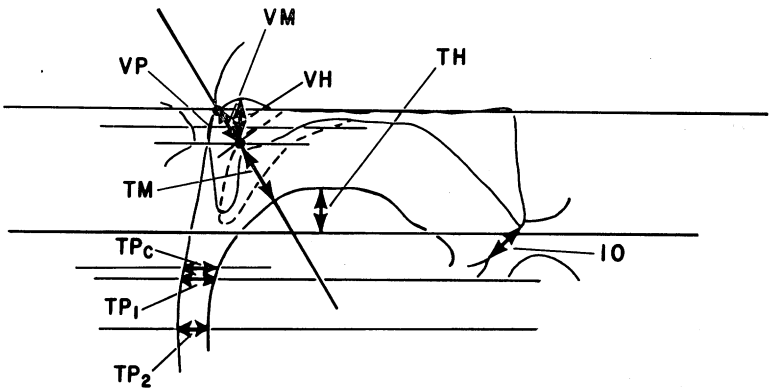

FIGURE 3. Sample tracing of cinefluorographic film showing measures describing palate, tongue, and jaw movements. (see also Appendix A)

tracing in Figure 3 and are described in Appendix A. Tracings and measurements were made of all frames exposed during the vowel portions of all three repetitions of each utterance type. The individual, or subject, score for each cinefluorographic measure was obtained by averaging these frame-by-frame measurements over all three repetitions. The individual scores were then averaged over all five subjects to provide a group mean for each of the measurements.

Electromyographic Records. The relationship between the force of muscle contraction and the electrical activity recorded by electromyographic procedures has been studied by a number of investigators (*1*, *2*, *4*, *18*). In general, these studies have shown that, for any given condition of muscle contraction, there is a close, rectilinear relationship between the force of muscle contraction and the integral of the EMG signal. However, the slope of the straight line relating force of muscle contraction and the integrated EMG varies for different conditions of muscle shortening and lengthening; that is, a different slope is obtained for isometric as compared to isotonic contraction, and the slope during isotonic contraction depends on the rate at which the muscle is shortening or lengthening.

In an experimental situation of this kind, the muscle contraction conditions are dictated by the movements required by the particular speech utterance and cannot be maintained constant. During the utterance of sustained, isolated speech sounds, the condition probably approximates isometric contraction since the structures are held relatively immobile. During syllable utterance the palate may or may not be moving, depending on the nature of the syllable, and the rate of movement must be related to the rate of syllable production. Thus, the information yielded by EMG records under such conditions is necessarily less precise than suggested by other investigators (cited in the previous paragraph) who were able to conduct more precisely controlled experiments. Despite these limitations, the practice of integrating EMG signals over time appears to provide the best available means of relating the information contained in the EMG record to the force of muscle contraction.

Two different types of integration process have been used in processing EMG signals. In both types the signal is first rectified to convert it to a unipolar signal and the instantaneous amplitudes in the unipolar signal are then summed in an integrating circuit. The fundamental difference between the two types of integration relates to the time constant of the integrating circuit which determines the effective time interval over which the signal amplitudes are summed. In the previously cited studies (*1*, *2*, *4*, *18*) relating the integral of the muscle action potential to force of muscle contraction, the time constants of integration were extremely long, so that muscle action potentials were integrated over the entire period of muscle action. However, it has become a relatively common practice in investigations utilizing EMG recording to employ integrating circuits with relatively short time-constants, of the order of five to twenty msec. (*7*, *8*, *9*, *11*, *20*). Such short time integration is essentially a smoothing operation, equivalent electrically to low-pass filtering of the signal. It is graphically very closely analogous to smoothing a curve through the peaks of the direct EMG signal by inspection. The principle advantage over such a graphical process, aside from the fact that an electrical circuit can perform the smoothing quickly and automatically, is that the electrical circuit takes account of both the amplitude and the frequency information in the direct EMG signal.

In the present instance, because of the nature of the experimental conditions, it was possible to employ a long (essentially infinite) time-constant. This type of integration circuit was employed because the data thus obtained are judged to be more nearly like those on which the fundamental relations between EMG signals and force of muscle contraction were established.

The method used for measuring the integrated electromyographic signals may be illustrated by reference to Figure 4, which is a section of a strip chart record for two repetitions of one of the sustained, isolated vowels. The lower of the three traces shown is the rectified, integrated electromyographic signal. The height of this trace at any point in time during an utterance is proportional to the sum of all voltage deflections in the signal from the beginning of the utterance to the given point in time. The curve rises more rapidly if the amplitudes of the individual voltage deflections are large than if the signal amplitudes are small; it also rises more rapidly as the frequency of the voltage deflections in the signal is increased. With surface electrodes, as were used in this study, the signal deflections represent a summation of presumably uncorrelated motor unit discharges. Variations in total amount of motor activity within the field of the electrodes may be reflected in the signal by changes both in signal amplitude and in signal frequency. Thus, the integrated curve, which is responsive to changes in both amplitude and frequency, provides an index of the total amount of motor unit activity within the field of the electrodes.

A measure of the total amount of electromyographic activity during the complete utterance would be provided by a simple measure of the height of the integrated curve at the end of the utterance. However, this measure would depend on the duration of the utterance as well as on the amplitude and frequency of the signal being recorded. Thus, two utterances, each of which involved the same average amount of activity, would give different measures if their durations were unequal. However, the average amount of activity during any given period of time is reflected by the rate of rise (slope) of the curve within this period (that is, the steeper the slope the greater the activity). Inspection of the data (see Figure 4) indicated that the slope was essentially invariant, for a given utterance, with time. Thus, slope was the criterion measure of electromyographic activity used in the present study and was obtained by dividing the change in height over the period of interest by the duration of this period.

The slope (rise/run) of the integrated trace was measured for the vowel portion (arbitrarily selected with reference to the audio signal) of each of the 20 repetitions of each of the several utterance types for each of the five subjects. The criterion measure computed for each subject was the average of these twenty measures of slope. A group mean over all five subjects was then computed for the several utterance types.

The middle trace in Figure 4 is the output of a differentiator circuit which

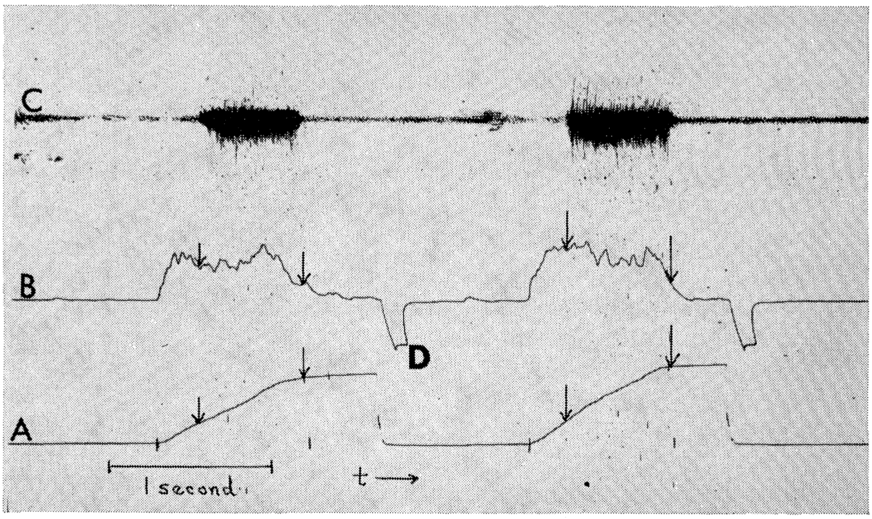

FIGURE 4. Strip chart record of two tokens of a sustained, detached vowel. "A" is the rectified, integrated electromyographic trace; "B" is the differential of the integrated trace; and, "C" is the audio signal. "D" represents the points at which the integrator was reset to zero. Arrows represent the onset and offset of voicing for the vowel. Time moves from left to right at 50 mm per second.

was connected in series following the integrator. The varying height of this trace reflects the short time variation in the slope of the integrated trace. Because integration and differentiation are opposite processes the output of the differentiator would be the rectified direct electromyographic signal except for the smoothing due to the time-constant of the differentiating circuit. The output of the differentiator circuit is therefore comparable to the result of the short time integration process previously referred to. In the present study the differentiated trace was not used for any of the basic measures.

Results

CINEFLUOROGRAPHIC OBSERVATIONS. The group means and standard deviations of the cinefluorographic measures of velar movement (VM), velar height (VH), and velopharyngeal opening (VP) made during the production of the sustained, isolated phone types are presented in Table 1. Inspection of Table 1 suggests that high vowels are characterized by greater velar elevation than low vowels, whereas the nasal consonant articulation exhibits less velar elevation than either the high or low vowels. Treatments x subjects analyses of variance *(17)* indicated that for each of the three velar measures, the over-all differences in velar positioning among the five phone types were significant at the 5% level of confidence.

As a further test of the significance of the differences observed in Table 1, Scheffé tests for post hoc comparisons *(12)* were performed. This test allows determination of whether or not any given comparisons or groups of comparisons made significant contributions to the over-all significance of an F ratio. The results of the Scheffé tests indicated a) that there was significantly greater palatal elevation for the high vowels as a group (/i/ and /u/) than for the low vowels as a group (/æ/ and /ɑ/), and b) that palatal elevation for each of the vowels was significantly greater than for the nasal consonant. In addition, palatal position for the nasal consonant was not significantly different from the rest position for the five subjects in this study. With reference to the last point, it should be noted that for the phone type /m/

TABLE 1. Means and standard deviations, in millimeters, of the cinefluorographic measures of VM, VH, and VP during the production of the sustained, detached phone types.

	High vowels				*Low vowels*				*Nasal*	
	/i/		/u/		/æ/		/ɑ/		/m/	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
VM	15.3	1.53	15.8	1.46	12.5	0.93	12.8	1.88	2.1	1.86
VH	12.6	1.00	12.9	0.62	10.3	0.74	10.0	2.03	0.2	0.24
VP	0.1	0.07	0.1	0.05	2.4	1.63	3.4	2.21	17.0	3.27

the velar measures were characterized by considerable between-subject variation. Three of the five subjects exhibited mean scores of less than .9 mm of movement for the measure VM.

No significant variations in velar positions were noted between the sustained and the short duration productions of the three phone types (see Table 2).

The group means and standard deviations obtained for the production of /i/ and /æ/ in syllables in which the vowels were preceded by each of the consonants /b, p, t, d, m/ are given in Table 3. Data for the two sustained vowels are also given in Table 3 to allow comparison of the vowels in context to vowels in the detached, isolated state. Inspection of Table 3 suggests that, for both /i/ and /æ/, the velar position is very similar among the several stop consonants and that velar position in these stop consonant-vowel syllables appears to be essentially similar to that of the sustained vowel. However, for both /i/ and /æ/, velar position as measured during the vowel which is preceded by the nasal consonant /m/ is considerably lower than that of the stop consonant-vowel syllables or the sustained, isolated vowel. Analyses of variance were performed to test the significance of the differences noted in Table 3. The F ratios were significant at the 5% level for all three velar measures for both /i/ and /æ/. Further, Scheffé tests indicated that the over-all significant differences demonstrated by the analyses of variance were due primarily to the position of the soft palate during the vowel portion of the nasal consonant syllable rather than to

TABLE 2. Means and standard deviations, in millimeters, of the cinefluorographic measures VM, VH, and VP during the production of the durational variations of the detached phone types /i/, /æ/, and /m/.

	VM	*VH*	*VP*
sustained /i/ (.89 seconds)			
mean	15.3	12.6	0.1
SD	1.53	1.00	0.07
short /i/ (.21 seconds)			
mean	15.6	12.4	0.1
SD	2.07	0.65	0.26
sustained /æ/ (.89 seconds)			
mean	12.5	10.3	2.4
SD	0.94	0.74	1.63
short /æ/ (.24 seconds)			
mean	12.1	10.2	2.9
SD	1.45	1.00	2.43
sustained /m/ (1.13 seconds)			
mean	2.1	0.2	17.0
SD	1.86	0.24	3.27
short /m/ (.22 seconds)			
mean	2.3	0.1	16.3
SD	1.85	0.12	2.86

TABLE 3. Means and standard deviations, in millimeters, of the measures VM, VH, and VP during the production of the vowels /i/ and /æ/ in various consonantal environments and in the sustained, detached condition.

	VM		*VH*		*VP*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
/bi/	15.5	2.14	12.5	0.79	0.1	0.10
/pi/	14.7	2.06	11.9	1.19	0.3	0.34
/di/	15.3	1.72	12.6	1.04	0.1	0.05
/ti/	15.2	1.48	12.6	0.52	0.1	0.10
/mi/	12.9	1.77	10.5	1.01	2.0	0.82
sustained /i/	15.3	1.53	12.6	1.00	0.1	0.07
/bæ/	13.2	1.92	10.8	1.33	1.6	1.21
/pæ/	12.5	1.64	10.5	1.43	1.6	1.57
/dæ/	13.4	1.55	11.5	1.10	1.2	1.08
/tæ/	12.4	1.80	10.4	1.72	2.1	2.16
/mæ/	8.7	1.42	6.1	2.36	6.9	2.16
sustained /æ/	12.5	0.93	10.3	0.74	2.4	1.63

differences among the various stop consonant-vowel syllables or to differences between the stop consonant syllable and the vowel produced in isolation. The data in Table 3 also suggest that the differences in velar positioning between the vowels /i/ and /æ/ in the several consonantal contexts are similar to those noted when these vowels are produced in the detached state. That is, the velum appears to rise higher for the production of /i/ than for /æ/ when these vowels are produced in consonant-vowels syllables as well as in the isolated condition.

TONGUE-PALATE RELATIONSHIPS. Pearson product-moment correlation coefficients were computed to determine the degree of relationship between each of the measures of tongue position and each of the measures of velar position. The correlation coefficients obtained for the detached vowels are given in Table 4 and, for the vowels /i/ and /æ/ in syllabic context, in Table 5. Examination of these tables indicates that, taken as a whole, there appears to be a considerable degree of interdependence between tongue position and velar position. This interdependence is most consistent between the measure of tongue height (TH) and the several measures of velar position. Somewhat surprisingly, the measures of tongue movement (TM) and velar movement (VM), which were expected to show a relatively high degree of relationship since they were measured along the same reference line, failed to do so. For these two measures the correlation coefficients show an inconsistent and frequently low degree of relationship.

ELECTROMYOGRAPHIC-CINEFLUOROGRAPHIC COVARIATIONS. In order to describe relationships between positions assumed by the soft palate and the electromyographic activity generated by the muscles of the palate in assuming that position, correlation coefficients were computed between the

TABLE 4. Pearson product moment correlation coefficients for selected pairs of cinefluorographic measures made during the production of the detached phones /i/, /æ/, /u/, and /ɑ/, by all five subjects.

	VM	*VH*	*VP*
VM		.84	−.69
VH			−.86
TP_c	.39	.55	−.54
TP_2	.16	.31	−.35
TP_1	−.10	−.11	.05
TM	−.47	−.33	.12
TH	.55	.56	−.46
IO	−.42	−.58	.42

TABLE 5. Pearson product moment correlation coefficients for selected pairs of cinefluorographic measures made during the production of the vowel portion of the consonant-vowel syllables /bi/, /pi/, /di/, /ti/, /bæ/,/pæ/ /dæ/, and /tæ/ by all five subjects.

	VM	*VH*	*VP*
VM		.80	−.47
VH			−.78
TP_c	.28	.51	−.62
TP_2	.13	.32	−.52
TP_1	.01	−.12	−.04
TM	−.17	.04	−.28
TH	.61	.54	−.45
IO	−.34	−.44	.48

three velar measures of velar movement (VM), velar height (VH), and velopharyngeal opening (VP) and the slope of the integrated electromyographic signal for the detached vowels and for the vowels in consonantal environment. The mean correlation coefficients, computed over all five subjects, are given in Table 6.

It is clear from Table 6 that a rather high correlation exists between velar position and velar electromyographic activity. It may be further noted from Table 6 that there is little difference between the correlations obtained for the isolated vowels and for the vowels in the consonantal environments. Also, the correlation coefficients for the measure VH and VM are very similar, although the coefficients for the measure VP are somewhat lower in magnitude than they. This latter observation may be explained by the fact that when the velopharyngeal port closes, the measure VP becomes zero; thus, no matter how forcefully the palatal muscles contract thereafter, the value of VP does not change. However, if the muscles of the palate

TABLE 6. Mean within-subject Pearson product moment correlation coefficients between velar position measures and slope of integrated electromyographic traces for. detached vowels and for vowels in consonant-vowel syllables.

measures	*slope*	
	detached	*syllable*
VM	.83	.80
VH	.79	.76
VP	−.69	−.71

continue to contract, the palate may continue to *rise* even after closure has been obtained. Therefore, the linear relationship between force of muscle contraction and the measures of VM and VH should extend over a greater range of the correlated variables than is the case for the measure VP. This would further suggest that, of the three velar measures reported in this study, the measure VP is probably the least valuable insofar as relationships with velar electromyographic activity are concerned.

ELECTROMYOGRAPHIC OBSERVATIONS. The group means and their standard deviations for the slopes of the rectified, integrated electromyographic records of the several utterance types are presented in Table 7. Data for the sustained, isolated /m/ were not obtained since the electromyographic signals occurring during the production of /m/, if any, were at such a low level that they were completely masked by the noise inherent in the system.

Examination of Table 7 indicates that there was clearly greater slope (that is, greater electromyographic activity) for the high vowels than for the low vowels. Application of analyses of variance and the Scheffé test indicated that a) the over-all difference in slope was significant at the 1% level; and b) the two high vowels *as a group* showed significantly greater slope than did the low vowels *as a group*.

The data presented in Table 7 also show very little differences in slope with changes in duration of vowel production. Indeed, analyses of variance

TABLE 7. Group means and standard deviations for slope of the integrated electromyographic signal produced during the production of all speech tasks.

	/i/		/æ/		/u/		/ɑ/	
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*mean*	*SD*
sustained	.36	.16	.23	.09	.48	.12	.24	.11
short	.38	.16	.26	.06				
b_	.30	.15	.20	.11				
p_	.29	.14	.19	.09				
d_	.31	.08	.20	.09				
t_	.27	.13	.19	.10				
m_	.29	.15	.12	.08				

revealed that these differences were nonsignificant at the 5% level for both /i/ and /æ/.

Statistical analyses of the slope of the vowel portion of the consonant-vowel syllables showed that: a) the slope of the high vowels in context was significantly greater than that for the low vowels in context; b) although for both /i/ and /æ/ the slope of the vowel in context appeared less than for the detached vowel, this difference was significant only for the vowel /æ/; and c) the vowel /æ/ in the syllable /mæ/ exhibited significantly less slope than in any of the other syllables or in the detached state.

Discussion

A primary motivation for the present research was to test an hypothesis which predicts that, although palatal position may vary complexly under conditions of the type imposed by the present experiment, the associated palatal muscle activity will show a much simpler organization (that is, it will be found at only two discrete levels).

TONGUE-PALATE RELATIONSHIPS. As would be expected from the results of previous research, the data from the present investigation indicated that palatal positioning varies with changes in phone type and consonantal environment. According to the hypothesis under test, a major reason for such variation is due to anatomical constraint due to interconnection between structures rather than to variation in activity of the palatal musculature. Specifically, the tongue and palate are presumed to be interconnected functionally so that a lower tongue position will result in a lower palate position, and vice versa. The data from the present research suggest that a direct relationship exists between tongue and palate position. While correlation between two variables does not indicate that a causal relationship necessarily exists, in the present instance, such a relationship between tongue and palate positioning seems likely on anatomical grounds. However, a plausible alternative explanation can also be provided. Perceptual studies of vowel nasalization (*13*) have established that a greater degree of opening at the velopharyngeal port can be tolerated for low vowels than for high vowels before the vowels are perceived as nasal in quality. In addition, both the acoustic theory of speech (*5*, *27*) and empirical investigation have shown that the acoustical effects of nasal cavity coupling are greater for vowels articulated with high tongue positions and corresponding constricted oral transmission channels than for vowels for which the tongue position is low and the oral tract is relatively open. Taken together, these findings indicate that the degree of velopharyngeal closure is more critical for high vowels than for low vowels, that is, the amount of velar elevation (and degree of velopharyngeal closure) required for the articulation of a perceptually non-nasal vowel is greater for high vowels than for low vowels. Thus, greater force of muscle contraction under conditions such as those presented by high vowels may be a requirement for the mechanism to produce speech that is non-nasal in quality. This alternative explanation for the observed correlation between tongue positioning and velar positioning does not depend on anatomical interconnections.

Duration Data. Moll and Shriner (*23*) observed a decrease in palatal movement as the speaking rate for the nasal consonant-vowel syllables was increased from one syllable per second to four syllables per second, indicating that changes in rate (duration) of syllable production effect velar movement. In the present study, neither palatal positioning nor electromyographic activity showed significant differences between "short" and sustained durations. The duration data in the present study are not directly comparable to the Moll-Shriner data, since the duration of detached vowels, rather than syllable rate, was controlled in the present experiment. The "short" phone types were produced at durations ranging from approximately .21 to .24 sec with an interval of approximately 2.0 sec between tokens, during which the palate returned to physiologic rest. Apparently, a duration of from .21 to .24 sec is not very short in relation to the duration of a phone type occurring in connected speech (*25*). It is possible that the "short" duration was long enough for the palate to reach its 'target position', and it is therefore probable that duration may not have been effectively varied in the present research.

Correlation of Electromyographic Data and Palatal Positioning. The Moll-Shriner hypothesis suggests that a relatively simple organization of velar muscle activity may underly the complex pattern of palatal positioning during speech production. Specifically, only two levels of muscle activity are assumed—one for non-nasal phones and a second, lower level for nasal phones. The hypothesis thus implies that within the class of non-nasal phone types, velar muscle activity does not vary significantly. The data from the present study are not consistent with this view. On the contrary, palatal muscular activity was found to vary systematically and significantly when palatal position showed significant variation. There was significantly greater palatal elevation and more electromyographic activity for high vowels than for low vowels in context and in the detached state. The covariation suggested by these observations is further demonstrated by the consistently high correlation coefficients that were obtained between the measure of electromyographic activity and velar elevation (ranging from .79 to .83). There are at least two possible explanations for the variations in palatal elevation that occur for various phone types in context: a) the palate elevates to greater or lesser degree because of constraints due to anatomical interconnections and timing, and b) the palate elevates in greater or lesser degree dependent on the velopharyngeal closure required for the utterance to be perceived as non-nasal. If the first explanation is correct, variation in velar muscle activity would not be required to produce the variations in palatal elevation. On the other hand, if the second explanation is correct one would expect more vigorous muscle activity as greater velopharyngeal closure is required. A close correspondence was observed between palatal movement and the amount of velar muscle activity in the present experiment. Hence, the second explanation appears to be more plausible. Further evidence to support the second alternative may be found in the correlation coefficient data. The coefficients obtained between electromyographic activity and velar positioning (from .79 to .83) were much higher than those between tongue height and velar positioning (from .55 to .61).

The present study also provided data pertinent to palatal function during the production of nasal phone types for which the hypothesis under study assumes a discrete low level of muscular activity. The results of the present research are not entirely consistent with this assumption. Although, on the average, palatal elevation during the production of the sustained /m/ was slightly above physiologic rest in the present study (approximately 2 mm), there was considerable between-subject variability. In a number of instances there was little or no elevation of the palate during nasal consonant production. Specifically, for three of the five subjects, mean palatal movement during production of the sustained, detached /m/ was less than .9 mm. The mean velar movement (VM) for one of these three subjects was only .02 mm above physiologic rest. In addition, electromyographic activity during the production of the detached /m/ was not consistently discernible for *any* of the subjects. It therefore appears that nasal consonants can be produced with little or no velar elevation. It may not be necessary, therefore, to assume a special level of activity for these phone types.

The present research represents a first attempt to obtain simultaneous cinefluorographic and electromyographic data from the soft palate. The observations made in this study need to be replicated and extended. In particular, the speech sample should be extended and the electrode placement should be refined and varied. More information is needed relative to the relationship between force of muscle contraction and the integrated electromyographic signal. Information obtained by the technique of electromyography, which records electrical discharge of muscle fibers, is, of course, relevant to the peripheral activity of the muscle. Some question may remain as to how close the relationships are between the electrical activity associated with muscle contraction and the neural signals that stimulate the muscle fibers (*24*). Although it is possible that the neural signals may be organized in the more simple fashion proposed by the Moll-Shriner hypothesis, experimental evidence demonstrating such an organization is not presently available.

Summary

The hypothesis of a very simple organization of muscular activity (for example, two discrete levels) underlying a more complex pattern of velar positioning was tested in the present research. The data obtained in this study were not consistent with this hypothesis. Palatal electromyographic activity during speech appeared to vary in a relatively continuous manner

and was positively correlated with velopharyngeal positioning. The concept of a "base" position of the palate proposed by Moll and Shriner as being characteristic of sustained, nasal consonant production, was not clearly evident in the data from this study. A majority of the subjects demonstrated little or no velar movement during production of the sustained, detached nasal consonant. A relatively marked positive correlation was obtained between tongue and palatal positioning during speech production, thus suggesting that a high tongue position is associated with a high palatal position. The Moll-Shriner hypothesis predicts such a relationship and suggests that it is due to anatomical interconnections between tongue and palate. An alternative is supported by the data obtained in the present research: greater palatal elevation may accompany vowels with high tongue position simply because such elevation is needed to prevent the vowel from being detected as nasal in quality. The latter explanation may be more consistent with the high correlation observed between palatal position and electroyographic activity.

reprints: *Dr. James Lubker*
Department of Otolaryngology
University Hospitals
Iowa City, Iowa 52240

Appendix A. Cinefluorographic Measures

a. Tongue-palate, closest (TP_c): the smallest distance between the tongue and the posterior pharyngeal wall.
b. Tongue-palate, one cm (TP_1): the distance between the tongue and the posterior pharyngeal wall, measured along a line drawn one centimeter below the upper central incisors and approximately parallel to the superior surface of the soft palate.
c. Tongue-palate, two cm (TP_2): the distance between the tongue and the posterior pharyngeal wall measured along a line drawn two centimeters below the upper central incisors and parallel to TP_1.
d. Tongue-height (TH): the distance between the highest point on the tongue and a line drawn approximately parallel with the superior surface of the hard palate and 30 millimeters below it.
e. Tongue-movement (TM): a measure included to provide an index of the combination of the anterior-posterior and superior-inferior tongue movements and that would further demonstrate movement along a line that would parallel the effective direction of interaction between the tongue and the soft palate; hence, this measure was made along an oblique line drawn to follow the movement of the levator eminence on the soft palate from the resting position to its position in maximal elevation; the position of the levator eminence with the palate at rest was chosen as the reference point and TM was defined as the distance from this point to the intersection of the upper surface of the tongue with the aforementioned oblique line.

f. Incisal-opening (IO): the distance between the upper and lower central incisors.
g. Velopharyngeal opening (VP): the distance between the superior-posterior surface of the soft palate and the posterior pharyngeal wall, measured along a line drawn parallel to TP_1 in such a manner that it intersects the portion of the posterior pharyngeal wall contacted by the soft palate during speech.
h. Velar-height (VH): the elevation of the soft palate above a horizontal line drawn parallel to TP_1 which passed through the reference point on the superior surface of the soft palate described for the measure TM; VH is the distance above this horizontal along a vertical line drawn through the levator eminence during maximum elevation of the soft palate.
i. Velar-movement (VM): the distance between the superior surface of the soft palate at rest and the superior surface of the soft palate during palatal movement, measured along the same reference line described for TM.

References

1. Bergstrom, R. M., The relation between the number of impulses and the integrated electrical activity in electromyography. *Acta Physiol. Scand.*, *45*, 97–101, 1959.
2. Bigland, B., and Lippold, O. C. J., The relation between force, velocity, and integrated electrical activity in human muscle. *J. Physiology*, *123*, 214–224, 1954.
3. Bjork, L., Velopharyngeal function in connected speech. *Acta Radiol. Stockh.*, suppl. *202*, 1961.
4. Close, J. R., Nickel, E. D., and Todd, F. N., Motor unit action potential counts: their significance in isometric and isotonic contractions. *J. bone and joint Surg.*, *7*, 1207–1222, 1960.
5. Fant, G., *Acoustic Theory of Speech Production*, The Hague, The Netherlands: Moulton & Co., 1960.
6. Fritzell, B., An electromyographic study of the movements of the soft palate in speech. *Folia Phoniat.*, *15*, 307–311, 1963.
7. Fromkin, Victoria A., Neuro-muscular specification of linguistic units. *Language and Speech*, *9*, 170–199, 1966.
8. Fromkin, Victoria A., and Ladefoged, P., Electromyography in speech research. *Phonetics*, *15*, 219–242, 1966.
9. Harris, Katherine S., Lysaught, G. F., and Schvey, M. M., Some aspects of the production of oral and nasal labial stops. *Language and Speech*, *8*, 135–147, 1965.
10. Harris, Katherine S., Rosov, R., Cooper, F. S., and Lysaught, G. F., A multiple suction electrode system. *Electroenceph. clin. Neurophysiol.*, *17*, 698–700, 1964.
11. Harris, Katherine S., Schvey, M. M., and Lysaught, G. F., Component gestures in the production of oral and nasal labial stops. Paper read at 63rd meeting of the Acoustical Society of America, May, 1962.
12. Hayes, W. L., *Statistics for Psychologists*, New York: Holt, Rinehart, & Winston, 1963.
13. House, A. S., and Stevens, K. N., Analog studies of the nasalization of vowels. *J. speech hear. Dis.*, *21*, 218–232, 1956.
14. Liberman, A. M., Cooper, F. S., Harris, Katherine S., and MacNeilage, P. F., Motor theory of speech perception. Paper presented at Stockholm Speech Communication Seminar, Royal Institute of Technology, Stockholm, 1962.

15. LINDBLOM, B., Spectrographic study of vowel reduction. *J. acoust. Soc. Amer.*, *35*, 1773–1781, 1964.
16. LINDBLOM, B., Dynamic aspects of vowel articulation. Proc. 5th Inter. Cong. Phon. Sci., Munster, 387–388, 1964.
17. LINDQUIST, E. F., *Design and Analysis of Experiments in Psychology and Education*, Boston: Houghton Mifflin Co., 1953.
18. LIPPOLD, O. C. J., The relation between integrated action potentials in a human muscle and its isometric tension. *J. Physiol.*, *117*, 492–499, 1952.
19. LUBKER, J. F., An electromyographic-cinefluorographic investigation of velar function during normal speech production. Ph.D. dissertation, University of Iowa, 1967.
20. MACNEILAGE, P. F. and SHOLES, G. N., An electromyographic study of the tongue during vowel production. *J. speech hear. Res.*, *7*, 209–232, 1964.
21. MOLL, K. L., Cinefluorographic techniques in speech research. *J. speech hear. Res.*, *3*, 227–241, 1960.
22. MOLL, K. L., Velopharyngeal closure on vowels. *J. speech hear Res.*, *5*, 30–37, 1962.
23. MOLL, K. L. and SHRINER, T., Preliminary investigation of a new concept of velar activity during speech. *Cleft Palate J.*, *4*, 58–69, 1967.
24. PARTRIDGE, L. D., Signal-handling characteristics of load-moving skeletal muscle. *Amer. J. Physiol.*, *210*, 1178–1191, 1966.
25. PETERSON, G. E. and LEHISTE, I., Duration of syllabic nuclei in English. *J. acoust. Soc. Amer.*, *32*, 693–703, 1960.
26. PODVINEC, S., The physiology and pathology of the soft palate. *J. Laryngol.*, *66*, 452–461, 1952.
27. STEVENS, K. N. and HOUSE, A. S., Perturbation of vowel articulations by consonantal context: an acoustical study, *J. speech hear. Res.*, *6*, 111–128, 1963.