Relationships Between Muscle Activity and Velar Position

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Five normal subjects were used to study the relations between muscle activity and velar position. The speech sample consisted of the sustained sounds /i/, /u/, /s/, nonnasal /ɑ/, and nasalized /ɑ/. Velar position was determined using lateral-view x-rays. Electromyographic activity was measured from hooked-wire electrodes intended to record from the levator veli palatini, palatoglossus, palatopharyngeus, and the superior pharyngeal constrictor muscles. A transnasal approach was used to insert electrodes intended for superior constrictor. It was found that 1) the level of levator activity was not directly related to velar position, 2) for a given velar position the level of levator activity was related to palatoglossus and/or palatopharyngeus activity in most cases, and 3) superior constrictor was active during all speech samples studied, but the level of activity was inconsistent both within and between subjects.

KEY WORDS: Soft palate, muscle activity, muscles, levator veli palatini, palatoglossus, palatopharyngeus, superior pharyngeal constrictor

A number of investigators have studied electromyographic activity occurring in the velopharyngeal muscles of normal subjects during speech (Lubker, 1968; Fritzell, 1969; Lubker, Fritzell, and Lindquist, 1970; Lubker and May, 1973; Fritzell, Kotby, and Moller, 1974; Minifie, Abbs, Tarlow, and Kwaterski, 1974; Bell-Berti and Hirose, 1975; Bell-Berti, 1976; Benguerel, Hirose, Sawashima, and Ushijima, 1977; Seaver and Kuehn, 1980). Several factors must be considered when interpreting the results of these studies and others dealing with electromyographic activity associated with velar movement. These factors include the following. 1) The relations between measures of electromyographic activity and muscle force vary as a function of muscle length, even within typical ranges of movement for most mammalian muscles (Bouisset, 1973; Carlson and Wilkie, 1974; DeLuca, 1979; Winter, 1979). 2) The relations between measures of electromyographic activity and muscle force vary as a function of the velocity of muscle shortening (Bigland and Lippold, 1954). 3) The temporal relations between electromyographic activity and muscle force vary with the twitch-tension characteristics of the active motor units (Carlson and Wilkie, 1974). 4) The elastic and viscous properties of the attachments between velar muscles and the

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points used on the velum for movement transduction are not known (Kuehn and Azzam, 1978), and the effective mass of the velum has not been measured. 5) Although the alignment of the velar muscles has been described in the anatomical literature, one can expect the directions of muscular forces to change as the position of the velum changes. It appears that quantitative biomechanical models are needed to incorporate the dynamic interactions of these passive and active forces as they are distributed in three dimensions throughout the velopharyngeal structures. In spite of the above considerations some investigators (Lubker, 1968; Fritzell, 1969) have observed high correlations between electromyographic activity in the velar muscles and velar movement. However, without a quantitative model of velar biomechanics it is not clear to what extent such correlations are largely coincidental or whether they reflect physiological relations in the operation of the velopharyngeal system.

Specification of a comprehensive model of velopharyngeal biomechanics for speech movements is beyond the scope of the present study. However, as a step in the development of such a model, changes in muscle activity accompanying static displacements of the velum were studied. By limiting analysis to static velar positions, the biomechanics of the velopharyngeal system are simplified and the effects of velocity of muscle shortening on relations between electromyographic activity and muscle force are avoided. If high correlations are found between electromyographic activity and displacement in the static speech tasks, it will help with the interpretation of the relevance of the correlations between displacement and muscle activity found in the dynamic tasks.

It is generally assumed that in normal speakers levator veli palatini (hereafter, levator) produces most of the force required to achieve velopharyngeal closure (Fritzell, 1969; Bell-Berti, 1976). However, Seaver and Kuehn (1980) have shown that palatoglossus and palatopharyngeus also are active when the velum is elevated. This activity appears related to small changes in velar height during velopharyngeal closure. The extent to which these and other muscles produce activity resulting in forces that influence velar position remains unclear. Therefore, an objective of the present investigation was to study activity levels in muscles which potentially position the velum and affect the size of the velopharyngeal port. The tensor veli palatini, salpingopharyngeus, and musculus uvulae were not studied. The tensor veli palatini is not thought to be active during speech (Fritzell, 1969; 1979; see also Honjo, Okazaki, and Nozoe, 1979) while the salpingopharyngeus is inconsistently present in man (Dickson, 1975). The role of the musculus uvulae is thought to change the shape of the velum rather than its position (Pigott, 1969; Azzam and Kuehn, 1977; Croft, Shprintzen, Daniller and Lewin, 1978; Maue-Dickson and Dickson, 1980; Lewin, Croft, and Shprintzen, 1980).

The purpose of this study was to record electromyographic activity from levator, palatoglossus, palatopharyngeus, and superior pharyngeal constrictor (hereafter, superior constrictor) and to relate this activity to static positions of the velum.

Method

Subjects

Five normal young adults, three males and two females, were used as subjects.

Speech Sample

The speech sample consisted of three tokens of sustained /s/, /u/, /i/, /ɑ/, and nasalized /ɑ/. The latter was produced by sustaining /ɑ/ in the word "mom." These speech sounds were selected to manipulate velar and lingual positions.

Electromyography

Stainless steel wires (Medwire, 316 SS 3T), 110 μm in diameter, were used for recording electromyographic activity. The teflon insulation was stripped 1 mm from the tips and each wire was threaded through a 30 gauge half-inch hypodermic needle. Hooks were formed in the bared ends of each wire. Only one wire was placed in each needle so that two needles were used for each bipolar recording. This enabled a larger spacing between electrodes compared to the single needle method and thus activity in a larger area of each muscle could be sampled (Sumitsuji, Matsumoto, Tanaka, Kashiwagi, and Kaneko, 1967).

The electrodes intended for palatoglossus and palatopharyngeus activity were inserted perorally into the midportion of the anterior and posterior faucial pillars respectively. The needles were directed in a line parallel with the plane of the hard palate. Needle insertion depth was approximately 3 mm so that the hooked portion of the wires penetrated the mucosal surface. Electrode spacing between pairs of wires for each muscle was approximately 5 mm in a line parallel to the long axis of each faucial pillar.

A peroral approach also was utilized to place electrodes intended for levator. The electrodes were inserted in the dimple of the elevated velum cranially, laterally, and posteriorly to follow the course of levator (Hirose, 1971). Approximate depth of needle insertion was 10 mm. Approximate spacing between electrode wires intended for levator was 5 mm in an anteromedial-posterolateral orientation.

A needle transport system was specially designed and constructed for transnasal insertion of electrode wires intended for superior constrictor (Figure 1). Prior to needle insertion, the nasal mucosa was anesthetized with cocaine. A Hopkins rod nasopharyngoscope was introduced through one nostril enabling visualization of the nasopharynx. The needle assembly was advanced through the other nostril until the end of the silastic tube was near the posterior wall of the nasopharynx as observed with the nasopharyngoscope. The subject was asked to swallow because a transverse fold of mucosa formed by the upper border of the superior constrictor can be observed during swallowing. The silastic tube was slid anteriorly to expose the needle tip. The needle was inserted into the mucosal fold just posterior to the salpingopharyngeal fold in the lateroposterior aspect of the nasopharyngeal wall. The depth of insertion was approximately 3 mm. The second wire was inserted in a similar fashion for bipolar recording. Approximate spacing between electrode wires was 7 mm in a lateral-medial orientation. Although a peroral approach for electrode insertion has been used to sample superior constrictor activity (Minifie et al., 1974; Bell-Berti, 1976), it is believed that the transnasal approach used in this study and also that of Fritzell (1969) is more effective in sampling activity of the most superior fibers of superior constrictor which insert into the velum (Dickson, 1975).

After all electrodes were inserted, the electromyographic activity patterns were observed on an oscilloscope during swallowing and ongoing speech. All four electrode pairs in all five subjects showed activity during these tasks.

The electrode wires were connected to Grass HIP511 high impedance probes and Grass P511 amplifiers. The electromyographic signals were high-pass filtered at 30 Hz and recorded on a Hewlett-Packard 3968A FM tape recorder. The tape-recorded signals were rectified, smoothed with a 200 msec time constant, and displayed with a Honeywell 1508 Visicorder. A third-order state-variable filter realization of an ideal averaging filter (Garland, Angel, and Melen, 1972) was used for smoothing. The long time constant could be used since only sustained velar positions were studied.

Levels of electromyographic activity were assessed by measuring the deviation of the smoothed trace from baseline in the midportion of each sustained speech sound. The baseline was obtained for each channel in the calibration mode with the corresponding electromyographic signal bypassed and with no calibration input.

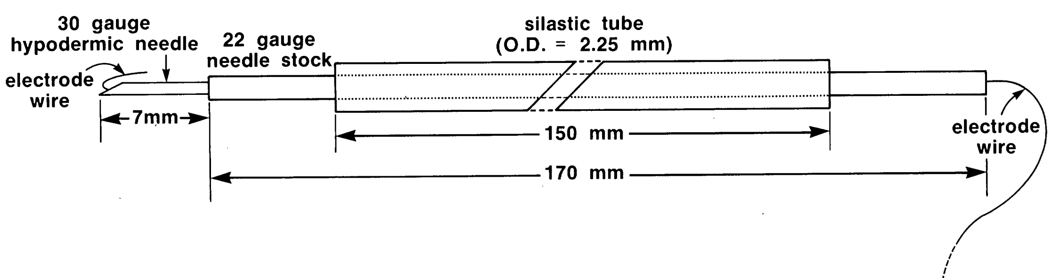

FIGURE 1. Needle transport system for inserting electrodes into superior constrictor. Silastic tube covered the tip of the hypodermic needle during passage through the nasal cavity and was slid anteriorly prior to needle insertion.

Radiography

Lateral-view still x-rays were obtained for each subject concurrently with recording of the electromyographic activity. Subjects were positioned in a cephalostat after the electrodes were in place. They were instructed to sustain each speech sound in a random order. An x-ray was taken shortly after the onset of each speech sound. Activating the x-ray produced onset and offset transients 600 msec apart in both the audio channel and electromyographic channels of the FM tape recorder. The transients were used to align the time of the electromyographic signals to the x-ray image. The level of electromyographic activity was measured 400 msec after the onset transient which was well within the exposure interval of the x-ray. As movement during the x-ray exposure interval would result in blurring of the x-ray image, and since all x-ray images were sharply defined it can be inferred that no appreciable movement occurred during the measurement intervals. A total of 16 x-rays (three tokens of the five sustained speech sounds plus one x-ray with the teeth in centric occlusion to provide a velar rest position) was obtained for each subject. The radiation dosage was less than 2 R for each subject.

A measure of velar position was derived from the projected x-rays (Figure 2). A template was drawn for each subject. The template consisted of prominent upper teeth fillings, the upper central incisors, and other cranial landmarks clearly observable on the x-ray images. A velar position reference line also was drawn on the template. The line extended from the most superior point on the elevated velum through the shortest distance to the nasal surface of the velum at rest. This line was determined with the aid of superimposed tracings of the velum for each subject. Velar position (VP in Figure 2) was determined for each sustained speech sound by measuring the point of intersection of the superior surface of the projected velar image on the velar position reference line from an arbitrary zero point on the same line. It has been demonstrated that the measure used for velar position in this study correlates highly with other measures of velar position (Shaw, Folkins, and Kuehn, 1980). Measurements were not corrected for x-ray enlargement. The standard error of measurement for velar position averaged 0.59 mm for the five subjects.

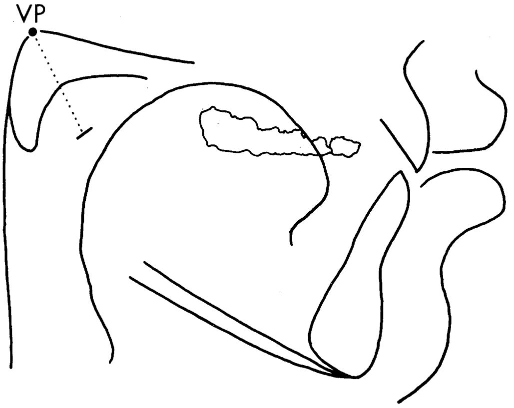

FIGURE 2. Lateral-view x-ray tracing demonstrating the velar position (VP) measure.

Results

Figure 3 shows the means of velar position and levator electromyographic activity for each subject. All measurements were normalized by computing percentages relative to the maximum value for each measure within subjects. For example, the highest velar position for Subject 1 occurred during one token of /s/ and all other velar position values for this subject were computed relative to the maximum value.

As expected, velar position was generally higher for /i/, /u/, and /s/ than for /ɑ/ and higher for /ɑ/ than nasalized /ɑ/. It also can be seen in Figure 3 that levator activity generally was greater for /ɑ/ than nasalized /ɑ/. This would be predicted by the differences in velar position and the assumption that levator is a major elevator of the velum. However, for /i/, /u/, and /s/, which involve similar velar positions, levator activity was quite variable. That is, levator activity did not appear to be directly related to the velar position for these speech sounds. For example, Subject 2 exhibited much greater levels of levator activity for /u/ than for /i/ and /s/ even though velar position was similar. The same pattern can be observed for Subject 3. Subjects 1 and 4, on the other hand, exhibited less levator activity for /u/ than for /i/ and /s/ while velar positions were similar. Finally, greater levator activity occurred for /s/ than for /i/ and /u/ in the presence of similar velar

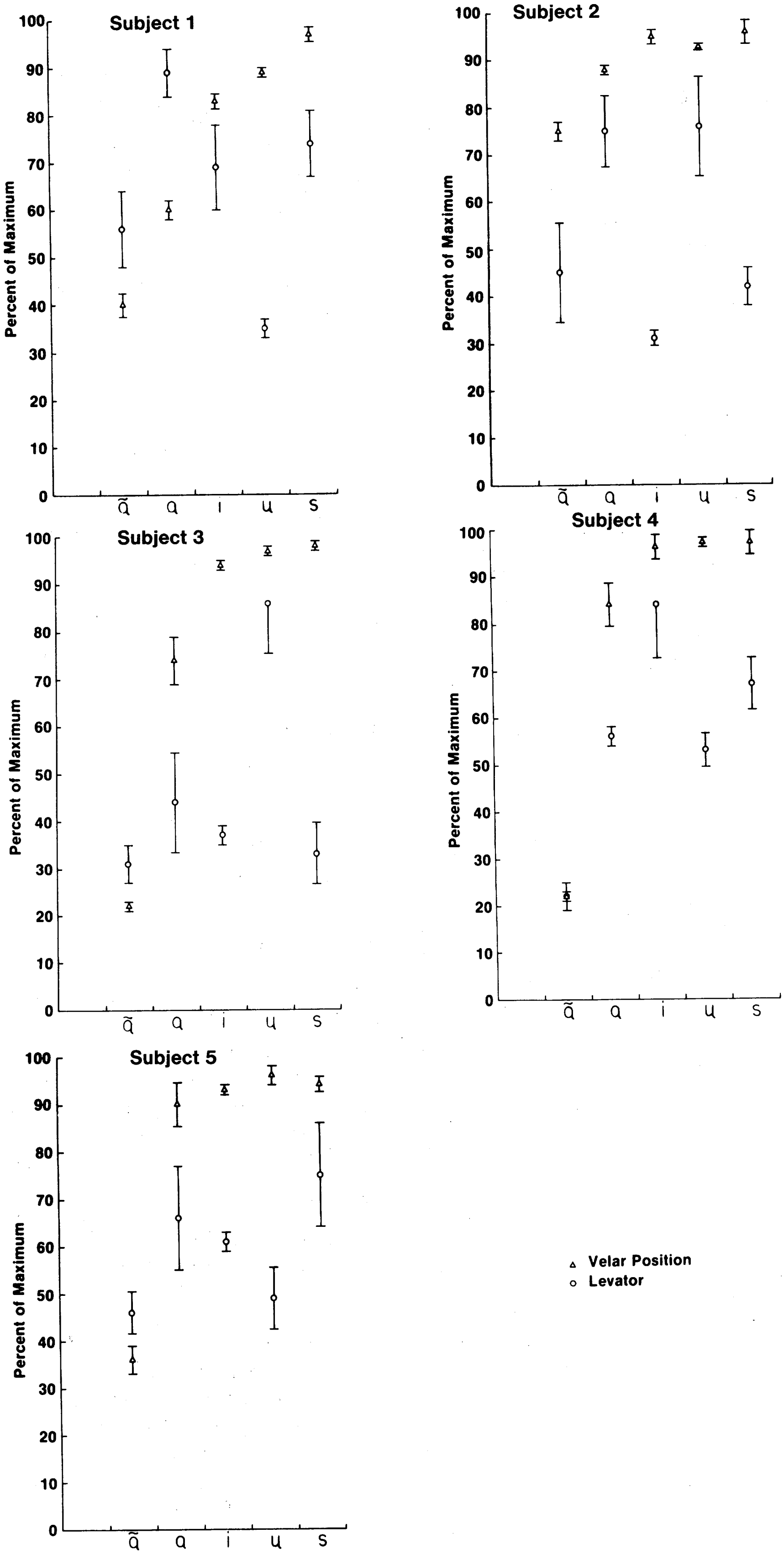

FIGURE 3. Mean velar position (triangles) and mean levator veli palatini electromyographic activity (circles). Vertical lines indicate standard deviations. The data have been normalized by computing percentages relative to the maximum value for each of the two measures within each subject.

positions for Subject 5. Pearson product-moment correlations were computed between velar position and levator activity for the 15 measurements (i.e., excluding rest position) for each subject. The correlations were −0.07 (Subject 1), 0.03 (Subject 2), 0.31 (Subject 3), 0.81 (Subject 4), and 0.44 (Subject 5). These correlations are low except for Patient 1. In summary, levator activity independent of other muscle activity did not vary consistently in relation to velar position.

A more consistent interaction was observed among levator, palatoglossus, and palatopharyngeus in achieving velar positions (Figure 4). That is, for a given velar position increases in levator activity were associated with corresponding increases in palatoglossus and/or palatopharyngeus activity. Conversely, decreases in levator activity were accompanied by decreases in palatoglossus and/or palatopharyngeus activity for a given velar position. Some exceptions to this general trend occurred for Subjects 4 and 5. These observations are supported by partial correlations between levator and the mean of palatoglossus and palatopharyngeus for each subject. These partial correlations reflect the relations between muscles with the effect of velar position on the electromyographic activity removed. The partial correlations were 0.97 (Subject 1), 0.93 (Subject 2), 0.68 (Subject 3), 0.51 (Subject 4), and 0.41 (Subject 5). The mean of palatoglossus and palatopharyngeus activity was used for the partial correlations because it appeared that the subjects switched between different combinations of palatoglossus and palatopharyngeus activity at the same levels of levator activity.

Figure 5 shows levels of activity for superior constrictor. Superior constrictor activity did not appear to fit the trend described above for the other muscles studied. That is, superior constrictor activity was not consistently related to changes in activity of the other muscles. Following the formal experimental procedures one of the subjects produced a number of activities without x-ray to observe changes in electromyographic activity in superior constrictor. It was noted that speech tasks supposedly involving tight velopharyngeal closure (e.g., /s/) could easily be produced with dramatically different levels of electromyographic activity from superior constrictor. Furthermore, in all subjects it was observed that high levels of superior constrictor activity were consistently related to laughter. Shprintzen, Daniller, and Siegel-Sadewitz (1980) have considered the musculus uvulae to be the "levity palatini." This term might also apply to the superior constrictor or the muscle may be labelled "superior consnicker" (anonymous reviewer).

Discussion

The finding that levels of levator activity independent of other muscle activity were not directly related to velar position is consistent with the observations of Seaver and Kuehn (1980), but appears to be contradictory to reports by Bell-Berti and Hirose (1975), Lubker (1968), and Fritzell (1969). From the latter two studies in particular, it often has been inferred that velar position is linearly correlated with electromyographic activity in levator.

A number of procedures in the present study are similar to the procedures used by Lubker (1968) such as the use of sustained speech sounds, electromyographic analysis with a long time constant, and measurement of velar position via x-ray. Lubker (1968) reported correlations of 0.79 and 0.83 between velar electromyographic activity and two velar position measures. However, it should be pointed out that Lubker employed large suction cup electrodes placed "in a relatively accessible position" on the oral surface of the velum. One cannot expect such electrodes to record activity exclusively from levator, and Lubker is careful to make this clear. Therefore, Lubker's high correlations between velar position and electromyographic activity may reflect an unknown composite of muscle activity other than activity from only levator.

With regard to Fritzell's (1969) study, correlations between velar height and levator activity ranged from 0.46 to 0.94 across subjects. In interpreting the lower correlations, Fritzell suggested the possibility that "superior constrictor, palatoglossus, and palatopharyngeus might play a more important role in some subjects, reducing the influence of the levator and its correlation with velar displacement" (p. 68). Results of the present study support this statement.

A major finding in the present study was the rather systematic interaction among activity levels for levator, palatoglossus, and pala-

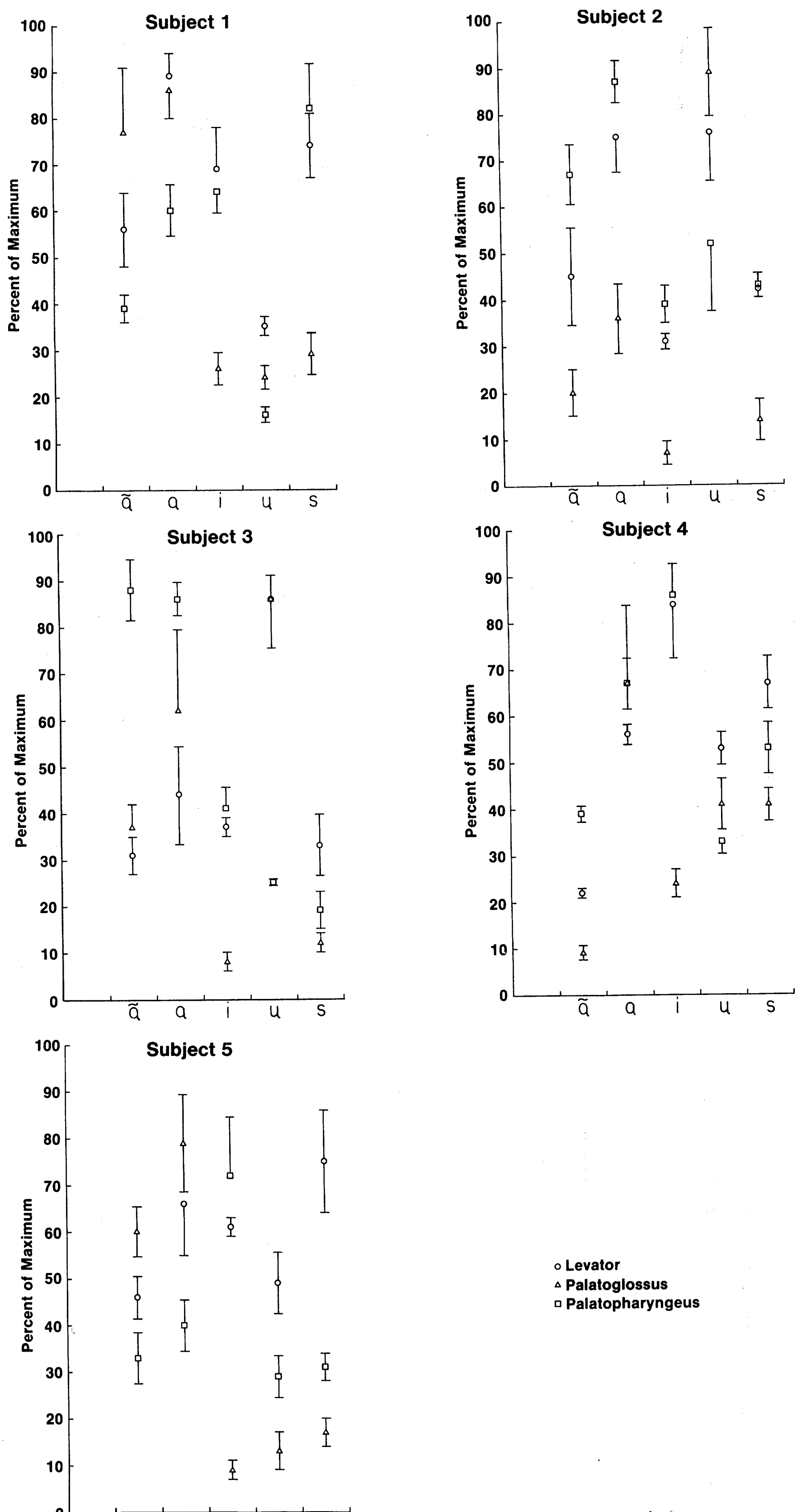

FIGURE 4. Mean levator veli palatini (circles), mean palatoglossus (triangles), and mean palatopharyngeus (squares) electromyographic activity. Vertical lines indicate standard deviations. The data have been normalized as in Figure 3.

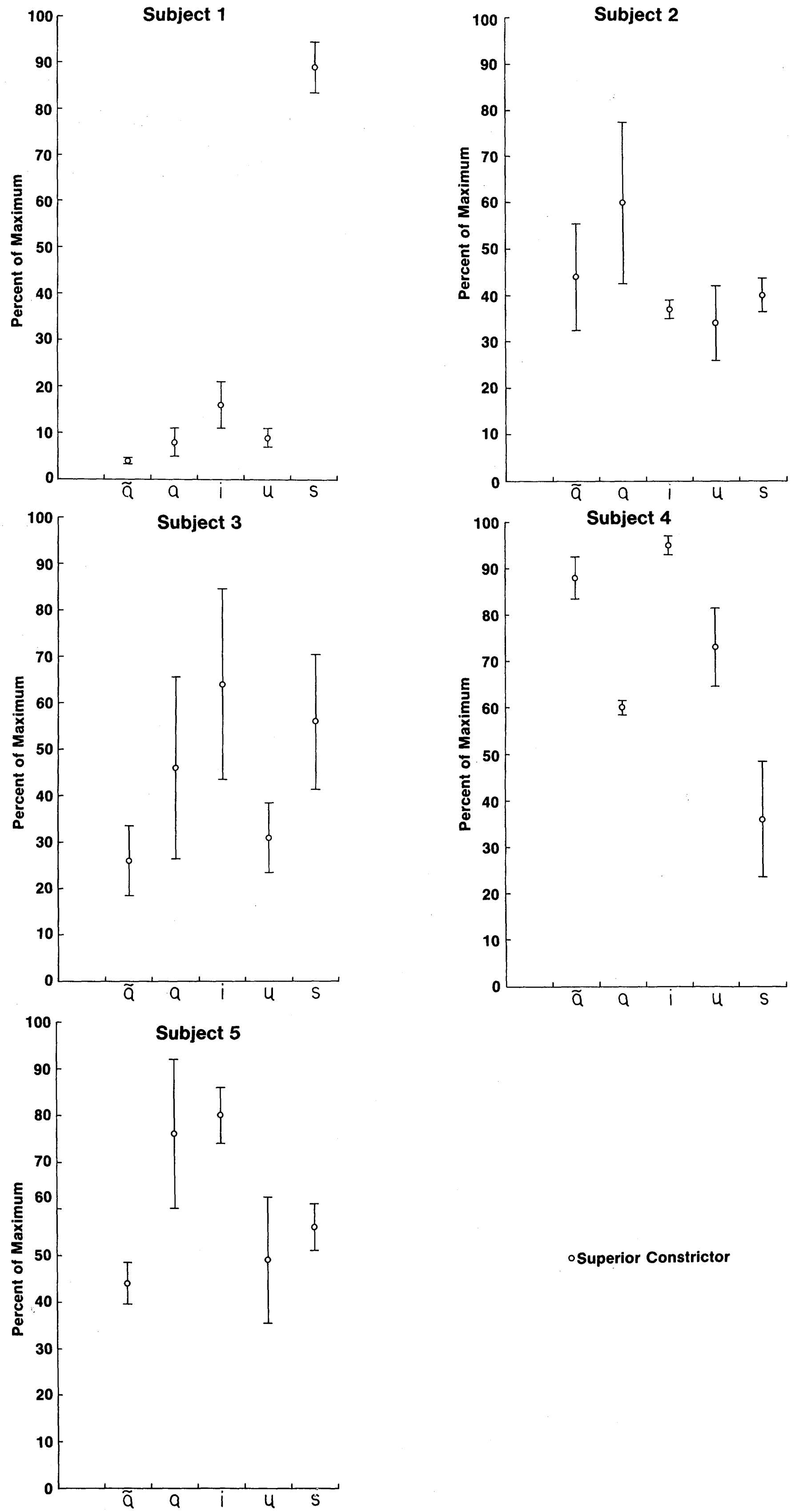

FIGURE 5. Mean superior pharyngeal constrictor electromyographic activity. Vertical lines indicate standard deviations. The data have been normalized as in Figure 3.

topharyngeus. Contraction of palatoglossus and palatopharyngeus provides a downward pull on the velum thereby opposing the upward pull by levator. Therefore, to achieve a given velar position, levator must contract more forcefully if opposed by greater activity of either or both palatoglossus and palatopharyngeus. It is likely that an important function of palatoglossus and palatopharyngeus for speech is to aid in positioning the tongue and pharynx. If the palatoglossus contracts to aid in tongue elevation or palatopharyngeus contracts to narrow the pharynx, levator must increase its force of contraction accordingly to achieve a desired velar elevation. In this fashion, there is a trading relation among the three muscles in positioning the velum. A given velar position may be achieved in the presence of variable combinations of muscle activity. Similar flexibility in the combinations of muscle activity has been demonstrated during speech for the lower lip muscles (Abbs, 1979) and the jaw muscles (Folkins, in press).

The muscular interaction observed in this study lends support to the "equilibrium" hypothesis advanced by Polit and Bizzi (1978, 1979). These investigators studied static positioning of monkey arm movements. They observed that a highly learned arm position could be reached eventually even when sensory information was eliminated and when the starting position was varied. They concluded that a controlled variable of the neuromotor system is not a level of muscle force but rather an equilibrium point resulting from the interaction of agonist and antagonist muscles. That is, by regulating the interaction between antagonistic pairs the arm could reach a particular target regardless of sensory information and initial conditions. In applying this logic to the velum, it should be pointed out that palatoglossus and palatopharyngeus are not direct antagonists to levator in the same sense as that of the antagonistic limb muscles. The limb muscles often have completely complementary actions at the joints. While the velum may rotate about its attachment to the hard palate, a true joint does not exist. The velum is a flexible structure, and in general the three-dimensional geometry of the velopharyngeal system is quite complicated. Only a portion of the force from palatoglossus or palatopharyngeus may act directly antagonistically to the line of action of levator (see Figure 3 in Kuehn and Azzam, 1978, for the relation between palatoglossus and levator). The degree of opposition between muscles may vary as a function of either velar position or tongue position. Furthermore, the antagonistic force provided by either muscle will be affected by the elasticity of the muscular tissue in the area of muscle insertion. The amount of elastic tissue appears to be considerable for palatoglossus (Kuehn and Azzam, 1978). Caution must be exercised in positing control mechanisms that might operate on the velopharyngeal system if such mechanisms are formulated on the basis of data derived from limb musculature. However, it seems plausible that the velum could be controlled in relation to a balance of muscular and nonmuscular factors rather than in relation to specifications between muscle force and movement.

The role of superior constrictor has presented an enigma to investigators interested in velopharyngeal functioning. Anatomically, the muscle is well situated to constrict the lateral pharyngeal walls thereby aiding velopharyngeal closure. Its most superior fibers, which insert into the velum in most individuals (Dickson, 1975), may even function to draw the velum posteriorly. However, electromyographic data pertaining to this muscle have been inconsistent. Fritzell (1969) found superior constrictor activity to be similar to levator activity. For example, the level of activity was greater for high vowels than low vowels for both muscles. Bell-Berti (1976) observed the opposite pattern for one of her subjects. Finally, Minifie, et al. (1974), found no difference in superior constrictor activity between high and low vowels. One potentially important difference among these studies is that Fritzell used a transnasal approach to insert electrodes whereas the other investigators used a peroral approach. Thus, the presumably more superior placements by Fritzell may have been more successful in sampling activity from the fibers that insert into the velum.

Whenever electromyographic activity is measured from human subjects, it is not possible to state with certainty the extent of muscle volume sampled by the electrodes and the degree to which the activity pattern measured is a valid representation of the muscle intended for study. The problem of validity concerning superior constrictor is especially great not only because of the nasal versus oral approaches to electrode insertion discussed above, but also because of the thinness of the muscle. Our informal observations of superior constrictor in cadaveric material indicate that the muscle is only about 2 mm thick in the adult. Since the electrode wire is bent back from the tip of the hypodermic needle, the margin of error for correctly positioning the wire in the constrictor muscle is small.

Although inconsistent across speech sounds and subjects, superior constrictor was active for every speech sound produced in this study. It is not known whether such activity was sufficient to contribute in a substantial way to the interaction of forces for velar movement or to produce displacement of the pharyngeal walls. Another possibility is that the levator contraction unassisted by any other muscle contraction results in lateral pharyngeal wall displacement (Maue-Dickson and Dickson, 1980). However, Iglesias, Kuehn, and Morris (1980) have presented evidence opposing this hypothesis.

Further research studying the interaction among velopharyngeal muscles appears warranted. Future investigations might include additional muscles in the region, particularly the musculus uvulae, to determine how they may assist in velar positioning. Dealing with static positions in these early efforts appears to have been profitable, but the dynamic components of velar biomechanics, as well as further specification of the three-dimensional distribution of forces influencing velar movements, remain fruitful areas for future study.

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