A Three Dimensional Cinefluoroscopic Analysis of Velopharyngeal Closure During Speech and Nonspeech Activities in Normals

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In 1965, Moll (*9*) performed an experiment using lateral view cinefluoroscopy to study velopharyngeal closure in normal subjects during speech and nonspeech tasks. The data obtained from a measure of variations in velar height led Moll to hypothesize that the mechanism of velopharyngeal closure is not the same for all activities which require closure. This hypothesis was consistent with an earlier suggestion by Bloomer (*4*) that velopharyngeal closure varies in pattern depending upon the activity being performed. Subsequently, Moll's (*9*) hypothesis was supported in part by Fritzell (*8*). EMG data reported by Fritzell suggested that the physiology of velopharyngeal closure during speech differed considerably from that of swallowing. However, the EMG patterns from the velopharyngeal musculature during speech, blowing, and whistling were shown to be somewhat similar.

Moll's original hypothesis of multiple patterns of velopharyngeal closure was based on data derived from two dimensional lateral view cinefluoroscopic examinations of the velopharynx of ten normal adult subjects. While Moll's study (*9*) has indicated that there may be some differences in velopharyngeal closure patterns across various activities, his fluoroscopic procedure did not permit him to observe the movements of the lateral aspects of the pharyngeal walls (LAPW) during such closure. Skolnick (*14*) has stressed the importance of the movements of the LAPW as a component of velopharyngeal closure. Skolnick and McCall (*16, 17*) indicate the necessity of evaluating closure with multi-view fluoroscopy in order to observe all of the movements and structures contributing to closure. Thus, in order

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to assess completely patterns of velopharyngeal closure during various activities, a multi-view fluoroscopic procedure is essential.

The present investigation was designed to essentially replicate Moll's experiment (*9*) in part utilizing the techniques of multi-view videofluoroscopy which permits an examination of the velopharyngeal apparatus in three dimensions. Data derived from frontal and lateral views of the naso- and oropharynx were analyzed to determine the presence or absence of multiple mechanisms of velopharyngeal closure operative during speech, blowing, whistling, gagging, and swallowing.

Experiment I

Bosma (*5*) and others (*2, 6, 7, 10, 14*) have described swallowing as a very consistent physiological behavior. The swallow has been regarded as being reflexive in nature, probably being mediated by the autonomic nervous system after supraspinal initiation, and highly consistent both within and between species (*5*). If the observations concerning the consistency of swallowing are correct, then swallowing should provide a good basis for a comparative investigation to determine the existence of multiple mechanisms of velopharyngeal closure for different activities. Therefore, the primary purpose of Experiment I was to verify the consistency of observed velopharyngeal activity during swallowing, both within and between subjects. In addition, the data permitted a fluoroscopic description of the kinesiology of velopharyngeal closure during swallowing by the human subject.

Subjects. The velopharynx of each of five normal adult subjects, all female, ranging in age from 19.0 to 22.4 years with a mean age of 20.2 years was studied in frontal and lateral fluoroscopic projections during reflexive swallowing. The subjects were judged as normal if they had no history of oral or pharyngeal surgery, no evidence of nasal speech, and no structural anomalies of the mouth and pharynx. Prior to the fluoroscopic examination, the pharynx and velum of each subject was coated with barium intranasally to better define the lateral aspects of the pharynx and the margin of the velum.

Data Collection. The radiographic technique for evaluating the velopharyngeal portal in lateral and frontal projections has been described in detail elsewhere (*15*). Each subject sat in a specially constructed chair with a head immobilization device positioned so that the subject's hard palate was approximately parallel to the horizontal. Five reflexive swallows were recorded videofluoroscopically on a ½ inch videotape recorder (SONY Model AV 3600) in frontal view, and two reflexive swallows were recorded in lateral view. The reflexive swallows were initiated by the introduction of small amounts of barium orally. The total time of x-ray exposure for each subject was under 30 seconds.

Data Reduction. Each swallow was observed initially in full speed, slow motion, and stopped frames (30 frames per second) on a 9-inch TV mon-

itor. The movements observed in the lateral and frontal views were noted and described. To permit a more detailed study of the consistency of the swallow within and between subjects a measurements technique for analyzing the movements observed in frontal view videofluoroscopy during the swallow was devised. It was noted that in all five subjects, a characteristic Y-shaped configuration of the pharyngeal walls was formed during the course of a swallow at that instant when the LAPW first reached the point of maximum medial excursion (Figure 1a). The measurement technique that was devised utilized a grid constructed on this characteristic configuration of the pharyngeal walls (Figure 1b).

The grid consisted of seven straight lines. As shown in Figure 1b, line A-A′ passed through points a-a′ which represented the uppermost portion of the LAPW contributing to the Y-shaped configuration. Five of the six remaining lines were drawn parallel to A-A′. Lines B-B′ passed through the point where the LAPW first approximate (denoted as point b and b′). Lines D-D′ and E-E′ divided the distance between lines A-A′ and B-B′ into thirds. Line C-C′ was constructed the same distance from B-B′ as B-B′ was from A-A′. Line F-F′ halved the distance from B-B′ to C-C′. Line G-G′, which provided the only vertical measure, was constructed perpendicular to line A-A′, passing through point b and b′. Point g denotes where line G-G′ passes through A-A′ and point g′ marks the point where the LAPW first approximate. The grid was constructed in this manner to fully cover the region of the naso- and oropharynx. More measurement lines were constructed in the upper half of the grid since this is the area of the velopharyngeal portal and of greater interest in evaluating velopharyngeal closure.

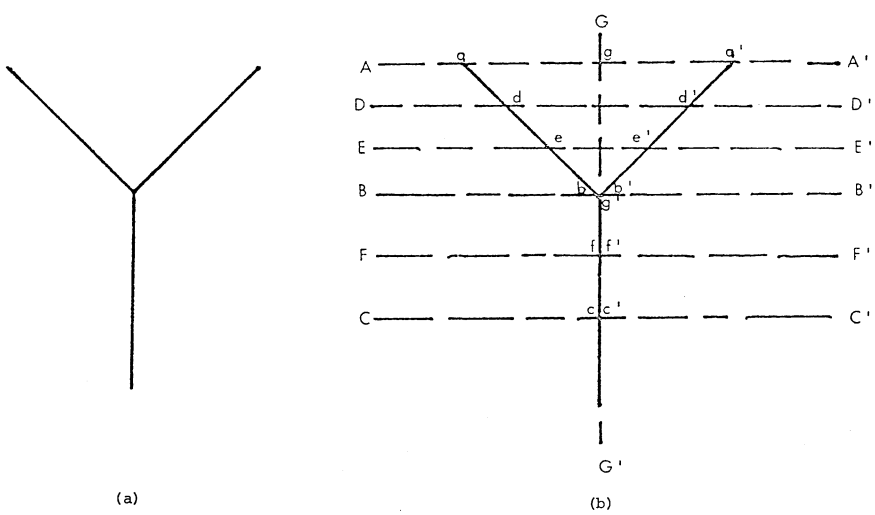

FIGURE 1. (a) Schematic configuration of LAPW at maximum medial excursion and (b) Measurement grid constructed over that configuration.

Once the grid was constructed on the frame during the course of the swallow where maximum medial excursion of the LAPW was first attained, it remained intact on the viewing surface during the rest of the swallow until the LAPW returned to rest position. The head immobilization device utilized during data collection insured stabilization of the head during the entire course of the swallow. Measurements were taken on each successive frame of the distance between points a and a′, b and b′, c and c′, d and d′, e and e′, f and f′, and g and g′ (Figure 1b). Since the barium coating of the LAPW varied in thickness, all measures along the horizontal lines were made at the edge of the coating closest to the LAPW. Measurements between points b and b′, c and c′, and f and f′ were zero until the LAPW began to move laterally.

Measurement ratios were used in comparing swallows both within and between subjects. This procedure was employed because of anticipated variation in the size of anatomical structure from subject to subject. The distance between points a and a′ was used as the referent for computation of the ratios. Thus, ratios were computed for each frame by dividing the measurements obtained between b and b′, c and c′, . . ., g and g′ by the measurement obtained between a and a′. This procedure served to reduce the effect of variation between subjects and permitted a comparison of the movements of the LAPW at various levels of each subject's pharynx.

Results and Discussion

The data* obtained from the measurements indicate that swallowing is in fact a very consistent physiological activity. Within subjects this consistency is striking. Standard error terms computed for each subject frame-by-frame as based on the ratios indicate that variance frame-by-frame across repeated swallows within subjects is small.* Thus, the course of repeated swallows over time is very consistent. Figure 2 graphically represents an average swallow for each subject through seven frames for all computed ratios. Note the similar trends between subjects.† Computation of the total within subject variance for each line of measurement, frames X subjects, across all 25 swallows based on the measures as recorded in millimeters yielded extremely small values, indicating that as a group, there was very little variation within subjects.*

The consistency of swallows between subjects, while not as great as that within subjects, is evident from the data shown in Figure 2. The trends of pharyngeal activity are very similar for all five subjects. It may be assumed that at least some of the variability observed between subjects is due to the inability to totally eliminate differences due to structural size.

Kinesiology of Velopharyngeal Closure During Swallowing. Viewed in full speed, the frontal view of the pharynx during swallowing for all five subjects reveals a pattern of activity in the LAPW similar to

* Complete lists of measurement data tabulated in Shprintzen (13).
† Complete tables available, Shprintzen (13).

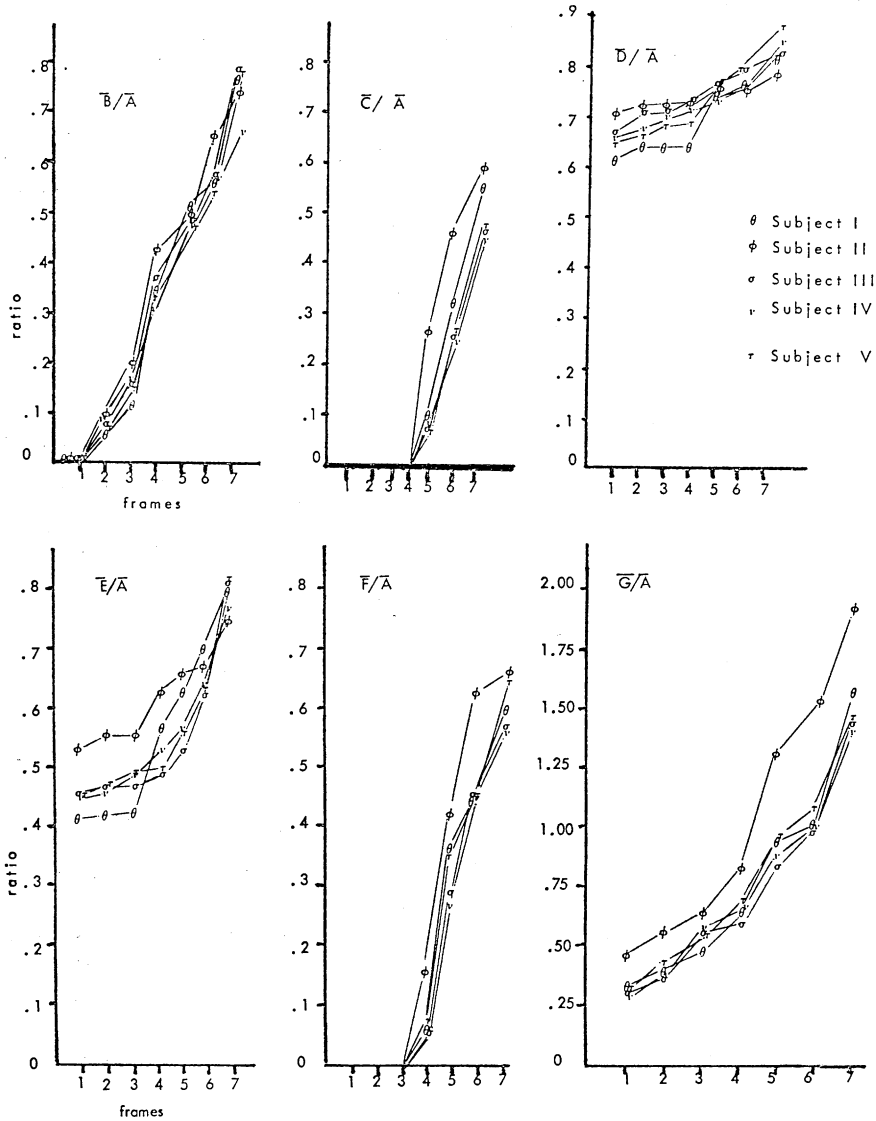

FIGURE 2. Graphic representation of ratios comparing subjects for each measure, frame-by-frame.

peristalsis. From their point of maximum medial excursion, the LAPW separate in a wave-like fashion until they are at rest. When observed in slow motion and consecutive stopped frames, the wave-like separation of the LAPW loses its continuous appearance. Rather, the peristaltic wave appears to have three discrete levels of function. A schematic drawing of a typical swallow progressing through seven frames after the LAPW have reached maximum medial excursion is shown in Figure 3. Through frame

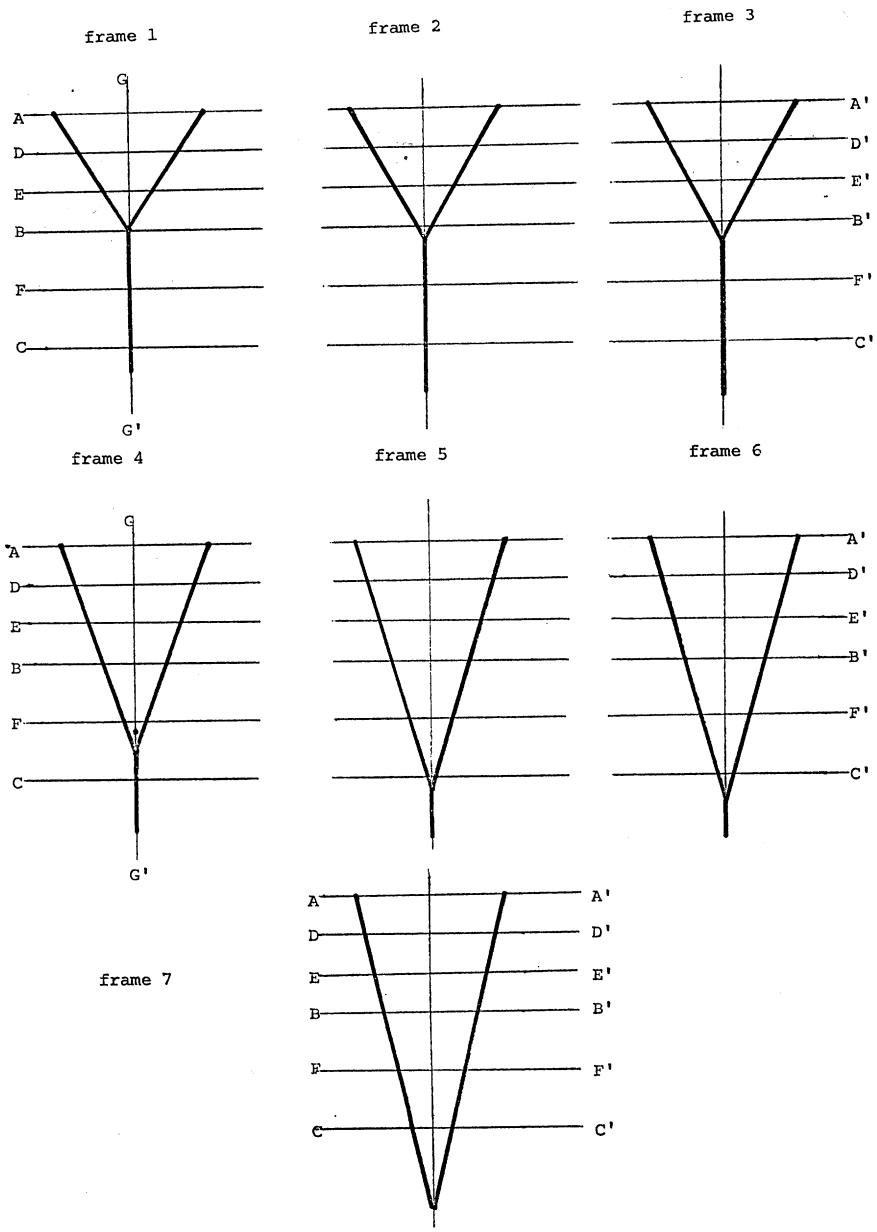

FIGURE 3. Schematic representation of the LAPW through seven frames of swallow.

3, in all five subjects there is a gradual slow separation of the LAPW resembling peristalsis. Then there is a discrete jump in the lateral movement of the LAPW disrupting the continuously slow separation observed through frame 3. A second large jump in the separation of the LAPW gen-

erally occurs after frame 6. During frames 4 through 6, the activity is continuous, but slightly more rapid than before frame 3. After frame 6 until the LAPW reach rest, the movement is again slow and gradual. The pharyngeal walls reached rest position at frame 13 for all five subjects.

These kinesiological observations and the data from Table 2 and Figures 2 and 3 would seem to be consistent with the findings of Doty and Bosma (*6*) and Shipp et al (*12*). In both of these studies, it was concluded that the superior, middle, and inferior constrictors fire in overlapping sequence during swallowing. It is possible that through frame 3, the kinesiology observed in this study reflects contraction of the superior constrictor muscle while after frame 3 it is deactivating as the middle constrictor is active. After frame 6, the LAPW in the upper portion are near rest position while in the lower portion of the oropharynx the LAPW are still near approximation. This may be due to activity in the inferior constrictor, which overlaps the middle and superior constrictors, while the other pharyngeal constrictors are deactivating.

Measurements were also taken after frame 7 through frame 13, when the LAPW reached rest position. After frame 7, little change in the configuration of the LAPW was noted. The activity was probably occurring at a level below the limits of the screen, perhaps in the lower portion of the inferior constrictor and/or the esophagus. All pharyngeal activity ceased in frame 13, or after approximately 450 msec. This is in general agreement with the data of Barclay (*1*) which put the course of the swallow at ½ second (500 msec.) and Basmajian and Dutta (*3*) who put the range of duration at 400 to 500 msec.

Observation of the lateral views for each subject indicate that the point of contact between the posterior aspect of the pharynx and velum during swallowing was generally low. That is, the levator eminence generally did not reach the height of the hard palate and the point of contact between the velum and pharynx was somewhat below the levator eminence. Contact was made between the velum and posterior aspect of the pharynx in all 25 swallows and no regurgitation of barium into the nasopharynx was noted. Slight anterior movement of the posterior aspect of the pharynx was noted in three subjects (III, IV, V). This anterior movement involved a broad verticle section of the posterior wall. Subject I showed marked anterior movement of the posterior wall. Intraoral inspection revealed that this subject had a broad and deep pharynx as compared to the other subjects. Subject II, who had a rather narrow pharynx, had no observable anterior movement of the posterior pharynx.

Summary

Measurements made from frontal view videofluoroscopic examinations of 25 swallows, 5 each from 5 subjects, reveals that kinesiologically, swallowing is a consistent activity both within and between subjects. Within subjects, the data indicates that the pattern of observed activity in the lat-

eral aspects of the pharyngeal walls over time for repeated swallows is remarkably consistent. Between subject consistency is evident from trends of pharyngeal activity over time even though subjects may vary anatomically. This observed consistency is in agreement with the data of Bosma (*5*). In addition, pharyngeal activity during swallowing involves approximation of the LAPW followed by a peristaltic-like separation of the pharyngeal walls which appears to have three discrete levels of function. This observation coincides with existing EMG data (*6, 12*) which indicates that phasic activity occurs during swallowing in the three pharyngeal constrictors. In conclusion, since swallowing does appear to be a consistent physiological activity, it should provide a basis for a comparative investigation to determine the existence of multiple mechanisms of velopharyngeal closure for different activities requiring such closure. The measurement technique for frontal view videofluoroscopy utilized in this experiment should be applicable for such an investigation.

Experiment II

Experiment II was designed as a comparative study of the kinesiology of velopharyngeal closure during speech, blowing, whistling, gagging, and swallowing.

Method and Procedures

Subjects. Five normal adult subjects, four female, one male, ranging in age from 33 to 45 with a mean age of 38.2 were studied in frontal and lateral videofluoroscopic projections while performing speech, blowing, whistling, gagging, and swallowing tasks. Subjects were judged as normal if they had no history of oral or pharyngeal surgery, no history of speech therapy or speech disorder, no evidence of nasal speech, and no structural anomalies of the oral and pharyngeal cavities.

Data Collection. The radiographic technique was the same as that utilized in Experiment I. However, the pharynx and velum of each subject was heavily coated with barium injected intranasally to define the LAPW and the margin of the velum prior to videofluoroscopic examination.

Each subject was required to perform five tasks while under both frontal and lateral videofluoroscopic projections. The tasks were presented in random order. Three repetitions of each task were selected for measurement and analysis. The tasks were:

Speech: Production of the following syllables in the carrier sentence "Say _____ again." /sup/, /sæp/, /tup/, /tæp/, /lup/, /læp/

Blowing: Each subject was instructed to blow a sustained air stream out of the mouth. The instructions were to "blow as if you are blowing on hot soup for a couple of seconds."

Whistling: Each subject was instructed to whistle a sustained note for a one second duration.

Swallowing: Each subject was instructed to perform a dry swallow.

Gag: Each subject was gagged with a tongue blade.

The videofluoroscopic recordings were later converted to 16mm motion picture film. Each frame of the film was numbered to provide an accurate record for referral to any frame for repeated measure.

Data Reduction. In lateral view, an anatomical reference line was utilized to mark the point of contact between the velum and posterior aspect of the pharyngeal walls. The anatomical referent was a line connecting the anterior tubercle of the atlas (first cervicle vertebra) to the juncture between the superior surface of the hard palate and the pterygomaxillary fissure (Figure 4). This line intersects the posterior aspect of the pharyngeal walls (PAPW). The point of intersection between the reference line and PAPW was used as a base of comparison with the points of the most superior contact between the velum and PAPW during each of the five activities. This difference was measured and recorded in millimeters.

In frontal view, the measurement grid described in Experiment I was utilized as a base of comparison for all five activities. Due to the heavy barium coating employed in this study, several reflexive swallows occurred during the frontal examinations of each of the five subjects. Once the measurement grid was constructed, it remained on the viewing surface as the five experimental tasks were viewed. Thus, it was possible to measure the amount of separation between the LAPW at various levels of the oropharynx for all five activities, as well as the degree of approximation, if any.

A stop-frame technique was used in this study to obtain measurements. The cinefluorographic examinations were stop-framed during each activity

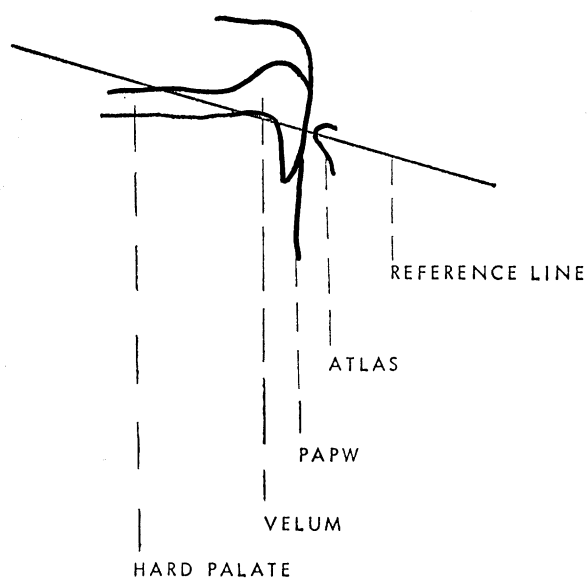

FIGURE 4. Example of lateral view reference line connecting the anterior tubercle of the atlas with the juncture of the pterygo-maxillary fissure and the superior surface of the hard palate.

for measurement after the grid had been constructed in frontal view and the reference line was constructed in lateral view. The criteria for measurement during each of the activities were the point of maximum velar elevation in lateral projection, and the point of maximum medial excursion of the LAPW in frontal projection. Since each subject was heavily coated with barium intranasally, the upper margin of the velum was also visible in frontal projection. Upon repeated observation of the frontal view films, noting the upper margin of the velum and the movements of the LAPW, it was determined that the moment of maximum medial excursion of the LAPW coincided with the moment of maximum velar elevation.

Results. A series of a priori orthogonal planned comparisons (*18*) were used to test the following hypotheses within subjects for each separate measurement:

1. μspeech = μwhistle
2. μswallow = μgag
3. μspeech = μblow = μwhistle
4. μspeech + μwhistle + μblow/3 = μswallow + μgag/2

The a priori nature of the statistical analysis was based on previous reviews of several fluoroscopic procedures performed on normals. The raw data consisted of the measures in millimeters obtained from the reference line in lateral view and the seven measurement lines on the grid in frontal view. F tests were performed to test each hypothesis.

In all five subjects, a difference was noted between the spontaneous swallows used as a basis for the grid, which occurred frequently during the examination and the dry swallow used in the procedure. The dry swallow involved greater velar elevation and medial excursion of the LAPW for all five subjects. Therefore, the dry swallow met the criteria for measurement and was used for data analysis.

*Data Analysis by Hypotheses**. Though the data analysis was entirely within subjects, a review of the significant tests hypothesis-by-hypothesis reveals the trends shown by each subject regarding velopharyngeal closure during each of the activities studied. While this is not a statistical test of between subject significance, the independence of each F test allows for the observation of the trends shown by each subject.

Hypothesis 1. The first hypothesis, that speech and whistling have the same closure mechanism, was not rejected within each of the five subjects for any of the measurements, frontal and lateral ($p > .05$). Out of a total of 37 independent significance tests, in no instance was the hypothesis rejected at the .05 level of significance. Tracings of each subject's closure patterns (Figures 5–9) indicate that the closure mechanisms for speech and whistling have the same characteristic patterns in both fluoroscopic views.

Hypothesis 2. The second hypothesis, that swallowing and gagging have a common pattern at their point of maximum velar elevation, was not rejected in any of the five subjects for any of the frontal or lateral view

* Complete data and sample analysis available, Shprintzen (13).

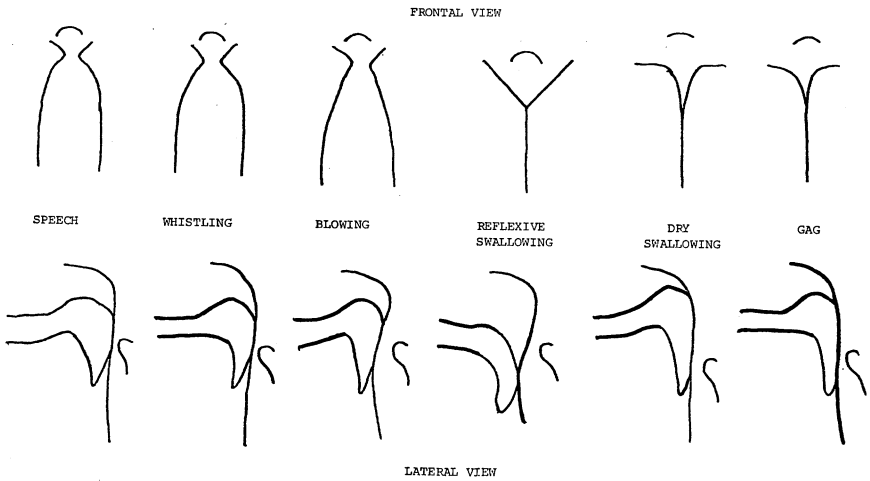

FIGURE 5. Tracings of frontal and lateral views for subject I during speech, whistling, blowing, reflexive swallowing, dry swallowing, and gagging.

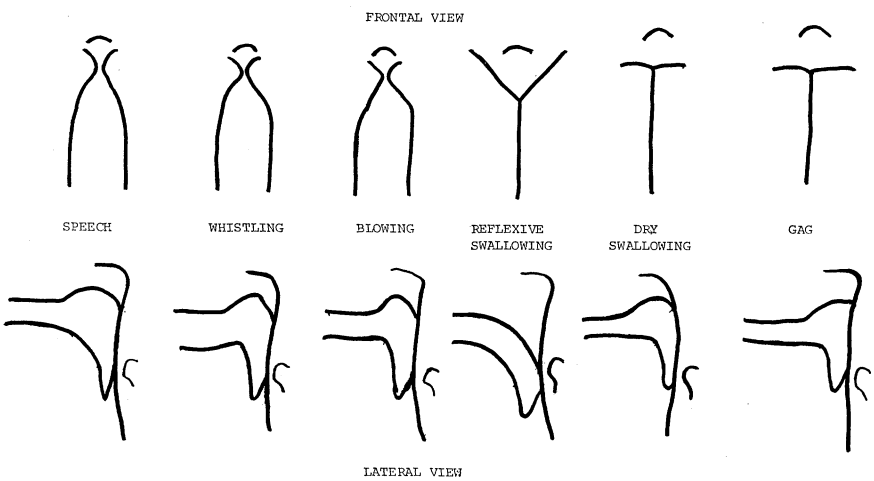

FIGURE 6. Tracings of frontal and lateral views for subject II during speech, whistling, blowing, reflexive swallowing, dry swallowing, and gagging.

measurements ($p > .05$). The results of the 37 significance tests on this hypothesis and the tracings (Figures 5–9) confirm that dry swallowing and gagging both employ the same closure mechanism within each of the five subjects.

Hypothesis 3. The third hypothesis, that speech, whistling, and blowing share a common mechanism was not rejected in any of the five subjects for any measurement ($p > .05$) with only one exception. For Subject I, the frontal view measurement C, the inferior most measurement in the oropharynx, the obtained F of 6.05 was slightly greater than $F\ .95\ (1, 10) = 4.96$. This rejection may be due to a small error term for this measurement

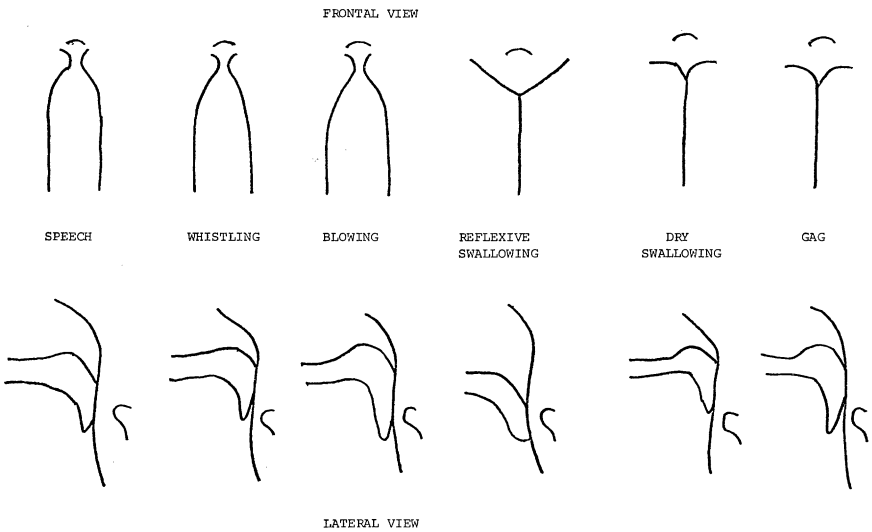

FIGURE 7. Tracings of frontal and lateral views for subject III during speech, whistling, blowing, reflexive swallowing, dry swallowing, and gagging.

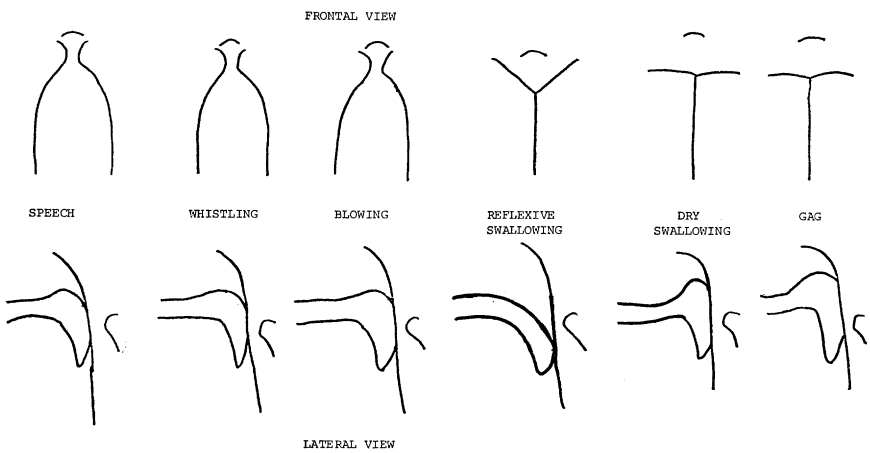

FIGURE 8. Tracings of frontal and lateral views for subject IV during speech, whistling, blowing, reflexive swallowing, dry swallowing, and gagging.

due to a lack of variation within activities for this subject, or it may be a chance rejection of the hypothesis. As in the previous two hypotheses, the results of the significance tests and the tracings (Figures 5–9) indicate that these three pneumatic activities do not differ significantly in closure mechanism.

Hypothesis 4. The fourth hypothesis, that speech, blowing, and whistling (pneumatic activities) have the same pattern of closure as swallowing and gagging (nonpneumatic activities) was rejected at the .05 level in each of the five subjects for all measurements with one exception. This exception

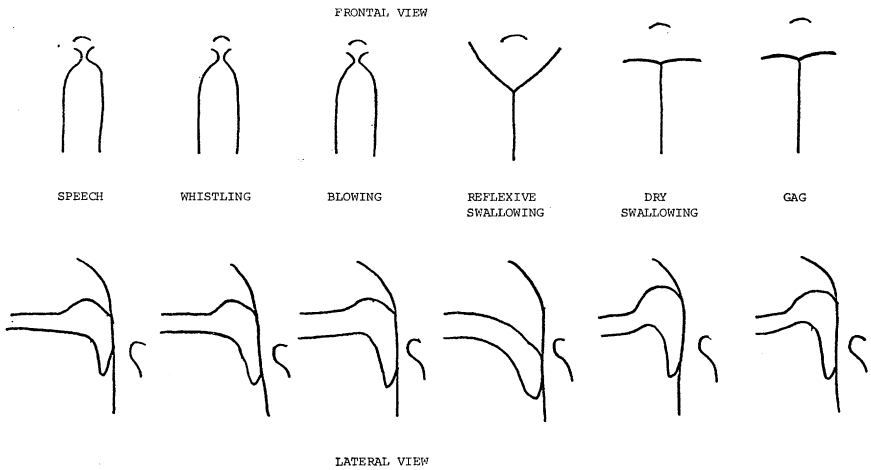

FIGURE 9. Tracings of frontal and lateral views for subject V during speech, whistling, blowing, reflexive swallowing, dry swallowing, and gagging.

was the lateral view measurement of Subject III. However, the hypothesis was rejected for all of the frontal view measurements for this subject. The tracings (Figures 5–9) confirm that in each of the subjects, the pneumatic activities differ strikingly from the nonpneumatic activities.

Thus, out of a total of 148 significance tests on the hypotheses put forth in the planned comparisons, in only one instance were hypotheses 1, 2, and 3 rejected at the .05 level of significance. Hypotheses 4 was rejected at the .05 level with one exception. These exceptions are well within the realm of chance rejections or non-rejections of the hypotheses. The tracings confirm the consistency of the pneumatic activities within each of the five subjects as well as the consistency of the nonpneumatic activities. However, the tracings also confirm the striking differences between the pneumatic and nonpneumatic activities.

Discussion

Using lateral view cinefluoroscopy and a measure of velar height, Moll (9) found one activity to be significantly different from the other activities studied which required velopharyngeal closure. Moll reported that blowing involved a significantly greater velar height than speech, swallowing, and gagging. However, Moll speculated that this difference for blowing may be due to the nature of the blowing tasks, blowing into a manometer. It is possible that this task involved either greater effort or an air pressure artifact, or perhaps both, which might force the velum upwards. Though Moll found only one significant difference in measures of velar height, he hypothesized that each activity which required closure does not necessarily employ the same closure mechanism.

It has become evident from the results of this study that a two dimensional analysis of velopharyngeal closure using lateral view alone is very

limited. While the results obtained in this study in lateral view were statistically similar to those obtained from the frontal view, one could not suspect from observing the lateral projection alone the striking differences in closure mechanism between the pneumatic and nonpneumatic activities. Similarly, the frontal view alone has its limitations. While the levator eminence is often visible in frontal view, the point of contact of the velum on the PAPW and the length of velum making contact are not. By using both views, and additional projections, if possible, it can be truly appreciated that one is studying velopharyngeal closure and not just the velar component of closure or the pharyngeal component of closure.

KINESIOLOGY OF VELOPHARYNGEAL CLOSURE MECHANISMS. It seems quite apparent from the results of this study that there is more than one pattern of velopharyngeal closure. Specifically, for the activities studied, there appear to be two closure mechanisms, and possibly three. Speech, whistling, and blowing share what may be labelled as a pneumatic closure mechanism because all three activities involve the utilization of an air stream. Dry swallowing and gagging, which do not appear to involve air flow, share another closure pattern which may be labelled as a nonpneumatic closure mechanism. It is possible that a third and separate mechanism exists for reflexive swallowing. However, it is also possible that the differences seen between dry and reflexive swallowing are indicative only of a difference in degree of activity within the same mechanism. This difference in degree may be a more likely choice since the course of the dry swallow appears to follow the same peristaltic-like pattern and the Y-shaped configuration does appear several frames after maximum medial excursion of the LAPW has been reached. A further analysis of swallowing may help to better understand the differences between dry swallowing and reflexive swallowing.

As the within subject analysis indicates, the lateral view films reveal that the point of contact between the velum and the PAPW is higher for the nonpneumatic activities than the pneumatic activities. Reflexive swallowing, however, shows the lowest contact point for all activities. The frontal view reveals some striking differences within subjects. During the pneumatic activities, the LAPW do not approximate at any point. In comparing the frontal view tracings for each of the five subjects, it can be seen that the LAPW are characteristically closest together in the region of the velopharyngeal portal and furthest apart in the lower portion of the oropharynx. During activities which require no pneumatic control, the LAPW are in approximation for the entire length of the oropharynx in Subjects II, IV, and V and for nearly the entire length in Subjects I and III. Therefore, it seems that there is greater specificity of LAPW movement for the pneumatic closure than the nonpneumatic closure mechanism which employs a total movement of the pharyngeal walls.

The observed configurations of the velopharyngeal apparatus during the two mechanisms of closure is logical when one considers the nature of the

activities involved. The pneumatic activities all involve the channeling of an air stream out of the mouth. The pharynx must therefore be opened enough in its lower portion to allow the passage of air. The velum must be elevated to fill the velopharyngeal portal and the lateral walls of the pharynx must narrow at the level of the velum to prevent the air from being channeled into the nasal cavity. The nonpneumatic activities have different purposes than the pneumatic activities. Swallowing involves passing materials down through the pharynx and into the esophagus. As was shown in Experiment I, a squeezing action similar to peristalsis performs this function which results in the LAPW approximation observed in Figures 5 through 9. Also, the velum must elevate to prevent any regurgitation of liquid or solid matter into the nasal cavity. Gagging requires the approximation of the LAPW, as well, probably to prevent intruding objects from passing through the pharynx and into the esophagus or trachea below.

It is not logical to assume that all activities requiring velopharyngeal closure employ the same pattern of closure, nor is it logical to assume that each activity utilizes a different closure pattern. The findings of this study are essentially inconsistent with the hypothesis that Moll (*9*) developed from his lateral view fluoroscopic data. This study indicates that normal subjects utilize the same observable patterns of closure for speech, whistling, and blowing. It may therefore be hypothesized that cleft palate individuals who can achieve closure during whistling and/or blowing, but who are incompetent during speech, may benefit from therapeutically approaching speech via the blowing or whistling mechanism. It may also be hypothesized that the reported lack of success using blowing procedures (*11*) is due to the erroneous assumption that the velum is "sluggish" or "weak" and must be exercised. It is possible that utilizing blowing or whistling in a different frame of reference for therapy may achieve successful carry-over to speech. This is not to say that blowing or whistling exercises would be helpful. Rather, it is hypothesized that the similarity in observed kinesiological activity between the three pneumatic activities may reflect similar physiological activity at the level of the velopharynx. It may therefore be possible to physiologically relate speech with either blowing or whistling for speech incompetent individuals who are able to achieve closure for the nonspeech pneumatic activities by appropriate learning procedures.

Summary

Patterns of velopharyngeal closure were observed and measured on repeated trials of speech, blowing, whistling, swallowing, and gagging tasks in both frontal and lateral cinefluoroscopic projections. The results of a statistical analysis reveal that for the five subjects studied, there are two separate and distinct patterns of velopharyngeal closure, and possibly a

third. One pattern, a pneumatic closure mechanism, is shared by speech, blowing, and whistling. The other pattern, a nonpneumatic closure mechanism, is shared by dry swallowing and gagging. There may also be a separate mechanism for reflexive swallowing. The pneumatic and nonpneumatic closure mechanisms show two strikingly dissimilar patterns of closure which are consistent with the dissimilar nature of the activities. It is possible that the similarity of the three pneumatic activities may have a direct bearing on the clinical treatment of velopharyngeal incompetence in speech.

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