A CEPHALOMETRIC STUDY OF VELAR STRETCH IN 8 and 10-YEAR-OLD CHILDREN

by

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INTRODUCTION

Introduction

Among the various diagnostic approaches used to obtain information about the structural and functional adequacy of the velopharyngeal mechanism is the technique of lateral cephalometric radiography. This approach permits the measurement of oral structures by providing well defined, two-dimensional, radiographic views of the palate and the nasopharynx. To determine whether components of the velopharyngeal mechanism are structurally (anatomically) adequate to serve their functional needs, measurements and comparisons are frequently made of such dimensions as pharyngeal depth, and velar length.[1-6]

The use of lateral cephalometric radiographic techniques in the evaluation of palatopharyngeal adequacy necessitates consideration of several important, clinically relevant issues. One question is whether measurements taken during physiological rest are similar or comparable to those obtained during functional activities such as speech. Stated differently, the question is to what degree observations of the velopharyngeal mechanism made while the system is resting, reflect the adequacy of the mechanism during functional activities such as speech.

Limited information concerning these questions is available for specific radiographic measurements used in evaluating palatopharyngeal form and function. For example, a number of investigators[3, 5-16] have measured functional pharyngeal depth. In general, normal speakers maintain a constant antero-posterior pharyngeal depth between states of physiologic rest and speech. Although some investigators have observed minor variations in pharyngeal depth, these depth changes are uncommon, are generally of small magnitude, and are considered to reflect compensatory movements developed by speakers with an atypical mechanism.[6,11]

A second measurement used by a number of investigators is soft palate or velar length. Graber, Bzoch, and Aoba (1959)[10] reported that "the soft palate increases significantly in length from the rest to functional position" in normal subjects. In 1968 Bzoch[9] reported a 49% increase in velar length between these two conditions for five normal subjects. In 1969 Pruzansky and Mason[17] studied 110 patients with congenital palatopharyngeal incompetence and reported that "in some individuals the soft palate (velum) increased in its intrinsic length during velopharyngeal valving." More recently, Simpson and Austin (1972)[6] have shown that in normal young adults the length of the velum does increase as it moves from its resting position to the functional positions assumed in speech. This phenomenon of functional palate lengthening has been termed "velar stretch" (Pruzansky and Mason, 1969).[17]

Unfortunately, only Simpson and Austin (1972)[6] have made systematic observations of velar stretch in normal-speaking subjects. To date, there have been no published reports of systematic observations of velar stretch in normal-speaking children. This situation is regrettable if one assumes that velar stretch represents an essential feature of normal velopharyngeal function. Study of the prevalence and magnitude of velar stretch in normal-speaking children should be of significant clinical value. Information about pertinent aspects of the stretch phenomenon in normal-speaking children is needed to provide a more complete description of the critical features of palatopharyngeal form and function, particularly as they relate to speech. Such observations assume more importance if one assumes that the potential of the velum to function adequately for speech cannot always be predicted simply on the basis of its resting length.

Hence, the general objective of this study was to use radiographic cephalometry to examine the prevalence, relative magnitude and selected components of velar stretch in normal-speaking eight and ten-year-old children.

REVIEW OF THE LITERATURE

Review of the Literature

I. Features of Velopharyngeal Function

A. Velopharyngeal Closing

The velopharyngeal port is bounded anteriorly by the soft palate (or velum) and laterally and posteriorly by the pharyngeal wall. The closing of the palatopharyngeal port is accomplished chiefly by an upward and backward movement of the soft palate and by medial displacement of the lateral pharyngeal wall. Forward displacement of the posterior pharyngeal wall is minimal (about 1 mm) during palatopharyngeal port closure maneuvers.[3,5-16]

Palatopharyngeal port closing or closure is evident during the production of most vowels and consonants.[5,10,18-20] Three operational positions of the velum are observed in midsagittal views of the velopharyngeal mechanism.[13,18,21] At rest, the oral surface of the soft palate rests against the dorsum of the tongue. This results in an open palatopharyngeal port uniting the pharyngeal and nasal cavities. At rest, the soft palate is at its greatest distance from the pharyngeal wall. In its most elevated position, the soft palate moves in a backward and upward motion and contacts the pharyngeal wall over a considerable length. This results in an open chamber uniting only the oral and pharyngeal cavities. The term "velopharyngeal closure" is used to describe circumstances in which the soft palate makes contact with the posterior pharyngeal wall. In intermediate positions, the soft palate elevates in a backward and upward motion; however, contact is not made between the soft palate and either the tongue or the pharyngeal wall. In other words, the soft palate assumes positions somewhere between the resting and maximally elevated positions. This results in a partial opening between the oral and pharyngeal and the nasal and pharyngeal cavities.

Spriestersbach and Sherman[13] and Westlake and Rutherford[21] observed that when velopharyngeal closure was achieved, approximately two-thirds of the anterior oral surface of the soft palate lies in a horizontal plane paralleling the palatal plane, while the posterior third of the soft palate lies in a vertical plane paralleling the pharyngeal wall. Moll[22] and Warren and Hofmann[3] using cineradiography techniques, reported that in the closed position the velum appears to oscillate against the pharyngeal wall.

Weinberg,[18] Westlake and Rutherford,[21] and Subtelny and Koepp-Baker[23] agreed that in young children the velum may contact a well developed adenoidal mass rather than the posterior pharyngeal wall. If the adenoid atrophies or is removed, the velum has to travel farther posteriorly to achieve velopharyngeal closure.

B. Variations in Velar Movement

Adequate function of the palatopharyngeal mechanism is necessary for normal speech.[15] Radiographic research has shown that palatopharyngeal closure or small degrees of velopharyngeal openings are present during the production of most non-nasal sounds spoken by normal speakers.[5,10,18-20] Closure of the velopharyngeal mechanism is seen more often during the production of high vowels (/i/ and /u/) than during the production of low vowels (/a/ and /ae/).[5,13-15,19,20,24,25] The palatopharyngeal valve is open during the production of the nasal consonants /m/, /n/, and /ng/, a phenomenon that allows the nasal, pharyngeal and oral cavities to serve as a resonant system.[10,18-20]

Subtelny, Koepp-Baker, and Subtelny,[26] and Westlake and Rutherford[21] reported that complete closure of the velopharyngeal valve is not necessary for non-nasal speech. In other words, small openings connecting the nasal and oral pharyngeal cavities are frequently present in the speech of normal talkers. This observation does not reduce the importance of an effective velopharyngeal valving mechanism. In their oral examinations of normal speakers, Westlake and Rutherford[21] noted that "effective valving takes place with minimal effort and that palatal closure differs from one person to the next."

Bzoch[9] and Moll and Shriner[20] felt that variations in intraoral breath pressure and/or physiological effort during speech may also affect the functioning of the palatopharyngeal valve. Moll and Shriner[20] hypothesized that "velar elevation represents part of a preparatory activity for utterance which occurs prior to the beginning of any phonation."

C. Velopharyngeal Incompetence

The importance of the velopharyngeal mechanism can best be understood by discussing velopharyngeal function among patients with cleft palate and among patients with congenital palatal incompetence. Velopharyngeal incompetence refers to the fact that these individuals can not effect adequate velopharyngeal valving maneuvers to support adequate speech. Among the multiple factors that may give rise to velopharyngeal incompetence are: (1) a velum which is too short, (2) a poorly mobile velum, (3) an excessively large nasopharyngeal depth and (4) a combination of any of the above.[17,27,28]

Velopharyngeal incompetence results in defective articulation and hypernasal speech.[21,29] Spriestersbach and Sherman[13] reported that, on the average, individuals with cleft palate are retarded in general articulation skills. Subtelny, Koepp-Baker and Subtelny[26] observed that in the continuous speech of adults with cleft palate hypernasality was noted with velopharyngeal openings of 3.5 to 7.0 mm. Although hypernasality was noted in the presence of velopharyngeal openings in excess of 7.0 mm, there was not necessarily a proportional increase in the severity of the nasality as a function of increased velopharyngeal opening.

Hagerty and Hill,[11] in a study of 50 subjects with normal palatopharyngeal structure and 50 subjects with repaired clefts of the palate observed that the forward movement of the pharyngeal wall was greater in the cleft group than in the normal group. The work of Flowers and Morris[30] and of Graber, Bzoch and Aoba[10] confirms this observation. Hagerty and Hill,[11] felt that forward movement of the pharyngeal wall produced a negligible effect on the speech output. Hagerty and Hill[11] observed that during the sustained production of /s/, velopharyngeal closure was present in all 50 normal-speaking subjects but palatopharyngeal closure was present in only 17 of the 50 subjects with cleft palate.

Spriestersbach and Sherman[13] said that inadequacies of tongue coordination and flexibility are not etiologically significant with respect to the speech problems of individuals with cleft palate. They also observed that nasal obstruction and nares constriction maneuvers are used by individuals with cleft palate to impound intraoral breath pressures during the production of speech and that these maneuvers should be identified when the articulatory skills of these individuals are evaluated.

In summary, velopharyngeal incompetence results in articulation errors and hypernasality due to a loss of intraoral breath pressure during the production of most consonants and vowels. Spriestersbach and Sherman[13] stated that velopharyngeal incompetence is the most important etiologic factor in articulation problems for cleft palate patients.

II Morphological and Developmental Factors Affecting Velopharyngeal Function

A. Adenoids

Adenoidal tissue can play a role in determining velopharyngeal adequacy. An inadequate velopharyngeal valve may be unmasked when adenoidal tissue atrophies or is removed.[21,23] In the midsagittal plane, the adenoidal tissue appears as a convex bulging of the nasopharynx facing the soft palate. Adenoidal tissue can extend from the roof of the nasopharynx to or slightly below the anterior tubercle of the atlas. Subtelny and Koepp-Baker[23] stated that the peak growth of adenoidal tissue "...may be reached as early as 9 to 10 years-of-age and is sometimes evident as late as 14 to 15 years." They found that adenoidal tissue grows in a downward and forward direction and atrophies in a backward and upward direction. Adenoids are usually removed when a hearing disturbance is caused by the adenoidal tissue obstructing the eustachian tube and preventing proper ventilation of the middle ear. Partial or lateral adenoidectomies, leaving a midline adenoid pad, are sometimes recommended to preserve an adequate velopharyngeal mechanism.[23,29,31]

B. Pharyngeal Depth

King,[32] in his study of pharyngeal growth, stated that the anteroposterior dimensions of the skeletal depth of the nasopharynx are established in early infancy and that there is minimal growth thereafter.

Using lateral cephalograms, he found that "from 3 months to 16 years the anteroposterior growth between the atlas and the posterior nasal spine amounted to only 3.8 mm in the male and 2.6 mm in the female." The growth in the nasopharyngeal depth is due to forward and downward growth of the palate and expansion of the wings of the sphenoid. King also found that there was a sizable increase in the vertical growth of the pharynx "...brought about posteriorly by an increase in the height of the cervical vertebrae and anteriorly by the descent of the hard palate, pterygoid process, mandible and hyoid bone."

C. Palatal Length

Subtelny[2] has shown that the soft palate has its most rapid growth during the first two years of life. He noted a steady increase in length of the soft palate after 4.5 years of age up to early adulthood, and found no significant differences in growth between the sexes. The angle formed by the palatal plane and the resting soft palate tends to become more acute with increasing age. In other words, he suggested that with age the velum tends to parallel the pharyngeal wall possibly due to the downward and forward growth of the skeletal face and the vertical growth of the pharynx.

III Radiographic Assessment of Velopharyngeal Function

A. Radiographic Techniques

The radiographic techniques used most frequently to assess the velopharyngeal mechanism are cinefluoroscopy and lateral cephalometric radiography.

Cinefluorographic observations provide views of the velopharyngeal mechanism during continuous speech. Moll[33] found that:

> ...a cineradiographic camera speed of at least 200 frames per second is necessary for detailed studies of individual phonemes in connected speech...and that the radiation dose at this speed would be approximately 6.0 roentgens per minute.

Lateral cephalometric radiographic procedures can be used to sample only selected types of speech utterances, i.e., sustained sounds. Many researchers have found this technique to be a useful clinical method of assessing the adequacy of the velopharyngeal mechanism. For example, in 1951 Williams[15] used lateral cephalograms since he felt this technique provided good visualization of the velopharyngeal valve. This method was selected again in a 1964 study by Subtelny.[34] She stated that:

> Cephalometric roentgenography provides a rigorous standardization of technique making it possible to control magnification and distortion, both of which are inevitable in radiographic films. There is no appreciable movement occurring during exposure. As a result soft tissue relationships are delineated clearly. These features make quantitative measurements in the palatopharyngeal region possible and applicable to a well defined skeletal reference.

She also felt that lateral cephalograms of a sustained sound have predictive value in defining potential velopharyngeal closure during continuous speech and that a valid assessment of velar elevation and the amount of velopharyngeal contact could be made. She summarized her statements by saying "cephalometric roentgenography is a reliable, valid, relatively accessible, and economical technique."[34]

Lubker and Morris[35] in 1968 reiterated Subtelny's findings when they stated:

> ...because of film processing delays, problems of data reduction, dangers from radiation dosage and equipment expense and maintenance, single-exposure films may be much more practical than cinefluorography in many clinical settings and in some research projects.

In summary, lateral cephalograms have been shown to provide useful diagnostic information for the evaluation of velopharyngeal function.

B. <u>Radiographic Assessment of Velar Stretch</u>

As stated previously, velar stretch refers to the change in length of the velum as it moves from rest to a functional position assumed in speech.

In 1959 Graber, Bzoch and Aoba[10] studied the consonant sounds (p, b, f, w, and m) in normal young adults and commented informally that there appeared to be a significant increase in length of velum from the rest to the functional position. On the basis of their clinical experience, Westlake and Rutherford[21] felt that the thickness and length of the soft palate might increase during function. They hypothesized that the levator veli palatini muscle is responsible for the increase in the length of the functioning soft palate.

In 1968 Bzoch,[9] using five normal young adult subjects producing syllables with the vowels /a/, /i/, and /u/, reported that "...the palate becomes both longer and thicker, at least in the midsagittal plane, during function for speech."

In 1969 Pruzansky and Mason[17] completed a cephalometric study of velar stretch among 110 patients with congenital palatopharyngeal incompetence. They termed the increase in the functional length of the palate the "stretch factor" and reported observing sizeable increases in the functional length of the palate during the production of both the consonant /s/ and the vowel /u/ in this group of patients with palatopharyngeal inadequacy.

Simpson and Austin[6] in 1972 completed cephalometric systematic observations of velar stretch in 10 male and 10 female subjects between the ages of 18 to 30 during the production of sustained /s/. They stated that "significant stretch was found for the entire velum."

Because of the limited amount of information concerning velar stretch in normal speakers and because of the importance stretch mechanisms may have in determining velopharyngeal adequacy for speech, the present research was conducted to determine the prevalence and magnitude of velar stretch, and its relationship to important structural measurements in normal-speaking 8 and 10-year-old children.

METHODS AND MATERIALS

Methods and Materials

Subjects

Twenty 8-year-old children and twenty 10-year-old children were studied in this investigation. Both groups had equal numbers of boys and girls.

All children studied had: (1) Class I occlusion, (2) normal speech, (3) no previous speech therapy, (4) no evidence of gross neuromuscular impairment or structural abnormality of the palate, and (5) no history of surgical removal of tonsils or adenoids. For purposes of this research, Class I occlusion referred to the fact that the mesial buccal cusp of the upper first permanent molar interdigitated with the buccal groove of the lower first permanent molar. In addition, the upper primary or permanent canine occluded between the lower primary or permanent canine and the lower first primary molar or first premolar.

To ensure that only normal-speaking 8 and 10-year-old children were used as subjects in this research, tape recordings were made of each child producing the stimulus items of the Iowa Pressure Test of Articulation,[36] the Templin-Darley Screening Test of Articulation,[37] and a short sample of spontaneous speech.[18] The Iowa Pressure Test of Articulation[36] is commonly used to assess the adequacy of velopharyngeal function. The 43 items of this test sample the speaker's articulatory proficiency for selected fricative, plosive and affricate consonants; i.e., sounds which are known to discriminate best between speakers with and without adequate velopharyngeal closure for speech.

The Templin-Darley Screening Test of Articulation[37] is commonly used to assess the general adequacy of a child's speech articulation. The 50 items of this test sample a speaker's articulation proficiency for various important speech sounds.

The speech recordings of each child were evaluated by a qualified speech pathologist* experienced in the clinical procedures used to evaluate velopharyngeal adequacy for speech. The evaluation consisted of classifying each of the test items for both tests of articulation into two categories: (1) correct sound production and (2) incorrect sound production. All forty subjects in this experiment articulated all test items correctly; i.e., none of them made errors in speech articulation in either of the articulation tests. An additional fourteen subjects were eliminated from this investigation due to incorrect sound production on the test items.

Cephalometric Procedures

Equipment A Wehmer cephalometer was used to obtain lateral cephalometric films for each subject. The target film distance used with this cephalometer was fixed at 5 feet. All radiographs were exposed at 15 ma/second for 36/60 second using a KVP setting of 88.

Experimental Conditions A standardized procedure was used to position each subject in a standing upright posture within the cephalostat.

*Recordings were evaluated by Bernd Weinberg, Ph.D., Associate Professor of Speech Pathology, Purdue University.

Each subject's head was fixed within the cephalostat by inserting head positioner ear-rods into the external auditory meatus of each subject's ears and by placing the nasion holder of the head positioner on the bridge of each subject's nose.

Lateral cephalometric films were obtained for each subject under three conditions: (1) subject at rest, (2) subject sustaining the vowel /u/, and (3) subject sustaining the voiceless fricative /s/. The rest radiograph of each subject was obtained under conditions in which the subject was instructed to keep his teeth together and breathe through his nose. The speech radiographs of each subject were obtained by instructing the subject to sustain the requested sound at a comfortable and constant level. The activities used in obtaining the speech radiographs were all tape recorded and subsequently evaluated to ensure that the intended sound was indeed produced by each speaker and that the radiograph was taken during the approximate midpoint of each subject's three-second sustained production of the sound under test.

<u>Measurement Procedures</u> The three cephalometric films obtained for each subject were traced on acetate paper and specific structural measurements were made on each radiographic film. All tracings were made on 0.003 acetate using a sharp 3H pencil. The following anatomical landmarks, structures and reference points were traced on all lateral cephalometric radiographs (Figure 1):

1. Sella (S): A point representing the center of the sella turcica; determined by inspection.

2. Nasion (N): A point representing the junction of the frontal and nasal bones.

3. Pterygomaxillary fissure (PTM): The contour of the maxillary tuberosity anteriorly and the pterygoid bone posteriorly.

4. Anterior Nasal Spine (ANS): The most anterior point on the anterior nasal spine.

5. Posterior Nasal Spine (PNS): A point representing the posterior projection of the horizontal plate of the palatine bone at the midline.

6. Palatal Plane (PP): A line constructed by connecting ANS and PNS.

7. Soft palate or Velum (V): The contour of the soft palate.

8. Posterior Pharyngeal Wall (PW): The contour of the soft tissue of the posterior pharyngeal wall.

9. Radiopaque marker (M): A point representing the center of the radiopaque marker; determined by inspection.

The rest radiographic tracing was superimposed on the tracings of the speech radiographs using sella, nasion, and pterygomaxillary fissure as reference landmarks. This superimposition of tracings provided more consistent location of anterior and posterior nasal spine as well as palatal plane.

The following measurements were made on the acetate tracings of each subject's rest radiographs. Measurements were made to the nearest 0.5 millimeter (Figure 2).

1. Pharyngeal depth (PNS-PW): The linear distance from the posterior nasal spine (PNS) to the posterior pharyngeal wall (PW) measured along palatal plane.

2. Palate length: The linear distance from the posterior nasal spine (PNS) to the most inferior point of the uvula (U).

3. Length of the anterior portion of the velum: The linear distance

from the posterior nasal spine (PNS) to the midpoint of the radiopaque marker (M).

The following measurements were made on the acetate tracings of each subject's speech radiographs (Figure 3). Again, measurements were made to the nearest 0.5 millimeter.

1. Velar length: The linear distance from the posterior nasal spine (PNS) to the most inferior point of the uvula (U); measured along an empirically constructed midline.

2. Length of the anterior portion of the velum: The linear distance from the posterior nasal spine (PNS) to the midpoint of the radiopaque marker (M).

3. Velar height (H): The highest point on the nasal surface of the velum relative to palatal plane; measured by constructing a perpendicular from this most superior point on the velum to palatal plane.

4. Velopharyngeal opening (VPO): The shortest linear distance between the soft palate and the posterior pharyngeal wall.

The measurements described above were used to calculate additional radiographic measurements. These included:

1. "Need" ratio: A percentage computed by dividing pharyngeal depth by velar length at rest and multiplying by 100. For example:

$$\frac{\text{pharyngeal depth}}{\text{velar length at rest}} \times 100 = \text{need ratio}$$

2. Total velar stretch: The difference in millimeters between the length of the soft palate at rest and its length during the sustained production of either /u/ or /s/.

3. Percentage of total velar stretch: Computed by dividing the amount

of total velar stretch by resting velar length and multiplying by 100. For example:

$$\frac{(\text{velar length during } /u/) - (\text{resting velar length})}{\text{resting velar length}} \times 100 = \text{Percentage of total velar stretch attained during } /u/ \text{ production}$$

4. Anterior velar stretch: The difference in millimeters between the length of the anterior portion of the soft palate at rest and its anterior length during the sustained production of either /u/ or /s/.

5. Percentage of anterior stretch: Computed by dividing the magnitude of anterior stretch by the resting length of the anterior portion of the palate and multiplying by 100. For example:

$$\frac{(\text{anterior length during } /u/) - (\text{resting anterior length})}{\text{resting anterior length}} \times 100 = \text{Percentage of anterior stretch attained during } /u/ \text{ production}$$

The procedure of using a radiopaque marker to divide the soft palate into an anterior and posterior portion was originally suggested by Simpson and Austin.[6] They attached a lead marker to the soft palate and used the posterior point of this marker as a reference landmark for the palatal division process. In the present experiment, radiopaque markers were also used to study the behaviors of selected portions of the soft palate. In the present work, the radiopaque marker was made of lead foil material obtained from periapical x-ray films manufactured by the Eastman Kodak Company. According to the Kodak Company,[38] the essential component of this foil material is lead. In addition, the foil material contains tin (0.75 ± 0.25% of total material weight) and antimony (1.5 ± 0.3% of total material weight). The foil material is approximately 0.0025 inches thick. The lead within this foil is uniformly coated on both sides with a smooth layer of tin.

The radiopaque markers used in the present experiment were hand-made by the experimenter. Specifically, a leather punch was used to make symmetrical, round radiopaque markers having a diameter of 3.7 mm. A standard series of procedures were used to place the markers on each subject's palate. Initially, an indelible pencil was used to mark the velar eminence of each subject's palate. The velar eminence of each subject was empirically determined and identified as the point of maximum soft palate elevation attained during the sustained production of the vowel /a/. Specifically, each subject was instructed to sustain this vowel and, through visual inspection, the experimenter identified and marked the velar eminence of each subject with an indelible pencil. The actual placement of the radiopaque marker was accomplished by placing a small amount of xylocaine topical anesthetic on the tip of the wooden end of a six-inch cotton tip applicator and placing one side of the marker on top of the xylocaine. A drop of commercial dental adhesive (Eastman 910) was then placed on the opposing side of the radiopaque marker. The marker was held against the indelibly marked velar eminence for approximately 30 seconds to ensure firm adhesion and the subject was then placed in the cephalostat. Each marker weighed about 0.0084 gram, while the combined weight of the adhesive plus the xylocaine topical anesthetic had an average weight of about 0.0043 gram.

The pilot study indicated that it was desirable to desensitize the soft palate prior to placing the radiopaque marker into each child's mouth. Accordingly, in the main study each subject's palate was brushed with a cotton tip applicator in the area of the velar eminence for about 0.5 to 1.0 minute before the marker was placed. The brushing procedure was used to keep the area on which the marker was placed dry and to desensitize the palate.

The radiopaque markers were removed from each speaker's mouth after a complete set of radiographs had been obtained. Before being removed, the marker and the lateral borders of the indelible pencil mark were visually inspected to ensure that the marker had not moved. The marker was removed by brushing the end of a cotton tip applicator against the marker. Subjects were then instructed to rinse their mouth thoroughly with water until all residual taste from the indelible pencil or dental adhesive was gone.

Measurement Reliability The accuracy and reliability of the investigator's cephalometric tracings and measurements were determined by having the experimenter trace and obtain a complete set of measurements (see preceding section) on randomly selected sets (rest and two speech radiographs) of cephalometric headplates for six subjects. The average difference in millimeters between repeated recordings of each cephalometric measure was used to assess the investigator's accuracy and reliability.

Analysis of Data

The general results of the cephalometric analysis of both 8 and 10-year-old children were subjected to descriptive statistical analyses to provide mean, standard deviation, and range values for each cephalometric measurement. Analysis of variance procedures were used to determine whether there were significant differences in the cephalometric measurements as a function of the age and sex of the children studied. Paired-comparison t-test procedures were used to evaluate the significance of the differences between the average characteristics of selected cephalometric measurements as a function of experimental condition and/or speech task. Finally, correlation procedures were used to assess the relationships between the amount of velar stretch and other cephalometric measurements.

RESULTS

Results

Measurement Reliability

The accuracy and reliability of the investigator's cephalometric tracings and measurements were determined by having the experimenter trace and obtain a complete set of measurements on randomly selected sets (rest and two speech radiographs) of cephalometric headplates for six subjects. The values obtained for repeated tracings and measurements of this series of cephalometric headplates are summarized in Table 1. The values for individual measurements as well as the average for each cephalometric measurement are given. The small difference between average values for each of the cephalometric measurements attests to the accuracy and reliability of the investigator's cephalometric tracings and measurements. The difference between individual measurements and the average difference between repeated readings of each cephalometric measurement are also shown in this table. Inspection of these values also supports the assumption that the investigator exhibited adequate tracing and measurement accuracy and reliability.

General Results of Cephalometric Analysis

The general results of the cephalometric analysis of both 8 and 10-year-old children are presented in Tables 2-5. The raw data for each group of subjects were subjected to descriptive statistical analysis to provide mean, standard deviation and range values for each cephalometric measure.

Prevalence of Velar Stretch

One objective of this study was to use radiographic cephalometry to examine the prevalence and relative magnitude of velar stretch in normal 8 and 10-year-old children. With respect to prevalence, the data in Tables 2-5 showed that during the production of /u/ and /s/ velar stretch was not observed in all 40 subjects. During the production of /u/, 36 children (90%) exhibited velar stretch; for /s/, 32 children (80%) manifested stretch. All 10-year-old boys exhibited stretch during both /u/ and /s/ productions. Among 10-year-old girls, 10 subjects (100%) employed stretch during sustained /u/, while 9 (90%) employed stretch during /s/. Among 8-year-old children, 8 boys (80%) and 8 girls (80%) exhibited stretch during sustained /u/, while 7 boys (70%) and 6 girls (60%) exhibited stretch during the production of the fricative /s/.

Velar stretch was not found in 12 of the 80 radiographic observations. In 10 of these instances, the length of the soft palate measured during the functional activity of speech was less than its resting length. In the remaining two instances, the length of the soft palate during speech was equal to its measured resting length.

Using radiographic cephalometry, the prevalence of stretch in the anterior portion of the soft palate, i.e., the distance in millimeters between PNS and the radiopaque marker, was also examined. The data in Tables 2-5 show that stretch for the anterior portion of the velum during the production of /u/ and /s/ was also not observed in all 40 children. During the production of /u/, 22 children (55%) exhibited anterior velar stretch; for /s/, 15 subjects (37.5%) demonstrated anterior velar stretch. Among 10-year-old children, 6 girls (60%) and 4 boys (40%) showed anterior stretch during sustained /u/, while 6 girls (60%) and 3 boys (30%) demonstrated anterior stretch during the production of /s/. Among 8-year-old children, 7 girls (70%) and 5 boys (50%) employed anterior stretch during sustained /u/, while 4 girls (40%) and 2 boys (20%) used anterior stretch during /s/.

Anterior velar stretch was not found in 43 of the 80 radiographic observations. In 33 of these instances, the anterior length of the soft palate measured during the production of /u/ and /s/ was shorter than its resting length. In the remaining 10 instances, the anterior length of the soft palate during speech was equal to its measured resting length.

Magnitude of Velar Stretch

A second general objective of this study was to use radiographic cephalometry to examine the magnitude of velar stretch in normal 8 and 10-year-old children. A summary of the average magnitudes of velar stretch for the children studied is tabulated in Table 6. The data tabulated here suggest that, on the average, the length of the soft palate during the production of /u/ and /s/ was greater than the resting palate length. Paired-comparison t-tests were used to evaluate the significance of the differences between average resting palate lengths and average velar lengths obtained during speech (Table 7). The results of these comparisons showed that the average length of the soft palate during the production of both /u/ and /s/ was significantly greater than the average resting length of the soft palate in both 8 and 10-year-old children.

Paired-comparison t-tests were also used to determine whether there were significant differences between the average soft palate lengths obtained during the production of /s/ and the production of /u/. These comparisons indicated that the average length of the soft palate obtained during the production of /u/ was significantly greater ($t=2.43$, $p<.05$, 8-year-old children; $t=3.53$, $p<.01$, ten-year-old children) than the average length of the soft palate during the production of /s/. This observation shows that, on the average, significantly more total velar stretch was observed during the sustained utterance of the vowel /u/ than sustained /s/ production.

The average stretch values shown in Tables 2-6 are somewhat misleading in that they were obtained by averaging data across all speakers within each subject group. Since stretch was not observed in all subjects, the magnitudes of velar stretch were recalculated using only subjects who used stretch. Among these subjects, the largest mean values of total stretch were seen in the 10-year-old girls. For example, among the 8-year-olds, the magnitude of stretch for /u/ was 4.0 mm for girls and 2.75 mm for boys; for /s/, the magnitude was 3.67 mm for girls and 2.5 mm for boys. Among the 10-year-olds, the magnitude of stretch for /u/ was 4.6 mm for girls and 4.2 mm for boys; for /s/, the magnitude was 4.39 mm for girls and 3.4 mm for boys.

In addition to total velar stretch, the magnitude of stretch in the anterior portion of the soft palate was examined and the average values for this variable are also shown in Tables 2-5. These data show that on the average, stretch in the anterior portion of the soft palate was small, i.e., about 1.0 mm or less. During the production of /s/, the average anterior stretch values were negative in three of the subject groups studied, suggesting that there was a general shortening of the anterior portion of the palate during speech. Paired-comparison t-tests were used to evaluate the significance of the differences between average resting anterior palate segment lengths and average anterior palate lengths obtained during speech. These comparisons showed that the length of the anterior portion of the soft palate during speech was not significantly different from its resting length in both 8 and 10-year-old children.

The average anterior palatal stretch values shown in Tables 2-5 are also misleading in that they were obtained by averaging data across all speakers within each subject group. The average data just discussed clearly indicated that anterior palate stretch was not observed in all subjects. Accordingly, anterior velar stretch was recalculated, using only subjects who exhibited stretch in this portion of the palate. Again, the largest values of stretch were seen in the 10-year-old girls. Among the 10-year-olds, the magnitude of anterior stretch for /u/ was 2.42 mm for girls and 1.38 mm for boys; for /s/, the values were 2.0 mm for girls and 0.83 mm for boys. Among the 8-year-olds, the magnitude of anterior stretch for /u/ was 1.7 mm for girls and 1.4 mm for boys; for /s/, it was 1.5 mm for girls and 0.75 mm for boys.

Sex and Age Differences

A third general objective of this research was to determine whether there were differences in velar stretch as a function of sex and age. Analysis of variance techniques were used to determine whether there were differences in average velar stretch and other commonly used cephalometric measurements as a function of the sex and age of the children studied. A summary of these analyses is presented in Table 8. Forty-two separate F-tests were performed. Seven of the 42 F values were significant. With respect to sex differences, the data in Table 12 showed a significant difference ($p < .05$) for the cephalometric measure of pharyngeal depth. In other words, girls had a significantly larger average pharyngeal depth than boys at both age levels (8 and 10 years of age). No other sex differences were found for any of the other cephalometric measurements.

There were significant differences between 8 and 10-year-old children for six cephalometric measures. For example, there were significant ($p < .025$) differences between 8 and 10-year-old children in terms of the average amount of total velar stretch during the production of both /u/ and /s/. Stated differently, the 10-year-old group showed a significantly greater average amount of velar stretch during both /u/ and /s/ utterances than did the 8-year-old group. In addition, there were significant differences between 8 and 10-year-old children in terms of average velar height and length characteristics. For example, 10-year-old children had significantly greater average velar height and longer velar length characteristics during the production of both /u/ and /s/ than did 8-year-old children.

Relationships between Stretch and other Cephalometric Measures

A fourth general objective of this study was to determine the relationships between velar stretch and other cephalometric measures. Correlation techniques were used to determine the significance of the relationships between the amount of velar stretch and other cephalometric measures. Two inter-correlation analyses were performed to assess these relationships: one for 8-year-old children and a second for 10-year-old children. Separate analyses were performed since significant age differences were found for stretch between 8 and 10-year-old children. The inter-correlation matrices showing the relationship among the cephalometric measurements used in this work are presented in Tables 9 and 10.

The correlation coefficients between the amount of total velar stretch during the production of both /u/ and /s/ and need ratio were significant for both 8-($p<.05$) and 10-($p<.001$) year-old children. These results indicate that as the need ratio increases, i.e., ratio between pharyngeal depth and resting palatal length, the amount of stretch exhibited by these children increased.

The amount of total velar stretch during the production of /u/ and /s/ was also found to be significantly correlated with resting palate length for 8-year-old children. For 10-year-old children the magnitude of total velar stretch during production of /s/, but not /u/, was significantly correlated with resting palate length. It is important to note that the signs for these coefficients are negative. Thus, with one exception (10-year-olds, condition /u/), as the resting length of the soft palate decreased the amount of total velar stretch increased.

For 10-year-old children, the amount of velar stretch during production of both /u/ and /s/ was significantly ($p<.01$) correlated with pharyngeal depth. This was not the case for 8-year-old children. Thus, among 10-year-old children, the data indicate that as pharyngeal depth increased, the amount of velar stretch also increased.

Taken together, these findings suggest that across age groups and speech conditions total velar stretch was more consistently related to need ratio than to resting palate length or pharyngeal depth. In other words, when pharyngeal depth and resting velar length were combined to form a need ratio, the relationships between total velar stretch during the production of both /u/ and /s/ and need ratio were significant for both 8 and 10-year-old children.

For both 8 and 10-year-old children, the amount of velar stretch during the production of /u/ was significantly correlated with the magnitude of velar stretch during the production of /s/. The correlation coefficients between these two variables were r=.89 (8-year-old children) and .82 (10-year-old children), suggesting that approximately 72% of the variance in stretch exhibited during /u/ was predicted by that manifested during /s/.

Finally, the amount of total velar stretch during the production of /u/ and /s/ was significantly correlated with the amount of stretch in the anterior portion of the soft palate during both /u/ and /s/ productions among 8-year-old children. Among 10-year-olds, the amount of total stretch during production of /u/ was also significantly correlated with the amount of stretch in the anterior portion of the soft palate during both /u/ and /s/ productions. Among 10-year-old children, the correlation between total velar stretch during the production of /s/ and the amount of stretch in the anterior portion of the palate did not reach significance. These findings suggest, with the exception just cited, that as the amount of total velar stretch increased, the magnitude of stretch in the anterior portion of the soft palate increased.

The inter-correlation matrices (Tables 9 and 10) also provide information about the inter-relationships between cephalometric measurements other than velar stretch. Of interest was the finding that pharyngeal depth was not significantly correlated with resting velar length. By contrast, pharyngeal depth was significantly correlated with need ratios:

for 8-year-old children, the coefficient relating these two variables was $r=.85$; for 10-year-old children $r=.88$. In passing, it should be noted that the relationships between resting velar length and need ratio was not significant among 8-year-old children, but reached significance ($p<.05$) among 10-year-old children. These observations suggest that, for the children studied here, the principal determinant of need ratio was antero-posterior depth of the pharynx rather than the resting length of the soft palate.

The inter-correlation data provide supplementary information about the differences in the length of the soft palate between rest and function. For example, among 8-year-old children, the inter-correlations between resting velar length and velar length during the production of /u/ and /s/ did not reach significance. Among 10-year-old children, the inter-correlations between these two variables reached significance ($p<.01$). In both groups of subjects, the magnitudes of these correlations clearly indicate that, as did the stretch factor data, the length of the soft palate attained during speech cannot be predicted well on the basis of its resting length.

Additional Observations

Lateral cephalometric radiographs are frequently used to assess the structural and functional adequacy of the velopharyngeal mechanism and to estimate the extent of velopharyngeal opening or closure in speakers suspected of having velopharyngeal incompetence. (Lubker and Morris 1968;[35] Moll 1965[33]) In the present research, radiographic observations of the velopharyngeal mechanism were completed on a series of normal-speaking 8 and 10-year-old children who were not suspected of having velopharyngeal incompetence. Such observations have important clinical relevance to the general topic of velopharyngeal competence--incompetence of speech.

For example, the prevalence of velopharyngeal closure and/or the amount of velopharyngeal opening during the production of /u/ and /s/ was assessed in the group of 40 children. With respect to prevalence, the data in Tables 2-5 show that all 40 children attained palatopharyngeal closure during the sustained production of /s/. During the production of /u/, 33 children (82.5%) exhibited closure; all 8-year-old boys and girls exhibited closure; 8 (80%) 10-year-old boys and 5 (50%) 10-year-old girls exhibited closure.

The magnitudes of velopharyngeal opening during the production of /u/ for the seven 10-year-old subjects who did not attain closure were small, ranging between 0.5 to 1.0 mm. One 10-year-old boy and girl had palatopharyngeal openings of 1.0 mm, while the remaining 10-year-old boy and four 10-year-old girls had openings measuring 0.5 mm.

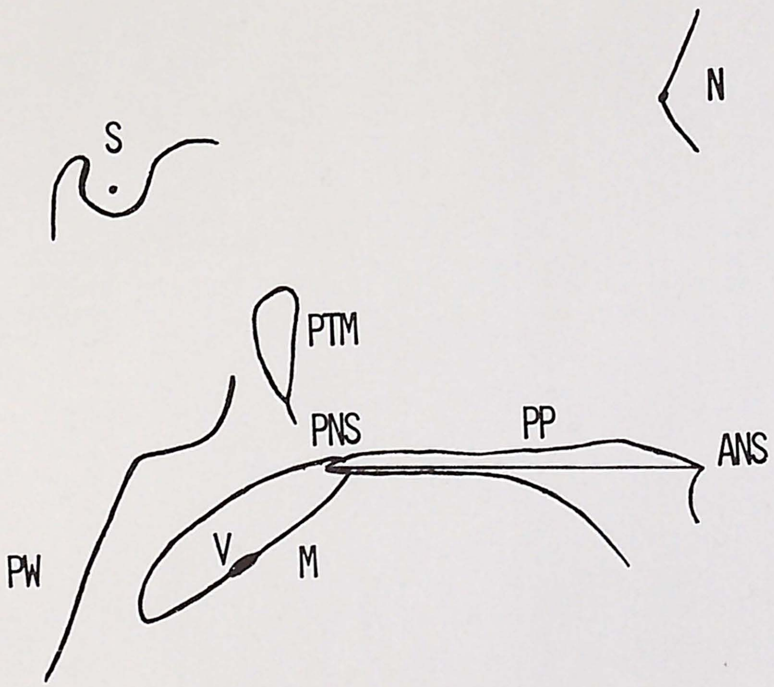
Finally, the magnitudes of velar height during the production of /u/ and /s/ were also evaluated in this group of normal-speaking children (Tables 2-5). Among the 8-year-old children, average velar height during the production of /u/ was 3.0 mm; during /s/ production the average was 4.03 mm. Among the 10-year-old children, average velar height during the production of /u/ was 4.2 mm; during /s/ production the average was 5.18 mm. Of clinical importance was the observation that across all subjects and speech conditions, the superior surface of the soft palate was never found to be below the palatal plane.

The present data show that, on the average, velar height was greater during the production of /s/ than during /u/. In fact, for 32 children

(80%), velar height during /s/ utterances exceeded those attained during /u/ productions. Seven children exhibited equal velar height characteristics during /s/ and /u/ productions. Paired-comparison t-tests were used to determine whether there were significant differences between average velar height attained during /u/ and /s/. These comparisons show that significantly greater velar heights were attained during the production of /s/ than /u/ for both groups of subjects ($t=7.43$, $p<.001$, 8-year-olds; $t=4.79$, $p<.001$, 10-year-olds).

FIGURES AND TABLES

FIGURE 1. Lateral cephalometric landmarks, structures and reference points.



N
S
PTM
PNS
PP
ANS
V
M
PW

FIGURE 2. Rest cephalogram measurements.

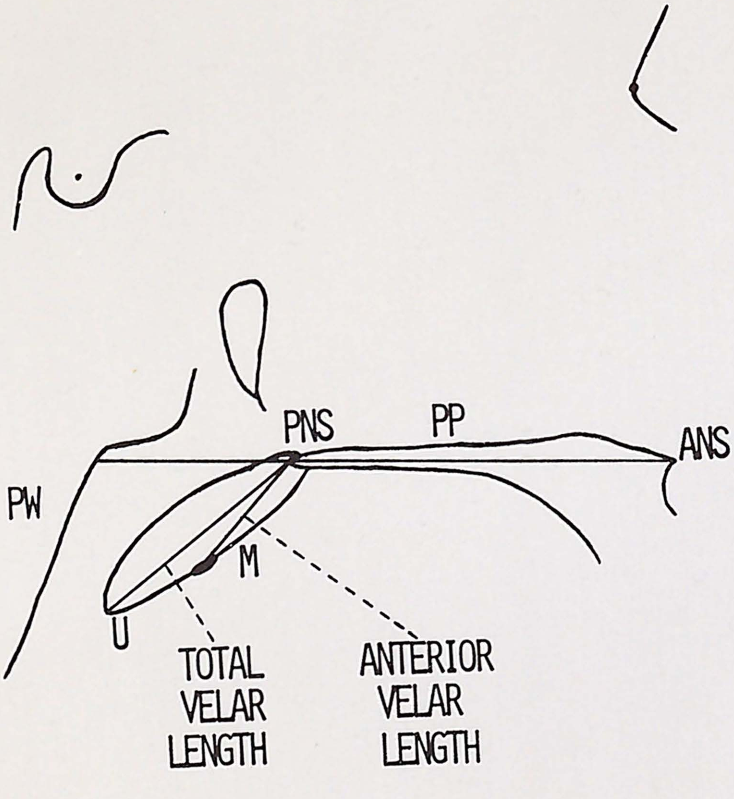
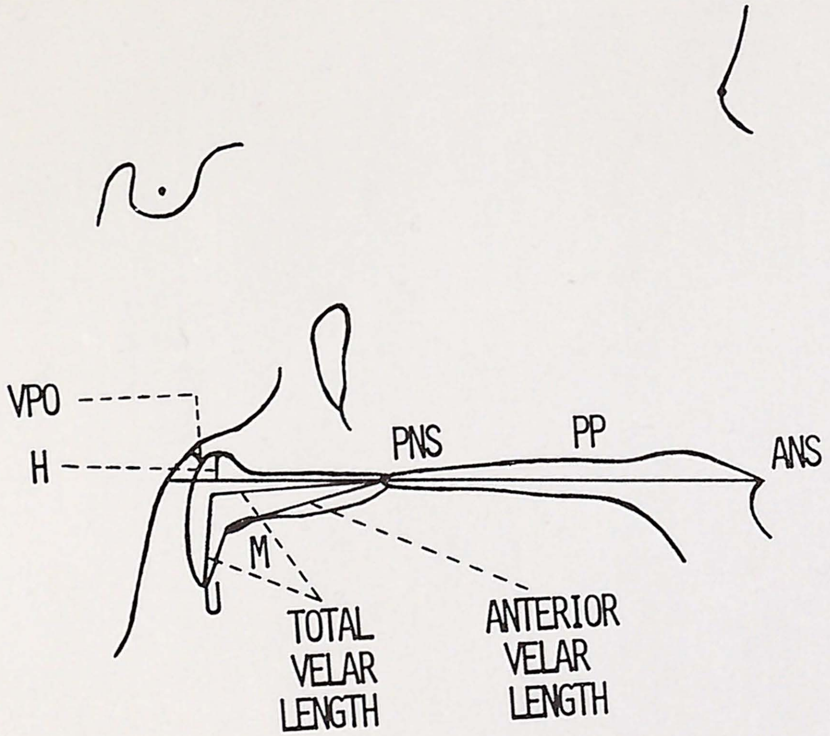

PNS
PP
ANS
PW
M
U
TOTAL
VELAR
LENGTH
ANTERIOR
VELAR
LENGTH

FIGURE 3. Speech cephalogram measurements.



VPO
H
PNS
PP
ANS
M
TOTAL
VELAR
LENGTH
ANTERIOR
VELAR
LENGTH

FIGURE 4. Palatal division process suggested by Simpson and Austin.

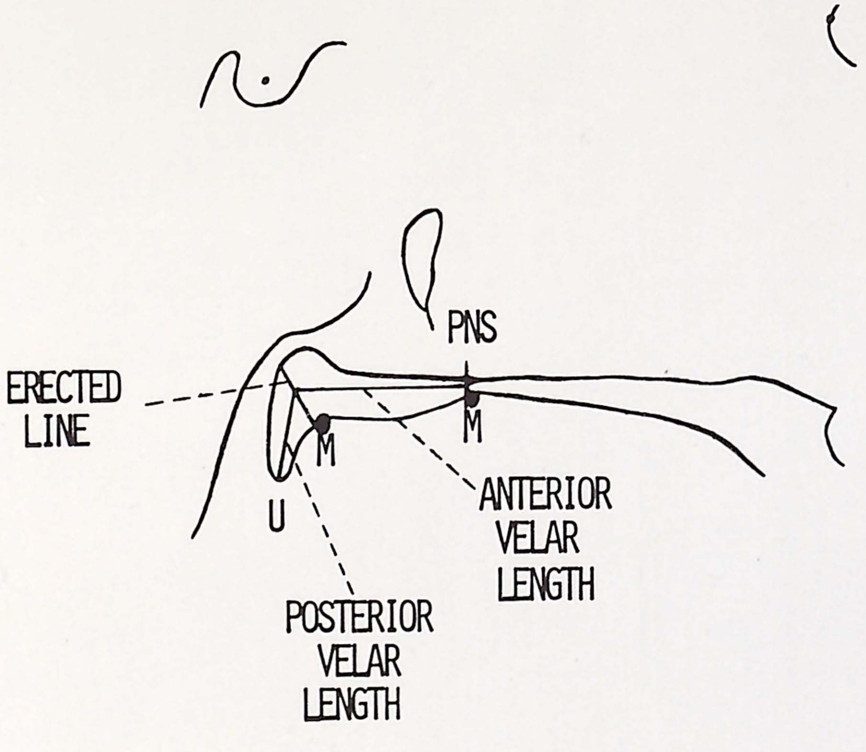

PNS
ERECTED
LINE
M
M
U
ANTERIOR
VELAR
LENGTH
POSTERIOR
VELAR
LENGTH

FIGURE 5. Palatal division process difficulties encountered in the present research.

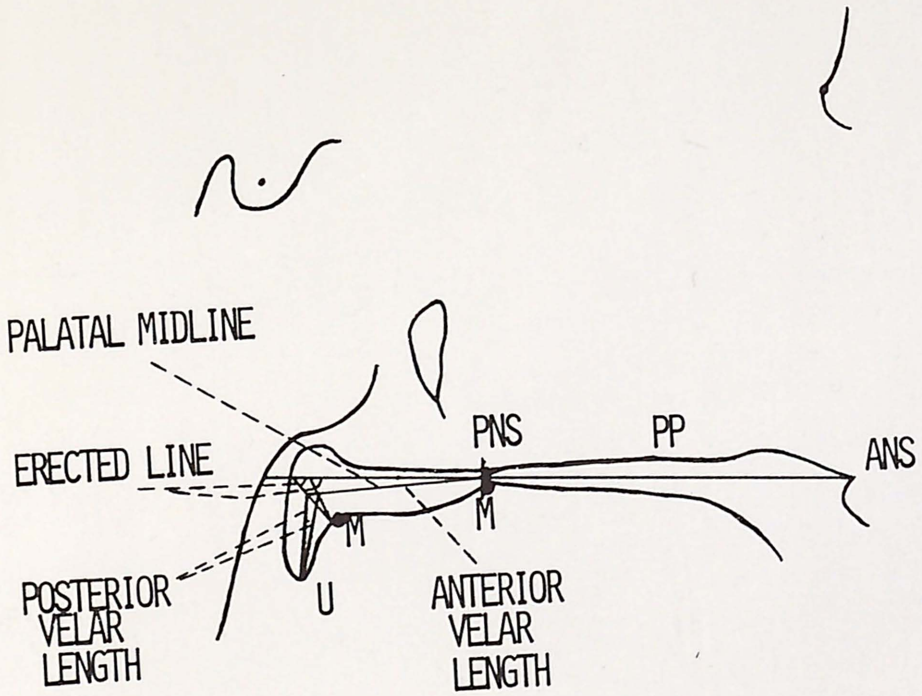

PALATAL MIDLINE
ERECTED LINE
PNS
PP
ANS
M
M
U
POSTERIOR
VELAR
LENGTH
ANTERIOR
VELAR
LENGTH

TABLE 1. Summary of values obtained for repeated tracing and measurement of 18 cephalometric headplates.

*MEASURES	SUBJECTS 1	2	3	4	5	6	AVERAGE
x Pharyngeal depth$_1$	25.0	22.0	24.0	26.0	26.0	26.0	24.83
+ Pharyngeal depth$_2$	25.5	22.0	23.5	25.5	26.5	27.0	25.00
Difference	00.5	00.0	00.5	00.5	00.5	01.0	00.50
Velar length (rest)$_1$	33.0	31.5	30.0	34.5	31.0	36.5	32.75
Velar length (rest)$_2$	33.0	31.5	29.0	34.0	31.0	36.5	32.50
Difference	00.0	00.0	01.0	00.5	00.0	00.0	00.25
Velar length (/u/)$_1$	34.5	35.0	32.5	32.5	34.0	35.0	33.92
Velar length (/u/)$_2$	35.0	35.5	32.5	33.5	34.5	34.5	34.25
Difference	00.5	00.5	00.0	01.0	00.5	00.5	00.50
Velar length (/s/)$_1$	32.5	35.5	32.5	32.0	32.5	33.5	33.08
Velar length (/s/)$_2$	32.0	36.0	32.5	32.5	32.5	33.0	33.08
Difference	00.5	00.5	00.0	00.5	00.0	00.5	00.33
Anterior velar length (rest)$_1$	17.0	16.0	17.0	19.0	17.5	18.0	17.42
Anterior velar length (rest)$_2$	17.5	16.0	15.5	19.0	17.5	18.5	17.33
Difference	00.5	00.0	01.5	00.0	00.0	00.5	00.42
Anterior velar length (/u/)$_1$	16.5	18.0	17.5	18.0	17.0	21.0	18.00
Anterior velar length (/u/)$_2$	16.5	18.0	16.0	18.0	17.5	20.5	17.75
Difference	00.0	00.0	01.5	00.0	00.5	00.5	00.42
Anterior velar length (/s/)$_1$	15.0	18.0	17.0	17.5	17.0	17.5	17.00
Anterior velar length (/s/)$_2$	15.0	18.0	16.0	17.5	17.0	18.0	16.92
Difference	00.0	00.0	01.0	00.0	00.0	00.5	00.25
Velar height (/u/)$_1$	03.5	02.5	02.0	01.5	04.0	05.5	03.17
Velar height (/u/)$_2$	03.5	01.5	02.5	02.0	05.0	06.0	03.42
Difference	00.0	01.0	00.5	00.5	01.0	00.5	00.58
Velar height (/s/)$_1$	04.0	02.5	03.0	03.0	05.5	06.5	04.08
Velar height (/s/)$_2$	03.5	02.0	03.5	03.5	06.0	07.0	04.25
Difference	00.5	00.5	00.5	00.5	00.5	00.5	00.50

*All values expressed in millimeters.

xOriginal measurement denoted subscript 1.

+Repeated measurement denoted subscript 2.

TABLE 2. The results of cephalometric analysis for 8-year-old boys.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	PHARYN-GEAL DEPTH	VELAR LENGTH REST	VELAR LENGTH /u/	VELAR LENGTH /s/	NEED RATIO %	TOTAL VELAR STRETCH[2] /u/	TOTAL VELAR STRETCH[2] /s/	TOTAL VELAR STRETCH[2] PERCENT /u/	TOTAL VELAR STRETCH[2] PERCENT /s/
1	8-6	26.00	34.50	33.50	33.00	75.36	-1.00	-1.50	-2.90	-4.35
2	8-3	26.00	30.50	34.00	32.50	85.25	03.50	02.00	11.48	06.56
3	8-10	26.50	36.00	34.50	33.00	73.61	-1.50	-3.00	-4.17	-8.33
4	8-8	25.00	32.00	33.50	34.50	78.13	01.50	02.50	04.69	07.81
5	8-2	24.00	27.00	29.00	29.00	88.88	02.00	02.00	07.41	07.41
6	8-9	28.00	30.50	37.50	36.00	91.80	07.00	05.50	22.95	18.03
7	8-4	22.00	29.00	32.50	33.50	75.86	03.50	04.50	12.07	15.52
8	8-9	23.50	28.50	31.50	30.50	82.46	03.00	02.00	10.53	07.02
9	8-7	14.50	26.50	27.50	27.50	54.72	01.00	01.00	03.77	03.77
10	8-11	25.00	30.50	31.00	29.50	81.97	00.50	-1.00	01.64	-3.28
MEAN		24.05	30.50	32.45	31.90	78.85	01.95	01.40	06.39	04.59
STANDARD DEVIATION		03.75	03.04	02.86	02.67		02.48	02.63		
VARIANCE		14.08	09.22	08.19	07.15		06.13	06.93		
RANGE		14.5-28.0	26.5-36.0	27.5-37.5	27.5-36.0		-1.5-7.0	-3.0-5.5		

[1]All values except % stretch and need ratio are expressed in millimeters.

[2]Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 2. The results of cephalometric analysis for 8-year-old boys. Cont'd.

Cephalometric Measures[1]

SUBJECT	AGE	ANTERIOR VELAR LENGTH			ANTERIOR VELAR STRETCH[2]		ANTERIOR VELAR STRETCH[2] PERCENT		VELAR HEIGHT		VELO-PHARYNGEAL OPENING	
NUMBER	YR. MO.	REST	/u/	/s/	/u/	/s/	/u/	/s/	/u/	/s/	/u/	/s/
1	8-6	19.00	18.00	17.50	-1.00	-1.50	-5.26	-7.89	1.50	3.00	0.0	0.0
2	8-3	17.50	17.00	17.00	-0.50	-0.50	-2.86	-2.86	4.00	5.50	0.0	0.0
3	8-10	18.00	21.00	17.50	03.00	-0.50	16.67	-2.78	5.50	6.50	0.0	0.0
4	8-8	17.00	16.50	16.50	-0.50	-0.50	-2.94	-2.94	4.00	5.00	0.0	0.0
5	8-2	15.50	15.50	14.00	00.00	-1.50	00.00	-9.68	3.50	5.00	0.0	0.0
6	8-9	20.00	20.50	19.00	00.50	-1.00	02.50	-5.00	3.00	3.50	0.0	0.0
7.	8-4	17.00	18.00	18.00	01.00	01.00	05.88	05.88	1.00	1.00	0.0	0.0
8	8-9	16.00	18.00	16.50	02.00	00.50	12.50	03.13	1.50	3.00	0.0	0.0
9	8-7	14.50	14.50	13.50	00.00	-1.00	00.00	-6.90	2.00	3.50	0.0	0.0
10	8-11	16.00	16.50	16.00	00.50	00.00	03.13	00.00	2.50	4.00	0.0	0.0
MEAN		17.05	17.55	16.55	00.50	-0.50	02.93	-2.93	2.85	4.00		
STANDARD DEVIATION		01.66	02.03	01.70	01.22	00.81			1.41	1.56		
VARIANCE		02.75	04.14	02.91	01.50	00.67			2.00	2.44		
RANGE		14.5-20.0	14.5-21.0	13.5-19.0	-1.0-3.0	-1.5-1.0			1.0-5.5	1.0-6.5		

[1]All values except % stretch and need ratio are expressed in millimeters.

[2]Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 3. The results of cephalometric analysis for 8-year-old girls.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	PHARYN-GEAL DEPTH	VELAR LENGTH REST	VELAR LENGTH /u/	VELAR LENGTH /s/	NEED RATIO %	TOTAL VELAR STRETCH[2] /u/	TOTAL VELAR STRETCH[2] /s/	TOTAL VELAR STRETCH[2] PERCENT /u/	TOTAL VELAR STRETCH[2] PERCENT /s/
1	8-7	25.00	33.00	34.50	32.00	75.76	01.50	-1.00	04.55	-3.03
2	8-11	22.00	31.50	35.50	35.50	69.84	04.00	04.00	12.70	12.70
3	8-10	24.50	30.00	33.50	33.50	81.67	03.50	03.50	11.67	11.67
4	8-5	25.50	29.00	35.00	31.50	87.93	06.00	02.50	20.69	08.62
5	8-0	28.50	27.50	36.00	33.50	103.64	08.50	06.00	30.91	21.82
6	8-11	25.00	32.50	32.50	30.50	76.92	00.00	-2.00	00.00	-6.15
7	8-1	23.50	32.50	30.50	29.00	72.31	-2.00	-3.50	-6.15	-10.77
8	8-11	31.50	28.00	31.00	32.00	112.50	03.00	04.00	10.71	14.29
9	8-1	22.00	29.50	33.50	31.50	74.58	04.00	02.00	13.56	06.78
10	8-10	30.50	33.50	35.00	33.50	91.04	01.50	00.00	04.48	00.00
MEAN		25.80	30.70	33.70	32.25	84.04	03.00	01.55	09.77	05.05
STANDARD DEVIATION		03.32	02.17	01.87	01.83		02.98	03.05		
VARIANCE		11.01	04.73	03.51	03.35		08.89	09.30		
RANGE		22.0-31.5	27.5-33.5	30.5-36.0	29.0-35.5		-2.0-8.5	-3.5-6.0		

[1] All values except % stretch and need ratio are expressed in millimeters.

[2] Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 3. The results of cephalometric analysis for 8-year-old girls. Cont'd.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	ANTERIOR VELAR LENGTH REST	ANTERIOR VELAR LENGTH /u/	ANTERIOR VELAR LENGTH /s/	ANTERIOR VELAR STRETCH[2] /u/	ANTERIOR VELAR STRETCH[2] /s/	ANTERIOR VELAR STRETCH[2] PERCENT /u/	ANTERIOR VELAR STRETCH[2] PERCENT /s/	VELAR HEIGHT /u/	VELAR HEIGHT /s/	VELO-PHARYNGEAL OPENING /u/	VELO-PHARYNGEAL OPENING /s/
1	8-7	17.50	16.50	15.00	-1.00	-2.50	-5.71	-14.28	3.50	4.00	0.0	0.0
2	8-11	16.00	18.00	18.00	02.00	02.00	12.50	012.50	2.50	2.50	0.0	0.0
3	8-10	17.00	17.50	17.00	00.50	00.00	02.94	000.00	2.00	3.50	0.0	0.0
4	8-5	18.50	19.50	16.50	01.00	-2.00	05.41	-10.81	3.00	4.50	0.0	0.0
5	8-0	17.00	20.50	19.50	03.50	02.50	20.59	014.71	3.00	4.50	0.0	0.0
6	8-11	18.50	16.00	15.00	-2.50	-3.50	-13.51	-18.92	3.00	4.50	0.0	0.0
7	8-1	20.00	17.50	16.50	-2.50	-3.50	-12.50	-17.50	2.00	2.00	0.0	0.0
8	8-11	15.50	17.00	16.50	01.50	01.00	09.68	006.45	6.00	7.50	0.0	0.0
9	8-1	17.50	20.00	18.00	02.50	00.50	14.29	002.86	2.50	2.50	0.0	0.0
10	8-10	21.00	22.00	20.50	01.00	-0.50	04.76	-2.38	4.00	5.00	0.0	0.0
MEAN		17.85	18.45	17.25	00.60	-0.60	03.36	-3.36	3.15	4.05		
STANDARD DEVIATION		01.70	01.95	01.78	02.02	02.18			1.18	1.59		
VARIANCE		02.89	03.80	03.18	04.10	04.77			1.39	2.52		
RANGE		15.5-21.0	16.0-22.0	15.0-20.5	-2.5-3.5	-3.5-2.5			2.0-6.0	2.0-7.5		

[1] All values except % stretch and need ratio are expressed in millimeters.

[2] Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 4. The results of cephalometric analysis for 10-year-old boys.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	PHARYN-GEAL DEPTH	VELAR LENGTH REST	VELAR LENGTH /u/	VELAR LENGTH /s/	NEED RATIO %	TOTAL VELAR STRETCH[2] /u/	TOTAL VELAR STRETCH[2] /s/	TOTAL VELAR STRETCH[2] PERCENT /u/	TOTAL VELAR STRETCH[2] PERCENT /s/
1	10-5	26.00	30.00	36.50	37.00	86.67	06.5	07.0	21.67	23.33
2	10-11	29.50	30.00	35.00	33.00	98.33	05.0	03.0	16.67	10.00
3	10-8	23.50	25.50	30.00	30.00	92.16	04.5	04.5	17.65	17.65
4.	10-6	21.00	32.50	37.50	34.00	64.62	05.0	01.5	15.38	04.62
5	10-6	24.50	31.00	32.50	31.50	79.03	01.5	00.5	04.84	01.61
6	10-2	19.50	28.50	31.00	30.00	68.42	02.5	01.5	08.77	05.26
7	10-2	25.50	30.00	32.00	32.50	85.00	02.0	02.5	06.67	08.33
8	10-0	26.50	27.50	32.50	31.50	96.36	05.0	04.0	18.18	14.55
9	10-11	27.00	35.00	37.00	35.50	77.14	02.0	00.5	05.71	01.43
10	10-5	33.00	30.00	38.00	39.00	110.00	08.0	09.0	26.67	30.00
MEAN		25.60	30.00	34.20	33.40	85.33	04.20	03.40	14.00	11.33
STANDARD DEVIATION		03.90	02.60	02.94	03.00		02.15	02.81		
VARIANCE		15.21	06.78	08.62	08.93		04.62	07.88		
RANGE		19.5-33.0	25.5-35.0	30.0-38.0	30.0-39.0		1.5-8.0	0.5-9.0		

[1]All values except % stretch and need ratio are expressed in millimeters.

[2]Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 4. The results of cephalometric analysis for 10-year-old boys. Cont'd.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	ANTERIOR VELAR LENGTH REST	ANTERIOR VELAR LENGTH /u/	ANTERIOR VELAR LENGTH /s/	ANTERIOR VELAR STRETCH[2] /u/	ANTERIOR VELAR STRETCH[2] /s/	ANTERIOR VELAR STRETCH[2] PERCENT /u/	ANTERIOR VELAR STRETCH[2] PERCENT /s/	VELAR HEIGHT /u/	VELAR HEIGHT /s/	VELO-PHARYNGEAL OPENING /u/	VELO-PHARYNGEAL OPENING /s/
1	10-5	17.50	17.50	16.50	00.00	-1.00	00.00	-5.71	7.00	7.50	0.5	0.0
2	10-11	16.50	18.00	16.50	01.50	00.00	09.09	00.00	5.00	6.00	0.0	0.0
3	10-8	15.00	15.50	16.00	00.50	01.00	03.33	06.67	2.00	3.00	0.0	0.0
4	10-6	17.00	19.00	17.50	02.00	00.50	11.76	02.94	1.00	2.50	0.0	0.0
5	10-6	18.50	17.00	16.50	-1.50	-2.00	-8.11	-10.81	4.00	5.00	0.0	0.0
6	10-2	17.50	17.50	17.00	00.00	-0.50	00.00	-2.86	0.00	1.50	0.0	0.0
7	10-2	16.00	16.00	16.00	00.00	00.00	00.00	00.00	4.50	6.50	0.0	0.0
8	10-0	15.50	17.00	16.50	01.50	01.00	09.68	06.45	5.00	5.00	0.0	0.0
9	10-11	20.00	19.00	18.00	-1.00	-2.00	-5.00	-10.00	4.50	7.50	1.0	0.0
10	10-5	20.50	19.00	19.00	-1.50	-1.50	-7.32	-7.32	7.50	7.50	0.0	0.0
MEAN		17.40	17.55	16.95	00.15	-0.45	00.86	-2.59	4.05	5.20		
STANDARD DEVIATION		01.82	01.23	00.96	01.25	01.14			2.42	2.21		
VARIANCE		03.32	01.52	00.91	01.56	01.30			5.86	4.90		
RANGE		15.0-20.5	15.5-19.0	16.0-19.0	-1.5-2.0	-2.0-1.0			0.0-7.5	1.5-7.5		

[1]All values except % stretch and need ratio are expressed in millimeters.

[2]Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 5. The results of cephalometric analysis for 10-year-old girls.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	PHARYNGEAL DEPTH	VELAR LENGTH REST	VELAR LENGTH /u/	VELAR LENGTH /s/	NEED RATIO %	TOTAL VELAR STRETCH[2] /u/	TOTAL VELAR STRETCH[2] /s/	TOTAL VELAR STRETCH[2] PERCENT /u/	TOTAL VELAR STRETCH[2] PERCENT /s/
1	10-11	27.00	29.50	32.50	35.00	91.53	03.00	05.50	10.17	18.64
2	10-2	27.00	35.50	39.00	38.50	76.06	03.50	03.00	09.86	08.45
3	10-11	32.00	31.50	38.50	38.00	101.59	07.00	06.50	22.22	20.63
4	10-8	31.50	30.00	35.00	34.50	105.00	05.00	04.50	16.67	15.00
5	10-10	29.50	31.50	36.50	35.50	93.65	05.00	04.00	15.87	12.70
6	10-1	30.00	29.00	34.00	32.50	103.45	05.00	03.50	17.24	12.07
7	10-11	34.00	29.00	38.00	35.00	117.24	09.00	06.00	31.03	20.69
8	10-0	26.00	30.50	32.50	33.00	85.25	02.00	02.50	06.56	08.20
9	10-11	26.00	29.00	34.00	33.00	89.66	05.00	04.00	17.24	13.79
10	10-3	24.00	35.50	37.00	35.00	67.61	01.50	-0.50	04.23	-1.40
MEAN		28.70	31.10	35.70	35.00	92.28	04.60	03.90	14.79	12.54
STANDARD DEVIATION		03.19	02.50	02.42	02.00		02.26	02.01		
VARIANCE		10.18	06.27	05.90	04.00		05.10	04.04		
RANGE		24.0-34.0	29.0-35.5	32.5-39.0	32.5-38.5		1.5-9.0	-0.5-6.5		

[1]All values except % stretch and need ratio are expressed in millimeters.

[2]Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 5. The results of cephalometric analysis for 10-year-old girls. Cont'd.

Cephalometric Measures[1]

SUBJECT NUMBER	AGE YR. MO.	ANTERIOR VELAR LENGTH REST	/u/	/s/	ANTERIOR VELAR STRETCH[2] /u/	/s/	ANTERIOR VELAR STRETCH[2] PERCENT /u/	/s/	VELAR HEIGHT /u/	/s/	VELO-PHARYNGEAL OPENING /u/	/s/
1	10-11	16.50	16.50	16.00	00.00	-0.50	00.00	-3.03	4.50	7.00	1.0	0.0
2	10-2	20.50	22.50	22.50	02.00	02.00	09.76	09.76	4.00	3.00	0.0	0.0
3	10-11	17.50	21.00	21.50	03.50	04.00	20.00	22.86	3.50	4.50	0.5	0.0
4	10-8	18.00	19.50	18.50	01.50	00.50	08.33	02.78	6.00	6.50	0.5	0.0
5	10-10	18.50	21.00	20.50	02.50	02.00	13.51	10.81	2.50	3.50	0.0	0.0
6	10-1	19.00	17.50	16.50	-1.50	-2.50	-7.89	-13.16	6.00	6.00	0.0	0.0
7	10-11	16.50	21.00	19.00	04.50	02.50	27.27	15.15	6.00	7.50	0.5	0.0
8	10-0	18.00	16.50	16.50	-1.50	-1.50	-8.33	-8.33	2.50	3.00	0.0	0.0
9	10-11	15.50	16.00	16.50	00.50	01.00	03.23	06.45	5.00	6.00	0.0	0.0
10	10-3	20.00	19.00	16.50	-1.00	-3.50	-5.00	-17.50	3.50	4.50	0.5	0.0
MEAN		18.00	19.05	18.40	01.05	00.40	05.83	02.22	4.35	5.15		
STANDARD DEVIATION		01.58	02.31	02.39	02.10	02.38			1.37	1.67		
VARIANCE		02.50	05.36	05.71	04.41	5.65			1.89	2.78		
RANGE		15.5-20.5	16.0-22.5	16.0-22.5	-1.5-4.5	-3.5-4.0			2.5-6.0	3.0-7.5		

[1]All values except % stretch and need ratio are expressed in millimeters.

[2]Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 6. Average velar stretch characteristics of normal-speaking 8 and 10-year-old children.

	SPEECH TASK							
	/u/				/s/			
SUBJECT GROUP	MEAN*	STANDARD DEVIATION	RANGE+ MIN.	RANGE+ MAX.	MEAN*	STANDARD DEVIATION	RANGE+ MIN.	RANGE+ MAX.
8-Year-Old Boys	1.95	2.48	-1.5	7.0	1.40	2.63	-3.0	5.5
8-Year-Old Girls	3.00	2.98	-2.0	8.5	1.55	3.05	-3.5	6.0
10-Year-Old Boys	4.20	2.15	01.5	8.0	3.40	2.81	00.5	9.0
10-Year-Old Girls	4.60	2.26	01.5	9.0	3.90	2.01	-0.5	6.5

*All values are expressed in millimeters.

+Minus values reflect a shortening in the functional length of the soft palate relative to its length at rest.

TABLE 7. Paired-comparison t-test results for evaluating differences between average resting palate length and average velar length obtained during speech.

SUBJECT GROUP	COMPARISON	MEAN VELAR LENGTH	STANDARD DEVIATION	t
8-year-old children	/u/	33.07	2.44	4.07
	versus			
	rest	30.60	2.57	
8-year-old children	/s/	32.07	2.24	2.38
	versus			
	rest	30.60	2.57	
10-year-old children	/u/	34.95	2.73	9.13
	versus			
	rest	30.55	2.55	
10-year-old children	/s/	34.20	2.61	6.83
	versus			
	rest	30.55	2.55	

Significant t-values with 19 degrees of freedom:

t Value	Level of Significance
2.09	$p<.05$
2.86	$p<.01$
3.88	$p<.001$

TABLE 8. Analysis of variance results: F values used to evaluate the significance of differences in average cephalometric characteristics occurring as a function of subject age and sex.

CEPHALOMETRIC MEASURE	Pharyngeal Depth	Velar Length			Need Ratio	Total Velar Stretch		Anterior Velar Length			Anterior Velar Stretch		Velar Height	
EXPERIMENTAL CONDITION	Rest	Rest	/u/	/s/		/u/	/s/	Rest	/u/	/s/	/u/	/s/	/u/	/s/
MAIN EFFECTS--SEX	4.66*	0.63	2.88	1.62	2.41	0.85	0.15	1.71	3.89	3.63	0.86	0.45	0.32	0.00
MAIN EFFECTS--AGE	3.92	0.04	5.36*	7.71+	3.33	5.99x	6.72x	0.22	0.24	1.89	0.09	0.89	5.17*	4.18*
INTERACTION--SEX AND AGE	0.06	0.30	0.02	0.67	0.03	0.17	0.04	0.03	0.24	0.44	0.55	0.73	0.08	0.08

Significant F values with 1 and 36 degrees of freedom:

F Value	Level of Significance	
4.11	*	$p < .05$
5.48	x	$p < .025$
7.39	+	$p < .01$

TABLE 9. Correlation matrix of the cephalometric measurements for 8-year-old children.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.000													
2	.296	1.000												
3	.526	.412	1.000											
4	.469	.341	.857	1.000										
5	.844	-.258	.298	.282	1.000									
6	.191	-.576	.507	.445	.512	1.000								
7	.104	-.652	.309	.490	.467	.894	1.000							
8	.464	.632	.554	.343	.094	-.101	-.310	1.000						
9	.521	.321	.730	.560	.336	.352	.155	.619	1.000					
10	.543	.273	.747	.733	.383	.411	.338	.560	.878	1.000				
11	.157	-.262	.320	.331	.315	.534	.510	-.277	.583	.495	1.000			
12	.101	-.368	.226	.433	.316	.551	.691	-.444	.300	.494	.826	1.000		
13	.596	.204	.160	.166	.490	-.049	-.056	.018	.170	.041	.190	.026	1.000	
14	.578	.073	.031	.015	.541	-.041	-.055	-.096	.039	-.093	.147	.001	.920	1.000

Values of $r = \pm .444$, $\pm .561$, $\pm .679$ needed for significance at the .05, .01, and .001 levels, respectively, with 18 degrees of freedom. Cephalometric measurements used in the correlation matrix were: 1. pharyngeal depth. 2. velar length (rest). 3. velar length (/u/). 4. velar length (/s/). 5. need ratio. 6. total velar stretch (/u/). 7. total velar stretch (/s/). 8. anterior velar length (rest). 9. anterior velar length (/u/). 10. anterior velar length (/s/). 11. anterior velar stretch (/u/). 12. anterior velar stretch (/s/). 13. velar height (/u/). 14. velar height (/s/).

TABLE 10. Correlation matrix of the cephalometric measurements for 10-year-old children.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.000													
2	-.031	1.000												
3	.494	.669	1.000											
4	.556	.570	.867	1.000										
5	.881	-.495	.119	.209	1.000									
6	.663	-.334	.477	.425	.737	1.000								
7	.639	-.444	.233	.483	.756	.820	1.000							
8	.193	.737	.567	.582	-.181	-.153	-.151	1.000						
9	.473	.594	.849	.700	.131	.374	.130	.552	1.000					
10	.472	.460	.726	.702	.181	.376	.275	.471	.910	1.000				
11	.346	-.046	.407	.224	.323	.570	.293	-.347	.590	.568	1.000			
12	.311	-.193	.234	.196	.351	.526	.419	-.420	.437	.603	.898	1.000		
13	.706	-.069	.312	.446	.655	.478	.560	.157	.060	.011	-.085	-.130	1.000	
14	.607	-.051	.224	.347	.556	.344	.433	.033	-.060	-.149	-.100	-.183	.887	1.000

Values of $r = \pm .444$, $\pm .561$, $\pm .679$ needed for significance at the .05, .01, and .001 levels, respectively, with 18 degrees of freedom. Cephalometric measurements used in the correlation matrix were: 1. pharyngeal depth. 2. velar length (rest). 3. velar length (/u/). 4. velar length (/s/). 5. need ratio. 6. total velar stretch (/u/). 7. total velar stretch (/s/). 8. anterior velar length (rest). 9. anterior velar length (/u/). 10. anterior velar length (/s/). 11. anterior velar stretch (/u/). 12. anterior velar stretch (/s/). 13. velar height (/u/). 14. velar height (/s/).

TABLE 11. A summary of velar length, pharyngeal depth, and need ratio characteristics of normal-speaking children.

		VELAR LENGTH						PHARYNGEAL DEPTH						NEED RATIO (%)					
	SUB-JECTS	BOYS		GIRLS		SEX COMBINED		BOYS		GIRLS		SEX COMBINED		BOYS		GIRLS		SEX COMBINED	
INVESTIGATOR	AGE	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N	MEAN	N
WILLIS (1952)	8-9	32.3	28					21.6	28					66.9	28				
	12-13	33.1	30					24.3	30					73.4	30				
SUBTELNY (1957)	8	28.8	13	28.3	12	28.6	25					19.9	25					68.7	23
	10	30.0	15	30.2	13	30.1	28					20.6	27					68.3	26
OWSLEY et al (1967)	9					29.3	245					25.6	245					87.4	245
	12					31.2	138					27.4	138					87.8	138
MOURINO (1974)	8	30.5	10	30.7	10			24.0	10	25,8	10			78.8	10	84.0	10		
	10	30.0	10	31.1	10			25.6	10	28.7	10			85.3	10	92.3	10		

All values except need ratio are expressed in millimeters.

DISCUSSION

Discussion

Prevalence of Velar Stretch

A principal reason for conducting this research was to examine the prevalence of velar stretch in normal 8 and 10-year-old children. Velar stretch was not observed in all 40 children during the production of /u/ and /s/. During the production of /u/, 36 children (90%) exhibited velar stretch; for /s/, 32 children (80%) manifested stretch.

Hence, velar stretch was not found in 12 of the 80 radiographic observations. In 10 of these instances, the length of the soft palate measured during the functional activity of speech was shorter than its resting length. In the remaining two instances, the length of the soft palate during speech was equal to its measured resting length.

To date, there has been only one published study which examined the prevalence of velar stretch in normal speakers. In this study, Simpson and Austin,[6] examined the prevalence of velar stretch in twenty normal adult speakers. Using lateral cephalometric techniques, they studied the prevalence of stretch during the production of sustained /s/ in 10 men and 10 women, ranging in age from 18 to 30 years. Simpson and Austin observed velar stretch in all 20 normal adult speakers. Thus, on the basis of the limited data available from the present study and the work of Simpson and Austin, it would be reasonable to conclude that during the production of the sustained fricative /s/, velar stretch is universally observed among normal adult speakers, but not universally observed among normal speaking 8 and 10-year-old children.

The 40 children in the present study all exhibited normal speech characteristics--a factor attesting to both the functional and structural adequacy of their velopharyngeal mechanisms. Although 36 children (90%) exhibited velar stretch during the production of /u/ and 32 children (80%) exhibited stretch during sustained /s/, 12 children did not exhibit velar stretch during the production of /u/ and/or /s/. Thus, despite the fact that about 85% of the children studied in the present work exhibited velar stretch during sustained /u/ or /s/, failure to exhibit velar stretch in about 15% of the observations should not be viewed as indicative of structural or functional inadequacy of the velopharyngeal mechanism in children of this age group.

Magnitude of Velar Stretch

A second general objective of this study was to use radiographic cephalometry to examine the magnitude of velar stretch in normal 8 and 10-year-old children (Tables 2-5). Since stretch was not observed in all subjects, the magnitudes of velar stretch were recalculated using only subjects who exhibited stretch. Among the 10-year-old children who employed stretch, the magnitude of stretch for /u/ was 4.4 mm or 14.4%; for /s/, the magnitude was 3.9 mm or 12.7%. Among the 8-year-old children, the magnitude of stretch for /u/ was 3.38 mm or 11.03%; for /s/, the magnitude was 3.09 mm or 10.08%.

As indicated in the previous section, only one published study has dealt with velar stretch among normal speakers. In that study, Simpson and Austin[6] observed velar stretch during the production of /s/

in all 20 normal-speaking adults they studied. The average magnitude of velar stretch reported by Simpson and Austin for this group of young adult speakers was 7.35 mm or 20.03%. Stated differently, Simpson and Austin observed about a 20% average functional increase in the length of the soft palate during /s/ production, a value almost twice (range, 10-13%) that observed among 8 and 10-year-old children exhibiting stretch in the present work during /s/.

Taken together, these observations suggest that the average degree of velar stretch may increase as a function of chronologic age. Indeed, evidence supportive of this general notion was gathered in the present experiment. Specifically, significant differences were found between the amount of total velar stretch in 8 and 10-year-old children (Table 8). The results of the present work show that, on the average, 10-year-old children exhibited significantly greater velar stretch during both /u/ and /s/ utterances than did 8-year-old children. There is an obvious need for additional observations concerning the relationship between the magnitude of velar stretch and chronologic age, since the available data relating stretch magnitude and age have been limited to a relatively small sample of normal young adults and 8 and 10-year-old subjects.

Finally, it is important to point out that in the present study components of velar stretch were examined during the sustained production of two speech sounds. Simpson and Austin[6] investigated velar stretch during the production of one of these sounds (/s/). The present work shows that there were significant differences between the average measured length of the soft palate during the production of /u/ and /s/. Specifically, the average measured length of the soft palate during production of /u/ was significantly longer than its average length during sustained /s/ for both 8 and 10-year-old children. Thus, on the average, significantly more total velar stretch was observed during the production of the vowel /u/ than during the fricative /s/. This observation suggests that the magnitude of velar stretch varies as a function of phonetic content.

Although, on the average, 8 and 10-year-old children exhibited greater stretch during the production of /u/ than /s/, the results of the correlation analysis showed that the magnitude of velar stretch measured during the production of /u/ was significantly correlated with the degree of stretch measured during /s/ productions. The correlation coefficients between /u/ stretch magnitude and /s/ stretch magnitude were $r = .89$, and $r = .82$ for 8 and 10-year-old children, respectively, suggesting that about 72% of the variance in stretch exhibited during the vowel was predicted by that manifested during /s/ production.

A review of the literature uncovered one published paper dealing with velar stretch during the production of more than one speech sound. In that paper, Pruzansky and Mason[17] reported observations of velar stretch in 110 patients with congenital palatopharyngeal incompetence obtained during the production of sustained /s/ and /u/ sounds. In this group of subjects with velopharyngeal inadequacy, average stretch was greater during the production of /s/ than during the production of /u/. It must be emphasized that Pruzansky and Mason evaluated stretch in patients with velopharyngeal inadequacy for speech. Thus, it would be reasonable to assume that many of these patients failed to achieve velopharyngeal closure during the production of the test stimuli.

Anterior Velar Stretch

Using a radiopaque marker to divide the soft palate into anterior and posterior portions was originally suggested by Simpson and Austin.[6] Their rationale for using this procedure was stated as follows:

> Through the attachment of the lead markers at the velar eminence, the velum was radiographically divided into an anterior and a posterior portion. In this way, the behaviors of both portions of the velum could be more accurately observed during stretch and possibly provide more information regarding the mechanisms responsible for this stretch.

The original intent of the present investigation was to procedurally replicate the Simpson and Austin experiment in an attempt to examine important variables of velar stretch in 8 and 10-year-old children. In accordance with this objective, it was anticipated that the radiopaque marker would be used as a landmark to divide the soft palate into two segments: an anterior and a posterior segment. Simpson and Austin completed the palatal division process in two steps. They measured the length of the anterior portion of the palate by calculating the distance along the midline of the palate, between the posterior surface of a marker placed below PNS and the posterior surface of the marker placed at the velar eminence (Figure 4). The lengths of the posterior portion of the palate were measured by calculating the distance, along the midline of the palate, between the posterior surface of the velar eminence marker and the tip of the uvula (Figure 4).

In the course of the present research, important experimental problems were encountered with the palatal division procedures described by Simpson and Austin. For example, this process required that the investigator erect a line from the posterior surface of the velar eminence marker to the constructed midline of the palate (Figures 4,5). If this erected line were extended, it would soon intersect with the palatal plane forming an angle at this point of intersection. It became obvious that as this angle became more acute, measurements of anterior palate length would increase and conversely, as this angle became more obtuse, measurements of anterior palate length would decrease. The line connecting the posterior surface of the velar eminence marker with the constructed midline of the palate was empirically constructed by the investigator and its orientation with respect to palatal plane was highly variable. Since there was no way to control for the inherent variation in the orientation of this erected line with respect to its fixed reference (palatal plane), and since variations in the orientation of this erected line produced rather sizeable variations in the measured length of both the anterior and posterior segments of the palate, attempts to radiographically divide the palate into an anterior and posterior portion were abandoned (Figure 5). Instead, only the length of the anterior portion of the palate was measured and this measurement differed from that used by Simpson and Austin. In the present work the length of the anterior portion of the palate was measured as the distance between PNS and the midpoint of the radiopaque marker located below the velar eminence. Measurements of the anterior portion of the soft palate were not made along the midline of the soft palate (Figure 1-3).

The procedure just described was used to examine the prevalence and magnitude of stretch in the anterior portion of the soft palate, i.e., the distance in millimeters between PNS and the radiopaque marker. With respect to prevalence, stretch of the anterior portion of the velum was also not observed in all 40 children during the production of /u/ and /s/. During the production of /u/, 22 children (55%) exhibited anterior velar stretch; for /s/, 15 subjects (37.5%) demonstrated anterior velar stretch. Hence, anterior velar stretch was not found in 43 of the 80 radiographic observations. In 33 of these instances, the anterior length of the soft palate measured during the production of /u/ and /s/ was less than its resting length. In the remaining 10 instances the anterior length of the soft palate during speech was equal to its measured resing length.

In their study of velar stretch in normal-speaking young adults, Simpson and Austin[6] also found that stretch of the anterior portion of the velum was not observed in all 20 adults studied. Unfortunately, their published description of anterior stretch prevalence does not enable the reader to determine how many subjects failed to exhibit anterior palatal stretch during the production of /s/.

With respect to magnitude, average values of anterior velar stretch for 8 and 10-year-old children were small, i.e., about 1.0 mm or less (Tables 2-5). In addition, paired-comparison t-tests revealed that the length of the anterior portion of the soft palate during speech was not significantly different from its resting length in both 8 and 10-year-old children. In contrast, Simpson and Austin[6] observed a significant increase in the functional length of the anterior portion of the soft palate in their group of normal adult speakers. On the average, Simpson and Austin reported about an 8% increase in the functional length of the anterior portion of the soft palate.

By way of summary, the present data suggest that 8 and 10-year-old children do not exhibit a significant functional increase in the length of the anterior segment of the soft palate during either sustained /u/ and /s/ productions. Moreover, the results of the present work suggest that the majority of the 8 and 10-year-old children achieve velopharyngeal adequacy for speech in the absence of significant anterior stretch.

Finally, the differences in the number of 8 and 10-year-old children manifesting stretch along the entire length of the velum and within the anterior portion of the velum; the differences in the magnitudes of total velar stretch and anterior velar stretch; the observation that the length of the anterior portion of the soft palate during speech was not significantly different from its resting length; and the correlation data relating anterior stretch and total velar stretch all support the notion that total velar stretch is not well predicted by the magnitude of stretch in the anterior portion of the soft palate during the production of either /u/ or /s/ among 8 and 10-year-old children.

Relationships between Stretch and other Cephalometric Measures

A fundamental objective of this study was to determine the relationships between velar stretch and other cephalometric measurements. Correlation techniques were used to assess relationships between the amount of velar stretch and other cephalometric measures.

The correlation coefficients between the amount of total velar stretch during the production of both /u/ and /s/ and need ratio were significant for both 8 and 10-year-old children. These results indicate that as the need ratio, i.e., ratio between pharyngeal depth and resting palatal length increases, the amount of stretch exhibited by these children increased. This finding is in agreement with Simpson and Austin[6] who reported that the relationship between the amount of total velar stretch during the production of /s/ and need ratio was significant ($p<.001$).

In the present study, the amount of total velar stretch during the production of /u/ and /s/ was found to be significantly correlated with resting palate length for 8-year-old children. For 10-year-old children, the magnitude of total stretch during the production of /s/ was significantly correlated with resting palate length. Such was not the case during /u/ production. It is important to note that these coefficients were negative. Thus, with one exception, as the resting length of the soft palate decreased, the amount of total velar stretch increased. Simpson and Austin[6] also reported a negative correlation between total velar stretch during /s/ and resting palatal length; however, the relationship between these two variables did not reach significance in their young adult subjects.

In the present work, the amount of velar stretch during the production of both /u/ and /s/ was significantly correlated with pharyngeal depth among 10-year-old children. This was not the case for 8-year-old children. Thus, among 10-year-old children, the data indicate that as pharyngeal depth increased, the amount of velar stretch also increased. Simpson and Austin[6] found that the amount of total velar stretch during /s/ was not significantly correlated with pharyngeal depth in their young adult subjects.

Taken together, these findings suggest that across groups (8-year-old children versus 10-year-old children) and speech conditions (/u/ versus /s/) total velar stretch was more consistently related to need ratio than to resting palate length or pharyngeal depth. In other words, when pharyngeal depth and resting velar length were combined to form a need ratio, the relationships between total velar stretch during the production of both /u/ and /s/ and need ratio were significant for both 8 and 10-year-old children.

Finally, correlation data support the notion that the amount of velar stretch is not well predicted by any single cephalometric measure employed in this research.

Utilization of Cephalometric Data for Velopharyngeal Adequacy

Lateral cephalometric radiographs are frequently used to estimate the extent of velopharyngeal opening and/or the prevalence of closure in speakers suspected of having velopharyngeal incompetence. In the present research, radiographic observations of the prevalence and/or the amount of velopharyngeal opening during the production of /u/ and /s/ were completed on a series of normal speaking 8 and 10-year-old children who were not suspected of having velopharyngeal incompetence.

With respect to prevalence, all 40 children attained palatopharyngeal closure during the sustained production of /s/. All 50 normal subjects in Hagerty and Hill's[11] study, and all 39 subjects in Weinberg's[25] study achieved velopharyngeal closure during the sustained production of /s/.

During the production of /u/, 33 children (82.5%) exhibited closure. All 8-year-old boys and girls exhibited closure; eight (80%) 10-year-old boys and five (50%) 10-year-old girls exhibited closure. The magnitude of velopharyngeal opening during the production of /u/ for the seven 10-year-old subjects who did not attain closure were small--ranging between 0.5 to 1.0 mm. In their observations of normal speakers, Benson[5] reported 91%, Moll[19] observed 89%, and Williams[15] found that 77% of his speakers exhibited velopharyngeal closure during the sustained production of /u/.

These findings of velopharyngeal closure during the production of /u/ and /s/ are extremely important with respect to their normative implications. For example, these data suggest that individuals with normal speech are more likely to exhibit velopharyngeal closure during the sustained production of /s/, than /u/. Some individuals with normal speech may manifest small residual openings of the velopharyngeal port during the production of sustained /u/. The failure to achieve complete closure during such speech tasks does not diminish the importance of an effective velopharyngeal mechanism and underscores the well established fact that velopharyngeal closure is not synonymous with palatopharyngeal adequacy for speech.[19]

Lateral cephalometric radiographs are also frequently used to assess the structural adequacy of the velopharyngeal mechanism. The data in this research provide descriptive information concerning the resting length of the soft palate and the anterior-posterior depth of the pharynx in normal-speaking 8 and 10-year-old children. Such information is useful to dentists, speech pathologists, and physicians who use lateral headplates to assess velopharyngeal adequacy. A summary of velar length, pharyngeal depth, and need ratio values for children studied here, with comparable measures obtained by other investigators, is provided in Table 11.

SUMMARY AND CONCLUSIONS

Summary and Conclusions

This investigation examined the prevalence, relative magnitude and selected components of velar stretch in normal-speaking 8 and 10-year-old children. For twenty 8-year-old and twenty 10-year-old children, lateral cephalometric films were obtained under three conditions: (1) subject at rest, (2) subject sustaining the vowel /u/, and (3) subject sustaining the voiceless fricative /s/. The cephalometric films were traced on acetate paper and specific radiographic measurements were made to describe important facets of velar stretch in children.

Data were obtained on the resting length of the soft palate, the antero-posterior depth of the pharynx, and the prevalence of velopharyngeal closure and/or the degree of velopharyngeal opening observed during selected speech utterances in normal-speaking 8 and 10-year-old children. Such information is expected to be useful to dentists, speech pathologists, and physicians who use lateral headplates to assess velopharyngeal adequacy.

Velar stretch per se was not observed in all 40 normal-speaking children. During the production of /u/, 36 children (90%) exhibited velar stretch; for /s/, 32 children (80%) manifested stretch. Paired-comparison t-test results showed that the length of the soft palate measured during speech was significantly greater than its resting length in both 8 and 10-year-old children. Moreover, significantly more total velar stretch was found during the production of the vowel /u/ than during the production of the consonant /s/ in both 8 and 10-year-old children. Although there was a significant increase in the length of the entire soft palate during the functional activities of speech, no significant increase in the anterior portion of the soft palate was associated with speech.

Analysis of variance techniques showed that 10-year-old children exhibited significantly greater velar stretch during both /u/ and /s/ utterances than did 8-year-old children. In addition, 10-year-old children exhibited significantly greater velar height and greater velar length characteristics during both /u/ and /s/ utterances than did 8-year-old children. Correlation procedures were used to examine the relationships between velar stretch and other commonly employed cephalometric measures. These analyses indicated that although velar stretch was significantly correlated with a number of commonly employed cephalometric measures, the amount of velar stretch was not well predicted by any single cephalometric measure used in this research.

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CURRICULUM VITAE

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1957 - 1961	St. Francis Xavier High School
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ABSTRACT

A CEPHALOMETRIC STUDY OF VELAR STRETCH IN 8 AND 10-YEAR-OLD CHILDREN

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This investigation examined the prevalence, relative magnitude, and selected components of velar stretch in normal-speaking 8 and 10-year-old children. For twenty 8-year-old and twenty 10-year-old children, lateral cephalometric films were obtained under three conditions: (1) subject at rest, (2) subject sustaining the vowel /u/, and (3) subject sustaining the voiceless fricative /s/. The cephalometric films were traced on acetate paper and specific radiographic measurements were made to describe important facets of velar stretch in children.

Data were obtained on the resting length of the soft palate, the antero-posterior depth of the pharynx, and the prevalence of velopharyngeal closure and/or the degree of velopharyngeal opening observed during selected speech utterances in normal-speaking 8 and 10-year-old children. Such information is expected to be useful to dentists, speech pathologists, and physicians who use lateral headplates to assess velopharyngeal adequacy.

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comparison t-test results showed that the length of the soft palate measured during speech was significantly greater than its resting length in both 8 and 10-year-old children. Moreover, significantly more total velar stretch was found during the production of the vowel /u/ than during the production of the consonant /s/ in both 8 and 10-year-old children. Although there was a significant increase in the length of the entire soft palate during the functional activities of speech, no significant increase in the anterior portion of the soft palate was associated with speech.

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