A Cephalometric Study of Velar Stretch in 8 and 10-Year Old Children

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The increase in the intrinsic or resting length of the soft palate measured during velopharyngeal maneuvers associated with speech has been termed velar stretch (*7*). To date, observations of the prevalence and magnitude of velar stretch have been very limited and obtained from lateral cephalometric radiographs. For example, Simpson and Austin (*9*) recently completed a systematic study of stretch phenomenon in twenty normal adult speakers. They observed velar stretch in each of twenty subjects studied and measured about a 20 percent average increase in the length of the soft palate during functional activities associated with speech.

Velar stretch has also been examined in persons with abnormal palatopharyngeal mechanisms. For example, Pruzansky and Mason (*7*) investigated stretch prevalence and magnitude in 110 patients with congenital palatopharyngeal incompetence and reported that "in some individuals the soft palate increased in its intrinsic length during velopharyngeal valving." Pruzansky and Mason (*7*) measured about a 16 and 26 percent average increase in velar length during the production of /u/ and /s/ in this series of patients.

Systematic observations of velar stretch in normal speaking subjects have apparently been restricted to young adults (*9*). To our knowledge, there have been no published reports of observations of stretch prevalence and magnitude in normal speaking children. This situation is regretable if one hypothesizes that velar stretch represents an important feature of normal palatopharyngeal function and if one hypothesizes that the potential of the velum to function adequately for speech cannot always be predicted simply on the basis of its intrinsic or resting length.

Hence, the general objective of the present study was to use radiographic cephalometry to examine the prevalence, relative magnitude and relationship between velar stretch and other commonly employed radiographic measurements in normal speaking 8 and 10-year-old children. It was assumed that data obtained in this project would, in part, contribute significant information necessary to a more complete description of palatopharyngeal form and function in normal-speaking children.

Methods

SUBJECTS, Twenty 8-year-old children and twenty 10-year-old children were studied. Both age groups had an equal (N = 10) number of boys and girls. All

children studied had Class I occlusion, normal speech, no previous history of speech therapy, no evidence of neuromuscular impairment or oral-facial structural abnormality, and no history of surgical removal of tonsils or adenoids.

To determine that only normal speaking children were used as subjects, tape recordings were made of each child producing the stimulus items of the Templin-Darley Screening Test of Articulation (*10*), the Iowa Pressure Test of Articulation (*4*) and providing a short segment of extemporaneous speech. The speech recordings of each child were made by one of the authors (a dentist) and independently evaluated by the other (a speech pathologist). All children participating in this experiment articulated all test items of both articulation tests correctly and were judged to be free of other speech or voice abnormalities.

CEPHALOMETRIC PROCEDURES. *Equipment and Experimental Conditions.* A Wehmer cephalometer was used to obtain lateral cephalometric films for each subject. A standardized procedure was used to position each subject in a standing upright position. Each subject's head was fixed within the cephalostat by head-positioner ear rods and by a nasion holder. All radiographs were exposed at 15 ma/sec for 36/60 second using KVP setting of 88.

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/. Subjects were instructed to sustain the requested sound at a comfortable and constant level. The activities used in obtaining the speech X-rays were all tape recorded and subsequently evaluated to insure that the intended sound was indeed produced by each speaker and that the X-ray was taken during the approximate midpoint of each subject's three-second sustained production of the sound under test.

Measurement Procedures. The three cephalometric films obtained for each subject were traced on acetate paper and specific structural measurements were made on each radiographic film. The anatomical landmarks, structures and reference points traced on all lateral cephalometric radiographs are illustrated in 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 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.
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 a radiopaque marker; determined by inspection.

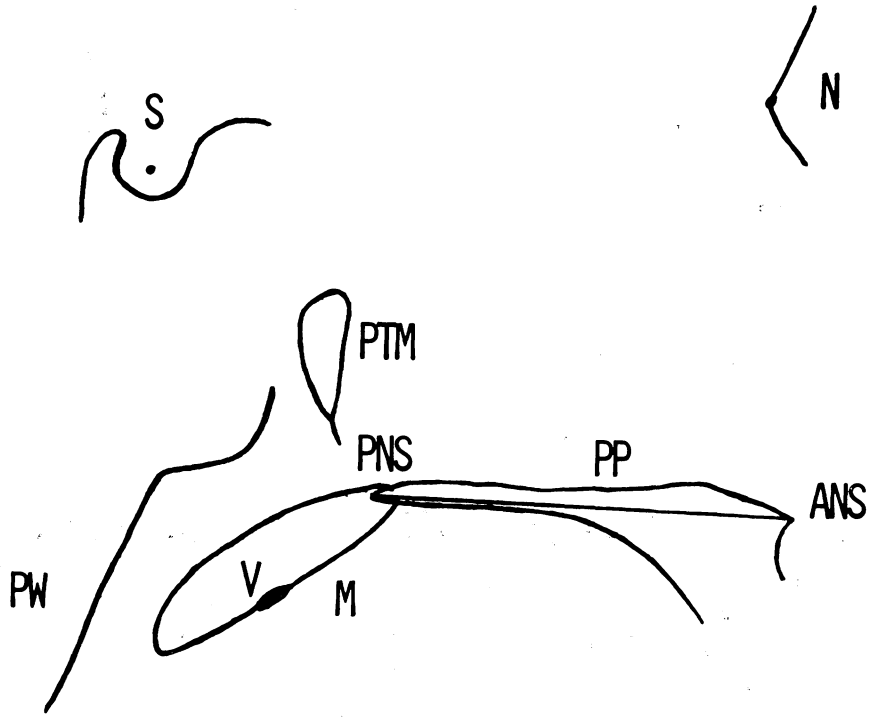

FIGURE 1

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

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 (PNS-U): The linear distance from the posterior nasal spine (PNS) to the most inferior point of the uvula (U); distance measured along a straight line formed between (PNS) and (U).
3. Length of the anterior portion of the velum (PNS-M): The linear distance from the posterior nasal spine (PNS) to the midpoint of the radiopaque marker (M).

Four 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 (PNS-U): The linear distance from the posterior nasal spine (PNS) to the most inferior point of the uvula (U); measured along a visually drawn midline.
2. Length of the anterior portion of the velum (PNS-M): The linear distance from the posterior nasal spine (PNS) to the midpoint of a radiopaque marker (M).
3. Velar Height (H): The highest point on the nasal surface of the velum

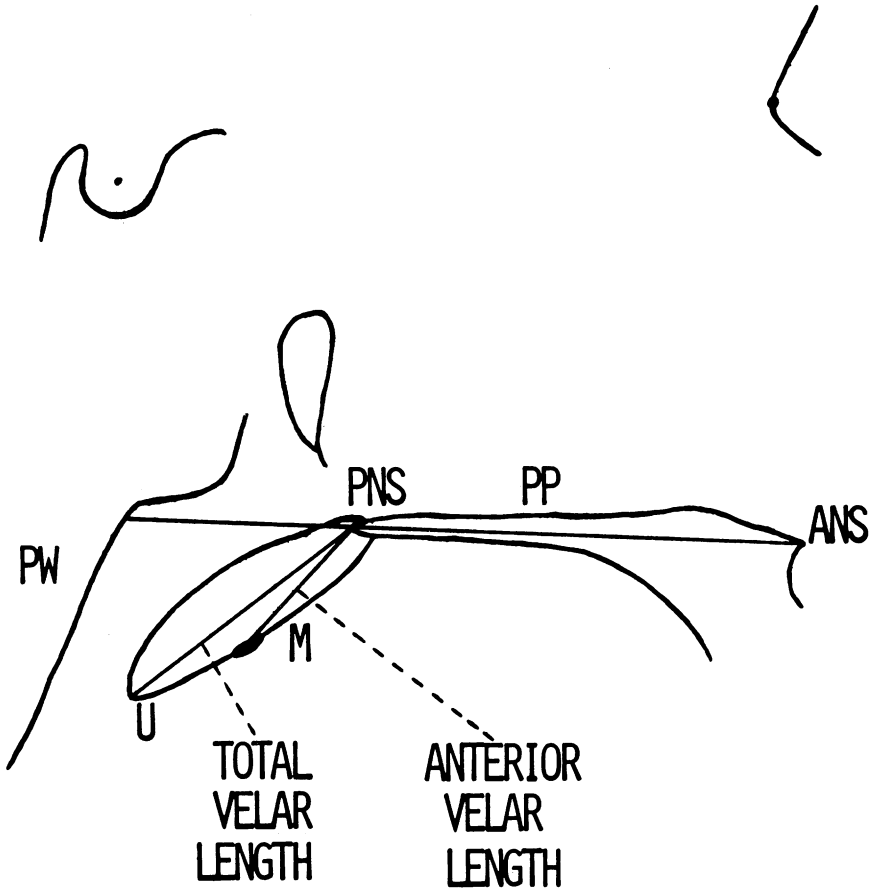

FIGURE 2

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 five (5) additional radiographic measurements:

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 measured 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:

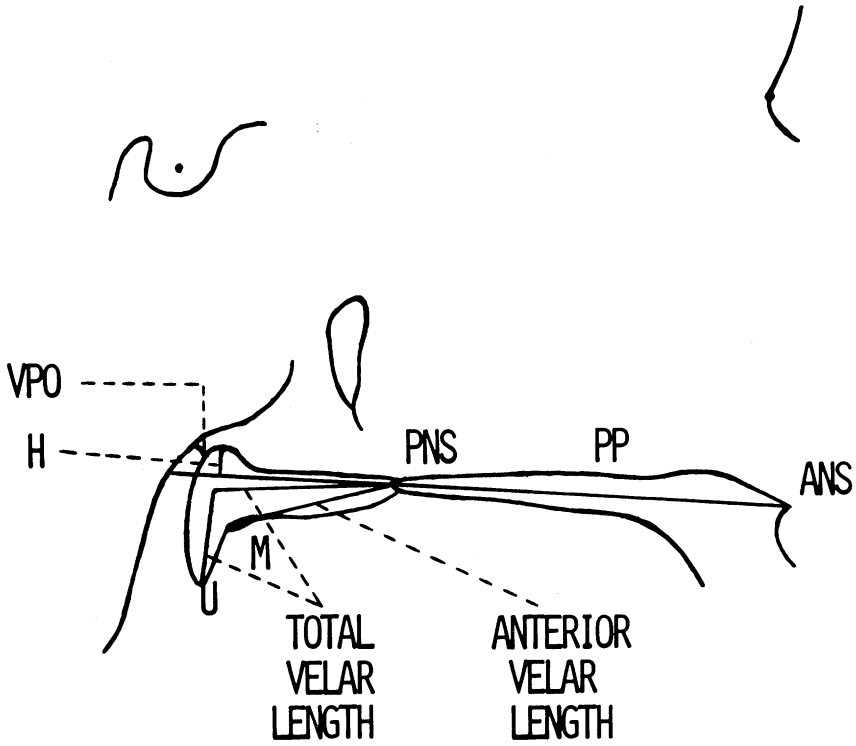

FIGURE 3

$$\frac{(\text{velar length during /u/}) - (\text{resting velar length})}{\text{resting velar length}} \times 100$$

= Percentage of total velar stretch attained during /u/ production

4. Anterior velar stretch: The difference in millimeters between the measured 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:

$$\frac{(\text{anterior length during /u/}) - (\text{resting anterior length})}{\text{resting anterior length}} \times 100$$

= Percentage of anterior stretch attained during /u/ production

The procedure of using a radiopaque marker to bisect the soft palate was originally suggested by Simpson and Austin (*9*). 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 used only to study the behavior of the anterior portion of the soft palate (*5*).

Results

MEASUREMENT RELIABILITY. The accuracy and reliability of the investigator's cephalometric tracings and measurements were assessed by having the experimenter re-trace and obtain an independent set of measurements on randomly selected sets of cephalometric radiographs for six subjects. An analysis of repeated measurements for this series of headplates indicated that there were no significant differences between the repeated average values for each cephalometric measurement and that the average error of measurement for individual measures was small (range .25 – .58 mm's). These observations support the assumption that the investigator demonstrated adequate tracing and measurement accuracy and reliability.

CEPHALOMETRIC ANALYSIS: GENERAL RESULTS. The general results of the cephalometric analysis are presented in Tables 1–4. The data in these tables provide descriptive information about the structural dimensions of important parts of the velopharyngeal mechanism of normal speaking 8 and 10-year-old children. We have chosen to provide this extensive summary because published information of this type is exceedingly limited (*King, 1952; Subtelny, 1957 and Owsley, et al., 6*), and we expect that information of this type will be useful to professionals who utilize lateral cephalograms to assess structural and functional adequacy of the velopharyngeal mechanism in children.

SEX AND AGE DIFFERENCES. Initially, an analysis was completed to determine whether there were differences in velar stretch and other commonly employed cephalometric measurements as a function of sex and age. Analysis of variance techniques were used to assess such differences and a summary of these analyses is presented in Table 5. Forty-two separate F-tests were performed. Seven of the 42 F values were significant. With respect to sex differences, the data in Table 5 showed a significant difference ($p<.05$) in pharyngeal depth. In other words, girls had a significantly larger average pharyngeal depth than boys at both age levels. 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 the average magnitude of total velar stretch during the production of both /u/ and /s/. Stated differently, 10-year-old children showed a significantly greater average amount of velar stretch during both speech utterances than did the 8-year-old children. There were also significant age differences in velar height and length characteristics. Ten-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.

PREVALENCE OF VELAR STRETCH. *Total Velar Stretch.* A fundamental objective of this study was to use radiographic cephalometry to examine the prevalence of velar stretch in normal 8 and 10-year-old children. The data in Tables 1–4 show that velar stretch was not observed in all 40 children. During the production of /u/, 36 children (90%) exhibited velar stretch; for /s/, 32 children (80%)

TABLE 1. Results of Cephalometric Analysis for 8-Year-Old Boys

		CEPHALOMETRIC MEASUREMENTS[1]																			
SUBJECT #	AGE YR.MO.	PHARYNGEAL DEPTH	TOTAL VELAR LENGTH REST	/u/	/s/	NEED RATIO %	TOTAL VELAR STRETCH[2] /u/	/s/	TOTAL VELAR STRETCH % /u/	/s/	ANTERIOR VELAR LENGTH REST	/u/	/s/	ANTERIOR VELAR STRETCH[2] /u/	/s/	ANTERIOR VELAR STRETCH % /u/	/s/	VELAR HEIGHT /u/	/s/	VELOPHARYNGEAL OPENING /u/	/s/
1	8-6	26.00	34.50	33.50	33.00	75.36	-1.00	-1.50	-2.90	-4.35	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	26.00	30.50	34.00	32.50	85.25	3.50	2.00	11.48	6.56	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	26.50	36.00	34.50	33.00	73.61	-1.50	-3.00	-4.17	-8.33	18.00	21.00	17.50	3.00	-0.50	16.67	-2.78	5.50	6.50	0.0	0.0
4	8-8	25.00	32.00	33.50	34.50	78.13	1.50	2.50	4.69	7.81	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	24.00	27.00	29.00	29.00	88.88	2.00	2.00	7.41	7.41	15.50	15.50	14.00	0.00	-1.50	0.00	-9.68	3.50	5.00	0.0	0.0
6	8-9	28.00	30.50	37.50	36.00	91.80	7.00	5.50	22.95	18.03	20.00	20.50	19.00	0.50	-1.00	2.50	-5.00	3.00	3.50	0.0	0.0
7	8-4	22.00	29.00	32.50	33.50	75.86	3.50	4.50	12.07	15.52	17.00	18.00	18.00	1.00	1.00	5.88	5.88	1.00	1.00	0.0	0.0
8	8-9	23.50	28.50	31.50	30.50	82.46	3.00	2.00	10.53	7.02	16.00	18.00	16.50	2.00	0.50	12.50	3.13	1.50	3.00	0.0	0.0
9	8-7	14.50	26.50	27.50	27.50	54.72	1.00	1.00	3.77	3.77	14.50	14.50	13.50	0.00	-1.00	0.00	-6.90	2.00	3.50	0.0	0.0
10	8-11	25.00	30.50	31.00	29.50	81.97	0.50	-1.00	1.64	-3.26	16.00	16.50	16.00	0.50	0.00	3.13	0.00	2.50	4.00	0.0	0.0
MEAN		24.05	30.50	32.45	31.90	78.85	1.95	1.40	6.39	4.59	17.05	17.55	16.55	0.50	-0.50	2.93	-2.93	2.85	4.00		
STANDARD DEVIATION		3.75	3.04	2.86	2.67		2.48	2.63			1.66	2.03	1.70	1.22	0.81			1.41	1.56		
VARIANCE		14.08	9.22	8.19	7.15		6.13	6.93			2.75	4.14	2.91	1.50	0.67			2.00	2.44		
MINIMUM		14.50	26.50	27.50	27.50		-1.50	-3.00			14.50	14.50	13.50	-1.00	-1.50			1.00	1.00		
MAXIMUM		28.00	36.00	37.50	36.00		7.00	5.50			20.00	21.00	19.00	3.00	1.00			5.50	6.50		

[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. Results of Cephalometric Analysis for 8-Year-Old Girls

			CEPHALOMETRIC MEASUREMENTS[1]																			
SUB-JECT #	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 % /u/	TOTAL VELAR STRETCH % /s/	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 % /u/	ANTERIOR VELAR STRETCH % /s/	VELAR HEIGHT /u/	VELAR HEIGHT /s/	VELO-PHARYN-GEAL OPENING /u/	VELO-PHARYN-GEAL OPENING /s/
1	8-7	25.00	33.00	34.50	32.00	75.76	1.50	-1.00	4.55	-3.03	17.50	16.50	15.00	-1.00	-2.50	-5.71	-14.28	3.5	4.0	0.0	0.0
2	8-11	22.00	31.50	35.50	35.50	69.84	4.00	4.00	12.70	12.70	16.00	18.00	18.00	2.00	2.00	12.5	12.5	2.5	2.5	0.0	0.0
3	8-10	24.50	30.00	33.50	33.50	81.67	3.50	3.50	11.67	11.67	17.00	17.50	17.00	0.50	0.00	2.94	0.0	2.0	3.5	0.0	0.0
4	8-5	25.50	29.00	35.00	31.50	87.93	6.00	2.50	20.69	8.62	18.50	19.50	16.50	1.00	-2.00	5.41	-10.81	3.0	4.5	0.0	0.0
5	8-0	28.50	27.50	36.00	33.50	103.64	8.50	6.00	30.91	21.82	17.00	20.50	19.50	3.50	2.50	20.59	14.71	3.0	4.5	0.0	0.0
6	8-11	25.00	32.50	32.50	30.50	76.92	0.00	-2.00	0.00	-6.15	18.50	16.00	15.00	-2.50	-3.50	-13.51	-18.92	3.0	4.5	0.0	0.0
7	8-1	23.50	32.50	30.50	29.00	72.31	-2.00	-3.50	-6.15	-10.77	20.00	17.50	16.50	-2.50	-3.50	-12.50	-17.50	2.0	2.0	0.0	0.0
8	8-11	31.50	28.00	31.00	32.00	112.50	3.00	4.00	10.71	14.29	15.50	17.00	16.50	1.50	1.00	9.68	6.45	6.0	7.5	0.0	0.0
9	8-1	22.00	29.50	33.50	31.50	74.58	4.00	2.00	13.56	6.78	17.50	20.00	18.00	2.50	0.50	14.29	2.86	2.5	2.5	0.0	0.0
10	8-10	30.50	33.50	35.00	33.50	91.04	1.50	0.00	4.48	0.00	21.00	22.00	20.50	1.00	-0.50	4.76	-2.38	4.0	5.0	0.0	0.0
MEAN		25.80	30.70	33.70	32.25	84.04	3.0	1.55	9.77	5.05	17.85	18.45	17.25	0.60	-0.60	3.36	-3.36	3.15	4.05		
STANDARD DEVIATION		3.32	2.17	1.87	1.83		2.98	3.05			1.70	1.95	1.78	2.02	2.18			1.18	1.59		
VARIANCE		11.01	4.73	3.51	3.35		8.89	9.30			2.89	3.80	3.18	4.1	4.77			1.39	2.52		
MINIMUM		22.00	27.50	30.50	29.00		-2.00	-3.50			15.50	16.00	15.00	-2.50	-3.50			2.00	2.00		
MAXIMUM		31.50	33.50	36.00	35.50		8.50	6.00			21.00	22.00	20.50	3.50	2.50			6.00	7.50		

[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. Results of Cephalometric Analysis for 10-Year-Old Boys

SUBJECT #	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 % /u/	TOTAL VELAR STRETCH % /s/	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 % /u/	ANTERIOR VELAR STRETCH % /s/	VELAR HEIGHT /u/	VELAR HEIGHT /s/	VELOPHARYNGEAL OPENING /u/	VELOPHARYNGEAL OPENING /s/
1	10-5	26.00	30.00	36.50	37.00	86.67	6.5	7.0	21.67	23.33	17.50	17.50	16.50	0.0	-1.0	0.00	-5.71	7.00	7.50	0.5	0.0
2	10-11	29.50	30.00	35.00	33.00	98.33	5.0	3.0	16.67	10.00	16.50	18.00	16.50	1.5	0.0	9.09	0.00	5.00	6.00	0.0	0.0
3	10-8	23.50	25.50	30.00	30.00	92.16	4.5	4.5	17.65	17.65	15.00	15.50	16.00	0.5	1.0	3.33	6.67	2.00	3.00	0.0	0.0
4	10-6	21.00	32.50	37.50	34.00	64.62	5.0	1.5	15.38	4.62	17.00	19.00	17.50	2.0	0.5	11.76	2.94	1.00	2.50	0.0	0.0
5	10-6	24.50	31.00	32.50	31.50	79.03	1.5	0.5	4.84	1.61	18.50	17.00	16.50	-1.5	-2.0	-8.11	-10.81	4.00	5.00	0.0	0.0
6	10-2	19.50	28.50	31.00	30.00	68.42	2.5	1.5	8.77	5.26	17.50	17.50	17.00	0.0	-0.5	0.00	-2.86	0.00	1.50	0.0	0.0
7	10-2	25.50	30.00	32.00	32.50	85.00	2.0	2.5	6.67	8.33	16.00	16.00	16.00	0.0	0.0	0.00	0.00	4.50	6.50	0.0	0.0
8	10-0	26.50	27.50	32.50	31.50	96.36	5.0	4.0	18.18	14.55	15.50	17.00	16.50	1.5	1.0	9.68	6.45	5.00	5.00	0.0	0.0
9	10-11	27.00	35.00	37.00	35.50	77.14	2.0	0.5	5.71	1.43	20.00	19.00	18.00	-1.0	-2.0	-5.00	-10.00	4.50	7.50	1.0	0.0
10	10-5	33.00	30.00	38.00	39.00	110.00	8.0	9.0	26.67	30.00	20.50	19.00	19.00	-1.5	-1.5	-7.32	-7.32	7.50	7.50	0.0	0.0
MEAN		25.60	30.00	34.20	33.40	85.33	4.2	3.4	14.00	11.33	17.40	17.55	16.95	0.15	-0.45	0.86	-2.59	4.05	5.20		
STANDARD DEVIATION		3.90	2.60	2.94	3.00		2.15	2.81			1.82	1.23	0.96	1.25	1.14			2.42	2.21		
VARIANCE		15.21	6.78	8.62	8.93		4.62	7.88			3.32	1.52	0.91	1.56	1.30			5.86	4.90		
MINIMUM		19.50	25.50	30.00	30.00		1.50	0.50			15.00	15.50	16.00	-1.50	-2.00			0.00	1.50		
MAXIMUM		33.00	35.00	38.00	39.00		8.00	9.00			20.50	19.00	19.00	2.00	1.00			7.50	7.50		

[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. Results of Cephalometric Analysis for 10-Year-Old Girls

CEPHALOMETRIC MEASUREMENTS[1]

SUBJECT #	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 % /u/	TOTAL VELAR STRETCH % /s/	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 % /u/	ANTERIOR VELAR STRETCH % /s/	VELAR HEIGHT /u/	VELAR HEIGHT /s/	VELOPHARYNGEAL OPENING /u/	VELOPHARYNGEAL OPENING /s/
1	10-11	27.00	29.50	32.50	35.00	91.53	3.00	5.50	10.17	18.64	16.50	16.50	16.00	0.0	-0.5	0.0	-3.03	4.5	7.0	1.0	0.0
2	10-2	27.00	35.50	39.00	38.50	76.06	3.50	3.00	9.86	8.45	20.50	22.50	22.50	2.0	2.0	9.76	9.76	4.0	3.0	0.0	0.0
3	10-11	32.00	31.50	38.50	38.00	101.59	7.00	6.50	22.22	20.63	17.50	21.00	21.50	3.5	4.0	20.00	22.86	3.5	4.5	0.5	0.0
4	10-8	31.50	30.00	35.00	34.50	105.00	5.00	4.50	16.67	15.00	18.00	19.50	18.50	1.5	0.5	8.33	2.78	6.0	6.5	0.5	0.0
5	10-10	29.50	31.50	36.50	35.50	93.65	5.00	4.00	15.87	12.70	18.50	21.00	20.50	2.5	2.0	13.51	10.81	2.5	3.5	0.0	0.0
6	10-1	30.00	29.00	34.00	32.50	103.45	5.00	3.50	17.24	12.07	19.00	17.50	16.50	-1.5	-2.5	-7.89	-13.16	6.0	6.0	0.0	0.0
7	10-11	34.00	29.00	38.00	35.00	117.24	9.00	6.00	31.03	20.69	16.50	21.00	19.00	4.5	2.5	27.27	15.15	6.0	7.5	0.5	0.0
8	10-0	26.00	30.50	32.50	33.00	85.25	2.00	2.50	6.56	8.20	18.00	16.50	16.50	-1.5	-1.5	-8.33	-8.33	2.5	3.0	0.0	0.0
9	10-11	26.00	29.00	34.00	33.00	89.66	5.00	4.00	17.24	13.79	15.50	16.00	16.50	0.5	1.0	3.23	6.45	5.0	6.0	0.0	0.0
10	10-3	24.00	35.50	37.00	35.00	67.61	1.50	-0.50	4.23	-1.40	20.00	19.00	16.50	-1.0	-3.5	-5.00	-17.50	3.5	4.5	0.5	0.0
MEAN		28.70	31.10	35.70	35.00	92.28	4.60	3.90	14.79	12.54	18.00	19.05	18.40	1.05	0.40	5.83	2.22	4.35	5.15		
STANDARD DEVIATION		3.19	2.50	2.42	2.00		2.26	2.01			1.58	2.31	2.39	2.10	2.38			1.37	1.67		
VARIANCE		10.18	6.27	5.90	4.00		5.10	4.04			2.50	5.36	5.71	4.41	5.65			1.89	2.78		
MINIMUM		24.00	29.00	32.50	32.50		1.50	-0.50			15.50	16.00	16.00	-1.50	-3.50			2.50	3.00		
MAXIMUM		34.00	35.50	39.00	38.50		9.00	6.50			20.50	22.50	22.50	4.50	4.00			6.00	7.50		

[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. Effects of Age and Sex on Average Cephalometric Measurements (F Values)

	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	5.99•	6.72•	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	• p .025
7.39	+ p .01

manifested stretch. All 10-year-old boys exhibited stretch during both /u/ and /s/ production. 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/.

Hence, velar stretch was not measured 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 two remaining instances, the length of the soft palate measured during speech was equal to resting length.

Anterior Velar Stretch. 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 1–4 show that stretch within the anterior portion of the velum was also not observed in all 40 children. For example, 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/.

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 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. *Total Velar Stretch.* A fundamental 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 velar stretch mangitudes for the children studied is tabulated in Table 6. The data tabulated here suggest that the average length characteristics of the soft palate measured during the production both of /u/ and /s/ were greater than resting palate length characteristics. Paired-comparison t-tests were used to evaluate the significance of the differences between average resting palate lengths

TABLE 6. Stretch Magnitude Characteristics

	SPEECH TASK /u/				SPEECH TASK /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	1.5	8.0	3.40	2.81	0.5	9.0
10 Year-old Girls	4.60	2.26	1.5	9.0	3.90	2.01	-0.5	6.5

[1]All values are expressed in millimeters. Minus values (Range) reflect a shortening in the functional length of the soft palate relative to its length at rest.

and average velar lengths attained during speech (Table 7). The results of these comparisons show that the average length of the soft palate measured 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 average soft palate length characteristics attained during the production of /s/ versus /u/. These comparisons indicated that average palate length measured during /u/ was significantly greater ($t = 2.43$, $p < .05$, 8-year-old children; $t = 3.53$, $p < .01$, 10-year-old children) than average palate length measured during the production of /s/.

Anterior Velar Stretch. The magnitude of stretch in the anterior portion of the soft palate was examined and the mean values for this variable are also shown in Tables 1–4. 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. In fact, average anterior stretch values were sometimes negative, suggesting a general shortening of the anterior portion of the palate during speech. Paired-comparison t-test results showed that for both 8 and 10-year-old children the length of the anterior portion of the soft palate measured during speech was not significantly different from its average resting length.

Relationships between Stretch and Other Cephalometric Measures. A final

TABLE 7. t-Test Comparisons of Average Resting Soft Palate Length vs Average Length Measured during Speech

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

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

objective of this study was to assess the relationships between velar stretch and other cephalometric measures. Correlation techniques were used to assess these relationships. Two inter-correlation analyses were performed: 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. The inter-correlation matrices showing the relationship between the cephalometric measurements are presented in Tables 8 and 9. In this report, emphasis is placed on briefly summarizing relationships between velar stretch and other cephalometric measurements and briefly discussing interrelationships between important cephalometric measurements other than stretch.

The data in Tables 8 and 9 indicated that the relationship between the amount of total velar stretch (variables 6 and 7) and need ratio were significant for both 8- ($p<.05$) and 10- ($p<.001$) year-old children. These results indicate that as need ratio increased, i.e., ratio between pharyngeal depth and resting palatal length, the magnitude of stretch used by these children increased.

For 8-year-old children, the amount of total velar stretch was significantly ($p<.01$) correlated with resting palate length. For 10-year-old children, total velar stretch magnitude during production of /s/, but not /u/, was significantly correlated with resting palate length. It is important to note that the signs for those coefficients were negative, showing that as the resting soft palate length decreased the amount of total velar stretch increased.

Among 10-year-old children, the amount of total velar stretch 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 the magnitude of velar stretch increased as a function of an increase in pharyngeal depth. Taken together, these findings suggest that total velar stretch was more consistently related to need ratio than to resting palate length or pharyngeal depth.

The inter-correlation data also provide information about the interrelationships between cephalometric measurements other than velar stretch. Of interest was the observation 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 were not significant among 8-year-old children, but reach 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 also 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, as did the stretch magnitude

TABLE 8. Correlation Matrix of the Cephalometric Measurements—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 9. Correlation Matrix of the Cephalometric Measurements—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/).

data, that the length of the soft palate attained during speech cannot be predicted well on the basis of its resting length. Finally, the correlation data offered here support the notion that the amount of velar stretch is not well predicted by any single cephalometric measure employed in this research.

Discussion

There has, to our knowledge, been only one published study concerned with the prevalence of velar stretch in normal speakers. In this study, Simpson and Austin (*9*) examined the prevalence of velar stretch in twenty normal adult speakers. Using lateral cephalometric techniques, they studied stretch phenomenon during the production of sustained /s/ in 10 men and 10 women, ranging in age from 18 to 30 years. Simpson and Austin measured velar stretch in all 20 normal adult speakers. Thus, on the basis of the limited data available, it appears that during the production of the sustained fricative /s/, velar stretch may be universal among normal adult speakers, but does not represent a universal functional structure of velopharyngeal function among normal speaking 8 and 10-year-old children.

It is important to remember that all 40 children examined in the present study 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/, in 12 observations velar stretch was not present during speech. Thus, although about 85% of the children studied exhibited velar stretch, failure to exhibit stretch in about 15% of the observations should not be viewed as an indicator of structural or functional inadequacy of the velopharyngeal mechanism in normal children of this age group.

As indicated above, only one published study has dealt with velar stretch among normal speakers. In that study, 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 during /s/. Taken together, these observations suggest that the average degree of velar stretch may increase as a function of chronologic age. Indeed, evidence supporting 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. On the average, 10-year-old children exhibited significantly greater velar stretch during both /u/ and /s/ utterances than did 8-year-old children. Hence, there is an obvious need for additional study of the relationship between the magnitude of velar stretch and chronologic age, since the available data relating stretch magnitude and age are exceedingly limited.

The results of the present study indicated that average values of velar stretch within the anterior portion of the palate were small and that the length of the anterior portion of the soft palate measured during speech was not significantly different from anterior resting length. Simpson and Austin (*9*) 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 show that 8- and 10-year-old children did not exhibit a significant functional increase in the length of the anterior segment of the soft palate during either sustained /u/ and /s/ productions. These results suggest that normal 8 and 10-year-old children usually achieve velopharyngeal adequacy for speech in the absence of significant anterior stretch.

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 studied by Hagerty and Hill (*2*) and all 39 normal children studied by Weinberg (*11*) 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, eight (80%) 10-year-old boys and five (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. In their observations of normal speakers, Benson (*1*) reported 91% and Moll (*3*) observed that 89% of their speakers exhibited velopharyngeal closure during the sustained production of /u/.

These findings related to the absence of presence of velopharyngeal closure during the production of /u/ and /s/ are important with respect to their normative implications. For example, the present data suggest that children 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/. However, 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.

Summary

Radiographic cephalometry was used to examine the prevalence, magnitude, and relationship between velar stretch and other commonly employed cephalometric measurements in forty (40) normal-speaking 8 and 10-year-old children. Velar stretch was not universally observed although the average soft palate length characteristics of these children measured during speech were significantly longer than the resting or intrinsic palate length measurements. Significant differences in average stretch magnitude were measured as a function of speech

task (/u/ vs /s/) and subject age (8 vs 10-year-olds). Although velar stretch was significantly correlated with several commonly used cephalometric measurements, stretch was not well predicted by any single cephalometric measurement used in this research. These findings are interpreted in terms of their implications for determining velopharyngeal adequacy for speech and their implications with respect to developmental features of velar function.

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