Effects of Velopharyngeal Incompetence upon Speech

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Cleft palate speech is intricate because many factors are involved in its production: type of cleft, age of operation, velopharyngeal closure, faulty habits of articulation, tongue inflexibility, malocclusion, et cetera. Among those factors, velopharyngeal incompetence has been accepted as a prime factor responsible for defective cleft palate speech (*2, 5, 9, 14, 15, 16*). Reported correlation coefficients, however, between velopharyngeal opening and defectiveness of speech are not very high (*3, 4, 5, 13, 16*). Many authors appear to agree with Subtelny, Koepp-Baker and Subtelny (*16*) when they ascribe the low correlation between velopharyngeal dimension and speech defect to the other factors influencing cleft palate speech and to the limitation of the experimental conditions. For most meaningful results, these other factors, such as faulty habits of articulation, should be excluded, and, in this connection, Warren and Devereux (*20*) recently made a series of analog studies of velopharyngeal function associated with speech. Additional research is needed.

This study was specifically designed for obtaining answers to the following questions. a) What is the critical size of velopharyngeal closure necessary for acceptable speech? b) What are the characteristics of speech produced with velopharyngeal incompetence of varying degrees?

Procedure

Subjects were eleven young male adults, all of whom had normal speech. Artificial velopharyngeal incompetence was created in each subject by inserting a polyvinyl tube in the velopharynx. While the subject produced consonant-vowel (CV) syllables or read a passage,

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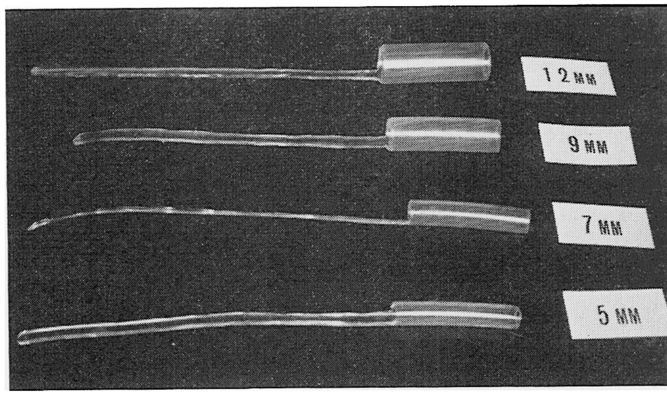

FIGURE 1. Polyvinyl tubes used for producing artificial velopharyngeal incompetence.

the voice was recorded on tape recorder and measurements were also made of oral pressure, nasal and/or oronasal air flow rate by use of a pneumotachograph. Judgments of articulation defectiveness and severity of nasality were made from the recordings.

The following procedure was used for insertion of the polyvinyl tube. The nose and pharynx were anesthesized with 4% Xylocain spray to eliminate discomfort and gag reflex. A polyvinyl tube, 4.5 cm in length and with a long shaft (Figure 1) was inserted in the velopharynx.[1] The polyvinyl tube was pulled through the mouth up to the velopharynx until only the margin of the tube was seen beyond the palatal arch, and was fixed there by applying adhesive tape on the shaft of tube pulled out over the face. The length of tube (4.5 cm) was necessary to prevent any chance of blockage of the openings at the ends of the tube by the soft palate. Before each task, the tube was confirmed to be at the right place so that just the lower margin of the tube was visible behind the posterior palatal arch. For purposes of learning the effect of the tube on aspects of speech other than velopharyngeal opening, the tasks were repeated with the same tube in place but with tube openings occluded tightly with a tampon.

Tubes of four diameters were used: 5, 7, 9, and 12 mm (inside measurements). Not all sizes of tubes were used for all subjects.

TASK 1. VOICE RECORDING. With the tube in place for the experimental condition, the subject produced the plosive or fricative CV syllables / pɑ, pi, pu, bɑ, bi, bu, kɑ, ki, ku, gɑ, gi, gu, sɑ, ʃi, su, zɑ, ji, zu / and read a Japanese passage which contains a variety of consonant syllables *Yabuno nakakara usagiga pyokonto dete kimashita.* No mask was worn on the face in this series of experiments. Voice signals were recorded on a tape recorder (Den-on DN-72R) through a microphone (Aiwa VM-18).

[1] A rubber urethral catheter is inserted in one nostril and pulled out of the mouth. The shaft of tube is secured to the oral end of catheter and drawn up at the right place.

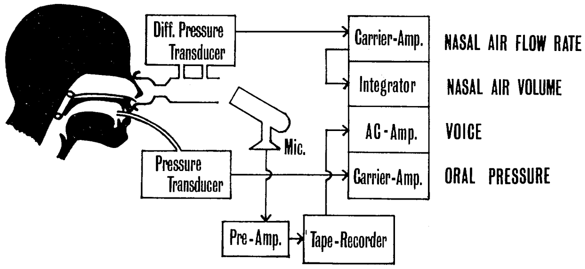

FIGURE 2. The diagram showing the experimental arrangement.

TASK 2. AERODYNAMIC MEASUREMENT. The subject again produced the same CV syllables as in Task 1 with a mask tightly worn against the face so that the air flow rate through the mouth and nose could be measured (Figure 2). Oronasal or nasal air flow rate was measured through the use of a pneumotachograph. The pneumotachograph was calibrated by measuring flow rate of a known volume of air during a known time period.

A pressure transducer was utilized for measuring intraoral pressure via a polyvinyl tube, 2.5 mm in size. The system was calibrated against a water manometer. The tube was held tightly between the lips. Subjects were instructed not to block the tube with the tongue and other structures or saliva. Signals for voice, air flow rate and pressure were simultaneously recorded on visigraph (San'ei FR 102). Because the size of the tube hampered speech production, only the labial plosives /p, b/ were used for this part of the experiment.

CALCULATION OF VELOPHARYNGEAL RESISTANCE. Velopharyngeal resistance during production of plosive sounds was obtained by dividing the peak value of intraoral pressure by the peak value of nasal flow rate and expressed in dyne sec/cm^5.[2] In general, the peak of flow rate synchronized with that of pressure. The total resistance thus calculated actually indicates a sum of resistances, including those of the velopharynx, the nasal cavity, and the pneumotachograph. To be exact, the velopharyngeal resistance is equal to the sum of the total resistance minus nasal and pneumotachographic resistances. The nasal and pneumotachographic resistances, which are constant for a given subject, are negligible however (1–5 dyne sec/cm^5) when the velopharyngeal resistance is great.

JUDGMENT OF SPEECH. The tapes were played back in a sound-treated room for five specialists in speech who judged whether the articulation

[2] Velopharyngeal Resistance is defined as

$$\frac{\text{pressure difference across the velopharynx}}{\text{air flow rate (volume velocity) through the nose (velopharynx)}}$$

$$\frac{\text{A cmH}_2\text{O}}{\text{B cm}^3\text{/sec}} = \frac{\text{A 980 dyne/cm}^2}{\text{B cm}^3\text{/sec}} = 980\,\frac{\text{A}}{\text{B}}\ \text{dyne sec/cm}^5$$

of a test syllable was correctly produced, distorted, or substituted. The classification system for assessing nasality was as follows: *one,* non-nasal; *two,* slightly nasal but still acceptable as within normal variation; *three,* fairly nasal; *four,* very nasal; and *five,* extremely nasal. Any value higher than *three* was considered to indicate unquestionable nasality or at least to the extent that a lay person would perceive the voice as nasal. As a reliability test, speech judgment was repeated twice by the same judges at monthly intervals. The results demonstrated high consistency of judgment.

Results

I. Velopharyngeal Opening and Nasality. The degree of nasality for each of the different tube sizes is shown in Table 1 and in the bar graph in Figure 3. High interlistener reliability can also be seen

TABLE 1. Ratings of nasality made by five judges for each of five tube diameters.

diameter of the tube	*voice*	*listener*						*mean*
		A	*B*	*C*	*D*	*E*		
0	No. 1	1	2	1	1	1	1.2	1.3
	2	1	1	1	1	2	1.2	
	3	1	1	1	2	2	1.4	
	4	1	1	1	1	2	1.2	
	5	1	2	1	2	2	1.6	
	6	1	1	1	1	1	1.0	
	7	1	1	2	1	1	1.2	
5 mm	No. 1	3	2	2	2	2	2.2	2.5
	2	2	3	2	3	3	2.6	
	3	3	3	3	3	3	3.0	
	4	2	3	2	2	2	2.2	
	5	2	3	2	3	3	2.6	
7 mm	No. 1	3	4	2	4	4	3.4	2.9
	2	2	3	3	3	3	2.8	
	3	1	2	2	2	3	2.0	
	4	3	3	3	4	4	3.4	
9 mm	No. 1	2	4	3	3	3	3.0	4.0
	2	4	4	4	4	4	4.0	
	3	2	3	4	3	4	3.2	
	4	5	4	4	5	5	4.6	
	5	3	5	3	5	5	4.4	
	6	4	5	4	4	5	4.4	
	7	5	5	3	5	5	4.6	
12 mm	No. 1	4	4	4	4	4	4.0	4.1
	2	3	5	3	4	5	4.0	
	3	4	5	4	4	5	4.4	

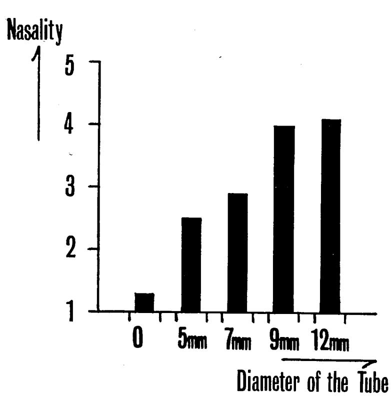

FIGURE 3

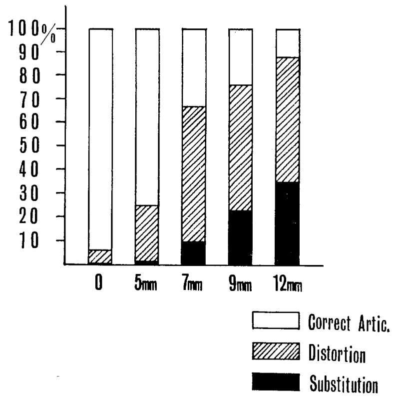

FIGURE 4

FIGURE 3. Histogram showing the mean nasality ratings for various tube sizes.
FIGURE 4. Means for percentage of articulation error for plosive and fricative consonants in relation to the size of tube in the velopharynx.

in Table 1. It is demonstrated that the speech is slightly nasal with a velopharyngeal opening of 5 mm in diameter, unquestionably nasal at 7 mm, and extremely nasal at 9 mm and 12 mm. No great amount of difference is observed between 9 mm and 12 mm of velopharyngeal opening.

II. Velopharyngeal Opening and Articulatory Errors. The listeners' judgments regarding articulatory errors are summarized in Figure 4. For the tube of 5 mm in diameter, the frequency of articulatory errors, including distortion and substitution, does not exceed 25% of all the CV syllables tested. When the size of tube is 7 mm, the frequency of distortion and substitution combined is higher than 60%. For tubes of 9 mm or 12 mm, articulatory errors occur even more frequently than for the 7 mm tube. The type of articulatory errors for each size of the tube is represented by Figure 5. When the 12 mm diameter tube is

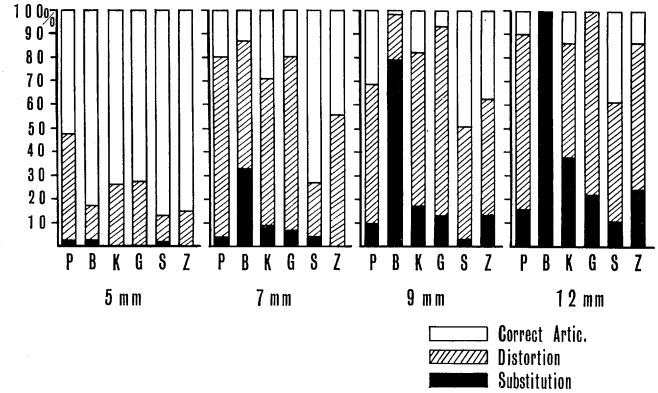

FIGURE 5. Means for percentage of articulation error for each of the plosive and fricative consonants in relation to the size of tube.

used, the voiced labial plosive /b/ is substituted by the nasal /m/ in almost every case, and the frequency of substitutions for the other CV syllables are less than 40%.

Glottal stops, pharyngeal fricatives, or omissions which are frequently encountered in cleft palate speech, were not found in the speech produced with a tube in the velopharynx. The frequency of articulatory

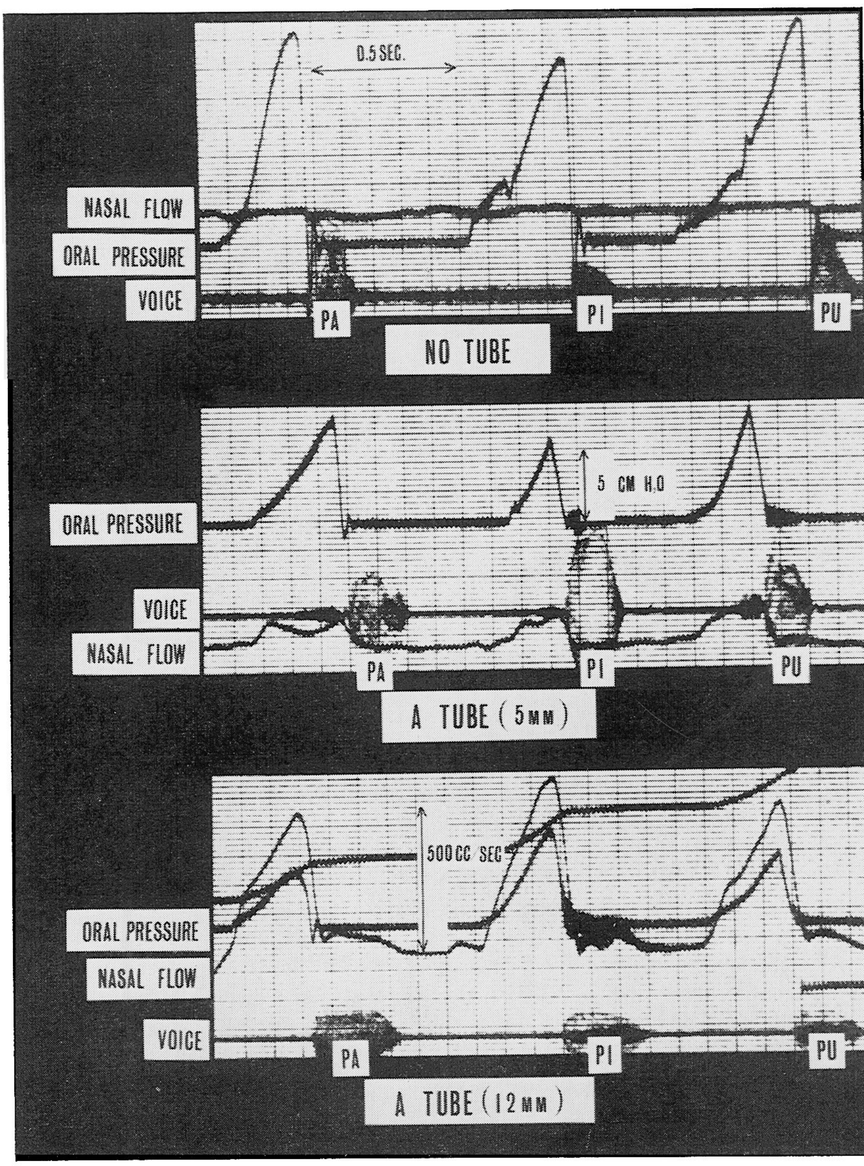

FIGURE 6. Recordings of nasal flow rate, oral pressure and voice.

errors (distortions or substitutions) increased with the size of the tube. It is of interest to note that the fricative consonants are not so much affected by the presence of tube in the velopharynx as the plosive consonants.

III. Velopharyngeal Opening and Aerodynamics of Speech. Registration of intraoral breath pressure, rate and volume of nasal air flow, and voice signal during CV production of /pa, pi, pu/ with and without a tube in the velopharynx is demonstrated in Figure 6. The aerodynamic pattern for artificial velopharyngeal incompetence (12 mm) is characterized by a low amount of intraoral pressure and a high rate of nasal flow prior to plosive sound production. The peak values of nasal flow rate for each of the different size tubes are shown in Figure 7. The nasal flow rate increases with the diameter of the tube: 200 to 300 cc/sec for 5 mm, and 600 to 700 cc/sec for 12 mm. The peak values of intraoral breath pressure are inversely related to the size of tube, as illustrated in Figure 8.

Figure 9 indicates the mean value of velopharyngeal resistance on production of /p/ for each of the different size tubes. On Figure 9, the fine lines at the left of the histogram show the measures of dispersion. As expected, the velopharyngeal resistance as calculated in the manner previously mentioned decreases as the size of the tube increases: about 50 dyne sec/cm^5 for the 5 mm tube, and 20 dyne sec/cm^5 for the 7 mm tube.

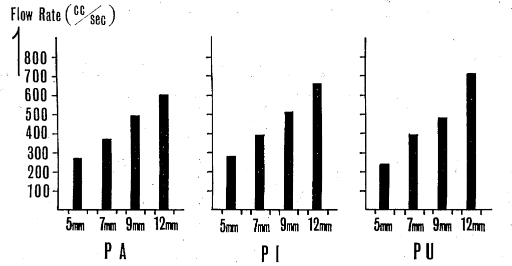

FIGURE 7. Maximum flow rate of air escape through the nose.

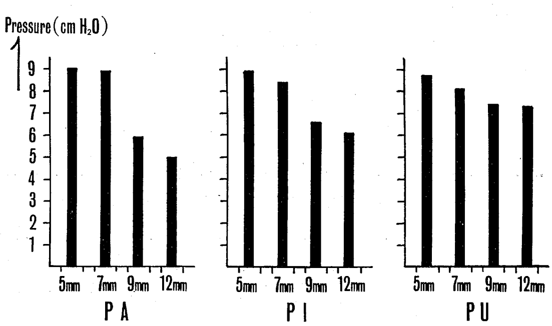

FIGURE. 8. Maximum intraoral breath pressure.

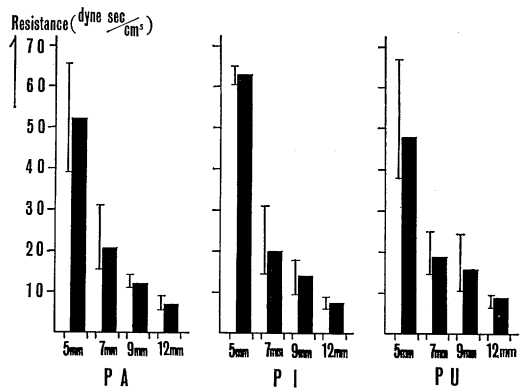

FIGURE 9. Velopharyngeal resistance for plosive production.

IV. Registration of Oronasal Flow during the CV Syllables. A dual phase of oronasal flow rate (that is, gentle slope abruptly followed by a rather steep slope) is generally observed when the plosive syllables are produced with a tube in the velopharynx (Figure 10). This characteristic pattern, however, is not very manifest in the case of the 5 mm tube. Based on comparison of the oronasal flow curve with the nasal flow curve, both synchronized at the moment of voice production, it was assumed that the point of abrupt change in oronasal flow rate indicates the moment of mouth opening. In other words, oronasal flow prior to this point is assumed to be identical to the nasal flow.

V. Additional Experiments. It seems necessary to examine the experimental conditions for artifacts due to the presence of a tube in the velopharynx, that is, the effect of the experimental task on aspects of speech other than velopharyngeal incompetence.

a) The use of superficial anesthesia of the nasopharyngeal mucosa by 4% Xylocain spray did not produce any substantial effect on speech, although hypersalivation, occasionally induced by anesthesia and by insertion of a tube, slightly prevented a normal clear speech. Before each task of reading a short passage or of producing CV syllables, the subjects were therefore asked to spit out any saliva collected in the mouth.

b) A question may arise whether or not any gap may exist between the wall of the tube and the velopharyngeal wall during production of plosive or fricative consonants, thus allowing an additional air leakage through the gap into the nose. In order to examine this possibility, a tube (the bore of which was tightly occluded with a cotton ball) was placed in the velopharynx. It was confirmed that during production of the plosive, no air escaped through the nose, and therefore no gap was assumed to exist around the tube.

Existence of an occluded tube in the velopharynx resulted in a slightly

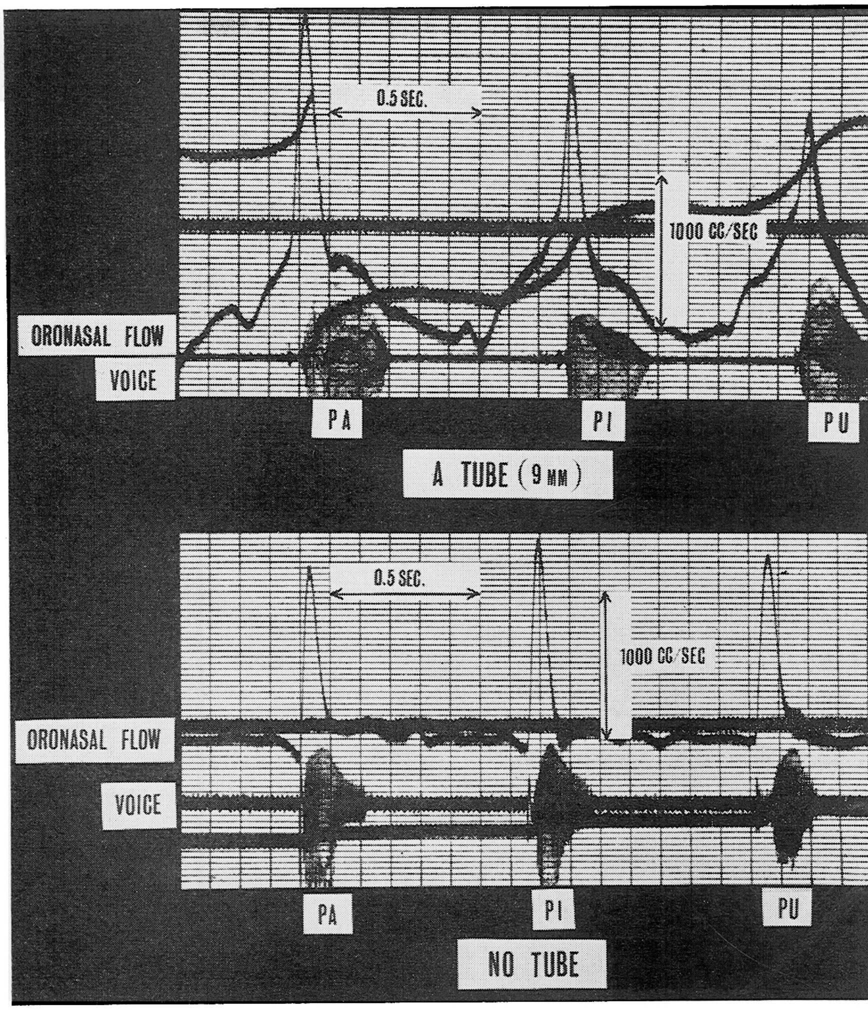

FIGURE 10. Recording of the oronasal flow rate and volume and voice. Note the dual phase of oronasal flow rate in case of 9 mm tube placed in the velopharynx.

deviated speech pattern, which is however almost negligible in terms of nasality and plosive or fricative production as compared with the speech distortion caused by the patent tube. Furthermore, a tube was placed in the velopharynx of a patient whose velopharynx is directly visible through the nasofacial defect. It was observed that the tube was approximated by the velopharyngeal mechanism from all directions, as if by the sphincter.

c) A compensatory movement of articulatory organs may develop in response to the artificial velopharyngeal deficiency. Since the speech pattern becomes perfectly normal after removal of the tube, it can be said that such compensation of articulation, whether real or not, is always temporary, reversible, and therefore entirely different from the faulty habit of articulation which is common in cleft palate. The effect of velopharyngeal incompetence upon speech as described in this paper includes the possible articulatory compensation which is only temporary and reversible.

Discussion

A. Critical Size of Velopharyngeal Opening for Acceptable Speech. It appears generally accepted that some degree of velopharyngeal closure, although perhaps not necessarily complete closure, is required for normal speech, particularly for plosive and fricative consonants. McDonald and Koepp-Baker (*10*) postulated a hypothesis that there is a critical point in the degree of closure of the velopharynx where the characteristic balance or ratio is established between oral and nasal resonance.

For determining a correct indication for speech therapy or pharyngeal flap operation, it is essential to know the exact degree of velopharyngeal closure necessary for acceptable speech. As shown in Figures 3 and 4, the nasality and the degree of articulatory defect increase gradually as the velopharyngeal dimension increases. There is no definite point of velopharyngeal dimension where the speech suddenly changes from normal to abnormal. To determine the critical point of velopharyngeal closure for acceptable speech is therefore directly connected with what we judge acceptable speech. If the point 2 in our scale (slightly nasal) is taken as still acceptable, our experimental results indicate that a diameter of 5 mm is the critical size of velopharyngeal dimension for acceptable speech. At 7 mm in diameter, the speech is unacceptable and unquestionably nasal and the articulation score for plosives and fricatives is 30%.

Although we failed to find the original report, Schmidt is said to have reported (*12*) that 6 mm is the critical size of velopharyngeal closure necessary for speech. Since we were unable to locate the original report, no comparison can be made between his results and ours. Through analyses of still x-ray films and cleft palate speech, Subtelny, Koepp-Baker and Subtelny (*16*) reported that cleft palate speakers with openings of from 3.5 to 7 mm had associated speech that generally was defined as very defective, both in quality and intelligibility.

Based on the findings obtained by the use of cineradiography, tomography, and sound spectrograph, Björk (*1*) reported that the velopharyngeal dimension in lateral projection must be at least about 4 mm in a normal adult for speech to be assessed as nasalized. Using a velopharyngeal model (*20*) and normal subjects (*17, 18*), Warren made investigations of pressure-flow patterns which he considered useful for measuring velopharyngeal orifice area during phonation. Based on the finding that the velopharyngeal impedance to air flow is high for sphincter sizes between 0 and 20 mm^2 and low above this range, and that oropharyngeal pressure diminishes rapidly when the orifice measures above 10 to 20 mm^2, he surmised that 10 to 20 mm^2 [3] is a critical size of the velopharynx. In the study of velopharyngeal orifice size in cleft palate speech (*19*), he further stated that the critical range of closure separating velopharyngeal adequacy from inadequacy may begin at approximately 20 mm^2.

As previously mentioned, it is our opinion that the critical degree of velopharyngeal opening should be determined on the basis of judgment of speech which involves the velopharyngeal incompetence alone. Cleft palate speech is usually associated with more than one factor: velopharyngeal inadequacy, faulty habits of articulation, tongue inflexibility, malocclusion, et cetera. In many patients who have had pharyngeal flap surgery, speech continues to be distorted or unacceptable chiefly because of the faulty habits of articulation, even though the velopharyngeal closure demonstrates improvement to a sufficient degree. Because of the factors involved in speech other than velopharyngeal incompetence, we feel that the cleft palate patient is not the most suitable type of subject with whom to determine the critical size of velopharyngeal orifice.

Laying aside the discussion of the methods by which the critical size of velopharyngeal orifice is to be determined, it is of interest to note that the value of 5 mm in diameter (area, 19.6 mm^2) obtained in this study coincides fairly well with the finding by Subtelny, Koepp-Baker and Subtelny (*16*) and with the value of 20 mm^2 as previously reported by Björk (*1*) and Warren (*17, 18, 19, 20*). In this study, the critical size of 5 mm in diameter was obtained using adults with normal speech patterns. From other research reports, it is evident that the degree of nasality depends not only on the size of the velopharynx but also on several other factors, such as mouth opening and the position of the tongue. If a speaker demonstrates a faulty habit of articulation, such as insufficient mouth opening or a rather high position of the tongue, the critical value of velopharyngeal orifice size may be different, perhaps less than 5 mm.

If we use an aerodynamic technique for testing velopharyngeal function (whether velopharyngeal closure is above or below the critical point), it is more convenient to express the critical value of velopharyngeal sphincter in dyne sec/cm^5 than in mm or mm^2. The results indicate that the critical value for velopharyngeal orifice, 5 mm in diameter, corresponds to 50 dyne sec/cm^5 when the nasal flow is 140 cc/sec. It should be noted, however, that the cross sectional area is not linearly related to aerodynamic resistance because of the turbulent air flow. Aerodynamic resistance for a given stricture increases with the rise of flow rate.

[3] The diameter of a circle of 20 mm^2 in area is a little over 5 mm (5.04 mm).

It is beyond the scope of this paper to describe the results of our aerodynamic studies for speakers with cleft palate (*6, 8*), but it is of great interest to note that all of the acceptable cleft palate speakers in our studies had a velopharyngeal resistance above 50 dyne sec/cm^5. From those studies and from this study indications are that a cleft palate patient whose velopharyngeal resistance is below 50 dyne sec/cm^5 can never be an acceptable speaker, while one with the resistance above 50 dyne sec/cm^5 was not always an acceptable speaker. We infer that velopharyngeal resistance above 50 dyne sec/cm^5 is a condition necessary but not sufficient for acceptable speech.

B. Phonetic Characteristics of Velopharyngeal Incompetence. The speech produced by the subject with a tube in the velopharynx was characterized by rather low frequency of error of /s/ and /z/ and a high frequency of the substitution of /m/ for /b/.

In the study of number and type of articulation errors in cleft palate, McWilliams (*11*) reported that the /s/ and /z/ sounds were most frequently and most consistently in error. Subtelny and Subtelny (*15*) also mentioned that the incidence of fricative errors was significantly greater than the incidence of plosive errors. These findings are all in contrast with the present findings that the fricatives are less sensitive to velopharyngeal incompetence than the plosives. In another series of experiments concerned with acquired hypernasality such as that resulting from surgery (*7*), it was revealed that fricatives are likewise less frequently misarticulated than plosives.

Judging from the present results and from those for acquired hypernasality, it appears that high incidence of fricative error in cleft palate speech would be due to a great extent to the other factors than velopharyngeal insufficiency. Fricatives are generally among the last sounds mastered by children, and lisping is one of the commonest articulatory defects, whatever the etiology, in our speech clinic. It is evident that the correct pronunciation of /s/ requires most accurate and delicate adjustment of the articulatory organs, and is therefore most easily influenced by dysfunction. A slight velopharyngeal insufficiency at the stage of speech learning may create a faulty habit of /s/ articulation. Fricatives are plastic and resistant to velopharyngeal insufficiency, once they are correctly learned. In this sense, it should be added that the critical value for acceptable speech which we obtained for those who had mastered articulation may not hold for those subjects who are just developing speech. The critical degree of velopharyngeal resistance before acquisition of correct articulation may be a little higher than that after it is mastered.

In short, it can be said that high incidence of fricative errors in cleft palate speech is closely related to the difficulties with which fricatives are learned and is further related to adequacy of velopharyngeal function while speech is being learned. The present results also suggest that surgical accomplishment of sufficient velopharyngeal function and subsequent speech therapy before a faulty habit of articulation is fixed is of critical importance, particularly for the correct production of fricatives. Moreover, it should be emphasized that fricative errors cannot be corrected by mere accomplishment of velopharyngeal closure.

The voiced labial plosive /b/ was most frequently substituted by /m/. This distinct and consistent error of /b/ into /m/ is considered to be due to the fact that /b/ and /m/ are almost identical in articulatory mechanism except for the requirement of velopharyngeal closure during /b/. In the presence of velopharyngeal insufficiency, those plosive consonants which have their nasal counterparts— /b/ for /m/, /d/ for /n/, /g/ for /ŋ/—are easily substituted for by their nasal counterparts, while voiceless consonants, /p/, /t/, /k/, are not so easily substituted for by any other consonant, if the place and manner of articulation are otherwise correct. Compared with cleft palate speech, the speech of artificial velopharyngeal incompetence gives us an impression of severe nasality, unproportionally so with regard to articulatory errors or intelligibility. Stated in other terms, it appears that pure velopharyngeal deficiency would chiefly be a problem of resonance and of plosive, and to a less degree of fricative, production.

In conclusion, the present results indicated the importance of factors in addition to velopharyngeal incompetence in cleft palate speech. Details of the results of aerodynamic features of cleft palate speech will be described elsewhere (*6*).

Summary

The purpose of this study was to determine the critical degree of velopharyngeal closure necessary for acceptable speech and to learn the characteristic pattern of speech defect related to velopharyngeal incompetence alone. In order to create artificial velopharyngeal insufficiency, polyvinyl tubes of varying diameters were placed in the velopharynx of subjects with normal speech. Analyses were made of the speech sample in terms of articulatory errors and nasality, velopharyngeal resistance, and aerodynamic pattern in relation to the size of velopharyngeal opening.

On the basis of the obtained data, the following conclusions were drawn. a) With the other factors related to speech being preserved as normal, the critical size of velopharyngeal closure necessary for acceptable speech was about 5 mm in diameter or 50 dyne sec/cm^5. b) The speech defects due to velopharyngeal incompetence alone were characterized by high incidence of substitution of /m/ for /b/ and relatively low frequency of error of fricatives. No articulatory faulty habits such as glottal stops, pharyngeal fricatives, or omissions, which are common in cleft palate subjects, were found in the speech of a

normal individual who had a tube in the velopharynx. The present results suggested that the factors other than velopharyngeal incompetence are also greatly responsible for defective speech in cleft palate individuals, particularly for speech errors involving fricatives.

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