Development of a Test for Velopharyngeal Competence During Speech

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As reviewed by Spriestersbach (*15*), the evidence now available suggests very strongly that difficulty in developing and maintaining appropriate intraoral air pressures during speech is the primary problem in speech physiology underlying speech deficits of the cleft palate population. It has been well established also that tests involving blowing activities which are designed to assess the cleft speaker's ability to generate intraoral air pressure have predictive value in determining whether or not that speaker has a significant velopharyngeal closure problem.

As has been reviewed elsewhere by Hardy (*2*), the two types of such tests which have been reported most frequently utilize a wet spirometer or pressure manometer. For the former test, a subject is asked to perform a vital capacity effort through the mouth with his nostrils occluded and another with his nostrils open. For the latter test, the subject is asked to blow with maximum effort into a pressure measuring device, once with the nostrils occluded and once with the nostrils open. In both tests, if the measure for nostrils open is less than for nostrils occluded, it is assumed that air leaked through an open velopharyngeal port during the nostrils-open effort. The two measures obtained during such tests are combined into a fraction with the nostrils-open measure divided by the nostrils-occluded measure. The extent to which the resulting value[1] is less than one is used as an index of velopharyngeal incompetence.

Hardy (*2*) has pointed out certain reasons why these tests, which are obtained during a blowing activity, may not be as precise as would be desirable in predicting significant velopharyngeal incompetency of the cleft speaker. One of the reasons which he suggests for this imprecision is that there may be dissimilarity in the function of the velopharyngeal port during blowing as compared to during speech production. McWilliams and

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[1] The values which are obtained from these tests have been referred to as *ratios,* i.e., oral manometer ratios or spirometer ratios. Since these tests are derived from a process of division and yield a quotient (which is usually expressed in decimals), the value obtained might more appropriately be referred to as a *quotient.* The term *fraction* does not seem appropriate since the quotient may be greater than a value of one.

Bradley (*10*) have recently reviewed a number of articles which suggest that palatal activity during blowing efforts may be quite different from during speech production in speakers with cleft palates. Moreover, they made observations from x-ray video tapes which indicated that there were systematic differences in velopharyngeal closure between blowing and speech in 37 patients with surgically repaired clefts.

There may be a number of reasons why the velopharyngeal mechanism performs differently during speech than during blowing activities. For example, Paillard (*12*), Shelton (*13*), Hixon and Hardy (*6*), Smith (*14*), and others have suggested that the central nervous system may regulate muscular patterns associated with speech production in a manner dissimilar to that with which it regulates other types of muscle movement patterns. Those authors also imply that the movement patterns of the articulators may differ during speech compared to nonspeech activities of the same structures.

In view of presently available information, the desirability of employing x-ray techniques to assess velopharyngeal incompetence seems unquestionable. However, the following points need consideration in this regard: first, for financial and technological reasons, it is probably impractical to assume that all diagnosticians who have the responsibility for managing cleft problems will have at their disposal cinefluorographic techniques. Second, with the increased efficacy in diagnosis of the cleft problem which has resulted from the use of the blowing tests described above, the conclusion must not be reached that these tests do not have value. If used with appropriate caution, they undoubtedly will continue to contribute significantly to the identification of velopharyngeal incompetency. Third, lateral head x-ray films show only a two-dimensional view of the velopharyngeal port. Consequently, some palatopharyngeal ports which appear to be closed when viewed by that technique may be open laterally. Therefore, a combination of observations probably will continue to be requisite for a definitive diagnosis of velopharyngeal problems, and the availability of a relatively inexpensive diagnostic test for assessing velopharyngeal competence during speech production which could be used in conjunction with other diagnostic techniques would be highly desirable. This article reports initial steps toward development of such a test.

Hardy (*3*) has reported a preliminary study, the results of which have been verified on a larger sample of neuromuscularly handicapped children (*4*), in which it was found that children with neuromuscular involvement of the speech articulators expire more air per unit of speech (syllable) than do children with normally flexible and mobile articulators. This finding has led to the suggestion that individuals with certain types of physiologically abnormal articulators valve the speech air stream with less efficiency than physiologically normal speakers.

If the velopharyngeal mechanism is incompetent during speech, a greater volume of air may flow through the velopharyngeal port than when the

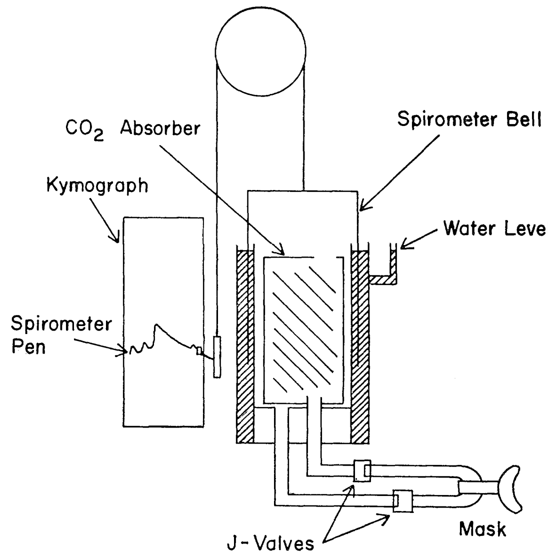

FIGURE 1. A drawing of the respirometer used to measure volume of air expired during speech by subjects of this study.

palate functions normally. By dividing liters per syllable of orally expired air by the liters per syllable of oral and nasal air expired, a quotient of less than that found for normal speakers might prove to be a reasonable indication of velopharyngeal opening during speech. Moreover, the cost of the instrumentation, as well as the relatively short time required for the procedure and calculations, makes such a technique feasible as a clinical diagnostic procedure.

Before such a measure could be used for clinical purposes, the value of such quotients during speech for physiologically normal speakers must be determined for a variety of speech activities, and the amount of intersubject and intrasubject variability of such quotients needs to be established. Therefore, the purpose of this investigation was to begin exploration of the use of the measure of liters per syllable of expired air to detect significant velopharyngeal malfunction during speech production.

Procedure

Subjects. The subjects for this study were 32 children with normal speech who were from six to 13 years of age.

Equipment. The criterion measures for this study were made with a Collins respirometer[2] (see Figure 1). The apparatus consists of a nine-liter wet spirometer with a pen attached to the bell which writes on a revolving drum. The drum rotates at a constant speed (in this case, 80 mm/sec). A time scale is thereby provided on a continuous paper roll.

[2] Warren E. Collins, Inc., 555 Huntington Avenue, Boston 15, Massachusetts.

As the subject speaks, the expired air which is trapped by the face mask (or mouth mask) is channeled into the spirometer through a carbon dioxide absorber. Inhalation is accomplished through a separate airway from the spirometer bell, which is filled with oxygen before the procedure begins. The two J-valves shown in Figure 1 are one-way valves which channel the airflow in the desired direction. The CO_2 absorber permits the subject to breathe in the apparatus for relatively prolonged periods of time. As the subject speaks or breathes into the apparatus, a graph of his respiratory exchange is made on the paper.

Although resistance to airflow may be an appreciable factor in this type of system, that resistance (which may more accurately be an impedance) is reduced by using the low resistance J-valves. In the case of the respirometer used in this study, the pressure build-up in front of the expiratory valve and in the chamber of the spirometer did not exceed 1.5 cm/H_2O of pressure at 250 liters per minute of flow.

An Electro-Voice Model 636 microphone, in conjunction with an Ampex 600 tape recorder, was placed six inches in front of the subject's lips. In addition, another microphone which led to an event marker on the respirometer drum was utilized.

Experimental Conditions. Each subject counted to 10 (to determine liters per syllable during a connected speech activity) and repeated the following consonant-vowel (CV) syllables: /pʌ, tʌ, kʌ, sʌ, tʃʌ/ and /fʌ/. The subjects were instructed to repeat *each* of these activities *three times:* with a face mask (condition A), with a mouth mask only (condition B), and with a mouth mask only and a weight of 150 grams on the spirometer bell (condition C). Condition A gave the total volume of air expired from both the mouth and nose during the speech activities. Condition B gave measures of volume of air expired from the mouth with the air from the nose escaping into the atmosphere. Condition C again gave the volume of flow from the mouth with the nasal flow escaping into the atmosphere, but the weight upon the spirometer bell added to the resistance of the oral air flow created by the instrument system.

Administration. Prior to the experimental procedures, each subject was given sufficient practice and coaching while breathing into the respirometer to insure his optimal performance. When it appeared that the subject was cooperating and that he understood the various tasks, and after a brief rest period, the experimental procedure began.

Before each speech activity, an acoustic signal was introduced into both microphones. This procedure provided both an audible click on the magnetic tape and an event mark on the spirogram.

Each subject was instructed to count to 10 without reference to the speed of utterance and to repeat the CV syllables as rapidly as possible. The subjects were instructed to repeat the syllables at least 25 times on one expiration, and if a subject produced a train of less than 25 syllables, he was asked to repeat that activity.

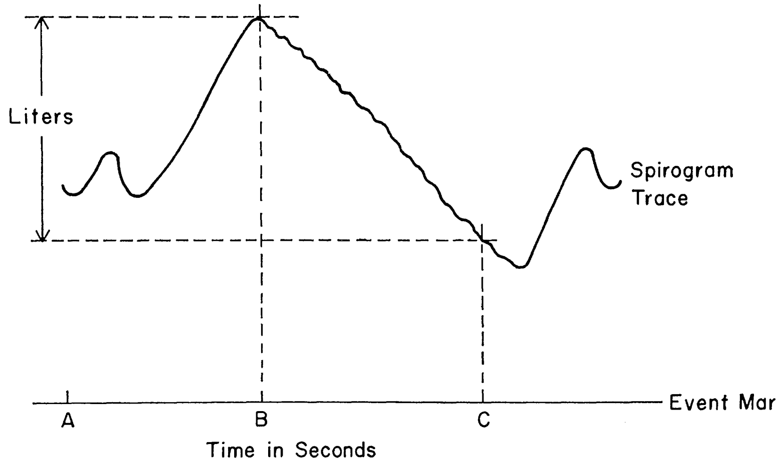

FIGURE 2. Drawing of representative spirogram trace showing an event mark (A) and the points on the trace where speech production began (B) and where the speech activity to be measured ended (C). Volume of expired air was measured in liters.

Vocal intensity was not rigidly controlled, since such control is difficult for children to maintain. However, under the assumption that vocal intensity would be a variable that might affect the amount of air expired during the speech effort, the subjects were required to speak in a 'comfortably loud' voice. The VU meter on the tape recorder was used to monitor the loudness level. If a subject was judged as speaking too softly or too loudly, the speech activity was repeated.

The order of the experimental conditions and the speech activities within each condition were randomized.

MEASUREMENT OF SPIROGRAMS. The tape recordings were played back at one-half (3¾ inches per second) the recording speed (7½ inches per second). By counting the number of syllables of a speech activity from the tape playback, and by measuring the length of tape over which the speech activity was produced from the click, a determination of the time over which the subject produced that speech activity was determined and marked on the spirogram from the event mark mentioned before.

Figure 2 shows a drawing of a representative speech activity as recorded on a spirogram with an illustration of the measurements that were made. Liters of air expired per syllable[3] were determined by dividing the volume of air expired during a given speech activity by the number of syllables in that activity. Such determinations were made over the words *one* through

[3] Computation of the respiratory values required the use of a correction factor applied to the measured volume. This factor, the BTPS correction, converts the measured volume to a volume of air at *body temperature,* at ambient *pressure,* and *saturated* with water. Such conversion is necessitated because the gas volume exhaled by a subject is 37 degrees centigrade, ambient pressure, and saturated with water, while the recorded volume on the spirogram is usually of a lower temperature, but, again, at ambient pressure and saturated with water. A thermometer is provided on the respirometer from which the spirometer temperature may be read for this purpose.

ten during the counting (which entailed 11 syllables) and the first twenty repetitions of each CV syllable.

Two persons were involved in measuring the spirograms. Of spirogram traces for the 2,016 speech acts measured for this study (32 subjects times seven speech acts, each of which was repeated three times within three experimental conditions), 54 were selected at random, and the two individuals repeated independently the entire measurement procedure for those 54 speech activities. Pearson product-moment correlation coefficients calculated to determine the reliability of the two measurers were .99 for the time over which the speech activities were measured on the spirograms and .98 for the criterion measures of liters of air expired per syllable. These high correlation coefficients indicated that the measurements made by the two persons could be pooled to form one body of data.

Since the tape recording procedure described above proved to be extremely time consuming, as the last three subjects were performing the experimental tasks, an investigator marked across the ink trace on the spirogram where a subject began the speech activity and when the end of the speech activity occurred (that is, when the subject had counted to ten, or when the subject had repeated 20 of the CV syllables). Measurements for those subjects were obtained by (a) using those marks as an indication of when the speech activity to be measured began and ended and (b) by the previously described method which utilized the tape recordings.

Results

Values and Intersubject Reliability of Criterion Measures. The mean values (in liters per syllable) for the three repetitions of each speech activity were computed for each subject. Those means were used as the criterion measures for the subjects, and the means and standard deviations of those criterion measures are presented in Table 1.

Analyses were accomplished to determine the significance of differences between the liters per syllable measures for the seven speech activities.

TABLE 1. Means and standard deviations, in liters of air expired per syllable, for 32 normally speaking children in three experimental conditions.

Speech activity	*A. Face mask*		*B. Mouth mask conditions*		*C. Mouth mask with weighted bell*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Counting	.032	.010	.029	.009	.027	.011
Repeating /pʌ/	.039	.017	.037	.015	.038	.018
Repeating /tʌ/	.035	.017	.038	.019	.037	.020
Repeating /kʌ/	.037	.016	.041	.018	.040	.017
Repeating /sʌ/	.056	.018	.059	.019	.058	.019
Repeating /tʃʌ/	.042	.016	.044	.018	.044	.019
Repeating /fʌ/	.052	.018	.053	.019	.053	.020

However, since the quotients derived from these measures are of principle interest in this report, the results of those analyses will not be given in detail. It is sufficient for the present purposes to point out that, for example, during the face mask condition, the subjects expired significantly less air during the counting activity than during repetitions of the CV syllables with the exception of /tʌ/. Also, in general, they expired more air during the productions of syllables containing the continuant consonants than for those containing stop-plosives, including the affricate /tʃ/.

It should be noted that the standard deviations given in Table 1 routinely show relatively low intersubject variation for the liters per syllable measures.

Because of *a priori* assumptions that oral cavity size and rate of syllable repetition might be variables which would be related to the liters per syllable measures, Pearson product-moment correlations were obtained to determine those relationships. These analyses were performed only with the face mask measures. For the former variable, molar width (in centimeters) was measured for each subject, and to the extent that that measure serves as an index of oral cavity size, little or no relationship was found between that variable and the liters per syllable measure. For example, for repetition of the syllable /pʌ/ with the face mask condition, the coefficient was .08. However, there were indications of a moderate relationship between rate of syllable utterance and liters of air expired during speech. (For example, for repetitions of /pʌ/, the obtained r was $-.40$.) As would be predicted, correlation coefficients such as the latter suggested a trend for liters of air expired per syllable to decrease as rate of syllable utterance increases.

Intrasubject Reliability. The intrasubject reliability of the measures for each speech activity within each condition was determined by use of an analysis of variance correlation (r_{kk}) similar to that given by Lindquist (*8*, p. 361).[4]

The correlation coefficients of all criterion measures for the conditions of face mask (A), mouth mask (B), and mouth mask with weighted spirometer bell (C) are given in Table 2. In only one instance is a coefficient below .80 and most are above .90. The coefficients are so homogenous that it is difficult to contend that differences due to type of mask used caused real differences in the reliability of any of the measures. These data suggest also that the mean of three determinations is a relatively good estimate of the true subject scores of each of these measures.

In order to estimate the number of repetitions of a speech activity which are required for the desired stability of criterion measures such as those

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[4] The correlation coefficients (r_{kk}) were obtained by the formula

$$r_{kk} = \frac{ms_S - ms_{AS}}{ms_S + (n/k - 1)ms_{AS}}$$

where n is equal to the number of sets of scores (3), and k is the number of scores (3) for which the reliability of the mean is being obtained.

TABLE 2. Correlation coefficients for the mean of three determinations of all criterion measures (liters of air expired per syllable) for 32 children manifesting normal speech. Reliability coefficients are shown for three experimental conditions.

Speech activity	*A. Face mask*	*B. Mouth mask conditions*	*C. Mouth mask with weighted bell*
Counting	.77	.91	.87
Repeating /pʌ/	.95	.92	.96
Repeating /tʌ/	.95	.96	.97
Repeating /kʌ/	.97	.95	.96
Repeating /sʌ/	.92	.93	.94
Repeating /tʃʌ/	.86	.94	.94
Repeating /fʌ/	.92	.92	.96

used in this study, the value of k in the correlation formula was changed to values of one, two, four and five, and the correlation computations were repeated. These estimated coefficients appear in Table 3 along with the coefficients from Table 2 repeated. Data in that table makes it possible to select the number of repetitions of a given speech activity for which the liters of air expired per syllable of speech are to be measured with assurance of a desired reliability. For example, if .90 is arbitrarily selected as that reliability which is needed, subjects must repeat a train of the syllable /pʌ/ at least twice, and the mean of the liters per syllable measure for those two activities must be used. However, for the syllable /sʌ/, the mean liters per syllable for three trains of syllables must be computed before that level of reliability is reached.

Quotients of Orally Expired Air/Total Air Expired. Table 4 shows the results of dividing the liters of expired air measured per syllable

TABLE 3. Reliability coefficients of means of three repetitions ($k = 3$) for liters of air expired per syllable during seven speech activities by 32 normally speaking children for three experimental conditions (repeated from TABLE 2). Estimated reliability coefficients are also shown for means of one, two, four and five repetitions ($k = 1, 2, 4$, and 5 respectively).

Speech activity	*Face mask*					*Mouth mask*					*Mouth mask with weighted bell*				
	k value					*k value*					*k value*				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Counting	.53	.69	.77	.81	.85	.77	.87	.91	.93	.94	.69	.82	.87	.90	.92
Repeating /pʌ/	.86	.90	.95	.96	.97	.80	.89	.92	.94	.95	.90	.95	.96	.97	.98
Repeating /tʌ/	.87	.91	.95	.96	.97	.90	.95	.96	.97	.98	.91	.95	.97	.98	.98
Repeating /kʌ/	.87	.94	.97	.98	.99	.85	.92	.95	.96	.97	.88	.94	.96	.97	.97
Repeating /sʌ/	.79	.88	.92	.94	.95	.82	.90	.93	.95	.96	.83	.91	.94	.95	.96
Repeating /tʃʌ/	.67	.80	.86	.89	.91	.83	.91	.94	.95	.96	.85	.92	.94	.96	.96
Repeating /fʌ/	.80	.89	.92	.94	.95	.79	.88	.92	.94	.95	.89	.94	.96	.97	.97

TABLE 4. Mean quotients and standard deviations of quotients which were obtained by dividing the liters of air expired per syllable during the two face mask conditions by the liters of air expired per syllable during the face mask conditions. Results of t-tests to test the differences of the mean quotients between conditions B and A (mouth mask/face mask) and conditions C and A (mouth mask with weighted bell/face mask) for the seven speech activities performed by 32 children with normal speech. All *t*s were not significant.

Speech activity	*Quotients Conditions*	*Mean*	*S. D.*	*t*
Counting	B/A	.939	0.259	1.094
	C/A	.869	0.245	
Repeating /pʌ/	B/A	.997	0.258	0.016
	C/A	.998	0.237	
Repeating /tʌ/	B/A	1.147	0.409	0.351
	C/A	1.114	0.323	
Repeating /kʌ/	B/A	1.145	0.282	0.301
	C/A	1.123	0.294	
Repeating /sʌ/	B/A	1.062	0.200	0.074
	C/A	1.058	0.223	
Repeating /tʃʌ/	B/A	1.094	0.325	0.316
	C/A	1.070	0.270	
Repeating /fʌ/	B/A	1.045	0.263	0.132
	C/A	1.036	0.268	

during both mouth mask conditions (B and C) by liters expired per syllable during the face mask condition (A). The mean quotients approach the value of one. Under the assumption that these normally speaking subjects were achieving necessary velopharyngeal closure during the seven speech activities, this finding would be expected.

As explained earlier, the condition of the mouth mask with a weight upon the spirometer bell was utilized under the assumption that there would be added resistance to oral air flow during that condition. Consequently, if there were instances of velopharyngeal opening during the speech activities, that added resistance should have a) caused more air to flow through the nasal port than during the mouth mask only condition and b) resulted in small quotients. The quotients obtained using the criterion measures for the mouth mask with weighted spirometer bell condition as the dividend (C/A) show a general trend of being lower than when the criterion measure for the mouth mask only condition was used (B/A). However, the differences between those two quotients for each of the seven speech activities are not statistically significant.

Further inspection of Table 4 shows that the standard deviations of the quotients are relatively small. This high intersubject reliability is somewhat surprising since the obtained quotients were derived from two measures, each of which has some inherent instability.

Difference in Quotients for Speech Activities. In order to determine if the quotients for the speech activities were significantly different, a

TABLE 5a. Differences between mean quotients for liters per syllable of air expired during conditions B and A (mouth mask/face mask) for seven speech activities with an indication of which of those differences* are significantly different at the 1% level (D = .129).

	/pʌ/	/tʌ/	/kʌ/	/sʌ/	/tʃʌ/	/fʌ/
Counting	.058	.208*	.206*	.123	.155*	.106
/pʌ/		.105	.148*	.065	.097	.048
/tʌ/			.002	.085	.053	.102
/kʌ/				.083	.051	.100
/sʌ/					.032	.017
/tʃʌ/						.049

treatment by subjects analysis of variance was performed for each type of quotient, using the speech activities as treatments and the subjects' quotients as subject scores. The two resulting *F*s were both significant at the 1% level of confidence. Critical differences between the treatment means were .129 and .144 for the B/A and C/A quotients, respectively. Table 5 shows the differences between the treatment means in matrices that indicate significant differences between the treatment means.

By comparing Table 5a with Table 4, it can be seen that, for the B/A quotients, the mean quotient for the counting activity was significantly lower than the mean quotients obtained during repetition of /tʌ, kʌ/ and /tʃʌ/. Also, the mean quotient for /pʌ/ was significantly lower than for /kʌ/. These results would suggest that more air escaped through the subjects' nostrils during the face mask condition while they were counting than escaped while they repeated /tʌ, kʌ/ and /tʃʌ/. Similarly, more air escaped nasally during their productions of /pʌ/ than of /kʌ/.

Likewise, comparison of Table 5b with Table 4 shows that the differences between the means of the quotients for the C/A quotients were significantly lower for the counting activity than for repetitions of all syllables with the exception of /pʌ/. These results indicate that more air escaped through the nostrils of the subjects during the mouth mask condition with weighted

TABLE 5b. Differences between mean quotients for liters per syllable of air expired during conditions C and A (mouth mask with weighted spirometer bell/face mask) for seven speech activities with an indication of which of those differences* are significantly different at the 1% level (D = .144).

	/pʌ/	/tʌ/	/kʌ/	/sʌ/	/tʃʌ/	/fʌ/
Counting	.129	.245*	.254*	.189*	.201*	.167*
/pʌ/		.116	.125	.060	.072	.038
/tʌ/			.009	.056	.044	.078
/kʌ/				.029	.053	.087
/sʌ/					.012	.022
/tʃʌ/						.034

spirometer bell for the counting activity than during repetition of the CV syllables, except /pʌ/.

COMPARISON OF THE TWO TYPES OF SPIROGRAM MEASUREMENT. To warrant the elimination of the tape recordings from the measurement procedure, the marks which were made upon the spirograms for the last three subjects (as they spoke into the respirometer) would have had to correspond closely with the time measurements which were made from the tape recordings. Correlation coefficients between the time measurements for the two procedures were quite high. For example, for the counting activity, the two types of measurements correlated .99. This very high correlation indicates that the marking of the spirograms by the investigator, as the subject speaks, results in a measure which is highly comparable to that obtained with the use of the more elaborate tape recording procedure. It follows, therefore, that the tape recording procedure can be eliminated in favor of the much less laborious method.

Discussion

The results of this investigation suggest that it is quite feasible to develop a test of velopharyngeal competence during speech production which utilizes measures of the volumes of air expired per syllable of speech. In addition, the results tend to corroborate a lingua-velar relationship; that is, for those speech utterances where the tongue is positioned relatively low in the oral cavity, velopharyngeal closure may be less firm than for those utterances where the tongue remains relatively high.

RESPIROMETER QUOTIENTS AS A TEST OF VELOPHARYNGEAL COMPETENCE. Perhaps the finding which best indicates the efficacy of the use of respirometer quotients in discriminating between speech activities which do and do not entail velopharyngeal closure is that for both types of quotients (B/A and C/A), there was a significant difference between those quotients for counting and certain syllable repetitions. During counting, intermittent palatal closure can be assumed since, as spoken by most speakers, there are five nasal sounds, /n/, in the words *one* through *ten*. It would therefore be expected that a) more air would flow through the nose during the counting activity than during repetitions of the syllables used in this study and b) the respirometer quotients for the counting activity would be smaller than for the syllable repetitions. Since the presently reported quotients for counting were significantly lower than for certain syllable trains, it would appear that the respirometer quotients discriminate very well between speech activities where minimal palatal opening exists.

The finding that the B/A respirometer quotients were significantly greater for the /tʌ/, /kʌ/, and /tʃʌ/ syllables than for the counting activity and that they were not significantly greater for the continuant consonant syllables than for counting may give even more information regarding velopharyngeal activity associated with different types of speech activities. It might be concluded that the increased time over which intraoral air pressure was impounded for the continuant consonant permitted more time for a small amount of air to escape into the nasal cavity. However, during the production of the syllables containing the stop-plosive consonants /t/ and /k/, and the affricate /tʃ/, where the time over which intraoral air pressure is impounded is relatively short, there was less opportunity for such leakage.

For the C/A respirometer quotients obtained (for which the oral airflow might have been impeded due to the weight on the spirometer bell), the quotients for the syllable repetitions were all significantly greater, with the exception of /pʌ/, than for the counting activity. (Discussion of this exception is given later.) Therefore, even though the data in Table 4 did not yield significant differences between the two types of quotients, the added resistance to the oral air flow evidently brought about a greater disparity between the quotients for specific speech activities.

These findings strongly indicate that the respirometer quotients can differentiate between speech activities during which there are varying degrees of velopharyngeal closure. In lieu of future corroborating research, they even suggest that the respirometer quotients may be capable of differentiating between extent of velopharyngeal closure to a more finite degree than can motion picture x-ray techniques which show only a lateral view of the closure mechanism.

Respirometer Quotients as a Clinical Tool. Since the intersubject variability of both the liters per syllable measures and quotients are relatively small, it seems a reasonable assumption that subjects with velopharyngeal incompetence could be differentiated from subjects with competence via this technique. The standard deviations of the quotients derived from total air expired and only orally expired air routinely approximated one-fourth the mean value of the group data. Had those standard deviations been one-half the mean value, or larger, it could not be predicted with great confidence that abnormal functioning of a palate could be detected by such a technique even after extensive future research.

For example, with respect to the quotients derived for repetitions of the syllable /sʌ/ for the C/A quotient, the standard deviation of .223 suggests that 15.87 % of children with normal speech will have a respirometer quotient of lower than .835. If two standard deviations below the mean were arbitrarily selected as a 'cut-off point' below which diagnosticians would specify that a speaker may have palatal incompetence, or at least has velopharyngeal function which deserves further scrutiny, the quotient would still have to be only .612, and the present data suggest that only 2.28 % of normally speaking children will have a respirometer quotient lower than that value. To complete the example, if the standard deviation of that quotient had been .446, two standard deviations below the mean would require a respirometer quotient of .166 before the diagnostician could, with confidence, predict that only 2.28% of normally speaking children will have a quotient so small.[5]

The intrasubject reliability is also high enough to encourage further development of this type of test. For example, if the analysis of the data had shown that subjects must repeat a train of syllables more than four or five times before the mean of the liters per syllable measures reached a desired level of stability, the time required to measure the spirograms and compute the quotients would undoubtedly reduce the practicality of the technique. However, requiring a subject to repeat a number of speech activities only three times each and using the mean of the three measures for each activity as a criterion measure is a feasible clinical procedure. The present results suggest that such a mean has sufficient stability for all the speech activities used in this study.

The present results are even more encouraging, since the administration procedures utilized were designed purposefully to be practical in a clinical situation with one exception (using the tape recordings to specify the time over which speech was produced by the subject and transferring that time scale to the spirograms). The present results suggest that that aspect of the procedure was unnecessary, since comparable data were obtained by an investigator simply marking the beginning and ending of the speech utterances on the spirograms as the subjects spoke into the respirometer.

Therefore, even with consideration of the complexities of the aerodynamics of the speech process, this respirometer procedure may eventually prove to be a relatively useful and practical diagnostic tool. The children being tested evidently will not have to conform to difficult criteria. That is, they can perform the syllable repetitions under the instructions of 'say ____ as fast as you can,' and they are not required to maintain rigorously a given level of vocal intensity in order to provide stable respirometer quotients.

For further development of the respirometer quotients as a diagnostic tool for velopharyngeal incompetence, the next logical step probably would be to replicate the above described procedures, or similar procedures, with a group of children for whom velopharyngeal incompetence has been confirmed. Additional research efforts might be directed toward expanding the present group of data to corroborate the present results. It might also prove profitable to direct such future work toward detection of specific speech activities which will most efficiently discriminate between normally and abnormally functioning palates. For example, the present results suggest that respirometer quotients for the syllable /sʌ/ may prove to be more discriminating than for repetition of the syllable /pʌ/ since the former

[5] These percentages of normally speaking subjects who should fall below given respirometer quotients are based upon a normal distribution. Frequency distributions for the respirometer quotients appeared to be essentially normally distributed with a slight positive skew (toward higher quotients) for a few of the speech activities. If these measures are so skewed in the normal population, even fewer normal subjects will fall below the quotients mentioned than the normal curve distribution would predict.

quotient seems to have less intersubject variation than the latter. However, for a second example, the respirometer quotients for the counting activity were, as discussed above, significantly smaller than for repetitions of certain syllables. A speech sample which is designed to require such intermittent palatal closure might prove to be a better type of speech activity for deriving a respirometer quotient which discriminates between normal and abnormal velopharyngeal function, since rapid opening and closing palatal movements may be a problem for some cleft speakers.

Eventually, it may be possible to develop this technique to the point that it will assist materially in the most difficult diagnosis of the cleft group, that is, the so-called borderline cases of velopharyngeal incompetence. For example, assume that a respirometer quotient derived from the C/A condition as described for the repeated syllable /sʌ/ at maximum rate of repetition and at a "comfortable level" of vocal intensity (or an especially designed connected speech sample) is the most discriminating of the respirometer quotients. Also assume that after even more research children with cleft palate who, by other diagnostic techniques, were suspected of having borderline closure problems showed successively smaller respirometer quotients from one through ten trains of the syllable /sʌ/. A conclusion might then be possible that this procedure could detect palates which, due to minimum functional integrity, fatigue during prolonged speech activity.

It is to be emphasized that this technique is not being presently recommended as a clinical tool. The efficacy of its use must await a substantial amount of future research such as that described above. Moreover, and perhaps more importantly, it is not being suggested that this technique eventually can be developed into a diagnostic tool which can be used alone to assess adequacy of palatal functioning during speech. Due to the complexities of the velopharyngeal mechanism and of speech physiology, it appears more probable that the respirometer quotients, even after they are refined by future research, should be used as only one of a number of observations in the assessment of velopharyngeal competence.

While it is not within the scope of this paper to review his work, Paesani (*11*) has completed a study in which some of the needed research discussed above was accomplished. Briefly, his results show that respirometer quotients do discriminate between children with velopharyngeal competence and those with incompetence, and that study makes the eventual use of this technique seem even more feasible for the diagnostician. Any investigator interested in further development of the respirometer quotients as a diagnostic tool should review Paesani's research in detail.

Confirmation of a Lingua-Velar Relationship. Harrington (*5*) has suggested the possibility that anatomical relationships of the tongue, pharyngeal, and palatal musculatures may be such that velopharyngeal closure is facilitated during speech acts where the tongue is relatively high in the oral cavity. He cites Ackermann (*1*) who suggested earlier that such a relationship was due to the palatal-glossal connection by the palatoglossus muscles, but he indicates that 'it . . . would be difficult to account for this relationship in terms of the action of any particular muscle.' Lintz and Sherman (*9*) indicated that their data seemed to confirm such a relationship, since vowels for which the tongue could be assumed to be relatively high in the oral cavity were perceived as being more nasal than were vowels for which the tongue positioning could be assumed to be relatively low.

The present results also seem to confirm such a relationship, even though this research was not designed to contribute to knowledge of that phenomena. The tongue positioning for repetition of /pʌ/ may be assumed to be relatively low in the oral cavity since it is probably dictated by the positioning for the production of /ʌ/. For the other syllables used in this study, the tongue can be assumed to be in an elevated position during a portion of each syllable for the consonant production, with the highest degree of elevation of the posterior portion of the tongue being associated with /k/. There is also justification (*7*, *16*) for believing that the tongue height for the vowel /ʌ/ during the syllable repetitions in this study was influenced by the articulatory positioning for the associated consonant. Note that for the respirometer quotients for the B/A conditions, the quotients for /pʌ/ were significantly lower than for /kʌ/. Also, if the syllables are rank ordered by the lowest to the highest quotients obtained during both the B/A and C/A conditions (Table 4) the following order is seen: a) the consonant /pʌ/, b) the continuants, c) the affricate, /tʃʌ/, and d) the two stop-plosives /tʌ/ and /kʌ/. The most plausible explanation of why these air flow data for the repetition of the consonant /pʌ/ consistently indicate proportionately more nasal flow than for the other types of consonants, particularly the other two stop-plosive consonants included in this study, is that the lower tongue position for that syllable contributed to some breaking of the velopharyngeal seal during that activity.

Summary

Thirty-two children with normal speech between the ages of six and 13 years served as subjects. The subjects produced seven different speech activities while they were expiring into a respirometer with a face mask, a mouth mask, and a mouth mask with a weight upon the bell of the respirometer. The criterion measures (liters of air expired per syllable of speech) were used to yield quotients of air expired from the mouth only divided by the air expired from both the mouth and nose for both weighted and unweighted measurements of oral air flow.

Statistical analyses of these data indicate that the following tentative conclusions are warranted: a) The respirometer quotients are capable of differentiating between speech activities during which there are minimal differences in degrees of velopharyngeal closure. b) Perusal of the intra- and intersubject reliability data of the measures, the differences in the respirometer quotients between types of speech activities, and the relatively short time required for the procedures suggest that this technique

may be practical as a clinical tool in assessment of velopharyngeal closure problems. c) There seems to be justification for earlier suggestions that there is a lingua-velar relationship. That is, velopharyngeal closure may be less firm during speech activities where the tongue position is relatively low in the oral cavity compared to those for which it is relatively high.

Suggestions for further research to develop the use of respirometer quotients as a diagnostic tool are offered.

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