Respiratory Volumes in Normal and Cleft Palate Speech

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Recent studies have indicated that the relationship between velopharyngeal opening and speech performance is not linear (*1*, *6*, *7*). Apparently, intelligibility and voice quality are influenced by a number of factors besides the adequacy of palatal closure. These may include nasal airway resistance, degree and duration of oral port constriction, lingual, glottal, and pharyngeal conpensatory adjustments as well as auditory acuity (*2, 3, 6, 7, 8, 9, 11, 12*).

There is also evidence that speech effort may be modified by cleft palate (*9*). Studies in this laboratory, using an analog model of the upper speech mechanism, have suggested that respiratory effort may influence intelligibility in individuals with palatal incompetency.

The purpose of the present study was to provide more definitive information on respiratory effort during speech. Specifically, the question considered was how velopharyngeal incompetency influences respiratory effort. The volume of air released from the lungs during phonation of test sounds was used as the measure of respiratory effort.

Method

The cleft palate group consisted of 18 subjects; 10 males, and 8 females. The normal control group was composed of 10 males, and 6 females. All subjects were over 16 years of age and spoke with a general southern dialect. Both groups were matched according to age.

The test sounds that each subject was asked to produce consisted of a series of words containing voiced and voiceless plosives and fricatives placed within the carrier phrase "Say ____ again". These words were *bat*, *pat*, *zat*, *sat*, *dat*, *tat*, *vat*, and *fat*. The instrumentation employed for measuring respiratory volumes during phonation is illustrated diagrammatically in Figure 1. It consisted of a Fleisch heated pneumotachograph with a Statham PM197 differential pressure transducer, Sanborn

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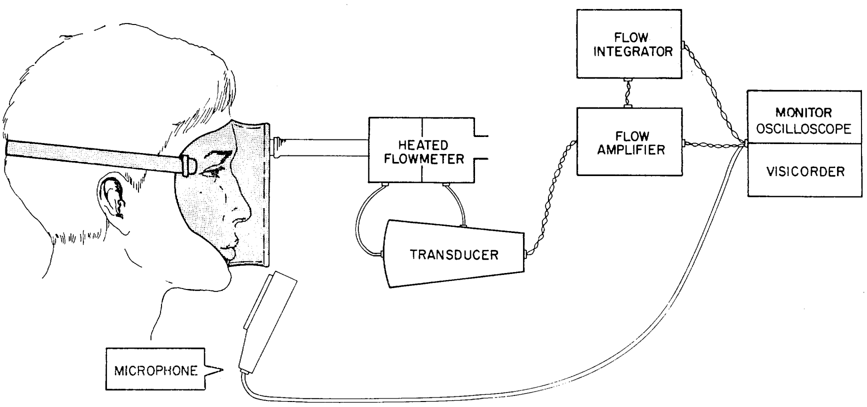

FIGURE 1. Diagrammatic representation of equipment used to record test sounds, airflow rates and respiratory volumes.

350-3700 volume integrater, Honeywell 131-2C carrier amplifier, Sonotone CM-30 microphone, and a Honeywell 1508 visicorder.

A well-adapted rubber face mask (Voit) covering the nose and mouth was used to direct airflow to the pneumotachograph. Calibration of air volume was accomplished with a specially designed volumeter and a rotameter (Fischer and Porter) was used to calibrate the volume rate of airflow.

The uni-directional microphone was placed six inches from the face mask to pick up sounds radiating from the pneumotachograph during phonation. Although face masks have been reported to restrict mandibular movement and, therefore, somewhat distort speech production (*4*), identical conditions were maintained throughout the study so that comparisons between individuals could be made reliably.

Volume Measurements. A method has been presented previously for establishing boundaries for speech elements according to physiologic and acoustic events (*13*). Although this investigation is concerned primarily with consonant production, the vowel sound had to be included so that measurements could be made for plosives. This was necessary because the release phase of plosive consonants merges with the vowel which follows.

Figure 2 illustrates the technique used to measure respiratory volumes for plosive sounds produced by a normal speaker. The points used for measurement do not necessarily represent the precise beginning of a consonant or the termination of a vowel. Rather they should be considered discernible patterns which are at the approximate beginning or end of the CV paradigm. Three features were used to locate these points. The first corresponds to the silent interval on the sound record (arrow 1). This interval begins at the termination of the *ay* in *Say* and includes the period in which air is impounded for the consonant. The second, and

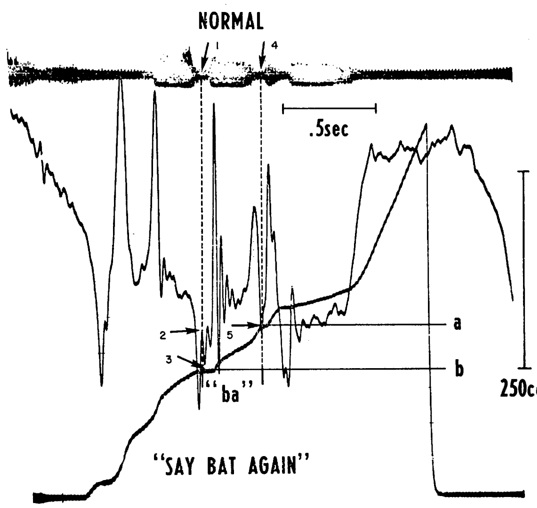

FIGURE 2. Typical sound, airflow rate and volume records of a voiced plosive by a normal speaker. Arrows indicate the points utilized for determining the beginning (b) and the end (a) of the volume measurement as described in the text.

most important feature (arrow 2), is identified as the initial peak on the airflow record, immediately following a downward deflection occurring within the silent interval. The downward deflection represents the cessation of air prior to the consonant sound. The third factor (arrow 3) is a plateau on the volume record indicating no airflow during the time air is impounded within the oral cavity.

The records differ somewhat for cleft palate subjects with velopharyngeal incompetency because of nasal emission of air during speech (Figure 3). The first peak on the airflow record (arrow 2) occurring during the silent interval (arrow 1) is less obvious because of nasal air leakage. In addition, the volume record (arrow 3) presents a slope rather than a plateau indicating nasal emission during the interval in which air should be impounded within the oral cavity. It is difficult to determine with certainty whether this point of measurement corresponds precisely with the initial point in the normal and, therefore, the possibility of some measurement error must be considered. However, if there is an error, it would result in an underestimation of the air volume for individuals with palatal incompetency.

The points for measurement of fricative sounds are considerably easier to identify (Figures 4 and 5). Two distinct peaks occur on the airflow record during production of the fricative sound. The first peak (arrow 2) is used to mark the beginning of the measurement. A dip between peaks apparently results from a decrease in volume rate of airflow during the interval of maximal oral port constriction. In the cleft subjects with palatal incompetency (Figure 5) the two peaks tend to merge because of in-

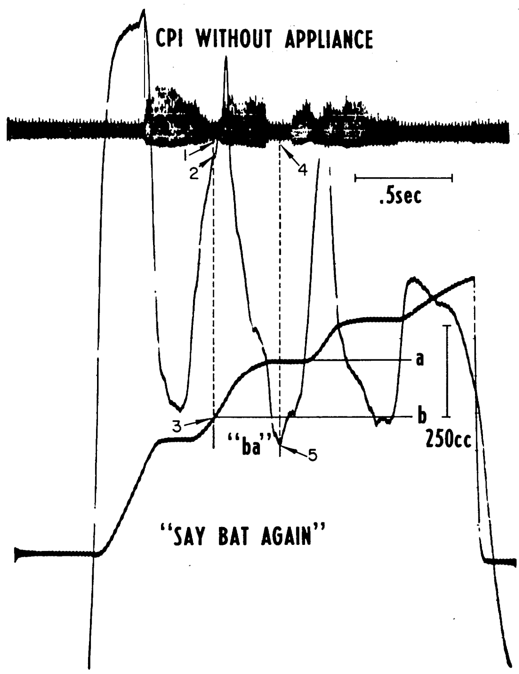

FIGURE 3. Typical voiced plosive produced by a speaker with velopharyngeal incompetency. The small peaks noted in the normal are masked to a great extent by nasal leakage. Similarly, the volume record shows a slope rather than a plateau. It is possible that volume is underestimated for these sounds because of measurement difficulty.

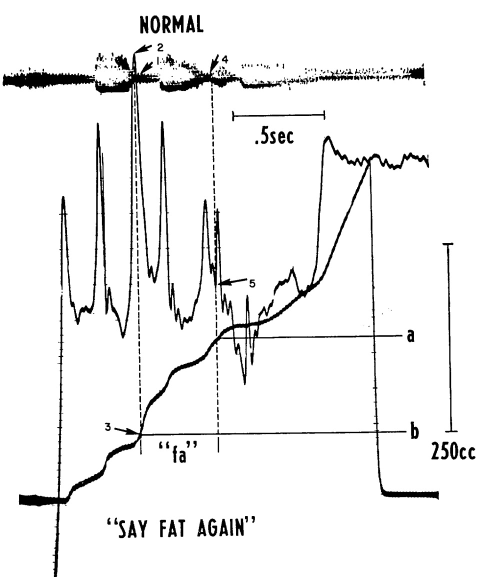

FIGURE 4. A typical normal voiceless fricative demonstrates two airflow peaks. The initial peak is used for measurement.

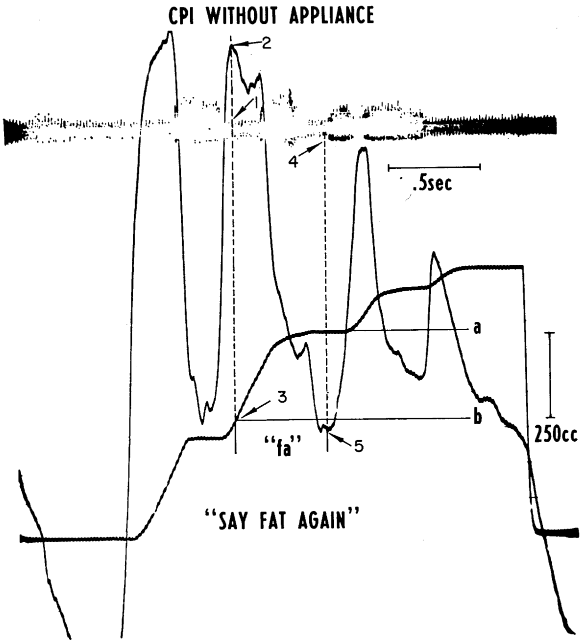

FIGURE 5. Merging of peaks occurs in fricatives produced by speakers with velopharyngeal incompetency.

creased nasal air leakage during the period of maximal oral constriction. However, the points are easily recognized for these sounds.

Termination of the vowel sound was considered to coincide with the downward deflection of the flow-rate record (arrow 5) which occurs prior to the release of air for the consonant *t* (Figures 2, 3, 4, 5). This is further identified by a break in the sound record (arrow 4). The volume record indicates a plateau in the normal subjects and change in slope in the cleft palate records. The volume of air released between these two measurements (a and b) is considered the respiratory volume for the test sound.

The cleft palate group consisted of prosthetically treated patients, all of whom demonstrated inadequate velopharyngeal closure when their appliances were removed. Eight subjects achieved adequate closure with their appliances. In order to differentiate between those subjects who obtained adequate closure and those who did not, velopharyngeal orifice size was measured during consonant production using an analog computer system (Honeywell). This instrumentation, described in detail previously (*8, 10*), calculates velopharyngeal orifice size from the respiratory parameters of orifice differential pressure and nasal airflow.

An orifice size greater than 0.2 cm^2 during plosive consonant production was considered inadequate, and an opening less than 0.2 cm^2 was considered adequate. Justification for selecting this dimension for differentiating competency of closure is based on a series of respiratory studies of normal and cleft palate speech (*7, 8, 9, 10*). Briefly, these studies demonstrated that whenever the velopharyngeal opening is greater than 0.2 cm^2 intraoral pressure and nasal emission of air are influenced more strongly by nasal airway resistance and degree and duration of oral port constriction than by the amount of opening of the velopharyngeal mechanism.

An additional requirement for this study was that the speakers had to produce the test sounds intelligibly. That is, speakers who omitted or distorted test sounds so as to make them unintelligible were not used. Judgments pertaining to intelligibility were made by a speech pathologist prior to and during the study.

Results

The data for the normal (N), cleft palate inadequate (CPI) and cleft palate adequate closure (CPA) groups are presented in Tables 1, 2, and 3. It should be noted that the ratio of males to females is identical in each group. This was considered advisable because a recent normative study (*13*) revealed that fricative sounds differ in respiratory volume according to sex. Also, only 16 subjects were included in the CPI group because of measurement difficulties in 2 subjects.

An analysis of variance disclosed significant differences in respiratory volumes according to adequacy of closure (Table 4). Comparison of volumes of each consonant type demonstrates that there are statistically significant differences between the normal group and the cleft group with inadequate closure. No statistically significant differences are observed between the normal and the cleft palate adequate closure groups

TABLE 1. Respiratory volumes for normals (cc).

subject	*sex*	*VP*	$\bar{V}P$	*VF*	$\bar{V}F$
SB	M	47	105	71	93
HC	M	42	87	45	88
DC	M	61	101	85	121
BG	M	54	74	60	94
CG	M	48	78	55	66
BG	M	75	104	85	99
JJ	M	37	73	65	122
JH	M	59	127	126	161
JH	M	94	132	140	159
JM	M	55	107	87	103
BB	F	35	77	60	75
BC	F	47	80	49	68
EE	F	17	62	23	54
CL	F	54	96	69	93
CM	F	52	98	60	83
JP	F	44	117	58	88
Mean		51.3	94.9	71.1	97.9
SD		17.1	20.3	29.1	30.2

TABLE 2. Respiratory volumes (cc) for cleft palate inadequate closure group (without appliances).

subject	*sex*	*VP*	$\bar{V}P$	*VF*	$\bar{V}F$
AC	M	30	103	163	303
VE	M	184	226	237	376
BJ	M	55	77	47	79
PP	M	155	213	164	189
WW	M	18	68	80	149
CG	M	123	160	159	169
PF	M	109	197	119	169
GG	M	51	122	95	212
SH	M	115	129	150	216
DH	M	148	163	165	179
NE	F	28	93	53	109
AO'D	F	98	193	132	253
EP	F	128	169	139	208
AS	F	144	235	183	277
LS	F	90	124	85	64
MB	F	92	130	118	151
Mean		98.0	150.1	130.6	193.9
SD		49.9	52.6	50.3	81.3

TABLE 3. Respiratory volumes for cleft palate adequate closure group (cc).

subject	*sex*	*VP*	$\bar{V}P$	*VF*	$\bar{V}F$
GC	M	107	130	127	141
PF	M	35	78	78	106
GG	M	64	106	76	147
SH	M	113	147	131	219
DJ	M	74	110	101	118
MB	F	38	118	99	130
BH	F	58	75	77	76
EP	F	35	63	56	53
Mean		65.5	103.4	93.1	123.8
SD		31.0	29.2	26.3	50.1

although the volumes are consistently higher for the latter. Differences between the two cleft palate groups are noted only for voiceless consonant sounds.

Figures 6 and 7 reveal that voiceless consonants are characterized by higher air volumes than their voiced cognates, and this relationship is observed for every palate group. This indicates that the effectiveness of palatal closure does not alter the need for greater respiratory effort for voiceless sound production. This finding is also demonstrated in Figures 8, 9, and 10, which compare patterns of airflow rates and respiratory volumes for a representative voiced-voiceless cognate pair in each group. It

TABLE 4. P-values for comparisons between palate groups.

	normal & CPA	*normal & CPI*	*CPI & CPA*
VP	N.S.*	.003	N.S.
VF	N.S.	.001	N.S.
$\bar{V}$P	N.S.	.001	.02
$\bar{V}$F	N.S.	.0004	.03

* .05 level of significance used.

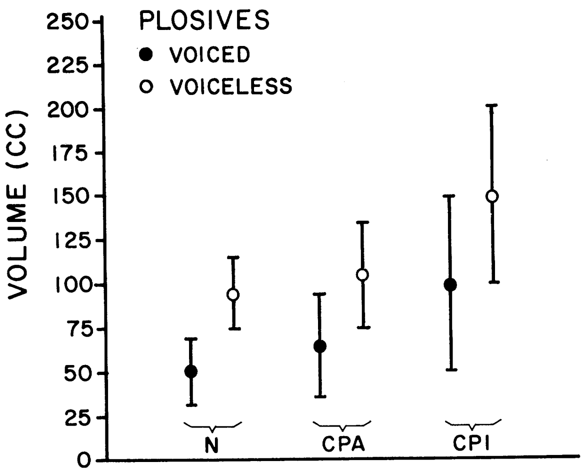

FIGURE 6. Comparison of voiced and voiceless plosive consonants for each group. Voiceless sounds require more volume than their voiced counterparts.

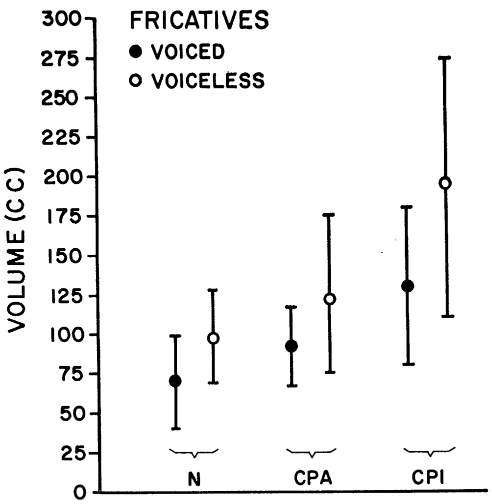

FIGURE 7. Comparison of voiced and voiceless fricatives. Differences in volume are noted among voiced and voiceless consonants. The highest volumes for both consonant types are seen in the CPI group.

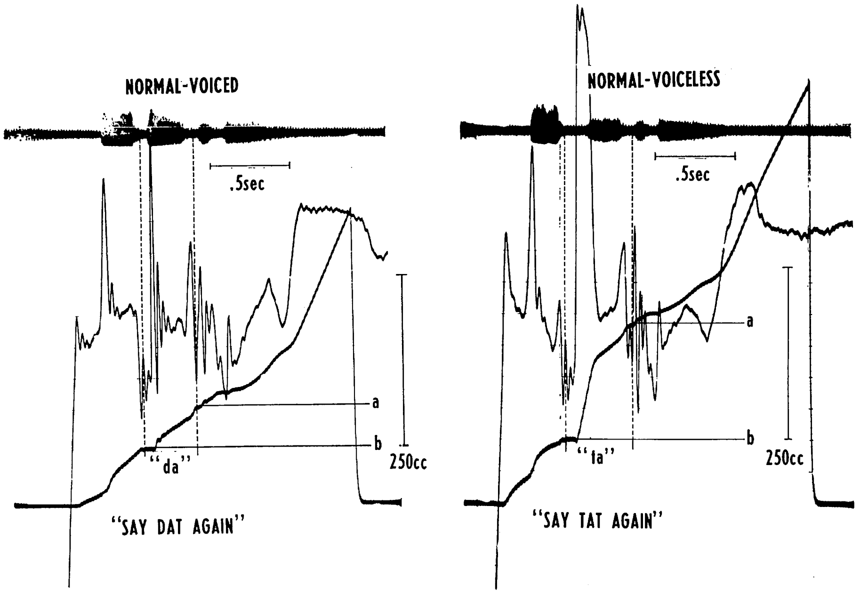

FIGURE 8. Comparison of airflow rates and volumes in a representative normal voiced-voiceless consonant pair. Peak airflow rate is higher and of longer duration for the voiceless sound.

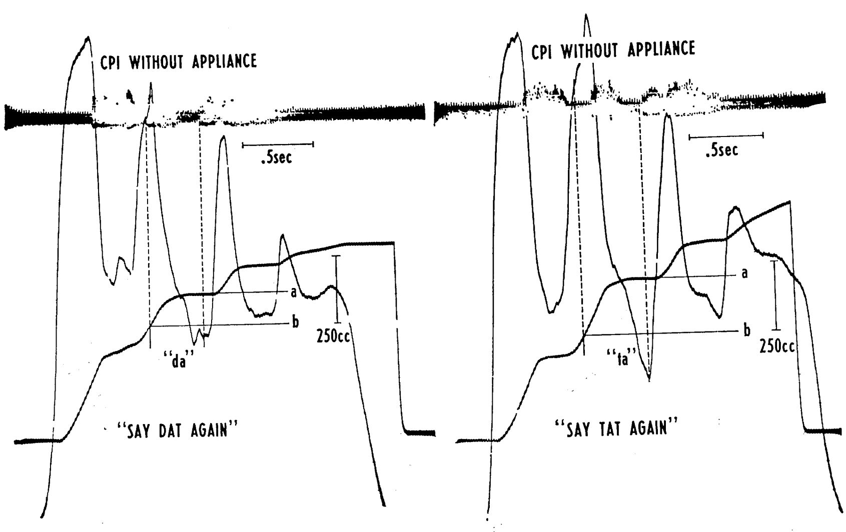

FIGURE 9. Comparison of airflow rate and volume patterns in a representative subject with velopharyngeal incompetency.

is obvious that the peak rate of airflow is higher for voiceless sounds. The highest rates of airflow are observed in the CPI group and the lowest in the normal group.

The flow rate records also reveal that palatal incompetency (Figure 9)

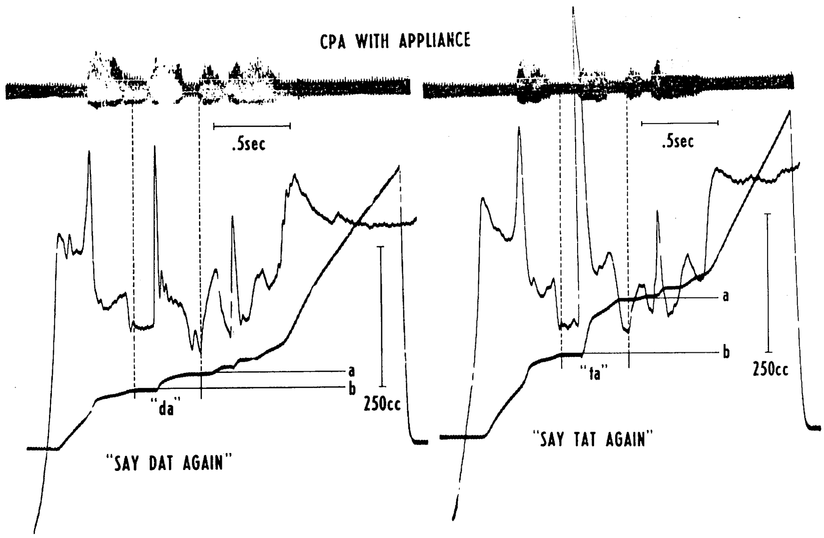

FIGURE 10. Typical records of a cleft palate subject with velopharyngeal competency achieved with a prosthetic speech appliance. The airflow and volume patterns are similar to the normal subjects.

masks the short, numerous peaks which occur during plosive production in the normals (Figure 8). This blending of peaks apparently represents the inability of the velopharyngeal mechanism to discretely control airflow direction. When palatal incompetency is corrected (Figure 10), the airflow patterns revert to a more normal appearance.

Discussion

The data clearly reveal that individuals with palatal incompetency exert greater respiratory effort during speech. Subjects with inadequate closure produced volumes approximately twice those of the normals.

There are two factors which determine respiratory volumes for speech: airflow rate and the interval of time taken for the production of the utterance (*13*). Recent studies indicate that both of these parameters are increased by cleft palate (*4*, *5*, *11*). Perusal of the present records indicates that peak airflow rates are highest in the CPI group and lowest in the normals. This finding has also been observed by others (*5*). Apparently, individuals with velopharyngeal incompetency attempt to raise intraoral pressure by increasing airflow rate during consonant production.

Similarly, there is evidence that prolongation of the interval for consonant production is also increased in cleft palate speakers (*11*). Warren and Mackler studied cleft palate individuals with intelligible speech and found that the interval of oral port constriction (which is an index of duration of consonant production) is increased. The investigators suggested that this is an attempt to improve consonant perception. Indeed, they demonstrated that cleft palate speakers with adequate closure utilize this mechanism to a greater extent than those with inadequate closure. The authors described the phenomenon as a compensatory mechanism utilized by those capable of benefiting most from it, namely, those with adequate closure in which nasal emission would not be a concurrent problem.

Although it is reasonable to conclude that differences in volumes observed among the three groups result from differences in airflow rates and utterance times, the criterion for subject selection must be re-emphasized. The present study only included speakers who were intelligible in spite of their incompetency. These findings do not apply to individuals who omit or distort consonant sounds to the extent that they are unintelligible.

The implications of these data are of interest, however, because of a probable relationship between respiratory effort and speech performance. For example, in the presence of palatal incompetency, the use of larger volumes of air for consonant production presumably increases nasal emission. However, the relationship between nasal emission, voice quality, and sound intelligibility is complex and determined to an extent by the magnitude of nasal airway resistance (*9*). Warren, Duany, and Fischer reported that nasal airway resistance is generally higher in individuals with cleft palate (*12*). This means that certain cleft palate speakers can compensate somewhat for palatal inadequacy by increasing respiratory effort since high nasal resistance raises intraoral pressure. However, nasal turbulence also occurs when airway resistance is high (*14*). Thus, an individual with nasal obstructions could conceivably produce undesirable turbulent noises and lessen intelligibility with greater respiratory effort. On the other hand, with a nasal cavity clear of obstructions it is possible to consider that less turbulence and noise would result from increased nasal emission.

Similarly, factors such as deviant tongue-palate contacts, which tend to increase oral cavity impedance, may have a detrimental effect on speakers using large respiratory volumes. Good oral port function could presumably result in better utilization of increased air volume.

The proposed relationships between respiratory effort and speech performance must still be considered speculative at this preliminary stage of study and no definitive conclusions should be drawn. However, the suggestion is that voice quality and intelligibility may be modified by changes in respiratory effort. Future investigations in this laboratory will explore this possibility.

Summary

Respiratory volumes used in the production of voiced and voiceless test sounds in carrier phrases were measured in 16 normal and 18 cleft palate subjects. The cleft palate group consisted of prosthetically treated patients, all of whom exhibited incompetent closure when appliances were

removed. Eight of the cleft palate subjects achieved competent closure when appliances were in place. The results reveal that respiratory effort is significantly greater in individuals with velopharyngeal incompetency and this apparently results from higher rates of airflow and prolonged intervals of utterance production. The findings also suggest that speech performance may be influenced by respiratory effort.

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References

1. Brandt, Sara, and H. L. Morris, The linearity of the relationship between articulation errors and velopharyngeal incompetence. *Cleft Palate J., 2,* 176–183, 1965.
2. Brooks, Alta R., R. L. Shelton, and K. A. Youngstrom, Compensatory tongue-palate-posterior pharyngeal wall relationships in cleft palate. *J. speech hearing Dis., 30,* 166–173, 1965.
3. Brooks, Alta R., R. L. Shelton, and K. A. Youngstrom, Tongue-palate contact in persons with palate defects. *J. speech hearing Dis., 31,* 14–25, 1966.
4. Lubker, J. F., and K. L. Moll, Simultaneous oral-nasal airflow measurements and cinefluorographic observations during speech production. *Cleft Palate J., 3,* 257–272, 1965.
5. Quigley, L. F., Jr., R. C. Webster, R. J. Coffey, R. E. Kelchehan, and H. P. Grant, Velocity and volume measurements of nasal and oral airflow in normal and cleft palate speech, utilizing warm-wire flow meter and two channel recorder *J. dent. Res., 42,* 1520–1527, 1963.
6. Subtelny, Joanne D., and J. Daniel Subtelny, Intelligibility and associated physiological factors of cleft palate speakers. *J. speech hearing Res., 2,* 354–360, 1959.
7. Warren, D. W., Velopharyngeal orifice size and upper pharyngeal pressure-flow patterns in normal speech. *Plastic reconstr. Surg., 33,* 148–162, 1964.
8. Warren, D. W., Velopharyngeal orifice size and upper pharyngeal pressure-flow patterns in cleft palate speech: a preliminary study. *Plastic reconstr. Surg., 34,* 15–26, 1964.
9. Warren, D. W., and W. E. Ryon, Oral port constriction, nasal resistance, and respiratory aspects of cleft palate speech: an analog study. *Cleft Palate J., 4,* 38–46, 1967.
10. Warren, D. W., Nasal emission of air and velopharyngeal closure. *Cleft Palate J., 4,* 148–156, 1967.
11. Warren, D. W., and S. B. Mackler, Duration of oral port constriction in normal and cleft palate speech. *J. speech hearing Res., 11,* 391–401, 1968.
12. Warren, D. W., L. F. Duany, and N. D. Fischer, Nasal pathway resistance in normal and cleft lip and/or palate subjects. *Cleft Palate J.*, 6, 134–140, 1969.
13. Warren, D. W., and M. T. Wood, Respiratory volumes in normal speech: a possible reason for pressure differences among voiced and voiceless consonants. *J. acoust. soc. Amer., 45,* 466–469, 1969.
14. Williams, R. W., Nasal airflow turbulence in normal and cleft lip and/or palate subjects. Unpublished Masters thesis, University of North Carolina, 1968.