Oral Port Constriction, Nasal Resistance, and Respiratory Aspects of Cleft Palate Speech: An Analog Study

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Recent studies of 'cleft palate speech' have indicated that measures of velopharyngeal function alone are not adequate to account for the articulatory errors which are observed (*2*, *3*, *5*, *10*). These studies suggest that the role of oral and nasal structures should be investigated, since compensatory mechanisms may be responsible for consonant deficits. It is not possible, however, with present technology to explore these complex structures in sufficient detail in the human. In this study, therefore, the effects of the oral and nasal structures on pressure and airflow associated with consonant production were investigated, using a simple mechanical model instead. The rationale for using an analog of the upper speech mechanism was presented in an earlier report (*10*). Briefly, justification is based on the assumption that simple hydraulic laws apply to the respiratory aspects of speech.

Method

The apparatus (see Figure 1) has been described previously (*7–10*). A polyethylene catheter is used to transmit pressure within the oropharynx to a differential pressure transducer. Flow rate is measured by a pneumotachograph attached to the model nose. The air source for these experiments is provided by a respiratory pump which produced airflow in the form of half sine waves.

A four-channel magnetic tape recorder is used to record the pressure-flow data which are later replayed into a dual-channel cathode ray oscillograph recording camera. Calibration of the pneumotachograph is accomplished with a rotameter and pressure is calibrated against a water manometer.

To simulate varying amounts of velopharyngeal opening in the experi-

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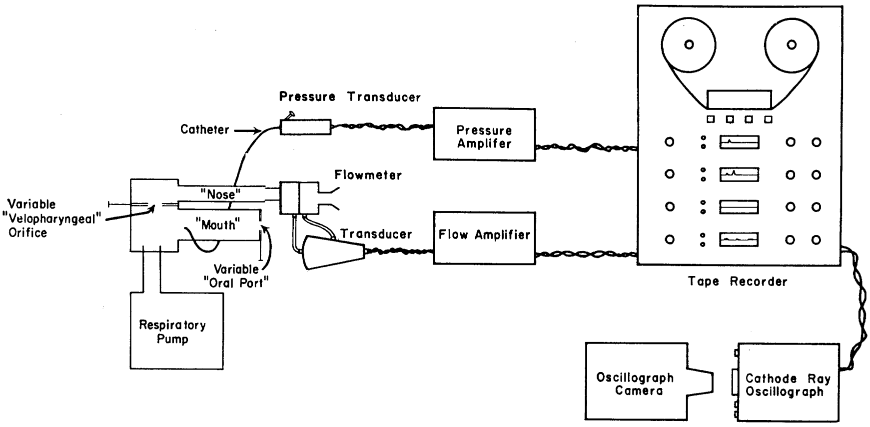

FIGURE 1. Diagrammatic representation of the analog and recording apparatus.

ment, the velopharyngeal orifice was varied in .05 cm^2 increments from 0 to 1.0 cm^2. Respiratory airflow rate was varied from .05 to 0.8 liters per second.

The oral port of the model was kept closed when simulating plosive sounds and was varied in size between 0 and 0.5 cm^2 for fricatives. Oral port size represents the degree of oral constriction resulting from placement of the tongue against the teeth, palate, alveolar ridge, or lips during fricative sound production.

The effect of nasal obstruction was simulated by corks which were inserted into the model nose, producing resistances of 2.5, 5.2 and 9.8 cm H_2O/liter/sec at flow rates of .2 liters per second. These values, taken from unpublished data, seem fairly representative of what can be expected in a cleft palate population.

Results

During the production of plosive consonants, and in the presence of velopharyngeal incompetence, pressure within the oral cavity is equal to the pressure drop across the velopharyngeal orifice and the nose. The pressure drop across the velopharyngeal orifice is equal to $k_1(\dot{V}/A)^2$ where k_1 is a constant related to the discharge coefficient and the density of air, $\dot{V}$ is the nasal airflow rate, and A is the area of the velopharyngeal orifice (*10*). The values of the constants are presented in the Appendix. The quadratic relationship between pressure and airflow indicates that airflow across the velopharyngeal orifice is turbulent. Airflow through the nose, however, may be turbulent or laminar and turbulent depending upon the volume rate of nasal airflow. The laminar aspect of nasal flow can be described by the Poiseuille equation $P = k_2\dot{V}$ and the turbulent portion by the quadratic relationship $P = k_3\dot{V}^2$. Figure 2 illustrates that at low rates

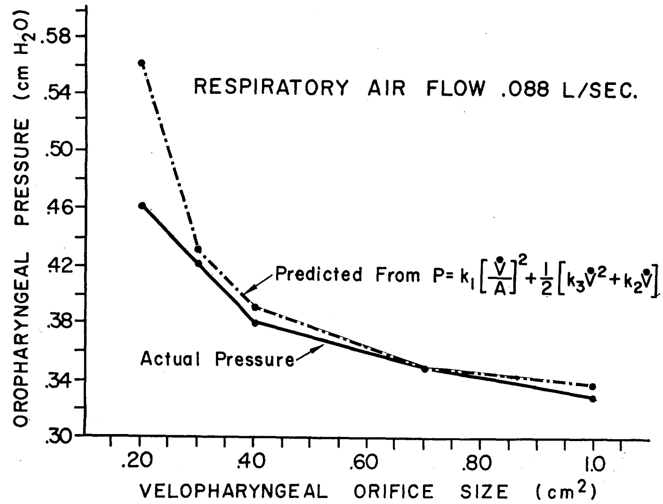

FIGURE 2. The relationship between oral pressure and velopharyngeal orifice size during plosive consonant production at a low volume rate of airflow. The orifice pressure drop decreases as degree of velopharyngeal incompetency increases, thereby decreasing the slope of the curve.

TABLE 1. Comparison of recorded pressures with those predicted from the equations 1 and 2, which are presented in the Appendix.

	velopharyngeal orifice area, cm²	*nasal airflow, L/sec*	*measured pressure, cm H_2O*	*predicted pressure cm H_2O*
				values predicted from equation 1
oral port, closed (simulated plosives)	1.0	.25	2.5	2.7
	.7	.25	2.7	2.7
	.5	.25	3.0	2.8
	.2	.25	4.0	4.3
				values predicted from equation 2
oral port, .10 cm² (simulated fricatives)	1.0	.142	.8	.7
	.7	.136	.9	.7
	.5	.133	.9	.7
	.2	.133	1.3	1.2
				values predicted from equation 2
oral port, .50 cm²	1.0	.043	.09	.12
	.7	.035	.10	.10
	.5	.042	.10	.12
	.2	.038	.10	.14

of nasal airflow oral pressure can be computed from the equation

$$P = k_1(\dot{V}/A)^2 + 1/2[k_2\dot{V} + k_3\dot{V}^2],$$

referred to as Equation 2 in Table 1.

As seen in Figure 3, at higher rates of nasal emission, turbulence is apparently present across the nose as well as across the velopharyngeal orifice as the data describe the relationship $P = k_1(\dot{V}/A)^2 + k_3\dot{V}^2$, referred to as Equation 1 in Table 1.

THE EFFECT OF SIMULATED FRICATIVES ON ORAL PRESSURE AND NASAL EMISSION OF AIR. Figure 4 illustrates that a slight opening of the oral

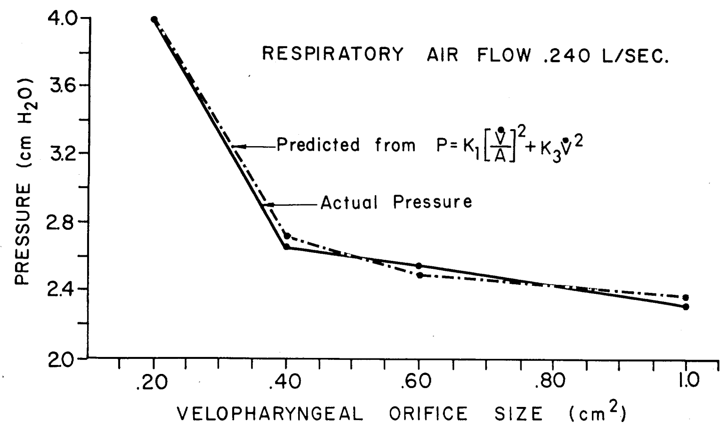

FIGURE 3. At higher rates of respiratory airflow, turbulence occurs across the velopharyngeal orifice and nose. This is indicated by the quadratic relationship between pressure and airflow.

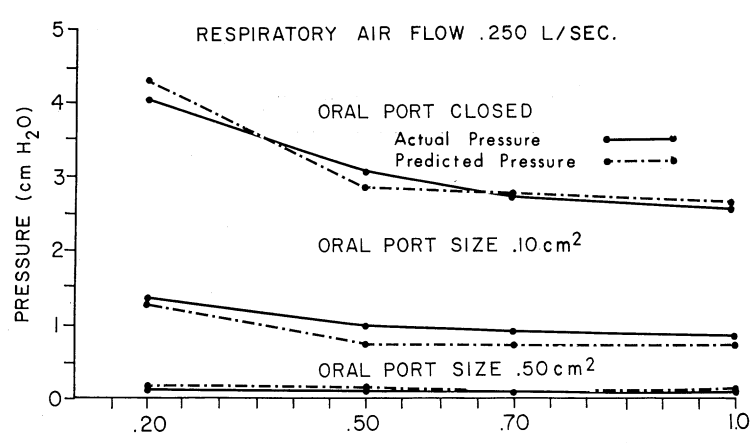

FIGURE 4. Opening the oral port for fricative sounds has a greater effect on oral pressure than increasing the size of the velopharyngeal orifice. Note that the equation can be used for predicting pressure associated with fricative sounds as well as plosives.

port for fricative sounds significantly reduces oral pressure, when compared to plosives, at identical respiratory airflow rates. Therefore, if fricatives are to be produced with pressures similar to those for plosives, respiratory effort must be increased. It should be noted that, in the range of velopharyngeal incompetency (openings of sizes larger than .20 cm²), the velopharyngeal sphincter appears to have no noticeable effect on pressure.

Table 1 demonstrates that the empirical equations relating oral pressure to orifice size and nasal airflow are applicable to fricative sounds as well as to plosives.

Nasal emission of air is also greatly influenced by the degree of oral port constriction. In this instance, shown in Figure 5, it is apparent that by opening the oral port 0.10 cm², nasal emission was decreased by approximately 45% when respiratory effort was kept constant. However, it is reasonable to assume that respiratory effort is usually increased when fricatives are produced, thereby increasing nasal emission of air. Again, it is seen in Figure 6 that the degree of velopharyngeal incompetency does not appreciably affect nasal emission of air.

THE EFFECT OF NASAL RESISTANCE ON ORAL PRESSURE. When the velopharyngeal sphincter is completely closed, the resistance of the nose has no effect on oral pressure. As the amount of opening increases, the portion of oral pressure due to nasal resistance becomes greater than that due to velopharyngeal orifice size (Table 2). Figure 7 demonstrates that, even in the slight-to-moderate range of incompetence (0.2 to 0.4 cm²), nasal resistance can account for as much as 30% to 90% of oral pressure amplitude.

Discussion

The inference can be made that, in the presence of velopharyngeal incompetency, pressure within the oral cavity during speech is determined

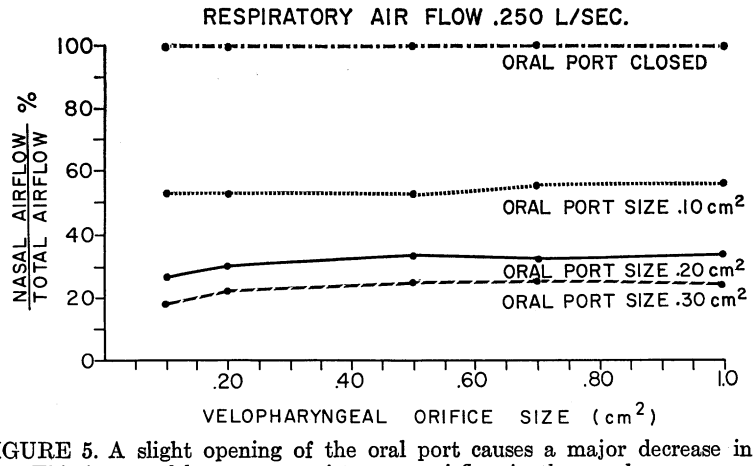

FIGURE 5. A slight opening of the oral port causes a major decrease in nasal airflow. This is caused by greater resistance to airflow in the nasal passages.

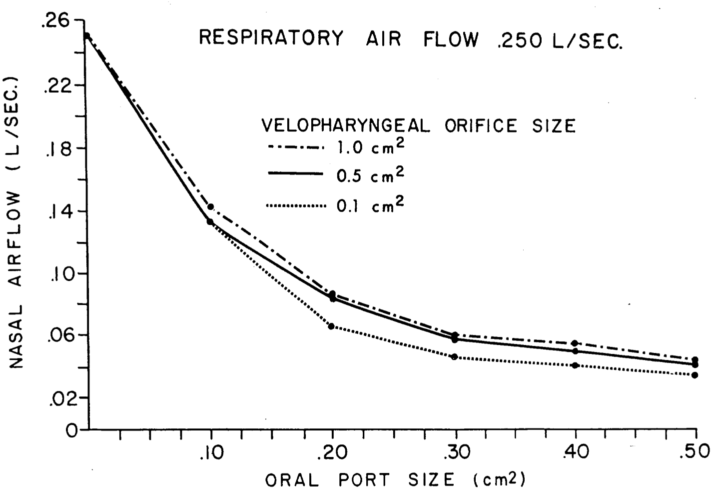

FIGURE 6. Increased amounts of velopharyngeal opening have little effect on nasal emission of air.

TABLE 2. Effects of nasal resistance on oral pressure amplitude. Three nasal resistances were used, all at a flowrate of .2 L/sec.

size of openings, cm^2		*pressure readings, cm H_2O*		
velopharyngeal orifice	*oral port*	*nasal component*	*velopharyngeal orifice component*	*oral pressure*
nasal resistance 1: 2.5 cm H_2O/L/sec				
.05	0.0	.56	8.42	8.98
.05	0.05	.23	2.80	3.03
.20	0.0	.51	.74	1.25
.20	0.05	.36	.45	.81
.40	0.0	.48	.31	.79
.40	0.05	.37	.19	.56
nasal resistance 2: 5.2 cm H_2O/L/sec				
.05	0.0	1.01	9.1	10.11
.05	0.05	.49	3.25	3.74
.20	0.0	1.06	.73	1.79
.20	0.05	.75	.54	1.29
.40	0.0	1.10	.26	1.36
.40	0.05	.82	.16	.98
nasal resistance 3: 9.8 cm H_2O/L/sec				
.05	0.0	1.95	8.55	10.50
.05	0.05	.61	3.04	3.65
.20	0.0	2.19	.68	2.87
.20	0.05	.93	.37	1.30
.40	C.0	2.13	.27	2.40
.40	0.05	.94	.12	1.06

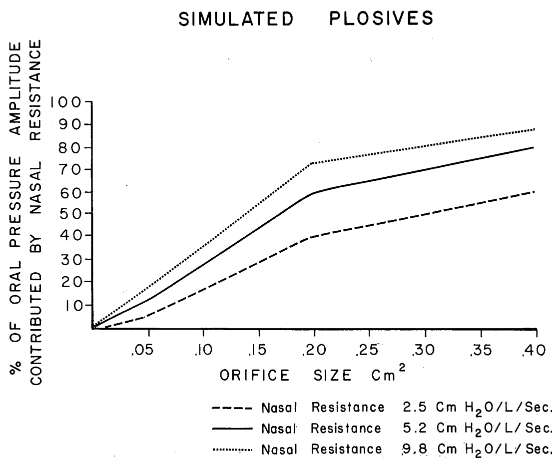

FIGURE 7. Nasal resistance is an important determinant of oral pressure amplitude in the presence of velopharyngeal incompetency. The nasal pressure component can account for more than 90% of oral pressure in certain situations.

by the volume rate of respiratory airflow, velopharyngeal orifice size, degree of oral cavity constriction, and amount of nasal pathway resistance. The data from the present study indicate that it is possible to treat these complex variables in simpler terms by relating oral pressure to velopharyngeal orifice area and volume rate of nasal airflow. This is possible because the volume rate of nasal airflow is dependent upon the degree of oral constriction and nasal pathway resistance.

The fact that two equations (one quadratic and the other quadratic and linear) are necessary to describe the relationship between pressure and airflow suggests that respiratory effort may be an important consideration in cleft palate speech. The volume rate of respiratory airflow during speech directly influences oral pressure amplitude as well as both the oral and nasal emission of air. However, the way in which it influences these parameters undoubtedly varies from individual to individual. For example, data from this study indicate that opening the oral port slightly for fricative sounds reduces oral pressure amplitude unless respiratory airflow rate is increased. Increasing respiratory effort may increase nasal emission of air, however, if velopharyngeal function is inadequate and if nasal pathway resistance is low. On the other hand, if nasal resistance is high, increased respiratory output can increase oral pressure amplitude with only minimal nasal emission of air. This high nasal resistance has been suggested as the reason why certain cleft palate patients with wide clefts have fairly intelligible speech (*3*, *10*).

An interesting question which arises from this study is whether the velopharyngeal mechanism has the same dichotomous effect on speech performance as it apparently has on the respiratory aspects of speech. The data indicate that when the velopharyngeal sphincter is incompetent, pressure and airflow characteristics are determined primarily by the degree of oral port opening, the amount of nasal resistance, and the amount of respiratory effort, rather than velopharyngeal orifice size. Thus the possibility arises that the relatively low correlation between speech adequacy and velopharyngeal incompetency (*1*, *4*, *6*) may be due to factors other than velopharyngeal function. This is not to say that speech is unaffected by velopharyngeal incompetency but rather that the degree of defectiveness may not always be influenced by the degree of velopharyngeal dysfunction in a one-to-one relationship.

Summary

A model of the upper speech mechanism was utilized to evaluate the effects of oral port constriction and nasal pathway resistance on the respiratory aspects of simulated cleft palate speech. Equations were developed which related oral pressure amplitude during consonant production to velopharyngeal orifice size and to the volume rate of nasal airflow. The data reveal that, in the presence of velopharyngeal incompetency, the effects of oral port constriction, nasal pathway resistance, and respiratory effort can mask the effects of velopharyngeal function. It is suggested that the relatively low correlation between velopharyngeal inadequacy and speech performance may be due to this dichotomous performance of the velopharyngeal mechanism.

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APPENDIX

Values of constants

$k_1 = 1.18 \text{ cm}^4 \text{ cm } H_2O \text{ SEC}^2/L^2$
$k_2 = 4 \text{ cm } H_2O/L/SEC$
$k_3 = 40 \text{ cm } H_2O/L^2/SEC^2$

Equations

Equation 1: $P = k_1(\dot{V}/A)^2 + k_3\dot{V}^2$
Equation 2: $P = k_1(\dot{V}/A)^2 + 1/2[k_3\dot{V}^2 + k_2\dot{V}]$

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