Air Flow Rate and Articulatory Movement during Speech

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Various procedures have been applied to the research of speech production. These methods may be classified into two general categories: a) *studies of articulatory movements*, by techniques such as direct observation (*3*), electromyography (*6*), and roentgenography (*7, 15*); and b) *studies of phonated sounds*, by techniques such as an articulatory test (*4, 19*), sound spectrography (*5*), and measurements of intraoral pressure and air flow (*1, 18*).

Articulatory patterns, recognition of sounds, and physical characteristics of escaped air during speech (such as flow rate, volume, and pressure) are closely related (*11*). Cinefluorography has made observations of articulatory patterns easy, but it is still difficult to measure physical characteristics of relatively minute quantities of air emerging orally or nasally. The criteria for the selection of instrumentation for measuring introaral pressure and air flow during speech have been discussed by Hardy (*8*). In 1965, Lubker and Moll developed electronic equipment to measure oral and nasal air flow rates and they assessed the relationship between these measurements and articulatory positions observed simultaneously by cinefluorography (*10*).

The purpose of this study is to develop comparable equipment for making simultaneous observations of air flow rates and articulatory movements and to present a preliminary report concerning the relationships between these two kinds of measurements.

Procedures

Subjects. Five postoperative cleft palate patients and five normal subjects (two males and three females in each group) were selected. The mean ages were 22 years and 8 months for the cleft palate group and 23 years and 4 months for the control group. In the cleft palate group, the mean duration after the final palatal operation was 4 years and 7 months. The results of articulatory tests indicated that three had good articulation, one had a moderate amount of errors, and that one had bad articulation.

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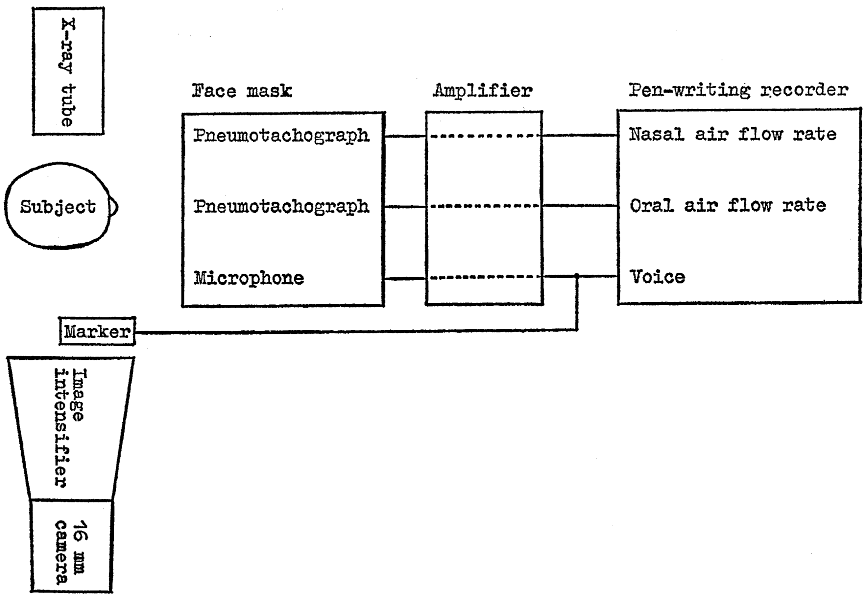

FIGURE 1. Diagram showing instrumentation for simultaneously measuring air flow rate and articulatory movements.

EQUIPMENT. Articulatory movements were observed by cinefluorography, and the air flow was measured during phonation simultaneously by pneumotachographs (Figure 1). For synchronization, a Sony Model F-38 microphone was used to record phonation not only on air flow recording but also on the x-ray film by a marker modified from a VU-meter.

The cinefluorographic equipment included a 7-inch image-intensifier made by the Schiemens. The articulatory movements were recorded by a 16 mm motion picture camera at a film speed of 24 frames per second. Details of this equipment and the procedures are reported elsewhere (*17*). After development, the cinefluorographic films were projected to life size by a motion picture analyzer (Osawa Model F-105) and tracing was made on a frame-by-frame basis. The following two measurements (in mm) were made on each tracing to determine the articulatory patterns: the shortest distance between the soft palate and the posterior pharyngeal wall (V-P), and the shortest distance between the tongue and the palate (T-V) (Figure 2).

Pneumotachographs were used to measure air flow rate. A face mask for anaesthesia was divided into nasal and oral chambers by a diaphragm, as shown in Figure 3. Air flow from the nostrils and from the mouth were transmitted separately to differential pressure heads, which were in tubes 4 cm in diameter and which were 20 cm from the lips. The electrical signals converted from the pressure deflections were amplified and fed to a pen-writing oscillator (Nihonkohden Model RM-150M) in which recording paper was moved continuously at a speed of

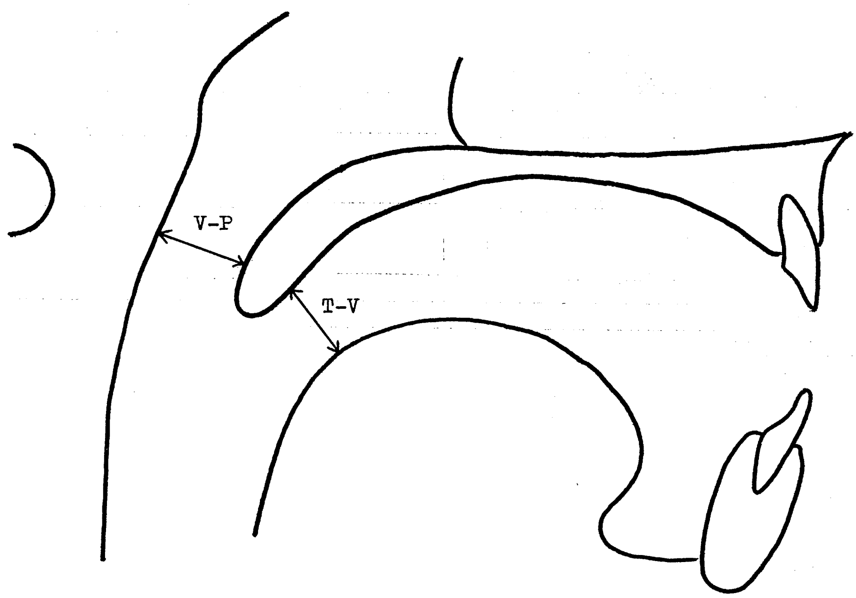

FIGURE 2. Diagram showing measurements which were made to describe articulatory positions: velum-pharynx distance (V-P), and tongue-palate distance (T-V).

60 mm per second. Air flow rate was expressed in ml/sec by comparing the measurement with the calibration curves. The effectiveness of the division of the mask chambers and more details about the instrumentation will be discussed elsewhere (*12*).

Five Japanese vowels /a/, /i/, /u/, /e/ and /o/ were selected as the test sounds, for they are considered to be pronounced most simply among Japanese sounds (*9*). After a period of practice, each subject was instructed to phonate the sounds at a comfortable intensity and pitch level.

Results

Relationship between Articulatory Patterns and Air Flow Rate in Reference to Time. Velum-pharynx distance (V-P), tongue-palate distance (T-V), nasal air flow rate (Nf) and oral air flow rate (Of) were measured and were illustrated on one abscissa, representing time. Figure 4 represents one cleft palate subject during phonating /a/, and Figure 5 represents a normal speaker.

In cleft palate phonation, no significant time lags in nasal and oral air flows were found concerning the onset of the flow and at the time-point of maximum flow rate. The maximum oral flow rates occurred no less than 0.30 seconds after the maximum velopharyngeal closure. Small intrasubject and intrasound differences were found in this time lag. In contrast, no nasal air flow was noticed when normal subjects pronounced Japanese vowels.

Relationship between Articulatory Patterns and Air Flow Rates

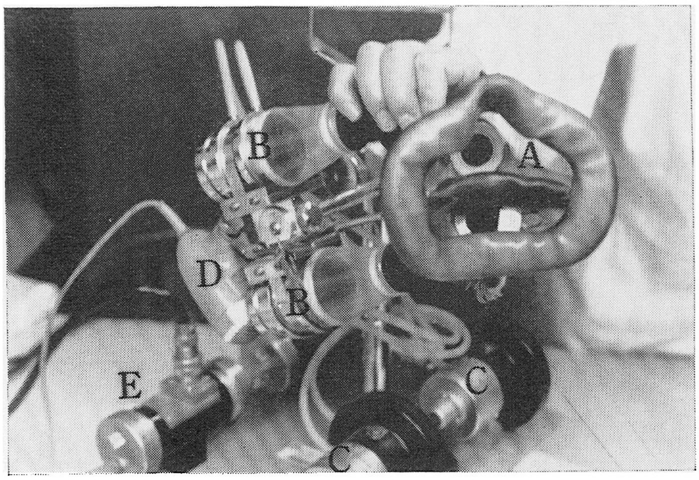

FIGURE 3. The mask and its attachments: A, face mask; B, resistor slit; C, differential pressure head to measure flow rate; D, microphone; and E, strain gauge to measure intraoral pressure (not used in this study).

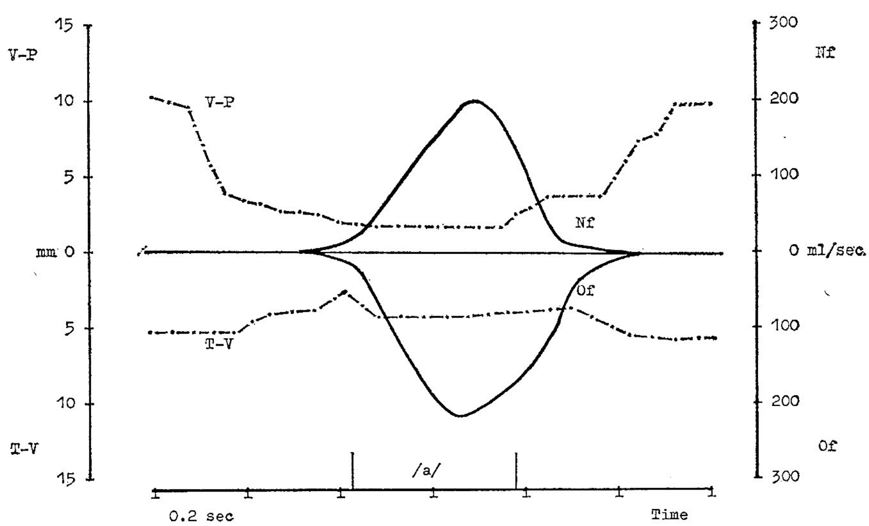

FIGURE 4. Data for air flow rate and articulatory position for a cleft palate subject in phonating /a/: V-P, velum-pharynx distance; T-V, tongue-palate distance; Nf, vasal flow rate; Of, oral flow rate.

IN REFERENCE TO HYDRODYNAMICS. Several analyses were made to study the relationships between the degree of velopharyngeal opening and air flow rate during phonation of cleft palate subjects. The maximum nasal air flow rate (Nf max) is plotted against the minimum velum-pharynx distance (V-P min) in phonation, as shown in Table 1. The ratio of the minimum velum-pharynx distance in phonation (V-P min) and that of at rest (V′-P′), and the maximum nasal air flow rate (Nf max) are shown in Table 2. No significant co-relationships were found in either of the

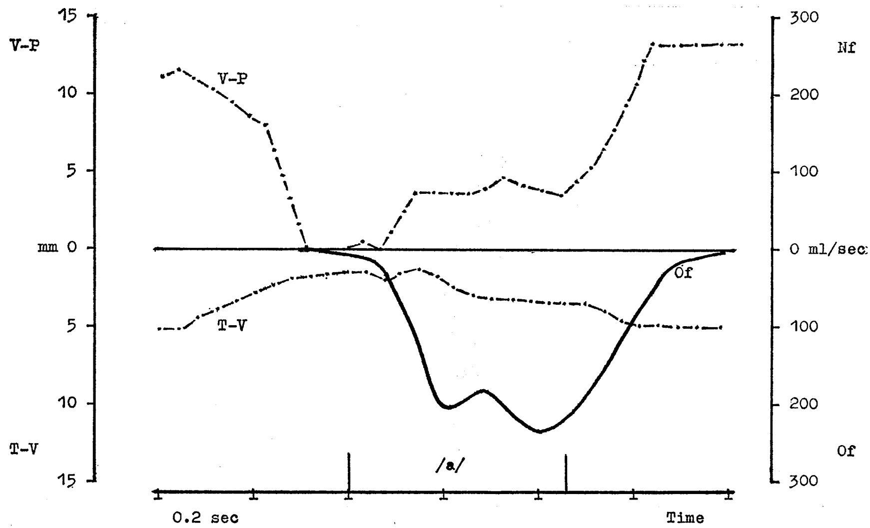

FIGURE 5. Data concerning air flow rates and articulatory positions for a normal subject in phonating /a/: V-P, velum-pharynx distance; T-V, tongue-palate distance; Nf, nasal flow rate; Of, oral flow rate. (No readings for Nf were obtained.)

TABLE 1. Data for the minimum velum-pharynx distance (V-P min) and the maximum nasal air flow rate (Nf max).

phoneme		subject				
		1	*2*	*3*	*4*	*5*
/a/	V-P min	2 mm	2	4	1	5
	Nf max	60.8 ml/sec	155.8	37.5	22.9	25.0
/i/	V-P min	2 mm	4	3	1	13
	Nf max	72.8 ml/sec	200.0	12.5	22.9	75.0
/u/	V-P min	2 mm	1	1	1	10
	Nf max	72.8 ml/sec	89.9	25.0	34.3	64.0
/e/	V-P min	3 mm	2	2	2	10
	Nf max	60.8 ml/sec	89.9	37.5	11.5	32.2
/o/	V-P min	3 mm	2	1	1	8
	Nf max	36.3 ml/sec	89.9	25.0	34.3	53.6

tables. Further, two kinds of ratios were calculated: one is between the miminum velum-pharynx distance (V-P min) and the minimum tongue-palate distance (T-V min) during phonation; the other is between the maximum oral flow rate (Of max) and the maximum nasal flow rate (Nf max). Significant co-relationships between these two ratios were found for only /a/, as shown in Table 3.

TABLE 2. Data concerning the ratio between the minimum velum-pharynx distance (V-P min) and that of at rest (V′-P′), and the maximum nasal air flow rate (Nf max).

phoneme		*subject* 1	2	3	4	5
/a/	V-P min/V′-P′	0.18	0.29	0.50	0.05	0.31
	Nf max	60.8 ml/sec	155.8	37.5	22.9	25.0
/i/	V-P min/V′-P′	0.18	0.57	0.37	0.05	0.81
	Nf max	72.8 ml/sec	200.0	12.5	22.9	75.0
/u/	V-P min/V′-P′	0.18	0.14	0.12	0.05	0.62
	Nf max	72.8 ml/sec	89.9	25.0	34.3	64.0
/e/	V-P min/V′-P′	0.27	0.29	0.25	0.11	0.62
	Nf max	60.8 ml/sec	89.9	37.5	11.5	32.2
/o/	V-P min/V′-P′	0.27	0.29	0.12	0.05	0.50
	Nf max	36.3 ml/sec	89.9	25.0	34.3	53.6

TABLE 3. Data concerning the ratio between the minimum velum-pharynx distance (V-P min) and the minimum tongue-palate distance (T-V min), and the ratio between the maximum oral air flow rate (Of max) and the maximum nasal air flow rate (Nf max).

phoneme		*subject* 1	2	3	4	5
/a/	V-P min/T-V min	0.40	0.33	0.80	0.01	0.62
	Of max/Nf max	1.88	1.74	2.62	1.75	2.27
/i/	V-P min/T-V min	0.25	0.50	1.00	0.05	0.31
	Of max/Nf max	1.57	1.00	6.25	1.75	1.36
/u/	V-P min/T-V min	1.00	0.50	0.25	0.14	2.50
	Of max/Nf max	1.82	2.04	2.38	1.16	1.49
/e/	V-P min/T-V min	0.14	0.20	0.33	0.16	1.40
	Of max/Nf max	2.18	1.61	1.61	1.75	2.38
/o/	V-P min/T-V min	1.33	0.40	0.20	0.11	8.00
	Of max/Nf max	2.63	2.04	4.76	2.33	1:43

Discussion

Nasal and oral air flows are strongly influenced by articulatory movements. Those relationships between these two parameters have been discussed already by Warren and DuBois (*22*). However, such a relationship can be described fully only by simultaneous observations of these parameters (*10*). Data obtained from such simultaneous observations may be analyzed in two ways, time and hydrodynamics.

TIME. Only Lubker and Moll (*10*) have made simultaneous recordings of articulatory movements and air flow. They noticed an increase in air flow from the nose while the amount of velopharyngeal opening remained constant and velar height decreased. They accounted for that finding either by the possibility that lateral roentgenography does not represent degree of velopharyngeal closure accurately, or the possibility that the position of the tongue might influence the air flow rate from the nose.

In the present study, the maximum oral air flow occurred about 0.30 seconds later than the completion of velopharyngeal closure. It is not known, however, whether the discrepancy is related to error. The following hypotheses may be made: a) air was forced out after completion of velopharyngeal closure; b) it took some time for air to pass from the uvula to the differential pressure head; c) continuous air flow records were related to discrete cinefluorographic films of 24 frames/sec, or d) some error existed. To discuss this time lag more sufficiently, it seems necessary to develop equipment which marks time more accurately, to improve the synchronization system, to record cinefluorography at higher speeds, to investigate further the characteristics of air flow during phonation, or a number of other possibilities.

HYDRODYNAMICS. The relationship between spirometer ratios in blowing and the degree of velopharyngeal closure in phonation has been discussed. However, the correlations between these parameters were not reported to be significant in two studies (*2, 20*). It may be because intraoral pressure was measured during blowing, which is different in velopharyngeal movements from that in phonation (*14, 16*). Development of equipment to measure air flow rate in phonation will enable a clearer study of articulatory patterns and will contribute much to the further investigation in this field.

In the present study, the velopharyngeal orifice remained closed and no nasal air flow was observed during normal speech. Therefore, the relationship between degree of velopharyngeal closure and air flow rate was discussed only for cleft palate speakers. The minimum velum-pharynx distance (V-P min), the minimum tongue-palate distance (T-V min), the maximum oral flow rate (Of max) and the maximum nasal flow rate (Nf max) were used to investigate the hydrodynamic relationships. These measures were selected because they were almost constant during the sustained normal phonation of Japanese vowels. In addition, difficulties were encountered in attempting a point-by-point comparison of the air flow record and the articulatory measures (*10*).

As seen in Tables 1 and 2, indexes of velopharyngeal closure adopted by previous investigators (*15, 20, 21, 23*) showed no significant relationship to the maximum nasal flow rates (Nf max). It may be that position of tongue was not considered, although it has been mentioned in the literature (*9, 13*).

It is a law in physics that when flowing gas is divided, the flow rate is in inverse proportion to the sectional area of tube. In cleft palate speakers, the nasal and oral flow rates may be strongly influenced by the smallest cross-sectional areas in nasal and oral cavities. The minimum velum-pharynx distance (V-P min) and the minimum tongue-palate distance (T-V min) were measured so as to represent such cross-sectional areas, and the ratio between these two measures was calculated for further discussion. The parameter of air flow rate was also expressed as a ratio between the maximum oral flow rate (Of max) and the maximum nasal flow rate (Nf max). A significant correlation between these two ratios was found only for /a/, in which the opening of the lips is largest, the intraoral acoustic impedance is least, and the tongue is located posteriorly in the mouth.

These findings may indicate that the position and the shape of the tongue should not be neglected in studying the hydrodynamic relation between articulatory movements and air flow rates. They are in agreement with those reported by Lubker and Moll (*10*).

Summary

Equipment was described whereby articulatory patterns and air flow rates could be assessed simultaneously. A preliminary study of simultaneous observation of these parameters, which seems useful to investigate cleft palate speech, was made on five cleft palate subjects and five normals in phonating Japanese vowels /a/, /i/, /u/, /e/ and /o/. The following findings were reported: a) in both groups, the maximum air flow rates occurred later than maximum velopharyngeal closure; and b) in the cleft palate group, a hydrodynamic correlation was found between the articulatory patterns and air flow rates in phonating /a/.

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