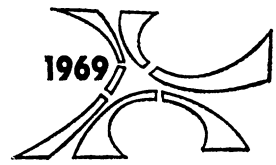
Speech, Intraoral Air Pressure, Nasal Airflow— Before and After Pharyngeal Flap Surgery



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The fundamental purpose of this study has been to appraise the efficacy of pharyngeal flap surgery. To accomplish this objective, recordings of speech, intraoral air pressure, and nasal airflow were obtained before and after surgery. Cephalometric films were also obtained to study anatomical and physiological features identified with success and failure after surgery.

Multiple measures of speech were made simply because some speech features are influenced by incompetent palatopharyngeal valving, whereas others are not. Since pharyngeal flap surgery is undertaken to correct incompetence, only those speech features pertinently related to valving should be employed to assess the efficacy of surgery.

Additional measures of intraoral air pressure and nasal airflow were obtained to further objectify appraisals of valving and to provide pressure flow data which could be studied relative to specific speech characteristics. The latter aspect of study, involving intercorrelations among pressure, flow, and speech parameters, was undertaken to study the effect of reduced intraoral air pressure and excessive nasal airflow upon communication.

Perhaps in the future, measures of intraoral air pressure and/or nasal airflow may be used to facilitate diagnosis of faulty palatopharyngeal valving and prognosis of deviate valving and distorted pressure flow features relative to communication. This long ranged projection of clinical use obviously requires intensive work to: a) specify palatopharyngeal valving; b) quantitatively define intraoral air pressure and nasal airflow; and c) re-

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Some of the findings in this study were reported at the 1969 International Congress on Cleft Palate, Houston.

TABLE 1. Sample characteristics.

classification of cleft	*number*	*age*	
		range yrs/mos	*mean yrs/mos*
submucous	14	7/2 to 33/8	13/0
posterior	20	6/1 to 43/6	15/4
unilateral cleft lip and palate	18	6/10 to 29/2	13/8
bilateral cleft lip and palate	8	6/11 to 23/5	11/5

late respective parameters to consonant intelligibility, articulation, nasality, and other perceptual features of speech.

The work summarized in this report is focused primarily upon the latter two aspects of study and upon an analysis of changes in pressure-flow and associated speech parameters after pharyngeal flap surgery. Study of palatopharyngeal valving per se could not reasonably be included since all patients in the preoperative status exhibited rather gross palatopharyngeal defects. After pharyngeal flap surgery, radiographic data in lateral projection cannot be used to assess valving dimension. Thus, for purposes of this study, nasopharyngeal port dimensions identified with modifications in pressure-flow and speech are *inferred* rather than *specified.*

SAMPLE. The sample included 60 subjects ranging from 6 to 43 years of age. Analysis of age distribution showed that 34 subjects were 6 to 12 years of age; 17 were teenagers; and 9 subjects were past 20 years of age. Sample characteristics are reported in Table 1.

The full sample was not utilized in all areas of data analysis. Cephalometric study included 60 subjects; speech study included data for only 58. For intercorrelated study of speech, pressure, and airflow, pre and postoperative measures were combined for 46 subjects thus yielding a sample of 92. Sample size is specified in each table of data reporting. All data were card punched and processed on an IBM System 360 computer.

Data were accumulated shortly before surgery and approximately eight months afterwards. None of the subjects received speech training between dates of pre and postoperative study. For this reason, the variable of speech training need not be considered in pre and postoperative comparisons of data.

Procedures

To fulfill over-all objectives, speech was defined by measures of articulation and intelligibility and by judgment ratings of articulation, intelligibility, nasality, nasal emission, and nasal grimacing. All recordings were made in a sound-treated room with constant mouth to microphone distance and high fidelity recording equipment.

Words from the Templin Darley Articulation Test were recorded at five-

second intervals and phonetically transcribed to determine type and percentage of articulation error for consonants appearing as single items. Consonants appearing in blends and in clusters were deleted from analysis to simplify the speech task, thus reducing the effect of age on articulation data, and to facilitate correlation of articulation measures with other parameters.

To measure intelligibility, 50 words from the Lehiste-Peterson Lists (consonant-vowel-consonant construction) were recorded at five-second intervals (*6*). A picture intelligibility test, constructed to phonetically match the Lehiste-Peterson Word Lists, was recorded for nonreaders. Tape recordings were played back for auditing by 10 adult listeners with normal hearing. Written responses of the 10 auditors were then analyzed to determine the percentage of words and/or sounds accurately identified. Words were scored as unintelligible when written responses were not phonetically equivalent with the intended utterance (*17*).

Sentences containing articulation test items were recorded for scaled ratings of nasality, articulation, intelligibility, and nasal emission. The latter three ratings were made on five or six point scales. Nasality was rated on a hypo-to-hypernasal, seven point scale, with a rating of *three* designating normal voice quality. The two-directional scale provided adequately for extreme variation in resonance before and after surgery. Since nasality is not synonymous with audible nasal emission, the latter feature was rated separately. Grimacing also was rated at the time of data collection during conversational live speech. All ratings, with the exception of grimacing, were made independently by two speech pathologists trained in the area of cleft palate.

Pressure-Flow Recording. Intraoral air pressure was recorded by a small strain gauge pressure transducer pasted to the palate slightly posterior to the rugae. Oral and nasal airflow were recorded simultaneously by a series of warm-wires mounted separately in free field, in the front of the nose and mouth (*28*).

Measures of pressure and oral-nasal airflow were made at the point of maximum intraoral pressure during articulations of /p/ and /s/ produced within the context of vowel /i/. A ratio of nasal flow relative to total flow (oral plus nasal) was derived to overcome differences in absolute values of flow resulting from possible variation in vocal effort and respiratory capacity.

Results

Articulation. The results of the articulation analysis are reported in Table 2 and illustrated in Figure 1. The total percentage of error decreased from 24% to 12% after surgery. This approximate 50% reduction in total error was also identified with three consonant groups requiring high intraoral air pressure. Reduction in error for plosives (10%), fricatives (22%), and affricates (32%) was significant at the .01 level. Nasal and glide errors were not significantly improved after surgery.

TABLE 2. Pre and postoperative measures of articulation expressed in percentage of error. Incidence of error type is expressed numerically (N = 58).

articulation measurement	*preoperative*			*postoperative*			*level of signif.*
	mean	*SD*	*95% confid. interval*	*mean*	*SD*	*95% confid. interval*	
percentage error							
total consonant error	24.33%	14.32	3.76	12.86%	12.40	3.26	.01
position							
initial	28.37%	17.41	4.57	13.18%	14.17	3.72	.01
medial	20.76%	12.44	3.27	10.63%	11.59	3.04	.01
final	27.39%	16.43	4.32	14.32%	14.10	3.70	.01
plosive	20.10%	18.11	4.76	10.28%	14.76	3.88	.01
voiceless	21.95%	23.39	6.14	10.35%	17.33	4.55	.01
voiced	18.10%	16.53	4.34	10.20%	14.31	3.76	.01
glide	7.89%	10.93	2.87	4.00%	9.72	2.55	—
fricative	47.12%	24.42	6.41	24.85%	23.09	6.07	.01
voiceless	53.98%	27.46	7.21	26.62%	26.77	7.03	.01
voiced	40.61%	25.43	6.68	22.90%	21.29	5.59	.01
nasal	6.00%	7.84	2.06	5.28%	8.00	2.10	—
affricate	56.89%	36.68	9.63	24.71%	33.07	8.69	.01
voiceless	59.05%	39.38	10.34	26.72%	37.42	9.83	.01
voiced	52.59%	43.35	11.38	20.69%	31.11	8.17	.01
incidence error type							
distortion	14.38	7.41	1.95	6.57	6.17	1.62	.01
substitution	4.88	5.74	1.51	3.60	4.98	1.31	—
omission	2.67	5.30	1.39	1.45	3.15	.83	—
glottal stop	1.62	2.87	.75	1.29	3.23	.85	—

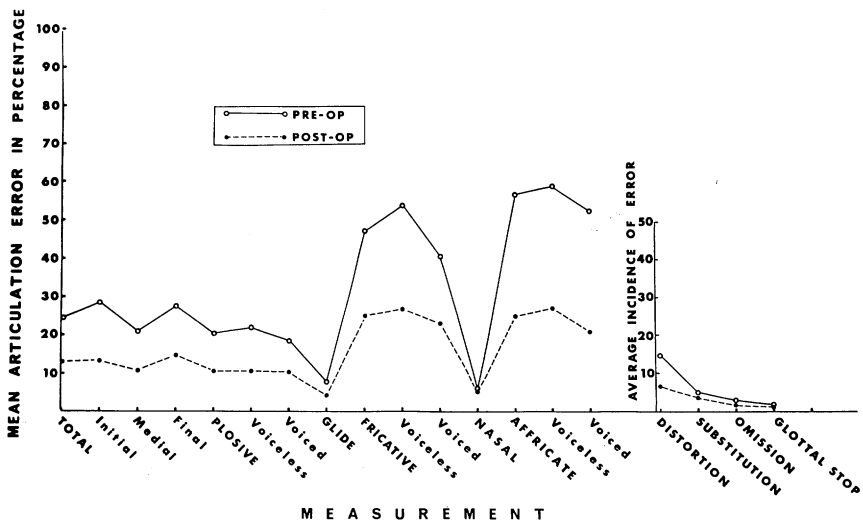

FIGURE 1. Means for articulation error, graphed for pre and postoperative conditions, show prominent fricative and affricate error. Reduction in incidence of distortion was significant.

Further analysis of error type showed incidence of distortion after surgery was lower at the .01 level, but substitutions, omissions, and glottal stops were not significantly reduced. Articulatory defects other than distortions resulting from nasal airflow generally persisted after surgery. Compositely, these findings indicate that the development of acceptable speech after surgery requires retraining when grossly defective articulation exists preoperatively.

INTELLIGIBILITY. Word intelligibility improved from 59% to 73% after surgery (Table 3, Figure 2). According to phonetic classification, intelligibility was significantly improved at the .01 level for vowels (7%), plosives (18%), and glides (9.5%). Improvement for fricatives (11%) was significant at the .05 level. Affricate intelligibility was better after surgery, but the extent of improvement was not statistically significant. No improvement was noted for the nasal consonant category.

ARTICULATION VERSUS INTELLIGIBILITY MEASURES. The results of articulation and intelligibility tests are in general agreement with both measures

TABLE 3. Pre and postoperative measures of intelligibility expressed in percentage (N = 58).

intelligibility measurement	*preoperative*			*postoperative*			*level of signif.*
	mean	*SD*	*95% confid. interval*	*mean*	*SD*	*95% confid. interval*	
word	59.40%	21.76	5.72	72.93%	16.29	4.28	.01
sound	76.02%	15.42	4.05	85.81%	10.20	2.68	.01
consonant	72.95%	17.75	4.66	83.93%	12.03	3.16	.01
initial	70.98%	19.33	5.08	83.98%	13.32	3.50	.01
final	74.76%	16.97	4.46	84.38%	11.35	2.98	.01
vowel	82.41%	11.47	3.01	89.07%	7.69	2.02	.01
plosive	66.10%	21.28	5.59	83.67%	15.95	4.19	.01
voiceless	74.52%	18.63	4.89	86.93%	12.78	3.36	.01
voiced	54.38%	27.47	7.21	79.31%	22.37	5.87	.01
initial	62.17%	25.59	6.72	82.31%	19.00	4.99	.01
final	69.26%	19.54	5.13	84.86%	14.74	3.87	.01
glide	80.60%	13.97	3.67	90.14%	8.56	2.25	.01
initial	78.93%	13.34	4.03	89.50%	8.93	2.34	.01
final	83.60%	14.38	3.78	91.38%	10.69	2.81	.01
fricative	68.09%	25.95	6.82	79.16%	18.35	4.82	.05
voiceless	70.35%	26.19	6.88	80.41%	19.34	5.08	.05
voiced	61.60%	27.94	7.34	76.34%	19.14	5.03	.01
initial	64.79%	28.77	7.56	76.69%	23.34	6.13	.05
final	71.72%	25.03	6.57	82.00%	15.43	4.05	.01
nasal	86.52%	10.65	2.80	85.24%	12.97	3.41	—
initial	92.50%	9.58	2.52	92.29%	9.43	2.48	—
final	82.69%	12.83	3.37	80.78%	17.22	4.52	—
affricate	63.91%	31.74	8.34	75.07%	27.13	7.13	—
voiceless	74.03%	32.31	8.49	80.76%	25.57	6.71	—
voiced	53.59%	37.61	9.88	68.38%	34.99	9.19	.05

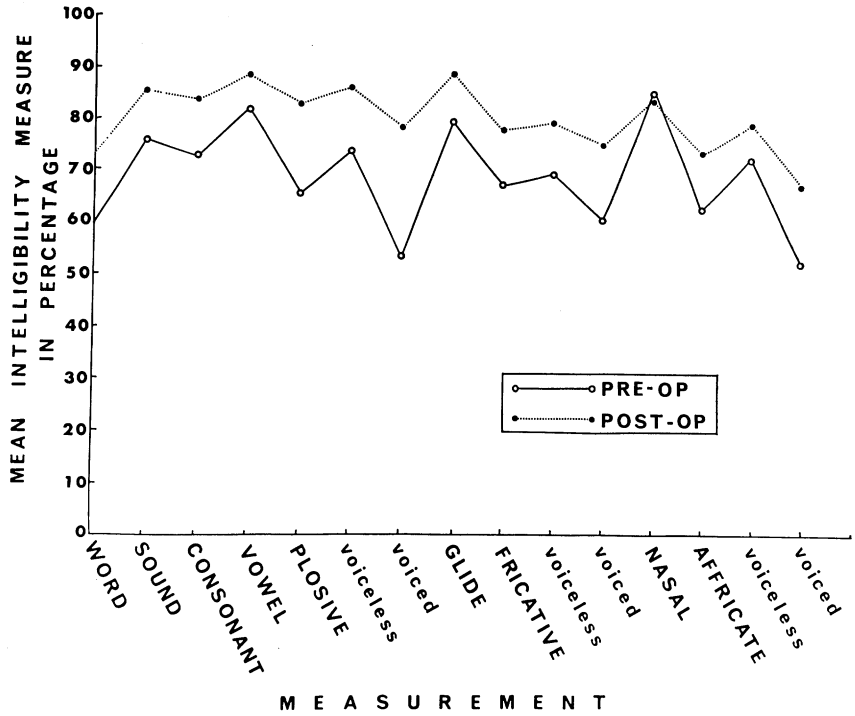

FIGURE 2. Means for intelligibility measures, graphed for pre and postoperative conditions, show marked postoperative improvement in voiced plosive intelligibility.

showing significant over-all improvement. Preoperatively, 76% of the sounds were correctly articulated and correctly identified. Postoperatively, 87% of the sounds were correctly articulated; 86% were correctly identified.

Despite striking similarity in over-all measures, gross differences in test results are apparent when comparisons between phonetic groups are made. Preoperative articulation measures were approximately 10% to 15% *higher* for plosive, glide, and nasal consonants, and 15% to 20% *lower* for fricatives and affricates than was indicated by the intelligibility index. These observations for the preoperative status are graphically displayed in Figure 3.

Postoperative measures of articulation and intelligibility (Table 4, Figure 4) are in much closer agreement. Thus, it appears that the degree of difference is reduced when the over-all quality of speech is less nasal or closer to normal. Stated in other words, excessive nasalization apparently serves to increase the divergence between intelligibility and articulation measures.

Speech improvement after surgery also differed as a function of the test employed (Table 5). Whereas improvement in total consonant error and intelligibility is equal, plosive and fricative improvement differs appreciably. Plosive intelligibility improved almost twice as much (18%) as

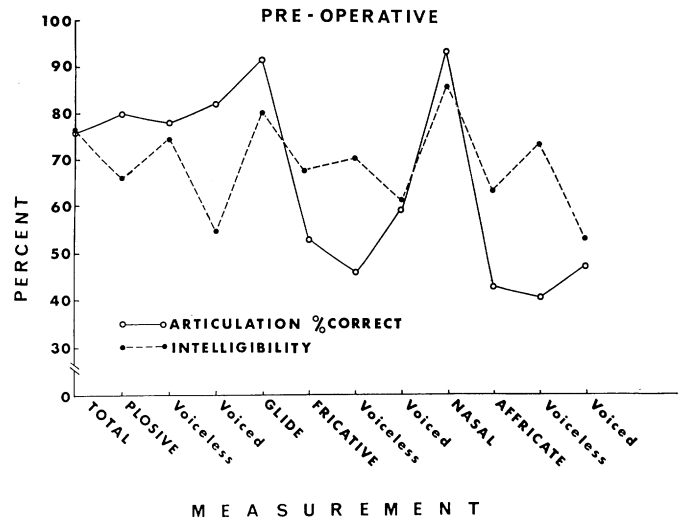

FIGURE 3. Means for preoperative measures of articulation and intelligibility display some marked differences between measures as a function of phonetic grouping.

articulation error (10%). In contrast, fricative and affricate intelligibility improved only half as much as articulation error. These observations suggest that manner of production is a variable which differentiates articulation and intelligibility measures of cleft palate speech.

Voicing and nasality appear to be other influential variables. Preoperatively, articulation scores for voiceless fricatives and affricates were poorer than for voiced counterparts. The opposite observation applies relative to

TABLE 4. Means for pre and postoperative measures of articulation and intelligibility. For purposes of comparison, percentages are used to designate accurate articulation and accurate identification of respective sound groups (N = 58).

sound group	*preoperative, mean*		*postoperative, mean*	
	articulation	*intelligibility*	*articulation*	*intelligibility*
total	75.7%	76.0%	87.1%	85.8%
plosive	79.9%	66.1%	89.7%	83.7%
voiceless	78.1%	74.5%	89.7%	86.9%
voiced	81.9%	54.4%	89.8%	79.3%
glide	92.1%	80.6%	96.0%	90.1%
fricative	52.9%	68.1%	75.2%	79.2%
voiceless	46.0%	70.4%	73.4%	80.4%
voiced	59.4%	61.6%	77.1%	76.3%
nasal	94.0%	86.5%	94.7%	85.2%
affricate	43.1%	63.9%	75.3%	75.1%
voiceless	41.0%	74.0%	73.3%	80.8%
voiced	47.4%	53.6%	79.3%	68.4%

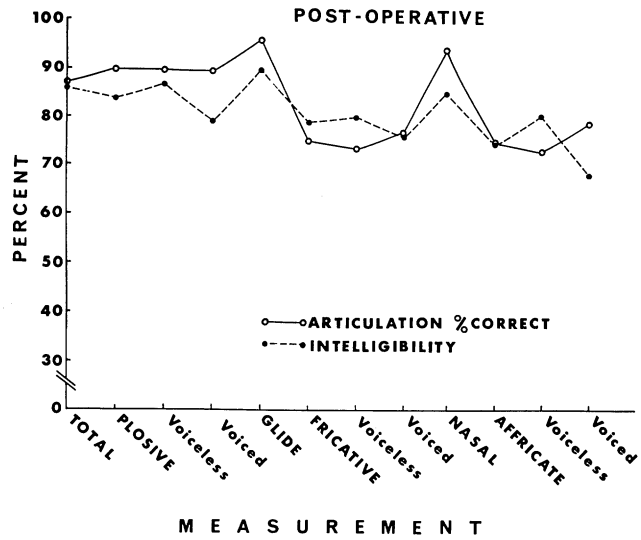

FIGURE 4. Means for postoperative measures of articulation and intelligibility show rather close correspondence between measures. Intelligibility of voiced plosives and nasals remains somewhat lower than indicated by respective articulation measures.

TABLE 5. Speech improvement after pharyngeal flap surgery defined by articulation and intelligibility testing. For purposes of comparison, per cent reduction in error is used to define improvement in articulation (N = 58).

phonetic group	*reduction in articulation error, mean*	*improvement in intelligibility, mean*
consonants	11.47%	10.98%
plosive	9.82%	17.57%
voiceless	11.60%	12.41%
voiced	7.90%	24.93%
glide	3.89%	9.54%
fricative	22.27%	11.07%
voiceless	27.36%	10.06%
voiced	17.71%	14.74%
nasal	.72%	−1.28%
affricates	32.18%	11.16%
voiceless	32.33%	6.73%
voiced	31.90%	14.79%
plosive + fricative		
voiceless	38.96%	22.47%
voiced	25.61%	39.67%

intelligibility. Preoperatively, all voiceless consonants were more intelligible than voiced counterparts. After surgery, articulation of voiceless continuants remained comparatively more defective. Voiceless consonant intelligibility remained better than voiced counterparts.

Relative improvement for voiced as opposed to voiceless consonants also differed as a function of the speech measure used (Table 5). Articulation of voiceless consonants improved to a greater extent (39%) than voiced counterparts (26%). In contrast, intelligibility of voiceless consonants improved less (22%) than voiced counterparts (40%).

Preoperative articulation data show that nasality and nasal emission were identified with very poor articulation scores for voiceless fricatives (46% correctly articulated). Corresponding intelligibility was much better (70% correctly identified). Reduction in nasality after surgery was associated with marked improvement in voiceless fricative articulation (26%). The corresponding improvement in intelligibility was much less (10%). Thus, distortion did not affect intelligibility as much as may have been anticipated.

In totality, variables of manner of production, voicing, and nasality all influence measures of articulation and intelligibility to a degree which does not appear uniform. Comparative analysis of measures according to phonetic features has shown that relative influence of respective variables depends partially upon whether the procedure involves articulation or intelligibility assessment. The specific analysis of preoperative data, identified with prominent nasality, has shown a somewhat sharper difference between articulation and intelligibility measures than has been described.

Since the characteristics of disordered speech and the relative degree of improvement after surgery varied as a function of the test employed, differences between measures are indicated. On the basis of this finding, it may be assumed that reports describing improvement after pharyngeal flap surgery and features of disordered speech are also influenced by the measurement procedures employed to extract data. To illustrate, most investigators who have studied cleft palate speech by articulation testing have reported a higher incidence of voiceless fricative errors (*3*, *9*, *20*, *24*, *25*) than has been reported by other investigators who have used intelligibility testing (*16*, *21*). Comparative study of pre and postoperative data for articulation and intelligibility suggests that these differences in results may be attributed to measurement procedure. Further work is recommended to improve understanding of the influence of measurement procedure upon derived data. Such understanding seems requisite to intelligent interpretation of test results and to an integration of existing research literature.

Judgment Ratings. The analysis of judgment ratings revealed significant improvement after surgery. Nasality, nasal emission, grimacing, intelligibility, and articulation were all improved beyond the .01 level. Averaged ratings of nasality and nasal emission indicated normal quality after surgery. Articulation and intelligibility ratings, however, failed to indicate normal communication skill. In this respect, judgments are in essential agreement with the results obtained by testing. Articulation and intelligibility were improved but not normal after surgery.

Grimacing was significantly reduced after surgery. Preoperatively, 36% of the sample had marked grimace. Only 3% had prominent grimace after surgery. These findings indicate the compensatory pattern of grimacing tends to be eliminated after surgery without the adjunct of training. In this regard, the findings differ from observations of glottal stops which remained consistent after surgery (Table 2). Even though most speakers were capable of generating adequate intraoral pressure for plosives, the preoperative pattern of glottal stop articulation persisted. For this reason, speech therapy seems indicated to eradicate persevering glottal stops.

INTERCORRELATIONS AMONG SPEECH MEASURES. Since articulation and intelligibility tests are both designed to measure speech, utilizing slightly different perceptual criterion in measurement, strong relationships between over-all measures of articulation and intelligibility would be anticipated. As articulation errors increased, intelligibility generally became progressively worse. The correlation calculated to estimate this relationship was −.72 (Table 6).[1]

In general, increased nasalization was associated with a progressive reduction in intelligibility (−.48) and a progressive increase in articulation error (.50). These latter two correlations indicate that over-all measures of articulation and intelligibility are about equally related to nasality.

The four major speech measures (articulation, intelligibility, nasality, and nasal emission) were all significantly interrelated at the .01 level. The high correlation between nasality and nasal emission (.83) provides statistical support for the clinical observation that the two features frequently do co-exist. Although the features are perceptually distinct, they are significantly related.

The correlation between nasal emission and fricative articulation was somewhat stronger (.52) than the analogous correlation between nasal emission and fricative intelligibility (−.35). This finding may be explained by the fact that articulation measures record nasal distortion as error; they are therefore more closely related to the ratings of audible nasal airflow. Distortion, of course, would not be reflected in intelligibility measures, unless it was severe enough to destroy phoneme identity within word context.

Other correlations reported in Table 6 indicate that nasalization affects the intelligibility of some consonant groups more than others. To illustrate, the correlation between nasality and plosive intelligibility was −.57. The correlation between nasality and fricative intelligibility was −.39. Although both *r*s are significant beyond the .01 level, these and previous observations, relative to voicing and manner of production, indicate nasality has a variable effect upon speech intelligibility, which probably

[1] Speech, pressure-flow, and morphological features were significantly altered by the pharyngeal flap procedure. Because of this fact, the preoperative and postoperative measures, secured eight months after surgery, were combined for 46 subjects. This procedure provided a larger sample (92) with broad distribution in measurement values for correlated study.

TABLE 6. Correlation coefficients of speech measures with other variables of intraoral air pressure, nasal airflow, and nasal flow ratios. Correlations of .267 and .205 respectively indicate .01 and .05 levels of significance (N = 92, since both pre and postoperative measurements were used.)

	intel-ligib. word	*plosive*	*vl. plo.*	*fricative*	*vl. fric.*	*artic. error tota*	*plosive*	*vl. plo.*	*frica-tive*	*vl. fric.*	*nas. rating*	*n.e. rating*	*pres-sure /p/*	*/s/*	*nasal flow /p/*	*/s/*	*nasal ratio /p/*
intelligib.																	
plosive	.93																
vl. plo.	.89	.96															
fric.	.89	.78	.73														
vl. fric.	.86	.75	.71	.98													
artic. error																	
total	−.72	−.74	−.70	−.70	−.71												
plosive	−.58	−.64	−.62	−.54	−.53	.88											
vl. plo.	−.50	−.57	−.56	−.45	−.46	.82	.94										
fric.	−.67	−.68	−.62	−.70	−.71	.91	.67	.62									
vl. fric.	−.64	−.66	−.58	−.65	−.65	.87	.66	.62	.93								
nas. rating	−.48	−.57	−.50	−.39	−.34	.50	.41	.40	.55	.54							
n. e. rating	−.46	−.58	−.48	−.35	−.31	.52	.45	.44	.52	.53	.83						
pressure																	
/p/	.50	.53	.48	.50	.49	−.55	−.43	−.41	−.54	−.54	−.56	−.53					
/s/	.50	.48	.38	.54	.55	−.67	−.53	−.50	−.69	−.68	−.48	−.51	.62				
nasal flow																	
/p/	−.29	−.36	−.31	−.19	−.15	.21	.11	.08	.29	.28	.51	.49	−.23	−.23			
/s/	−.34	−.42	−.41	−.23	−.19	.23	.18	.18	.26	.23	.55	.47	−.28	−.19	.74		
nasal ratio																	
/p/	−.39	−.47	−.39	−.30	−.26	.41	.29	.27	.48	.45	.68	.64	−.42	−.33	.78	.62	
/s/	−.48	−.56	−.54	−.46	−.43	.51	.37	.34	.54	.50	.72	.66	−.50	−.41	.61	.73	.74

varies in accordance with physiological, pressure-flow, and acoustical parameters of respective sound groups. This concept with supportive intelligibility data has been expressed previously by Prins and Bloomer (*15*, *16*) and others (*17*, *21*). Extensive articulation data reported by Van Demark (*23*) are also in basic agreement in the sense that a variable effect of nasality upon speech adequacy has been indicated.

Postoperative Speech Status. Postoperative speech status is summarized as follows: 79 % of the total sample had normal voice quality; 8 % were denasal; 8 % were nasal; less than 4 % were hypernasal. Almost 90 % of the sample had no noticeable nasal emission. These figures reveal a high percentage of success relative to speech quality after pharyngeal flap surgery.

The postoperative results, defined by testing, are less impressive. Only 40 % of the sample had near normal intelligibility postoperatively[2]; 22 % failed to achieve satisfactory intelligibility, which was defined as loss exceeding 40 %.

Articulation data, after surgery, were somewhat more favorable than was indicated by intelligibility measures. Half the sample had minor errors ranging from zero to 10 %; but 20 % of the sample retained moderate or severe defects of articulation, defined as error exceeding 20 %.

In general, the results relative to voice quality are in agreement with other studies of speech after pharyngeal flap surgery (*2*, *14*, *18*, *19*). Prominent and relatively consistent success was obtained. Unfortunately, normal articulation and intelligibility were not generally associated with the improved quality. In the majority of subjects, normal speech was not realized eight months after surgery. These findings contraindicate predictions of normal communication as a result of reduced nasality and nasal emission after surgery.

The fact that normal quality generally was obtained suggests that the potential for normal speech existed after surgery, although it remained unfulfilled. This concept of postoperative speech potential was verified in most instances by analysis of intraoral air pressure and nasal airflow.

Pressure-Flow Before and After Surgery. To provide for pre and postoperative comparison, as well as intercorrelated studies of pressure, nasal airflow, and speech, the sample was reduced to 46 subjects. Means and standard deviations for pre and postoperative measures of intraoral pressure and nasal airflow are reported with associated t values in the upper portion of Table 7. As shown, all pre and postoperative comparisons were significant beyond the .01 level.

On the basis of means, intraoral pressure during implosion improved from 4.28 cm H_2O to 7.57 cm H_2O as a consequence of surgery. Nasal airflow was reduced from approximately 670 ml/sec to less than 100 ml/sec after surgery. Ratios were reduced from .42 to .09. Compositely, these fig-

[2] Normal intelligibility was defined as loss ranging from zero to 20%. This criterion is based upon Tikofsky's intelligibility data for ten normal speakers, using the Lehiste-Peterson word list (*22*). Since an average loss of 10% was reported, zero to 20% was considered to represent a range of normal performance.

TABLE 7. Pre and postoperative measures of intraoral pressure, nasal airflow, nasal flow ratios, and speech. Significance at the .01 level is indicated by an asterisk (N = 46).

measurement	*preoperative*		*postoperative*		*paired differences*		
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*t*
intraoral pressure (cm H_2O)							
implosion /p/	4.28	3.08	7.57	3.24	−3.29	3.80	−5.87*
articulation /s/	2.81	2.75	5.36	3.41	−2.55	3.16	−5.47*
nasal airflow (ml/sec)							
implosion /p/	672.17	606.45	91.13	157.35	581.04	613.45	6.42*
articulation /s/	649.80	428.11	90.93	144.97	558.86	457.61	8.28*
ratio: nasal flow/total flow							
implosion /p/	0.42	0.20	0.09	0.16	0.32	0.23	9.28*
articulation /s/	0.48	0.20	0.10	0.13	0.38	0.25	10.29*
speech intelligibility (%)							
word	59.13	21.75	73.41	15.83	−14.28	17.74	−5.46*
plosive	65.58	21.59	84.58	15.44	−19.00	18.46	−6.98*
voiceless plosive	74.13	18.50	87.28	12.77	−13.15	15.01	−5.94*
fricative	69.21	26.05	80.47	17.16	−11.26	19.28	−3.96*
voiceless fricative	71.67	25.86	81.52	18.65	−9.84	19.13	−3.49*
articulation error (%)							
total	23.60	14.54	12.27	12.81	11.32	11.50	6.67*
plosive	20.39	19.47	10.67	15.78	9.71	18.82	3.50*
voiceless plosive	22.98	24.60	10.70	18.80	12.27	22.51	3.70*
fricative	45.11	24.67	22.46	23.26	22.64	20.68	7.42*
voiceless fricative	50.59	28.26	24.07	26.42	26.51	28.44	6.32*
nasality rating	6.08	0.78	3.26	1.27	2.82	1.48	12.95*
nasal emission rating	3.71	1.12	1.39	0.68	2.32	1.11	14.13*

ures indicate the flap was effective in making it possible for most speakers to modify the breath stream appropriately during consonant production.

The pertinence of these modifications in pressure and airflow relative to communication is strongly supported by the speech data reported in the lower portion of Table 7. The modifications described were associated with significant speech improvement.

PRESSURE-FLOW RELATIONSHIP. For reasons previously stated, nasal airflow was quantitatively defined by volume velocity measurements (ml/sec) and by ratios relative to total flow. Although, as expected, the two measures are closely related (.78 and .73), greater confidence is placed in the ratio data. Discussion of nasal airflow is therefore restricted primarily to the ratios although both measures are included in Table 6.

The relationship between nasal airflow and intraoral pressure is of specific interest because two features, excessive nasal airflow and reduced intraoral pressure, theoretically co-exist as a consequence of palatopharyngeal in-

competence. The data (Table 6) show intraoral pressure was negatively related to nasal flow ratio at the .01 level. Respective correlations (−.42 and −.41) show intraoral pressure elevation was associated with proportional reduction in nasal airflow.

Since intraoral pressure is significantly related to the direction of airflow, both measures might be used to assess palatopharyngeal or pharyngeal flap valving and might also be studied relative to communication in order to appraise clinical significance.

PRESSURE AND SPEECH. Correlations between measures of pressure and speech were significant beyond the .01 level (Table 6), thus confirming intraoral pressure as a major determinant of communication adequacy. Correlations between pressure and word intelligibility (.50) were slightly lower than respective correlations between pressure and articulation error (−.55 and −.67). In general, however, pressure during implosion of /p/ appears to be about equally related to intelligibility and articulation measures with correlations ranging from about .40 to .55. Pressure during articulation of /s/ seems somewhat more closely related to error with correlations ranging from −.50 to −.69.

A significant negative relationship between intraoral pressure and nasality was also indicated (−.56 and −.48). Respective correlations between pressure and nasal emission are about equal (−.53 and −.51) to those established between pressure and nasality.

To summarize, all correlations between intraoral pressure and speech measures are significant and roughly equivalent. Pertinent interrelationships between four major speech measures and intraoral pressure are graphed in Figure 5. For illustrative purposes, means for speech measures were established for data grouped on the basis of intraoral pressure categories. As shown, intelligibility improved and articulation error decreased as pressure increased from zero to the 4.1 to 6 cm H_2O pressure level. Beyond this level, both intelligibility and articulation curves tend to flatten. Further improvement in speech was not identified with progressively higher amplitudes of pressure. Curves established for nasality and nasal emission are similar in contour.

The variable effect of reduced intraoral pressure upon intelligibility and articulation measures and upon phonetic category is illustrated in Figure 6. Again, means for speech measures were established for data grouped on the basis of intraoral pressure. At very low pressure levels, plosive intelligibility is better and plosive error less than indicated by the corresponding fricative measures. As pressure increased, the divergence between plosive and fricative intelligibility is reduced. In contrast, the divergence between plosive and fricative articulation error tends to remain. A relatively high percentage of fricative error is retained when intraoral pressure is not deficient. Thus, without regard to pressure gradients, a preponderance of fricative error is indicated.

The observations made suggest the basis for the persistent fricative errors

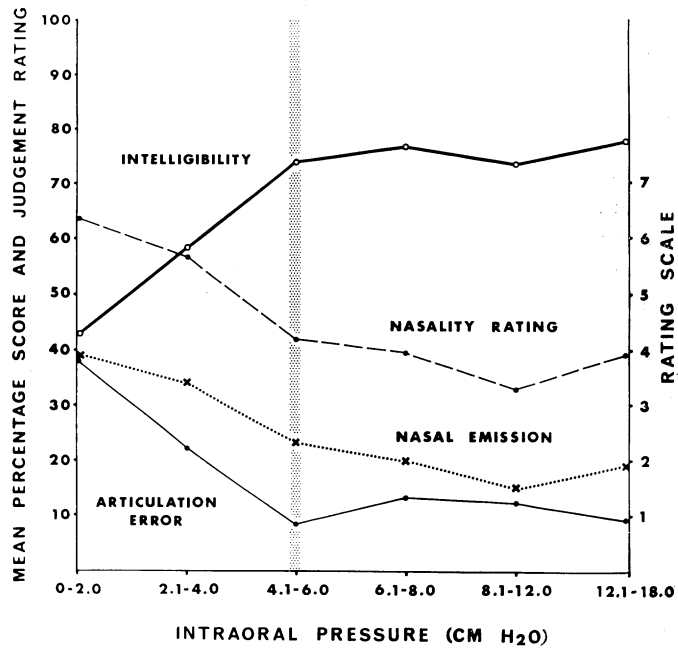

FIGURE 5. Speech measures, averaged on the basis of six intraoral pressure categories, show intelligibility improved and articulation error decreased as pressure increased from 0 to the 4.1 to 6 cm H_2O level. Curves for nasality and nasal emission are similar in contour with all four curves tending to flatten at progressively higher pressure levels.

may not be inadequate pressure or faulty palatopharyngeal valving, but rather improper management of oral airflow. A recent report by Isshiki (*5*) supports this interpretation.

An alternative explanation for persistent fricative error may be related to a compensatory increase in respiratory effort during fricative production which introduces high resistance to oral flow. Under these conditions, the amplitude of intraoral pressure may not necessarily be lowered, but increased nasal airflow through a small palatopharyngeal opening may result with audible nasal emission. Such distortion may not be perceptually apparent during plosive production because of differences in the oral port constriction and in the time pattern of sound generation. It is likely that both explanations contribute to the proportionately high incidence of fricative error.

The correlation between plosive and fricative articulation (.67) is lower than analogous correlations of .82 reported by Barnes and Morris (*1*) and .84 reported by Van Demark (*23*). Present data (Figure 6), showing plosives were articulated more accurately than fricatives at very low intraoral pressure levels, provide a possible explanation for the somewhat lower correlation obtained in this study.

Clinically, the data displayed in Figure 6 suggest that speech training for speakers with poor intraoral pressure might best be focused primarily

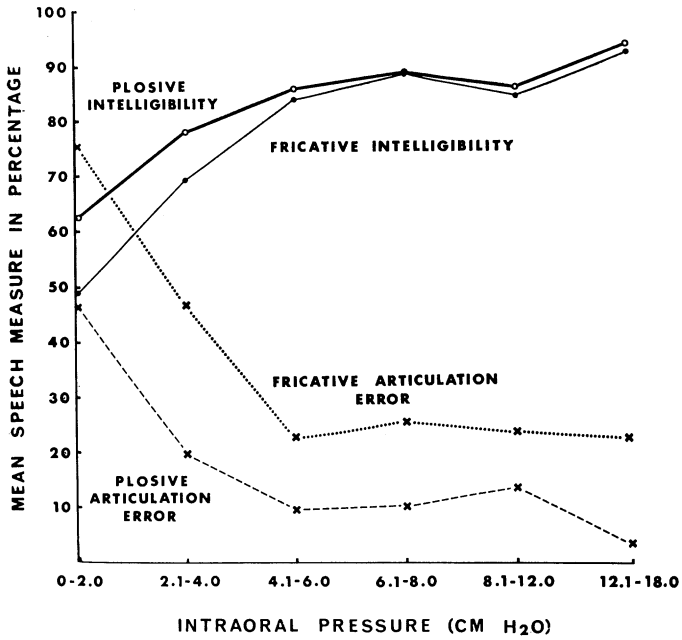

FIGURE 6. Means for plosive and fricative intelligibility and articulation graphed according to pressure category, show similarity between plosive and fricative intelligibility when pressure exceeds the 4.1 to 6 cm H_2O level. Fricative and plosive articulation remains divergent when pressure is reasonably adequate. Both articulation and intelligibility measures show plosives are produced more adequately than fricatives when intraoral pressure is deficient.

on producing consonants with low intraoral pressure requirements such as glides. Thereafter, training for plosive rather than fricative articulation is recommended. At near normal pressure levels, fricative intelligibility may be reasonably good although distortion persists.

Nasal Airflow, Nasality, and Nasal Emission. A fundamental question of research and clinical interest pertains to the relationship between nasal airflow and nasality. This area of inquiry has broad clinical implications since efforts are frequently made to relate airflow to palatopharyngeal valving and speech adequacy.

All correlations between nasality and nasal airflow, measured in ml/sec or in ratios, were significant with correlations ranging from .51 to .72. Correlations between nasal emission and nasal airflow were also significant with correlations ranging from .47 to .66.

To illustrate these relationships graphically, nasal flow ratios were averaged for data grouped on the basis of nasality and nasal emission ratings (Figure 7). The means show normal or denasal speech was generally associated with nasal flow ratios of .10 or less. Hypernasality, designated by ratings of 6 or 7, was generally associated with ratios exceeding .40. Curves for nasal emission and nasality were similar in contour. Nasal emission and

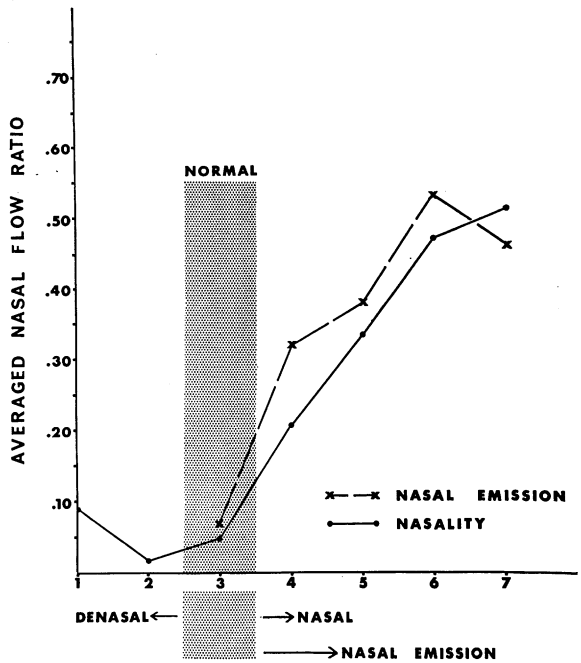

FIGURE 7. Nasal flow ratios, averaged for subjects falling within each rating category, show nasal emission and nasality increase progressively as ratios increase. On the basis of means, hypernasality and prominent nasal emission, designated by ratings of 6 and 7, were identified with ratios exceeding .40. The stippled area, corresponding to ratings of 3 on the nasality scale (1 on the converted 1 to 5 nasal emission scale) designates normal quality and no perceptible nasal emission.

hypernasality are not the same from the auditory viewpoint. The term nasal emission refers to distortion resulting from audible flow of air through the nose, which is most evident during voiceless fricative production. Hypernasality refers to resonance distortion, most apparent during vowel production.

Further study of raw data defining nasal flow in ml/sec showed denasal and normal quality was generally associated with nasal flow approximating 100 ml/sec. Measures identified with hypernasality *varied greatly*. On the basis of averaged data, hypernasality was generally associated with a volume velocity of nasal airflow exceeding 300 to 400 ml/sec.

As anticipated, correlations between nasal flow ratios and nasality were considerably higher (.68 and .72) than analogous correlations between nasal flow measures (ml/sec) and nasality (.51 and .55). These combined findings lend emphasis to the fact that nasal flow, measured in absolute or in proportional units, was significantly related to the perception of nasality and nasal emission. Both perceptual features were therefore identified with airflow through the nose.

NASAL AIRFLOW, ARTICULATION, AND INTELLIGIBILITY. Correlations between flow ratios and measures of total articulation error and word intelli-

gibility were significant with correlations ranging from .39 to .51. These values, however, are considerably lower than respective correlations between nasal flow ratios and nasality and nasal emission. In the latter instances, correlations ranged from .64 to .72.

Interrelationships among speech, pressure, and nasal ratios are graphed in Figure 8. Again, for illustrative purposes, speech measures and nasal flow ratios were grouped on the basis of six intraoral pressure categories. The means for intelligibility and articulation data have been described previously. The associated curve for nasal flow ratios progressively decreased, indicating proportionately less nasal airflow as intraoral pressure increased to a level exceeding 4.00 cm H_2O. Again, the curve is observed to flatten at progressively higher pressure levels. On the basis of these observations, the 4.1 to 6 cm H_2O pressure level may be suggested as requisite to speech adequacy.

Flow ratios and speech were more closely related than measures of nasal flow in ml/sec and speech. For some speech measures, no significant relationship could be established. At best, the correlations between nasal flow and speech were weak with correlations ranging from .21 to .34 for total articulation error and word intelligibility.

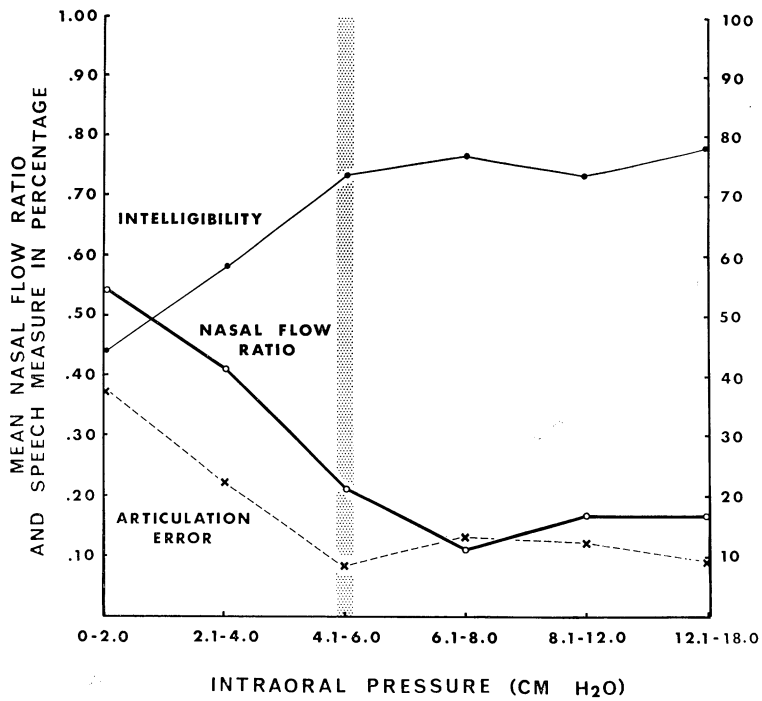

FIGURE 8. Means for nasal flow ratios, intelligibility, and articulation measures for respective intraoral pressure categories are graphed to display inter-relationships. As shown, nasal flow ratio progressively decreases as intraoral pressure increases to the 4.1 to 6 cm H_2O pressure level.

Extreme variability in nasal flow measures was also evident as indicated by the standard deviations reported in Table 7. Although variation in flow may be attributed to differences in vocal effort, thoracic capacity, nasal pathway resistance and characteristics defining oral port constriction (*26*, *27*), the basic fact remains. Measures defining volume velocity of nasal flow are extremely variable. To overcome the variability encountered, cumbersome conversion of flow measures to ratios seems to be required.

After conversion, corresponding correlations between flow ratios and speech measures are improved but lower than analogous correlations between measures of intraoral pressure and speech. In general, pressure was more closely and more consistently related to all speech measures. For these reasons, intraoral pressure recording is recommended in preference to nasal flow recording for prediction of total speech performance.

Cephalometric Analysis. In overview, a favorable postoperative potential for normal communications skill was evident in about 80% of the subjects studied. In searching for physiological and anatomical features responsible for failure, cephalometric data were subdivided in terms of speech results and comparatively analyzed. Space does not permit a full report of cephalometric data (*11*) but a few pertinent findings may be mentioned.

Success and failure were differentiated specifically by measures restricted to the nasopharyngeal and pharyngeal regions. The area of the nasopharyngeal space, defined by planimetric measure (Figure 9), was significantly larger in speakers who did not attain near normal speech quality or pressure-flow relationships after surgery. Related linear and angular measures defining nasopharyngeal depth, velar mobility, site and degree of palatopharyngeal constriction, which can influence area size, were also found to differentiate success and failure. A difference in tongue position relative to pharyngeal wall was also revealed.

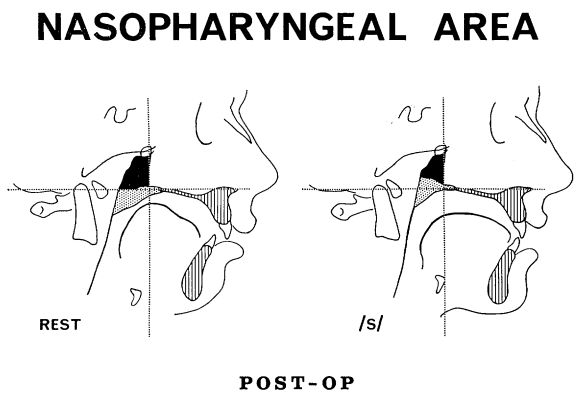

FIGURE 9. Nasopharyngeal area was defined planimetrically using the pterygomaxillary fissure, the superior-posterior contour of the nasopharyngeal space, and the superior surface of the pharyngeal flap at rest and during function.

In terms of flap morphology, all subjects had attachments located below the level of the palatal plane. This finding indicates that considerable healing down or reattachment of the flap and pharyngeal tissue occurred during the eight-month interval after surgery. Good speech tended to be associated with higher flap attachments located in closer relationship to the palatal plane. Very low pharyngeal attachment tended to reduce the dimension between tongue and posterior pharyngeal wall.

Discussion

This study was undertaken primarily to evaluate the efficacy of pharyngeal flap surgery. Major findings relative to surgery have been discussed within the text. Although speech results generally confirm information existing in current literature, considerable new information has been provided through analysis of pressure-flow parameters and through study of their respective relationships to speech. The relevance of reduced intraoral pressure and excessive nasal airflow to disordered speech has been identified at least superficially and merits brief discussion.

In totality, derived data support the concept that palatopharyngeal valving or pharyngeal flap valving during speech serves to control the breath stream, thereby reducing nasal resonance and assisting in the modification of intraoral air pressure. Theoretically, appropriate pressure-flow management is associated with satisfactory speech production. In the past, improved speech after surgery has been attributed to reduced nasal airflow and more adequate intraoral pressure. This theoretical interpretation has been strongly supported by multidimensional study.

At the present time, various techniques are used to study airflow and pressure. Since instrumentation and procedures employed to secure information influence the type of data reported, comparisons are difficult and perhaps premature. In overview, the correlations between intraoral pressure and articulation of plosives and fricatives were significant. These results encourage continued use of the Iowa Pressure Articulation Test (*10*), containing fricatives, plosives, and affricates, to discriminate adequate and inadequate velopharyngeal closure and associated potential to generate intraoral air pressure during speech.

Within the past few years, intercorrelated studies of various articulation measures have been undertaken, but relatively few efforts have been made to define differences between intelligibility and articulation measures. Although these differences may appear trite, speech sounds do differ in pressure-flow features just as they differ in physiological and acoustical characteristics. By differential and intercorrelated study of individual speech sounds and sound groups, insight into the relative importance of the various parameters may be obtained.

In articulation testing, the auditor usually responds to the speaker's accuracy in producing a predetermined individual sound. In intelligibility testing, the auditor has no predetermined set as to which sounds will be

produced. He attempts to identify and discriminate between respective phonemes as sounds are produced within linguistic units. Thus, in the latter instance, the auditor is responding to the acoustical features of specific sounds and to the acoustical transitions resulting from physiologic movements effected to produce sounds in sequence.

The influence of one articulatory gesture upon adjacent gestures and the perceptual importance of the acoustical transitions resulting from physiological movements are two facts which have been stressed repeatedly by phoneticians. Recently, Huntington has re-emphasized the point that "... articulatory inter-actions are the rule rather than the exception". She writes, "Under these circumstances, the identity of a sound in speech clearly relies on its influence upon sounds adjacent to it as well as upon its own inherent distinctive articulatory attributes" (*4*, p. 20).

Within the reference of this background information, it is completely comprehensible that a given speaker may well be able to articulate a consonant acceptably without error and still be unable to produce the same consonant intelligibly within word context. It is also understandable that significant but relatively low correlations between articulation and intelligibility measures may exist for some phonetic groups.

Correlations between speech measures were not established separately for the preoperative data; however, it is evident that the differences between speech measures were much greater when speech was hypernasal. Theoretically, this latter factor, as well as compensatory articulatory adjustments, would exert a marked effect upon the acoustical transitions. Hence, intelligibility for some groups (such as plosives) might well be considerably lower than analogous articulation. Since the relative value of the transition to the perception varies as a function of the phoneme (*7*, *8*, *12*, *13*), it would appear that the intelligibility of some sound groups would be more affected than others. Hence, relative differences between intelligibility and articulation may well vary as a function of phonetic grouping.

When attention is focused upon differences between measures of articulation and intelligibility, the question of why correlations between measures are not higher might reasonably be rephrased to read: Why are they not lower? Certainly, further work is needed.

A meager approach in the suggested direction of study is described in this writing. The articulation test used was not ideally suited for comparative study of intelligibility and articulation even though analysis procedures were purposely modified to facilitate correlations. Despite this limitation, preliminary observations are stimulating and warrant further investigation with better control of phonetic content.

Information yielding a sharper discrimination between articulation and intelligibility measures would assist in a) interpreting and integrating existing research reports, especially as they pertain to postoperative cleft palate speech; b) determining the effect of defective articulation and/or deviate voice quality upon communication as appraised by intelligibility testing; and c) developing a standardization for speech data accumulation

and analysis. Hopefully, the latter factor would facilitate pooling of speech data with considerable benefit in research.

Summary

Pre and postoperative data, including recordings of speech, intraoral pressure, nasal airflow, and cephalometric films, were analyzed to appraise the efficacy of pharyngeal flap surgery. Speech data showed approximately 80% of the subjects had near normal voice quality after surgery. Intelligibility and articulation were also significantly improved. These changes in speech were identified with higher intraoral air pressure and reduced nasal airflow after surgery. Intercorrelations among various speech, pressure, and airflow parameters have revealed significant relationships between intraoral pressure and speech adequacy, defined by intelligibility and articulation tests and by nasality ratings. A negative relationship, between intraoral pressure and nasal airflow, and a positive relationship, between nasal airflow and perception of nasality and nasal emission, were established. Success and failure after pharyngeal flap surgery were differentiated on the basis of cephalometric measures primarily related to the nasopharyngeal region. In totality, derived data support the concept that pharyngeal flap valving during speech serves to control the breath stream, thereby reducing nasal resonance and assisting in the modification of intraoral air pressure. In the past, improved speech after surgery has been attributed to reduced nasal airflow and improved intraoral pressure. This theoretical interpretation has been strongly supported by multidimensional study.

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