Airflow and Pressure in Syllable Production By Cleft Palate Individuals

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Some postoperative cleft palate subjects are defective in producing connected speech or consonant-vowel syllables, even though they can pronounce the isolated consonant sufficiently well (*3, 4, 11, 13*). Although various methods have been applied in the research of cleft palate speech (*1, 9, 12, 15*), few findings have been reported to explain this articulatory deficiency. Most of the studies of connected speech consider phonetic context (*16, 17*), and do not compare isolated and repeated syllables. Since the objective of speech therapy is to achieve good conversational speech in which speech is produced rapidly, it is important to describe the effects of rate on articulatory performance.

Recently developed instrumentation is capable of precise recording of the rapid fluctuations of airflow and pressure during speech, and several valuable investigations on these parameters have been reported (*6, 10, 12, 16–21*). Thus the aerodynamic methods appear to be suitable to investigate the articulatory performances during the rapid production of syllables.

The present study was designed to compare the mechanisms of isolated and repeated syllable-production from the viewpoint of hydrodynamics, and to discuss the causes of deficiency in the repeated CV syllables.

Procedure

INSTRUMENTATION. As illustrated in Figure 1 and Figure 2, three kinds of equipment were used. Oral airflow was captured by an anesthetist's mask fitted to the lower part of the face. Nasal airflow was collected by a Y-shaped rubber tube secured to the nostrils. These airflows were led separately into polyethylene tubes, and the pressure increase on the input side of a mesh in the tube sensed by differential pressure flowmeters (Nihon Kohden MFP-1A). A plastic catheter of 3 mm in the outer diameter, 2 mm in the inner diameter, and 75 cm long was inserted through a

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nostril. The tip of the catheter reached about 1 cm below the posterior end of the soft palate. Intraoral static air pressure fluctuation was transmitted through this catheter and was converted into electrical signals by a strain gauge (Nihon Kohden MFP-1T). It was confirmed prior to the experiment for each subject that air did not leak from any part of the apparatus. No one complained that the apparatus interfered with articulatory processes.

A dynamic microphone (Sony F-38) was placed 35 cm in front of the mouth to record voice and to measure intensity of phonation.

The electrical signals of oral and nasal airflow rates and intraoral air pressure were amplified by Nihon Kohden RP-2 amplifiers, and voice and intensity by Model RB-2 amplifiers. These signals and the time mark were recorded separately but simultaneously by an ink-writing 8-channel recorder (Nihon Kohden W1-380TR) at the paper speed of 50 mm per second (Figure 3). Calibration of the flow rate was accomplished by a rotameter, and that of pressure was by a water manometer. The flow rate measured on the recording paper is linear up to 400 cc/sec, and error is within 5% in this range. The pressure is linear up to 160 mm H_2O, and the error is within 5%.

SUBJECTS. Eighteen males and eighteen females with surgically repaired cleft palate were selected. The subjects were older than 15 years of age, had had the final cleft palate operation more than six months pre-

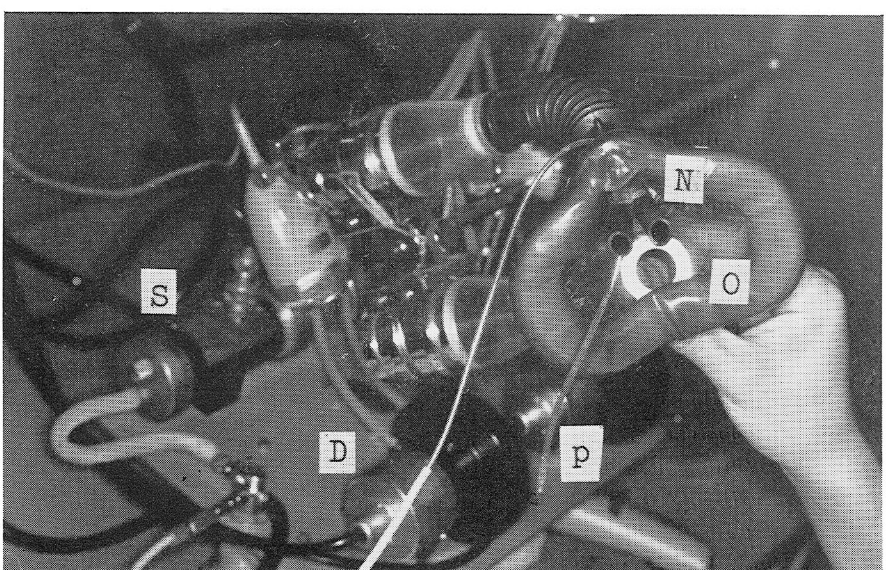

FIGURE 1. Peripheral parts of the apparatus. O, mask for oral airflow; N, Y-shaped tube for nasal airflow; P, plastic tube for intraoral pressure; D, differential pressure flow meter to measure airflow rate; and S, strain gauge to measure intraoral pressure.

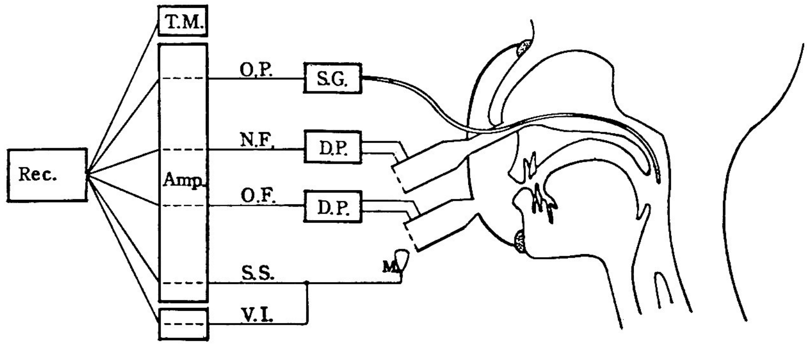

FIGURE 2. Diagrammatic representation of the apparatus. S.G., strain gauge; D.P., differential pressure flow meter; M., microphone; O.P., intraoral pressure; N.F., nasal airflow; O.F., oral airflow; S.S., speech sound; V.I., voice intensity; T.M., time marker; Amp., amplifying system; and Rec., recording system.

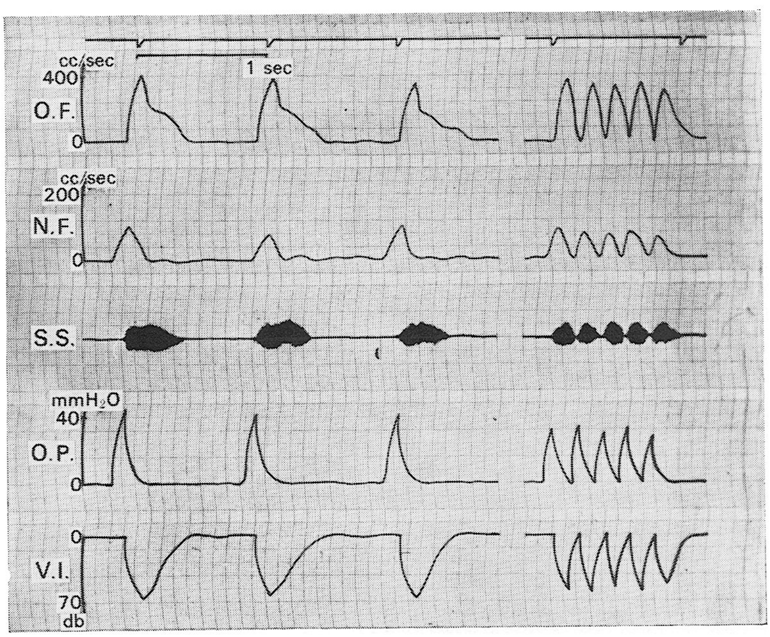

FIGURE 3. A record of producing /pa/ five times successively by a cleft palate subject. The left half is for isolated speech, and the right for connected speech. O.F., oral airflow rate; N.F., nasal airflow rate; S.S., speech sound; O.P., intraoral pressure; and V.I., voice intensity.

vious to the experiment, were normal in intelligence and psychological status, had no speech disorders other than cleft palate speech, were not hard of hearing, had acceptable tongue movements during articulation, and lived in the vicinity of Osaka.

The 36 subjects were classified by an articulatory test. Phonation of the speech materials, explained below, were tape recorded by a Sony 777 tape recorder, and were presented to seven experienced examiners who worked at the Speech Clinic of the Osaka University Dental School Hospital. Articulatory proficiencies in isolated and repeated syllables were scored separately by each examiner with a three-point scale: *two*, excellent, *one*, fair, and *zero*, bad. Thus the most excellent speakers were given 14 points (7×2). Those who received more than eleven points were judged to demonstrate acceptable phonation. This scoring method was examined by Matsuya (*10*), who reported that speech assigned more than 11 points, using this scale, shows relatively normal consonant patterns on sound spectrograph. Subjects who had acceptable phonation in both the isolated and the repeated syllables were assigned to Group 1. Group 2 consisted of those who had acceptable phonation in the isolated syllables but not in the repeated ones (Table 1).

Seven male and seven female adults, all judged to have normal speaking ability, were selected as the control group.

SPEECH MATERIALS. Six plosives /p, t, k, b, d and g/ were chosen, and were combined with /a/, a combination pronounced easily by Japanese people. After some practice, each /pa/, /ta/, /ka/, /ba/, /da/, and /ga/ was produced five times successively at speeds of one CV syllable per second, as the isolated syllables, and at five per second, as the repeated ones, at the intensity of 70 ± 5 db/35 cm. Duration and intensity of phonation were thus controlled, but pitch was natural for each subject.

MEASUREMENTS. As illustrated in Figure 4, the maximum intraoral air pressure (Pr) was measured in mm H_2O, the maximum oral and nasal airflow rates (Of and Nf, respectively) in cc/sec. The cross-sectional area at the velopharyngeal constriction (A) can be calculated from a hydraulic equation (*8*) (see Appendix for derivation of equation):

$$A = Nf \sqrt{\frac{Z}{2g \cdot Pr}} \qquad \text{where } Z = \text{coefficient}, \quad g = \text{acceleration of gravity}$$

TABLE 1. Numbers of cleft palate subjects in the two groups who performed the experimental tasks.

	group 1	*group 2*
/pa/	23	7
/ta/	27	9
/ka/	18	12
total of voiceless	68	28
/ba/	12	13
/da/	13	19
/ga/	18	12
total of voiced	43	44

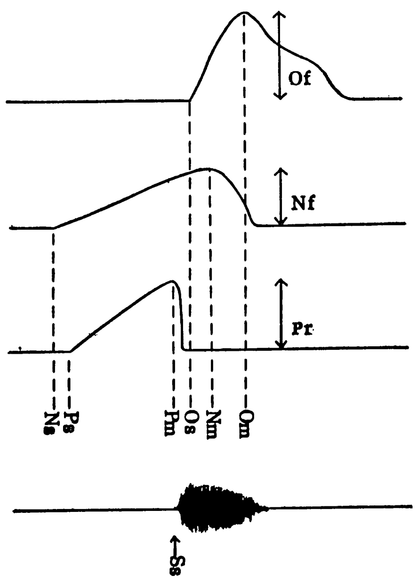

FIGURE 4. Diagrammatic representation of measured items. Of, the maximum value of oral airflow rate; Nf, the maximum value of nasal airflow rate; Pr, the maximum value of intraoral pressure; Ns, onset of nasal airflow; Os, onset of oral airflow; Ps, onset of intraoral pressure; Nm, time point for the maximum nasal airflow rate; Om, time point for the maximum oral airflow rate; Pm, time point for the maximum intraoral pressure; and Ss, onset of speech.

In the present study, the ratio of the areas in the isolated and the repeated syllables was calculated.

Time measurements of pressure and flow rates patterns were made in msec, using the time mark as a basis. The onset of a phenomenon was considered to be the point at which the pattern began to rise from the base line. As shown in Figure 4, following time durations were measured from the initiation of phonation (Ss): Ns-Ss, to the onset of nasal airflow; Nm-Ss, to the time point for the maximum nasal airflow rate; Os-Ss, to the onset of oral airflow; Om-Ss, to the time point for the maximum oral airflow rate; Ps-Ss, to the onset of intraoral air pressure; and Pm-Ss, to the time point for the maximum intraoral air pressure.

In addition to these, the following durations were measured to discuss the time-relationships between the patterns: Ps-Ns, from the onset of nasal airflow to that of intraoral air pressure; Pm-Nm, from the maximum point of nasal flow rate to that of intraoral pressure; Os-Nm, from the maximum point of nasal flow rate to the onset of oral airflow; Om-Nm, from the maximum point of nasal flow rate to that of oral flow rate; Os-Pm, from the maximum point of intraoral pressure to the onset of oral flow; and Om-Pm, from the maximum point of intraoral pressure to that of oral flow rate.

The length of duration, Y-X, was expressed as a positive value (+) if

X occurred prior to Y, and as a negative value (−) in the reverse condition.

ANALYSIS. Although each CV syllable was produced five times successively for both experimental conditions, the first phonation was excluded from the data since preparation time was too long. The fifth one was also eliminated, since the oral airflow pattern was usually different from that of the others. Measurements were therefore made on the middle three syllables, and in order to reduce the within-subject variation the mean was calculated. Statistical treatments were made by means of the analysis of variance and the t test, at the significance level of 5%.

Results

Two preliminary analyses were made preceding the analysis for each experimental group. First the uniformities of phonation among /pa/, /ta/, and /ka/, and among /ba/, /da/, and /ga/ were examined for the normal speakers, applying the analysis of variance (Table 2). For either the isolated syllables or the repeated ones, no significant differences among voiceless or voiced consonants were found for any parameter. Therefore, in the future analysis, /pa/, /ta/, and /ka/ were combined into the voiceless consonant group, and /ba/, /da/, and /ga/ comprised the voiced one. Secondly, the usefulness of the twelve kinds of durations to discuss the time-relations of pressure and flow patterns was evaluated, using the results of cleft palate speakers as a whole (Table 3). Results of the t tests were also included in the table, where t_1 refers to the value of t between the isolated and the repeated syllables of the cleft palate group, t_2 is that between the isolated syllable of the cleft palate and the control groups, and t_2' is that between the repeated syllables for the two groups. As six durations in the voiceless consonant group and nine in the voiced group showed significant differences either in t_1, t_2, or t_2', or some combinations of them, the twelve conditions were judged to be useful for the study.

Next, differences between the two cleft palate groups and the normal group were analyzed. The maximum values of the intraoral pressure, oral airflow rate, and time measurements of the patterns for the normal group are in Tables 4, 5, and 8, respectively. Since no nasal airflow existed in most of the normals, items related to the nasal flow were not measured in this group.

The maximum values of the intraoral pressure, oral and nasal airflow rate, the cross-sectional area at the velopharyngeal constriction, and the time measurements of the patterns for the cleft palate Group 1 and for Group 2 are shown in Tables 4, 5, 6, 7, 9, and 10, respectively. In the tables, t_cs are the results of t tests between the isolated syllable and the repeated one in each group, and t_gs are those between the repeated ones of the two groups.

The uniformity of articulatory performances in the isolated syllables

TABLE 2. Summary of analysis of variance testing uniformity of articulatory performances among voiceless consonant syllables and among voiced ones in the normal group. None of the Fs are significant.

source of variance	*df*	*Pr*		*Of*		*Os-Ss*	
		mean square	*F*	*mean square*	*F*	*mean square*	*F*
voiceless							
isolated CVs							
among syllables	2	1204.0	2.52	25719.0	0.62	28.0	0.08
within syllables	39	475.9		40906.1		343.5	
repeated CVs							
among syllables	2	1326.5	1.93	9127.0	0.17	1038.5	2.26
within syllables	39	686.3		52607.6		459.2	
voiced							
isolated CVs							
among syllables	2	189.0	0.62	210.5	0.01	498.0	0.91
within syllables	39	303.5		40512.5		546.8	
repeated CVs							
among syllables	2	286.5	0.57	7659.5	0.46	260.0	0.41
within syllables	39	498.5		16445.1		630.2	

source of variance	*df*	*Om-Ss*		*Ps-Ss*		*Pm-Ss*	
		mean square	*F*	*mean square*	*F*	*mean square*	*F*
voiceless							
isolated CVs							
among syllables	2	2086.0	1.30	1229.5	0.19	38.5	0.39
within syllables	39	1601.0		6630.0		99.3	
repeated CVs							
among syllables	2	450.0	0.64	39.5	0.02	209.0	1.23
within syllables	39	702.9		2444.1		169.8	
voiced							
isolated CVs							
among syllables	2	1644.5	1.17	1123.5	0.31	559.0	1.08
within syllables	39	1406.0		3629.8		516.5	
repeated CVs							
among syllables	2	27.5	0.02	1573.5	0.81	207.5	0.51
within syllables	39	1571.6		1945.7		402.4	

among the normal group, the cleft palate Group 1, and Group 2 was examined by the analysis of variance (Table 11). No significant difference appeared in the items, except for the maximum value of pressure (Pr) and for the duration between the onset of pressure and that of speech (Ps-Ss).

TABLE 3. Means and standard deviations for durations (in msec) for total cleft palate subjects and summary of t tests between isolated and repeated CVs and between normal and cleft palate groups. Asterisked ts are significant at the .05 level.

	Ns-Ss		*Nm-Ss*		*Os-Ss*		*Om-Ss*		*Ps-Ss*		*Pm-Ss*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	−72	110	39	57	30	18	128	25	−139	88	8	20
repeated	−44	87	49	65	41	23	144	36	−89	55	5	25
t_1	−3.98*		−1.11		−4.05*		−3.67*		−4.37*		0.78	
t_2 isolated					−0.39		−2.59*		−5.79*		−1.48	
$t_{2'}$ repeated					−2.03		−0.67		−2.72*		0.00	
voiced												
isolated	−98	74	27	40	32	34	135	34	−116	69	11	17
repeated	−63	56	31	42	52	35	153	53	−71	38	14	22
t_1	−3.74*		−0.84		−4.08*		−3.05*		−5.68*		−0.43	
t_2 isolated					1.13		0.74		−0.17		2.97*	
$t_{2'}$ repeated					−0.42		0.65		−0.26		0.25	

	Ps-Ns		*Pm-Nm*		*Os-Nm*		*Om-Nm*		*Os-Pm*		*Om-Pm*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	−38	103	−18	48	−8	51	85	69	16	76	110	51
repeated	−28	67	−31	60	−8	65	103	82	33	36	147	50
t_1	−0.65		1.38		0.00		−1.55		−3.62*		−4.58*	
t_2 isolated									1.95		0.01	
$t_{2'}$ repeated									−0.80		−1.35	
voiced												
isolated	−12	75	−5	42	6	47	108	64	16	29	117	45
repeated	−5	37	−15	27	21	41	125	66	35	30	140	55
t_1	−0.83		2.59*		−2.38*		−1.84		−4.48*		−3.21*	
t_2 isolated									0.06		0.71	
$t_{2'}$ repeated									−0.32		0.39	

Discussion

The apparatus used in the present study, as described earlier in this paper, appears to be valid for the purposes outlined here; however, the results of the present study must be generalized to conversational speech with caution (*5*). Conversational speech may well be more complicated and at a faster rate than was the speech sample used here. Therefore additional research is needed.

INTRAORAL AIR PRESSURE. The maximum value of the intraoral air pressure during the isolated syllable production for the normal group was

TABLE 4. Means and standard deviations for the maximum value of intraoral air pressure (in mmH_2O) and *t* tests for the differences between isolated and repeated CVs in each group (t_c) and between repeated CVs of cleft palate Group 1 and cleft palate Group 2 (t_g). None of the *t*s is significant.

	normal		*cleft palate 1*		*cleft palate 2*	
	M	*SD*	*M*	*SD*	*M*	*SD*
voiceless						
isolated	82.7	22.6	31.1	29.9	31.8	29.8
repeated	83.0	26.7	29.6	26.3	25.8	30.3
t_c	−0.07		0.31		0.38	
t_g					0.58	
voiced						
isolated	50.9	17.3	37.2	20.8	43.4	32.3
repeated	50.1	21.7	35.2	24.2	34.3	20.6
t_c	0.18		0.41		1.12	
t_g					0.19	

TABLE 5. Means and standard deviations for the maximum value of oral air flow rate (in cc/sec), and *t* tests for the differences between isolated and repeated CVs in each group (t_c) and between repeated CVs of cleft palate Group 1 and cleft palate Group 2 (t_g). None of the *t*s is significant.

	normal		*cleft palate 1*		*cleft palate 2*	
	M	*SD*	*M*	*SD*	*M*	*SD*
voiceless						
isolated	358	198	293	189	415	219
repeated	339	221	278	167	362	219
t_c	0.28		0.47		0.90	
t_g					−1.97	
voiced						
isolated	327	194	325	195	303	196
repeated	309	143	333	191	291	166
t_c	0.35		−0.19		0.31	
t_g					1.06	

nearly the same as that reported by others (*9, 12, 16*). The value was, however, significantly larger than that of cleft palate Group 1, which had acceptable speech. This may indicate that normals speak with greater amounts of intraoral pressure than is needed for recognition of the sounds as normal productions. Matsuya (*10*) reported when normals whispered plosives the intraoral pressure was 20 mm H_2O, which was about the same as that of the cleft palate Group 1 in the present study.

TABLE 6. Means and standard deviations for the maximum value of nasal air flow rate (in cc/sec), and t tests for the differences between isolated and repeated CVs in each group (t_c) and between repeated CVs of cleft palate Group 1 and cleft palate Group 2 (t_g). None of the ts is significant.

	cleft palate 1		*cleft palate 2*	
	M	*SD*	*M*	*SD*
voiceless				
isolated	114	111	110	99
repeated	85	91	75	71
t_c	1.58		1.52	
t_g			0.54	
voiced				
isolated	128	118	114	83
repeated	107	85	90	78
t_c	0.97		1.30	
t_g			0.93	

TABLE 7. Means and standard deviations for the ratio of velopharyngeal size, and t tests for the differences between the isolated and repeated CVs in each group (t_c). Asterisked ts are significant at the .05 level.

	cleft palate 1			*cleft palate 2*		
	M	*SD*	t_c	*M*	*SD*	t_c
voiceless	0.919	0.271	1.74*	1.214	0.446	2.04*
voiced	1.048	0.429	−0.60	1.063	0.352	1.01

The air pressure in the normals and in the cleft palate Group 1 in the repeated CVs showed little difference from that in the isolated ones, but it decreased somewhat in the cleft palate Group 2, especially in the voiced syllables. This fact indicates that to produce the repeated CVs correctly it is necessary to maintain air pressure as high as in the isolated ones. This is logical since the value of air pressure is an index of the amount of consonant energy. In the studies by Morris and associates (*11*) and Spriestersbach and associates (*13*), good articulatory performance in consonant blends was related to the ability to impound sufficient air in the oral cavity. In addition to this, it is also necessary that air pressure reach its maximum just before the initiation of phonation to be converted effectively into sound energy. As shown in Table 10, the length of time from the maximum point of air pressure to the onset of sound (Pm-Ss) was larger in the repeated CVs than in the isolated ones for the cleft palate Group 2. Thus it can be said that deficiency of consonants

TABLE 8. Means and standard deviations for durations (in msec) for the normal group, and summary of t tests for differences between isolated and repeated CVs (t_c). Asterisked ts are significant at the .05 level.

	Os-Ss		*Om-Ss*		*Ps-Ss*		*Pm-Ss*		*Os-Pm*		*Om-Pm*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	28	18	119	40	−232	79	3	9	25	22	116	38
repeated	35	19	139	26	−116	48	5	13	30	24	134	28
t_c	−1.79		−2.75*		−8.28*		−0.76		−1.06		−2.70*	
voiced												
isolated	36	23	139	37	−118	59	18	22	18	17	122	36
repeated	40	24	156	38	−73	43	15	19	25	9	141	29
t_c	−0.53		−1.98		−4.03*		0.55		−1.86		−2.66*	

TABLE 9. Means and standard deviations for durations (in msec) for the cleft palate Group 1, and summary of t tests for differences between isolated and repeated CVs (t_c). Asterisked ts are significant at the .05 level.

	Ns-Ss		*Nm-Ss*		*Os-Ss*		*Om-Ss*		*Ps-Ss*		*Pm-Ss*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	−79	113	29	61	26	21	121	42	−134	91	5	15
repeated	−47	85	35	44	27	34	141	46	−95	49	2	16
t_c	−1.58		−0.64		−0.22		−2.65*		−2.68*		1.09	
voiced												
isolated	−109	81	17	42	33	30	134	50	−115	54	7	12
repeated	−74	57	18	38	41	31	148	56	−76	38	11	16
t_c	−2.22*		−0.15		−1.14		−1.18		−3.66*		−1.22	

	Ps-Ns		*Pm-Nm*		*Os-Nm*		*Om-Nm*		*Os-Pm*		*Om-Pm*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	−39	98	−10	53	−1	54	90	74	17	64	112	49
repeated	−30	73	−29	63	−5	63	103	83	28	39	146	54
t_c	−0.56		1.59		0.30		−0.85		−1.87		−3.25*	
voiced												
isolated	6	53	−3	29	19	55	128	83	22	25	127	53
repeated	0	37	−7	30	24	40	130	76	31	28	140	46
t_c	0.51		0.57		−0.46		−1.52		−1.38		−1.23	

TABLE 10. Means and standard deviations for durations (in msec) for the cleft palate Group 2, and summary of *t* tests for differences between isolated and repeated CVs and between repeated CVs of cleft palate Group 1 and Group 2 (t_g). Asterisked *t*s are significant at the .05 level.

	Ns-Ss		*Nm-Ss*		*Os-Ss*		*Om-Ss*		*Ps-Ss*		*Pm-Ss*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	−80	112	48	29	25	19	121	40	−138	93	10	18
repeated	−38	91	62	64	37	19	136	22	−80	61	13	28
t_c	−1.36		−0.94		−2.24*		−1.62		−2.36*		−0.40	
t_g	−0.55		−2.05*		−1.40		0.58		−1.04		−1.45	
voiced												
isolated	−102	68	25	32	25	34	127	42	−120	73	10	10
repeated	−56	42	36	35	52	33	155	51	−70	42	18	27
t_c	−3.56*		−1.46		−3.79*		−0.85		−5.48*		−1.69	
t_g	−1.63		−2.19*		−1.62		−0.63		−0.71		−1.30	
	Ps-Ns		*Pm-Nm*		*Os-Nm*		*Om-Nm*		*Os-Pm*		*Om-Pm*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
voiceless												
isolated	−21	114	−33	31	−23	41	69	38	14	24	99	25
repeated	−19	28	−37	45	−24	63	74	72	32	25	127	46
t_c	−0.07		0.24		0.09		−0.27		−2.24*		−2.48*	
t_g	−2.61*		0.43		1.20		1.41		−0.36		1.28	
voiced												
isolated	−11	77	−15	25	0	38	98	44	13	30	110	34
repeated	−12	31	−20	19	16	28	121	54	35	25	142	48
t_c	0.04		1.08		−2.08*		−2.10*		−3.57*		−3.47*	
t_g	1.53		2.24*		1.07		0.62		−0.61		−0.11	

energy in the repeated CVs of the cleft palate subjects was caused by either the insufficiency of intraoral air pressure or the faulty use of air pressure due to the time gap, or by both.

AIRFLOW RATES. Several scholars have considered the possibility that adequacy of cleft palate speech is strongly influenced by the leakage of air through the nose, and the amount of nasal airflow has been measured in several ways (*2, 13, 17*). Articulatory performance, however, has not been found to have a close relationship to the amount of nasal airflow (*10*). The volume of nasal airflow during production of plosives is affected by the velopharyngeal size and the intensity of respiratory effort, but it is also dependent upon the rate of speech production and on the duration of phonation. Accordingly, flow rates and time-relationships of the speech patterns are expected to provide more effective information

TABLE 11. Summary of analysis of variance testing uniformity of articulatory performances in isolated CVs among three experimental groups. Asterisked *t*s are significant at the .05 level.

source of variance	*Pr*			*Of*			*Os-Ss*		
	df	*mean square*	*F*	*df*	*mean square*	*F*	*df*	*mean square*	*F*
voiceless									
among groups	2	38571.5	49.61*	2	106255.0	2.67	2	216.5	0.53
within groups	135	776.8		135	39740.2		128	412.2	
voiced									
among groups	2	1971.5	3.30*	2	7157.0	0.18	2	1470.0	1.62
within groups	123	597.5		123	39626.0		124	907.3	
	Om-Ss			*Ps-Ss*			*Pm-Ss*		
	df	*mean square*	*F*	*df*	*mean square*	*F*	*df*	*mean square*	*F*
voiceless									
among groups	2	60.0	0.03	2	123658.0	16.05*	2	295.0	1.45
within groups	129	1790.7		111	7708.5		112	203.1	
voiced									
among groups	2	1587.5	0.78	2	354.5	0.09	2	255.5	0.91
within groups	123	2023.1		118	3905.5		120	281.4	

than the volume in comparing the mechanisms of the isolated and the repeated syllables production. Van Hattum and Worth (*17*) reported that the air volume expelled through the nose, which is the integral of flow rate along time, was less in reading sentences than in syllables. But as the duration of phonation was shorter in sentences, the volume might decrease in proportion to the phonation duration, and the 'volume' seemed not to be a satisfactory parameter.

Results from the present study revealed that the maximum values of nasal and oral flow rates tended to decrease in the repeated CVs, especially in the nasal flow rate of the cleft palate Group 2. Taking into account the work of Warren and Devereux (*20*), it can be inferred that the loss of energy in the defective consonants of the cleft palate Group 2 was not compensated because of the reduced flow rate resulting from relatively less respiratory effort.

The value of the nasal flow rate has been utilized as a parameter to measure the velopharyngeal size and nasal resistance by other investigators (*6, 18*) and in the present study.

Velopharyngeal Size. If flow rate is considered to be proportional to the velopharyngeal contracture, the cross-sectional area of the contracture can be calculated by the hydrodynamic equation described in the Appendix. The equation was essentially the same as the principle formula utilized by Warren and DuBois (*19*). Although the value of the coefficient in the equation should be determined precisely before applying the equation, the ratio between the areas in the two experimental conditions was calculated to eliminate the effect of the coefficient.

The one-tailed t tests revealed that, in voiceless syllables, velopharyngeal size during the repeated CVs production decreased in Group 1 but increased in Group 2, in relationship to the isolated syllable for each group. The differences, however, were not significant in the voiced syllables. When the size increased, it became more difficult to impound air in the oral cavity to maintain a great amount of intraoral pressure (*13, 15*). This might be a reason for the poor articulatory performance in the repeated syllables of the cleft palate Group 2.

The studies of Subtelny and Subtelny (*15*) and Warren and Devereux (*20*) indicated that when the cross-sectional area was larger than about 0.2 cm^2, the amount of the intraoral pressure was plateaued. This fact may support the finding in the present study that the deviation of the area was greater than that of pressure.

TIME-RELATIONSHIPS. Time-relationships of the patterns of airflow rates, air pressure, and speech sounds have been studied briefly by others (*7, 16, 22*). The measured durations in the present study, however, were selected to investigate the time-relationships more completely. These durations were considered to be effective as they showed significant differences between the experimental conditions (t_1 in Table 3), between the experimental groups (t_2 and t_2' in Table 3), or both, and because the numbers of the items were balanced among the patterns.

Time-relationships for the isolated and for the repeated syllables were essentially the same in both the normal group and in the cleft palate Group 1. On the other hand, in Group 2 the oral airflow for the repeated CVs, especially in the voiced consonants, was delayed as compared to that of the isolated ones, and the nasal airflow for the repeated ones was delayed more than that for Group 1. These deviations caused the disharmony between the transmission of airflow and that of pressure, which might make conversion of pressure energy into sound energy insufficient. Decrease of air energy or less respiratory effort would be a common reason for these deviations (decrease of the maximum values of intraoral pressure and nasal flow rate). This hypothesis is supported by findings of Stetson (*14*) that the respiratory movements of the chest during connected speech were different from those during isolated sounds.

Comparisons were made between the voiced and voiceless consonants separately, but an apparent difference between the manners of phonation was found only in the changes of velopharyngeal size. No further discussions can be made concerning the effect of manner of phonation on the articulatory deficiency in the present study. Although statistical treatments were performed on all data, only a few differences were found significant. These might be explained by the possibility that not all individuals in Group 2 showed slight differences in an item, but a few subjects showed marked differences, while others did not, and the mean of the group revealed no significant difference. Therefore the cause of articulatory deficiency in the repeated CVs was not identical for all subjects. However, there were differences among subjects and one or more combinations of the possible reasons discussed above might cause those differences.

Summary

The purposes of the present study were to investigate the physical characteristics in CV syllables production, and to discuss the reasons for defects in the repeated syllables of cleft palate subjects. Production of one CV per second (isolated syllable) and five CVs per second (repeated syllables) were compared from the viewpoint of hydrodynamics. Postoperative cleft palate adults, eighteen males and eighteen females, were selected and were classified according to articulatory performances into two groups. Those in Group 1 could produce the isolated and the repeated syllables sufficiently, and those in Group 2 could speak the isolated ones well but not the repeated syllables. Further, seven male and seven female normal adults were chosen as a control group. The oral and the nasal airflow rates were measured by differential pressure flowmeters, and the intraoral air pressure was measured by a strain gauge. Velopharyngeal size was calculated from the parameters, and the time-relationships of the patterns were also measured. The data were compared at the 5% significant level.

For the normal and the cleft palate Group 1, the maximum value of the intraoral pressure, nasal airflow rate, velopharyngeal size, and time-relationships of the patterns revealed no significant differences between the isolated and the repeated CV syllables of either group. On the contrary, in repeated syllables of the cleft palate Group 2, velopharyngeal size became larger, decreasing the amount of the air pressure, and time-relationships were deviated. In a case with less respiratory effort, these might be combined. One or combinations of these factors could be considered as the reason(s) for the articulatory deficiency in the repeated syllable production of the cleft palate subjects.

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APPENDIX: Derivation of the hydrodynamic equation.

When a steady stream flows along a pipe with rigid walls, a sudden contraction of the pipe cross section causes a flow energy loss, $h_{f'}$. To derive the hydrodynamic equation, the following symbols will be used:

s, cross-sectional area at the smaller portion of the pipe (cm^2)

v, average axial velocity of air across a section at the smaller portion (cm/sec)

V, volume flow rate of air (cc/sec)

Δp, difference of pressure at the larger and the smaller portions ($dynes/cm^2$)

g, acceleration of gravity (cm/sec^2)

Z, dimensionless quantity depends on the device

Then h_f can be described in a form (*8*):

$$h_{f'} = Z \cdot \frac{V^2}{2g} \qquad \text{(Equation 1)}$$

This is developed from the energy equation, the momentum law, and the equation of continuity. Detailed explanations in developing this are found in a textbook of hydrodynamics.
As $V = v \cdot s$, $v = V/s$. If we assume that the friction head, $h_{f'}$, is nearly equal to Δp, and replaces v, Equation (1) can be written as

$$\Delta p = \frac{Z}{2g} (v/s)^2, \quad \text{or} \quad s = v \cdot \sqrt{\frac{Z}{2g \cdot \Delta p}} \qquad \text{(Equation 2)}$$

Consider the trachea as the larger cross-sectional part of the pipe, and the velopharyngeal port as the smaller part. The pressure decreases nearly to zero after the exhaled air passes the velopharynx, so that the intraoral pressure, Pr, is taken as the differential pressure. As lips are closed before phonation and air passes into the nose, V equals Nf in the present study. Thus the cross-sectional area as the velopharyngeal contraction, A, is derived from Equation (2).

$$A = Nf \sqrt{\frac{Z}{2g \cdot Pr}}$$

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