An Approach for the Cinefluorographic Study of Articulatory Movements

1969

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Articulation consists of the quick and subtly coordinated activities between oral structures such as soft palate, tongue, cheeks, lips, and teeth. The articulatory mechanism is mainly composed of velopharyngeal function and tongue activity. There have been many studies of the velopharyngeal mechanism (*1, 3, 6, 7, 10, 22*), but tongue activity, and the correlation between velopharyngeal function and tongue activity, have scarcely been investigated yet. Indeed, in the speech clinic, abnormal patterns of tongue movement are observed often. These patterns presumably are related to velopharyngeal incompetency of cleft palate subjects, since there are no indications that there is organic deficiency of the tongue.

The present study was designed to investigate the correlation between velopharyngeal function and tongue activity by using cinefluorographic technique so that the coordinated function might be evaluated. The behavior of the velopharyngeal movement is essentially different from that of the tongue movment. Therefore, in order to analyze the correlation between the two, it is necessary to use time element as the parameter for matching phenomena. Moll (*13*), Powers (*16*), Björk (*2*), Nylén (*15*), and Lubker (*9*) have used their own synchronization systems in the cinefluorographic study of articulatory movements and have demonstrated that useful and reliable data for normal and cleft palate subjects can be obtained. Fujiki and Wada (*4*) have also devised a synchronization system between cinefluoroscopy and phonetic sound, which uses the method of correct time for synchronizing articulatory movements. Their methodology has been used in this study.

Procedure

The details of the synchronization system with correct time measurement have been described in the previous report (*4*).

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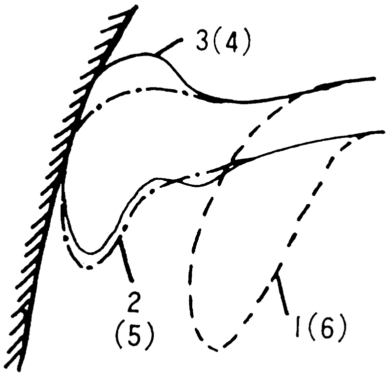

FIGURE 1. Velar movement and its time points: 1) start of the movement (rest position), 2) velopharyngeal closure, 3) maximum velopharyngeal closure, 4) release of maximum velopharyngeal closure, 5) velopharyngeal opening, 6) end of the movement (rest position).

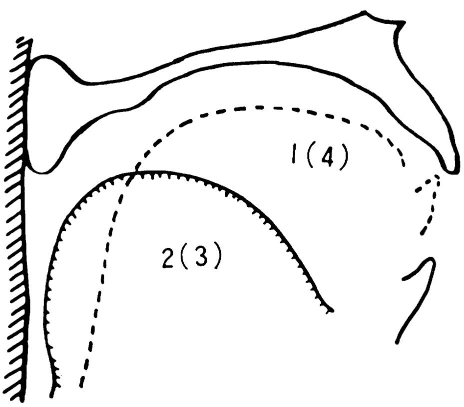

FIGURE 2. Tongue movement and its time points (vowel): 1) start of the movement (rest position), 2) tongue constriction, 3) release of tongue constriction, 4) end of the movement (rest position).

Subjects were three groups of men, age 16 to 24 years. One group, N, was five adults who showed normal articulation. The other two groups were postoperative cleft palate patients examined more than two years after their palate surgery. Five patients, group G, showed complete velopharyngeal closure and acceptable speech for the Japanese consonant /k/. An additional five patients, group P, exhibited incomplete velopharyngeal closure and unacceptable speech for the Japanese consonant /k/.

Speech samples were five Japanese vowels /a/, /o/, /u/, /e/, /i/, and consonant /ka/, /ko/, /ku/, /ke/, /ki/ (*20*). Each subject was instructed to perform each phonation three times in normal pitch and intensity.

The cinefluorographic equipment consisted mainly of an x-ray tube

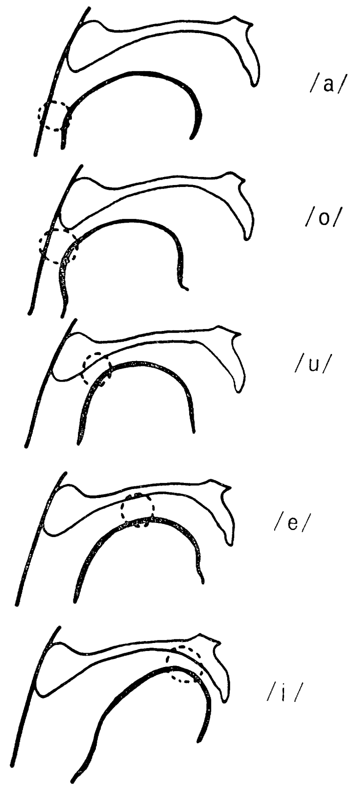

FIGURE 3. The position of tongue constriction in the Japanese vowels (mark ◯). The constriction area of the vocal tract caused by the tongue was located in sequence of /a/, /o/, /u/, /e/, /i/ from the back to the front.

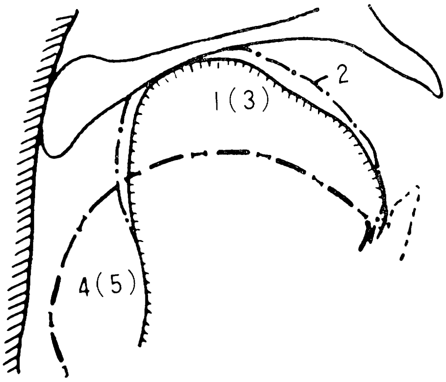

FIGURE 4. Tongue movement and its time points (consonant /k/): start of the movement (rest position), 1) tongue-palate closure, 2) maximum tongue-palate closure, 3) tongue-palate opening, 4) tongue constriction of vowel subsequent to /k/, 5) release of its tongue constriction and end of the movement (rest position).

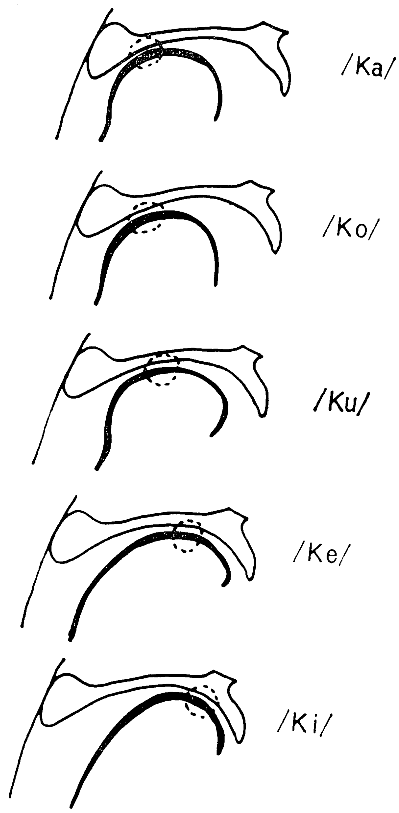

FIGURE 5. The position of tongue constriction in the Japanese consonant /k/ (mark ○). The constriction area of the vocal tract caused by the tongue was located in sequence of /ka/, /ko/, /ku/, /ke/, /ki/ from the back to the front. The preceding consonant /k/ was affected by the characteristics of the subsequent vowels. These were traced from the frames at the onset of phonation.

with a 0.6 mm focal spot, a 7-inch image intensifier tube, and a 16 mm cinecamera, Arriflex 16. Each subject was seated in a chair with the head relatively fixed by a head positioner consisting of ear rods and forehead bumper. Camera speed was 64 frames per second. The radiation dosage for each subject was approximately 2.4 roentgens.

In order to visualize the structures more clearly, two kinds of contrast medium were used prior to the cinefluorographic procedure. The midline of the tongue, the palate, and the posterior pharyngeal wall were coated with a barium sulfate solution; iodoform powder was sprayed to the epipharynx and the nasal side of the soft palate.

Each frame was projected to life size with the film-motion analyzer (Filmotion Model F-105), and tracings were made to observe the articulatory structures qualitatively. The quantitative analysis of the

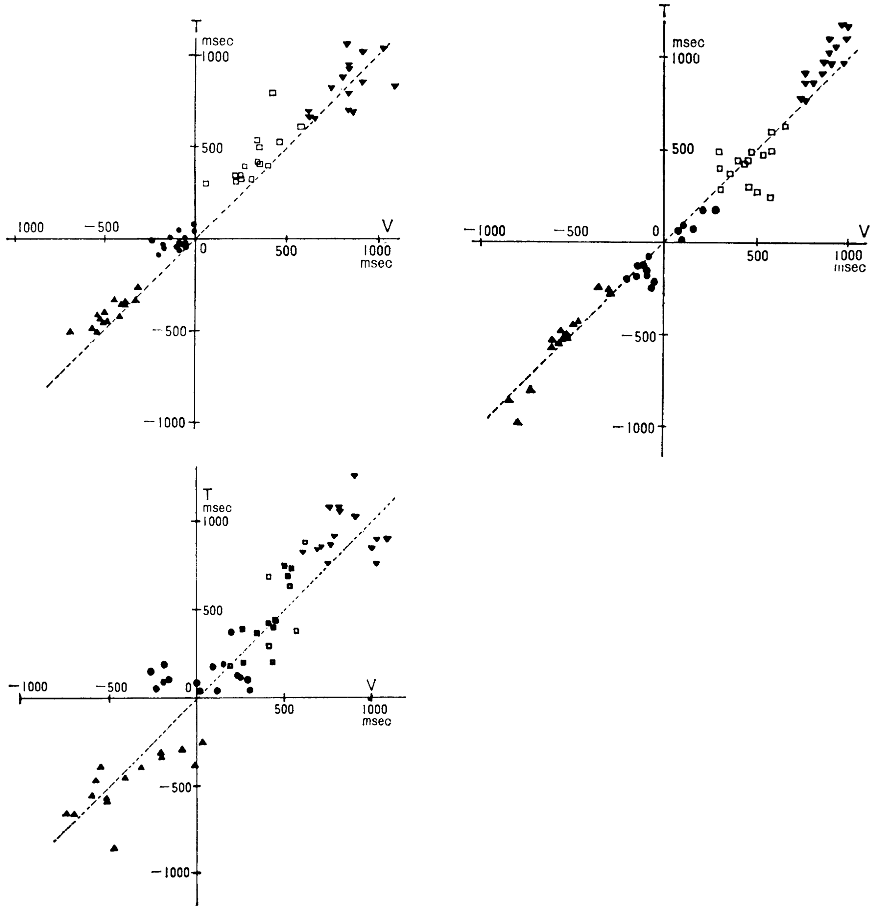

FIGURE 6. Time relationship between the velar movement and the tongue movement (vowel /i/). Upper left, normal group (N); upper right, good speech group (G); lower left, poor speech group (P).

unit of articulation

	velum	*tongue*
▲	start of movement	start of movement
●	V-P closure	constriction
□	release of V-P closure	release of constriction
▼	end of movement	end of movement

time elements was made of the synchronized cinefluorogram with the phonetic sound wave, based on the onset of phonation (*4*).

Results

General Patterns of Articulatory Movements. Patterns of velar movement are shown in Figure 1, and Figure 2 illustrates patterns of tongue movement in a vowel. In normals, the velopharyngeal closure

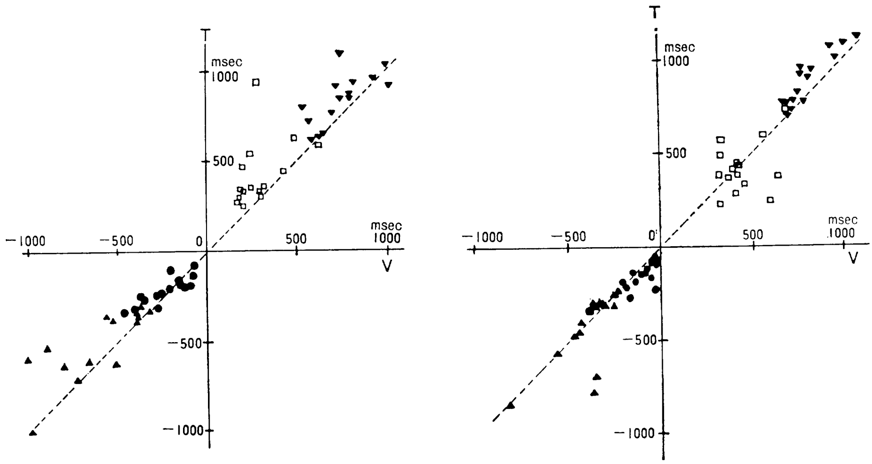

FIGURE 7. Time relationship between the velar movement and the tongue movement (consonant /ki/). Left, normal group (N); right, good speech group (G).

unit of articulation

	velum	*tongue*
▲	start of movement	start of movement
●	V-P closure	T-pal. closure
□	release of V-P closure	release of tongue constriction in subsequent vowel
▼	end of movement	end of movement

was complete and the tongue constriction was observed in a certain position of vocal tract according to each vowel sound. This tongue constriction was being formed during the phonating and released at the end of its phonation. The positions of this constriction in Japanese vowels are shown in Figure 3, which are traced frames at the onset of phonation.

In the Japanese consonant /k/, the pattern of velar movement was similar to the vowels. However, the pattern of tongue movement was peculiar, as shown in Figure 4. The tongue contacts with the palate in the tongue-palate closure almost at the same position. The degree of closure then increases, until the intraoral pressure can be obtained. Thus, it was observed that the consonant /k/ sound was produced as a result of the explosion of this air pressure by the quick opening of this tongue-palate valving. The interesting findings were the positions of tongue constriction at the onset of phonation. As Figure 5 shows, these positions were influenced with the character of vowels which were subsequent to the /k/ sounds. In the good speech group, the patterns of both velar and tongue movements were almost the same as the normals. But, in the poor speech group, abnormal patterns of articulatory movement were observed; no velopharyngeal closure was seen in any trial or in any subject. Although the tongue constrictions

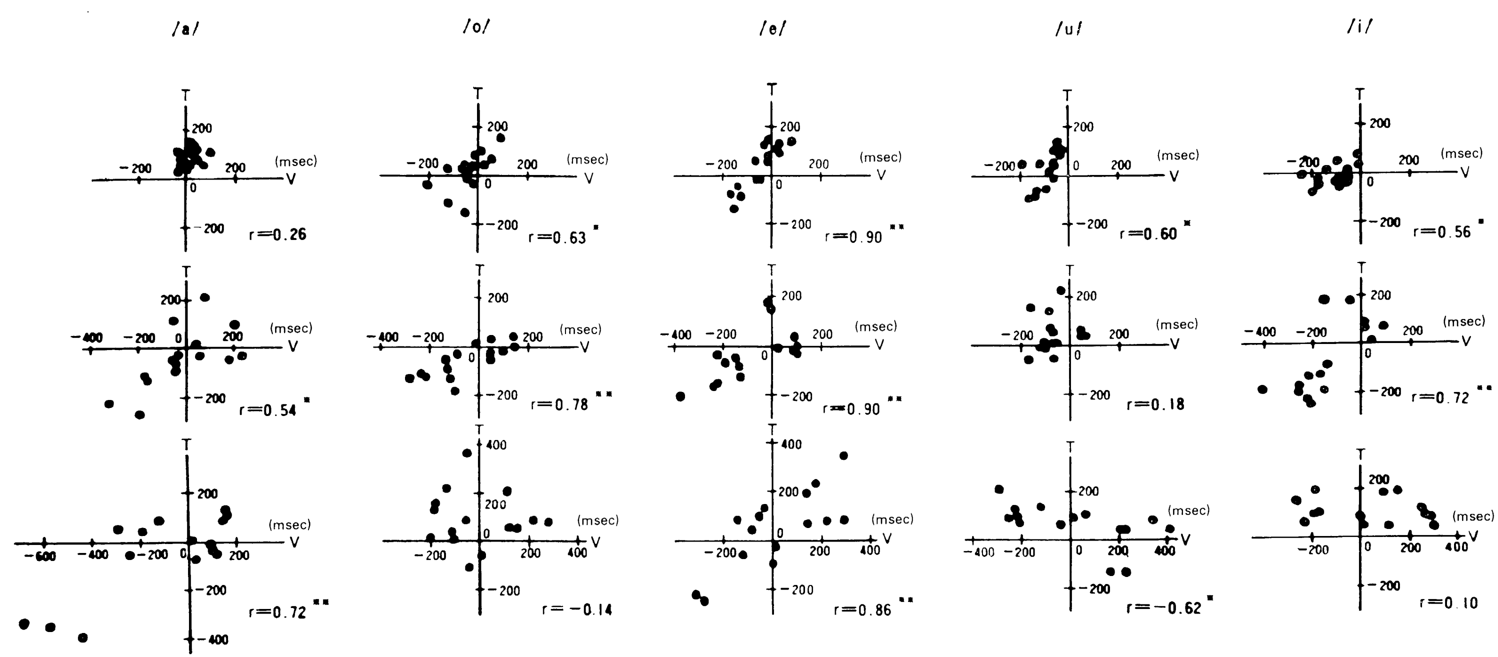

FIGURE 8. Distribution of articulatory unit in vowels (velopharyngeal closure —tongue constriction). Upper, normal group (N); middle, good speech group (G); lower, poor speech group (P).

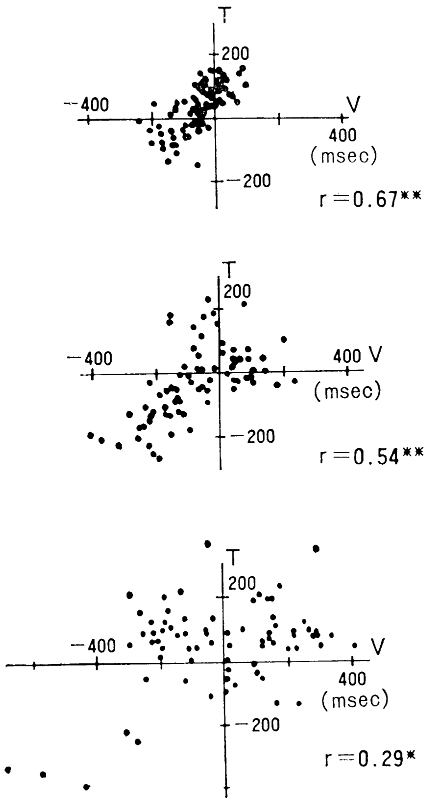

FIGURE 9. Distribution of articulatory unit (75 vowels) (velopharyngeal closure—tongue constriction). Upper, normal group (N); middle, good speech group (G); lower, poor speech group (P).

were observed in the vowels, the tongue-palate closure was almost incomplete in the trials of consonant /k/. Thus, no one in this group could produce the /k/sound.

THE TIME POINTS OF ARTICULATORY POSITIONS. From the observation of the articulatory movements as described above, the physiologic characteristics of the articulatory positions were decided, and their time points were drawn as follows. In the velar movement, in both vowels and consonant /k/, the time points are considered to be the start of the movement (rest position), the point of velopharyngeal closure, the point of maximum velopharyngeal closure, the release of maximum velopharyneal closure, the point of velopharyneal opening, and the end of the movement (rest position) (Figure 1). Since velopharyngeal seal was not created in the poor speech group, closure was interpreted as the moment when the narrowest velopharyngeal port was made.

Regarding tongue movement in the vowels, time points are considered to be the start of the movement (rest position), the point of tongue "constriction", the release of tongue "constriction", and the end of the

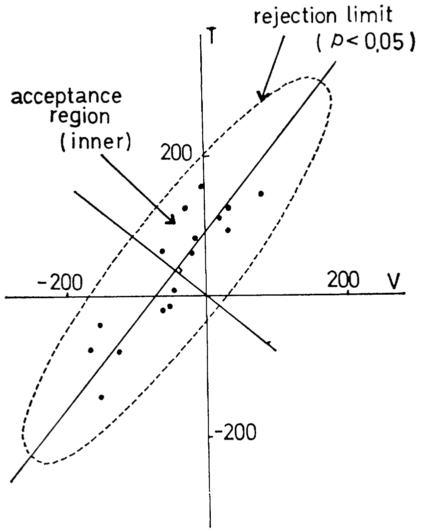

FIGURE 10. Area of acceptance region. Articulatory units are distributed in this area in $p < 0.05$ (vowel /e/ in normal group).

movement (rest position) (Figure 2). In the consonant /k/, time points are the start of the movement, the point of tongue-palate closure, the maximum tongue-palate closure, the point of tongue-palate opening, the point of tongue "constriction" of vowel subsequent to /k/, the release of the tongue "constriction", and the end of the movement (rest position) (Figure 4). These time points were considered to be significant both physiologically and acoustically, and were measured in relation to the onset of phonation.

THE CORRELATION BETWEEN VELAR MOVEMENT AND TONGUE MOVEMENT. In the process of articulatory movement, these time points of velum and tongue were "combined" as they corresponded with each other. These combined elements might be considered as "the articulatory units" between velum and tongue. As Figures 6 and 7 show, these articulatory units were plotted in the coordinate graph. The abscissa (the V-axis) shows the time scale of velar movement, and the ordinate (the T-axis), the time scale of tongue movement. O represents the onset of phonation; the time before the onset of phonation was represented as negative, and after, as positive. Figure 6 shows the Japanese vowel /i/ for group N, G, and P. Such articulatory units are located along the 45° line as the articulatory movements proceed. If they are on this line, both velar and tongue movements occur exactly at the same time. Each group of these marks has a certain distribution and correlation respectively. In groups N and G, each group of the articulatory units shows the relatively small distribution and an apparent correlation, while in group P, the correlation is low and the distribution seems to be larger, as compared with the other two groups.

TABLE 1. Distribution area of articulatory unit in vowels. Calculated as the acceptance region in $p < 0.05$ (velopharyngeal closure—tongue constriction). Data are $msec^2 \times 10^3$.

group	*/a/*	*/o/*	*/e/*	*/u/*	*/i/*
N	37	127	84	83	75
G	487	155	328	149	382
P	770	512	499	446	487

TABLE 2. Score of intelligibility test. Mean percentages of the test sounds produced correctly.

group	*/a/*	*/o/*	*/e/*	*/u/*	*/i/*
N	100	99	100	100	98
G	97	93	98	90	97
P	91	97	76	79	77

In Figure 7, data for the Japanese consonant /ki/ in groups N and G are shown. Similar to the vowel, each group of the articulatory units has a distinctive distribution and correlation; they are almost the same in the two groups. These results suggest that the degree of coordinated function between velum and tongue is high in the normal group, and that it varies according to the quality of speech production in the cleft palate subjects.

THE EVALUATION OF COOPERATIVE FUNCTION OF VELAR ACTIVITY AND TONGUE MOVEMENT. Among the four kinds of these articulatory units in the speech production of the vowels, the most important unit is the correspondence of "velopharyngeal closure" and "tongue constriction". Figure 8 shows the scattergrams of this unit in five vowels. The upper is the normal group (N), the middle is the good speech group of cleft palate subjects (G), and the lower is the poor speech group of cleft palate subjects (P). The distribution of the marks is larger in group G, and much larger in group P than in group N.

This fact suggests that this correspondence factor is highly related to intelligibility. Including all the vowels, this difference is remarkable as shown in Figure 9. If the distribution is relatively small, the articulatory movement occurs at the constant time point, and the coordination is made with regularity in each trial and in each subject. Therefore, the distribution gradation is one of the indicators used to evaluate coordinated function between velum and tongue.

In order to quantify this distribution, the rejection limit was calculated at the 95% level. Figure 10 shows the area of the acceptance region of /e/ in the normal group which is defined by the rejection

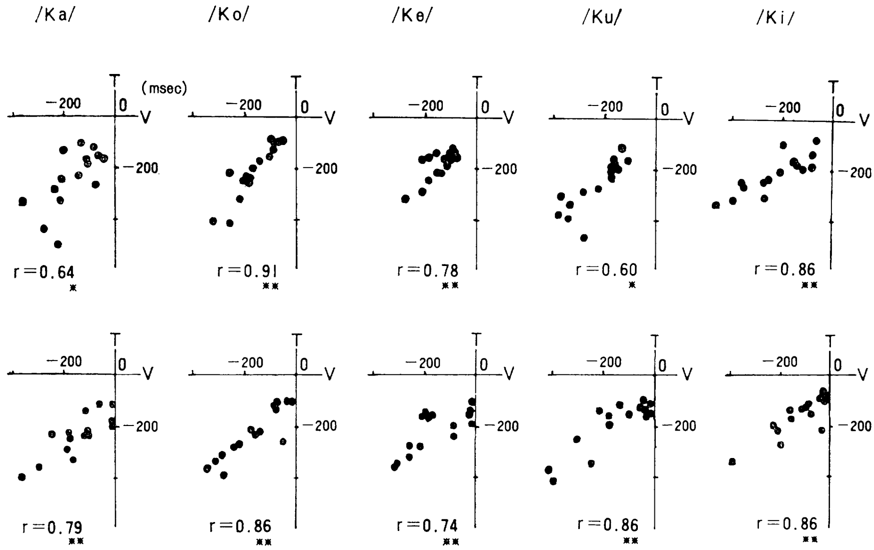

FIGURE 11. Distribution of articulatory units in /k/ consonants (velopharyngeal closure—tongue-palate closure). Upper, normal group (N); lower, good speech group (G).

limit. Each of these articulatory units is included in this area. Table 1 shows this distribution area of articulatory unit calculated as the acceptance region. The greater value indicates that the distribution is larger, which means the cooperative function is lower. This finding corresponds to the score on the intelligibility test, as shown in Table 2. These data reveal that groups N and G have the high coordinated function between the velopharyngeal closure and the tongue constriction, while in the group P, the function is lower. However, even if the coordinated function is low, the vowels are produced mainly by the tongue constriction activity, which appears to be characteristic of vowel production.

On the other hand, in the speech production of the /k/ sound, the most important articulatory unit is the correspondence of "velopharyngeal closure" and "tongue-palate closure". The poor speech group (P), however, did not show tongue-palate closure, and there was no production of /k/ sound in all subjects. So, this group was excluded from the comparison with other groups.

Figure 11 shows the scattergrams of this unit. The distribution of the points seems to be almost the same between normal group (N) and good speech group (G). In the good speech group, however, there were few cases who showed velopharyngeal closure so close to the onset of phonation. This fact might suggest that the disturbance of velar movement exists to some extent in cleft palate subjects. Figure 12 shows these manifestations including all the /k/ sounds. The distribution area

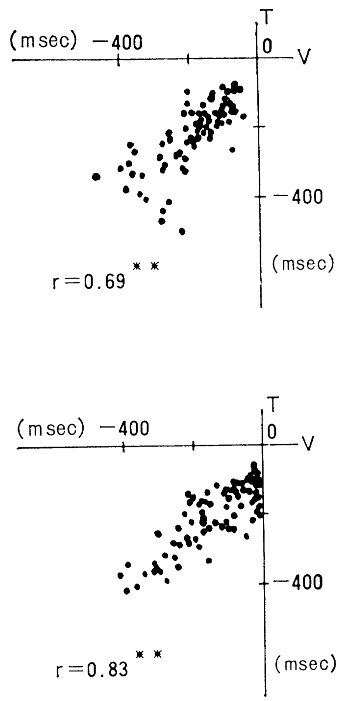

FIGURE 12. Distribution of articulatory units (75 /k/ consonants) (velopharyngeal closure—tongue-palate closure). Upper, normal group (N); lower, good speech group (G).

is shown in Table 3 as the acceptance region at the 95% level for the evaluation of the cooperative function, while Table 4 shows the score of the intelligibility test.

From these results, both groups have a high degree of coordinated function between "velopharyngeal closure" and "tongue-palate closure" necessary for the normal production of /k/ sound.

Discussion

The speech samples in this study are the vowels and the consonant /k/ of the Japanese. The production of this consonant requires not only complete velopharyngeal closure, but also tongue-palate closure, both of which create high intraoral pressure. The /k/ sound is produced as the result of an explosion of the air stream caused by the quick opening of this tongue-palate valving.

Most of the cleft patients have a disturbance of the articulatory function in this consonant. In addition, they show many difficulties in obtaining the normal articulatory pattern, even if the clefts have been repaired successfully (*3, 12, 14, 19*). Thus, this consonant is one of the appropriate speech samples for the analysis of the articulatory pattern

TABLE 3. Distribution area of articulatory unit in /k/ consonants. Calculated as the acceptance region in $p < 0.05$ (velopharyngeal closure—tongue-palate closure). Data are msec^2 $\times$ 10^3.

group	*/ka/*	*/ko/*	*/ke/*	*/ku/*	*/ki/*
N	200	99	58	145	138
G	137	143	159	190	113

TABLE 4. Score of intelligibility test. Mean percentages of the test sounds produced correctly.

group	*/ka/*	*/ko/*	*/ke/*	*/ku/*	*/ki/*
N	98	100	100	99	98
G	96	97	94	90	94

of tongue movement and also for the evaluation of the correlation with velar movement.

To quantify the information from the cinefluorographic films, there have been many attempts to measure the structural positions and movements (*9, 13, 16*). In the present study, various time points were selected at the moments when the articulatory movements assumed positions which were physiologically significant: start or end of the movement, the contact of two structures, the structural constriction, et cetera. The time points of the articulatory positions of the velum were selected as described in the results.

The analysis of the movements of the tongue is difficult because of its amorphous contour during the movement. Laminagraphs and cephalograms (*5, 23*) have been used to demonstrate tongue position with satisfactory measurement, but the measures have the severe limitations that they are made only before or during the phonation. Moll (*13*) and Powers (*16*) reported tongue-pharyngeal wall distance and the tongue-alveolus distance with significant results.

Stevens and House (*18*) defined the parameters of the vocal tract analog in vowel production: position of tongue constriction, the size of constriction formed by the tongue, and the dimensions in the vicinity of the mouth opening. In this study, this notion was applied; the time point was selected when the vocal tract was made narrowest by the physiological tongue constriction.

The Japanese consonant generally consists of the combination of CV (preceding consonant + subsequent vowel). The tongue-palate closure in the various Japanese /k/s, when strictly observed, took the different positions which were affected by the characters of the subsequent vowels; the sequence of /ka/, /ko/, /ku/, /ke/, /ki/ was displayed from the back to the front in the vocal tract. These results correspond closely to those of the palatogram and to the findings of Hattori (*8*). In addition, these phenomena are observable at the very moment of the onset of phonation, as shown in Figure 5, and suggest the features of coarticulation of the CV combination in a primitive form.

The time relationship between the articulatory movement and the sound varies among the subjects and even within trials for the same subject (*2, 21*). This study also showed the remarkable time variations in both velar and tongue movement. Therefore, it seems impossible to compare the mean values between groups; significant difference was small among the sounds and nonexistent among the groups.

These data developed the notion about interaction between velar and tongue movement, since the relative timing is one of the most important factors in speech production. Inadequate timing, such as the time lag between these two oral structures, seems to be proof that the articulatory cooperation is poor even if each of the structures shows no articulatory placement errors. Consequently, the articulatory unit was defined in this study as the combination of the articulatory positions of both structures which are significant acoustically and physiologically.

As one of the criteria of the coordinated function, the distribution gradation of articulatory unit was selected such that both articulatory movements assume positions at the constant time point. It was also assumed that the correlation coefficient might be another indicator of the coordinated function since there is a possibility that time delays, if present, are similar for the structures. A positive significant correlation was obtained (Tables 5 and 6). For the articulatory unit of the "velopharyngeal closure" and "tongue constriction" in the vowels, the absence of coordinated function was demonstrated in /o/, /u/, and /i/ in the poor speech group. In addition, the distribution area is relatively large, as shown in Table 1 and Figure 8. On the other hand, the good speech group and the normal group showed a statistically significant correlation except for /u/ in the good speech group, and for /a/ in the normal group. These exceptions might be explained by the fact that the distribution area is relatively small, as shown in Table 1 and Figure 8. It was remarkable in /a/ of the normal group that both articulatory movements took their positions at the more constant time point.

As for the articulatory unit of the "velopharyngeal closure" and "the tongue-palate closure" in the /k/ sounds, the correlation coefficients show the statistical significance in both groups. This result corresponds to that of the distribution area, as shown in Table 3 and Figure 11. In the good speech group, the fact that some of the velopharyngeal closures occurred near the onset of phonation suggests the disturbance of velar movement, but these significant correlations and distribution areas reveal that the tongue perhaps assumed

TABLE 5. Correlation coefficients of each articulatory unit (vowels). One asterisk indicates significance at the 5% level; two asterisks indicate significance at the 1% level.

velum	tongue	group	/a/	/o/	/e/	/u/	/i/
		N	0.60*	0.76**	0.86**	0.98**	0.89**
▲ start of movmt.	start of movmt.	G	0.96**	0.98**	0.94**	0.96**	0.98**
		P	0.98**	0.94**	0.90**	0.43	0.82**
		N	0.26	0.63*	0.90**	0.60*	0.56*
● V-P closure	constriction	G	0.54*	0.78**	0.90**	0.18	0.72**
		P	0.72**	−0.14	0.86**	−0.62*	0.10
		N	0.95**	0.95**	0.80**	0.81**	0.23
□ release of V-P closure	release of constriction	G	0.45	0.79**	0.65**	0.93**	0.39
		P	0.92**	0.89**	0.51	0.80**	0.61*
		N	0.60*	0.94**	0.98**	0.76**	0.54*
▼ end of movmt.	end of movmt.	G	0.90**	0.87**	0.95**	0.96**	0.86**
		P	0.69**	0.83**	0.69**	0.38	0.17

TABLE 6. Correlation coefficients of each articulatory unit (/k/ consonants). One asterisk indicates significance at the 5% level; two asterisks indicate significance at the 1% level.

velum	tongue	group	/ka/	/ko/	/ke/	/ku/	/ki/
▲ start of movmt.	start of movmt.	N	0.84**	0.66**	0.79**	0.85**	0.72**
		G	0.66**	0.54*	0.64*	0.94**	0.72**
● V-P closure	T-pal. closure	N	0.64*	0.91**	0.78**	0.60*	0.86**
		G	0.79**	0.86**	0.74**	0.86**	0.86**
□ release of V-P closure	release of tongue constriction in subsequent vowel	N	0.91**	0.96**	0.53*	0.73**	0.32
		G	0.61*	0.42	0.93**	0.75**	0.29
▼ end of movmt.	end of movmt.	N	0.84**	0.62*	0.77**	0.78**	0.70**
		G	0.91**	0.95**	0.93**	0.59*	0.92**

positions to compensate for the velar disturbance or to assist the velar activity.

In the cleft palate patients, the articulatory errors involving the absence of coordinated function have been pointed out (*11, 17, 19*), but the correlation or the analysis of the coordinated function have not been made in a quantitative form. From the results of the present study, it appears that the poor speech group (with velopharyngeal incompetence) could not obtain the coordinated function due to the perturbation of the articulatory movements. However, it is unknown exactly whether the palatal incompetency has influence upon the tongue movement or whether the abnormal habit of tongue movement acquired before surgical repair exists independently of the velopharyngeal incompetency.

Further investigation of this problem would be important to obtain information about the coordinated function of these oral structures.

Summary and Conclusion

By the method of synchronization and time measurement in cinefluorography, the coordinated function of velar and tongue movement was evaluated on the speech production of Japanese vowels and /k/ sounds in normal subjects and in postoperative cleft palate subjects. Three groups of subjects were studied: a normal group and two groups of cleft palate patients, one with good speech and velopharyngeal competency, and the other with poor speech and velopharyngeal incompetency. The articulatory patterns were observed and the time relationship between the articulatory movements and phonation was analyzed. From the results of this study the following conclusions were drawn. a) The position of tongue constriction in /k/ sounds was located in a sequence of /ka/, /ko/, /ku/, /ke/, /ki/ from the back to the front, and this sequence corresponds to that in the vowels, demonstrating that the character of the subsequent vowels had influence upon their positions. b) In the patterns of articulatory movements, some articulatory units can be defined by the combination of the articulatory positions between the velum and the tongue which are considered to show the physiologic significance. c) Through the analysis of the articulatory units, the coordinated function of the tongue and palate was evaluated. The normal group showed a strong relationship demonstrating a small dispersion and a high correlation of all units throughout the articulatory process, while the cleft palate groups showed that the relationship corresponded with scores of an intelligibility test. d) Some of the cleft palate patients had disturbance of velar movement, to some extent, regardless of whether their speech was acceptable. Vowel production was considered normal although in some instances quality was not good.

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