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ARTICULATORY MOVEMENTS IN APRAXIA OF SPEECH

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Introduction

Since Broca[1] designated " disorder limited to speech output" which does not result from muscle weakness as aphemia, a fairly large amount of studies have been developed on the symptoms. However, discussions on the nature of the disorder have been controversial and its underlying mechanism still remains unknown. Regarding the nature of aphemia(apraxia of speech), three interpretations have been presented, that is, aphasia, apraxia and dysarthria. Recent acoustic and physiological studies have suggested that apraxia of speech is a kind of motor impairment. Among them dirct and simultanous observations of articulators, such as those using X-ray microbeam system are thought to be promising to clarify the nature of the disorder. An important factor which would affect the data is purity and severity of the disorder. Since pure form of apraxia of speech is rare,in many of studies, patients with apraxia of speech were contaminated with aphasia. The symptoms greatly vary in severity. Some are mute and some make numerous substitution errors, while others show only distortion errors with dysprosody.

In the present study, two patients with pure apraxia of speech were studied with regard to their articulatory movements using an X-ray microbeam system in order to clarify the general tendencies of the movements as well as the underlying mechanism for the articulatory disturbances such as the substitution, addition distortion or omission of sounds.

Method

Subjects

A detailed description of the case histories and the results of speech and language examination have been reported elsewhere (Sugishita et al.[3]) A brief description of the subjects are as follows:

Case 1 is a 58-year-old, right-handed man. Neurological examination showed a right-sided, lower facial weakness and a right hemiparesis predominantly in the arm, and a right hypesthesia. CT scans and MRI revealed an infarct mainly in pre and post-central gyri. The results of the Japanese edition of the Western Aphasia Battery (WAB) at 5 weeks after onset showed well-preserved auditory and reading comprehension, a mild

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disturbance in writing and a severe speech disturbance. His spontaneous speech was effortful and limited to only 2 or 3 syllables. At 9 months after onset, the writing disturbance had greatly improved, but speech was still severely affected by the substitution, distortion and addition of sounds.

Case 2 is a 27-year-old, left handed man who suffered a subcortical hemorrhage in the right frontal lobe and had an operation to remove the hematoma and the nidus. Neurological examination showed a mild, left-sided, lower facial weakness and a mild paresis of the left arm. MRI and CT scans showed an abnormal low intensity (density) area mainly in the right precentral gyrus. Three weeks after onset, the WAB was carried out and revealed a glaring discrepancy between the speech disturbance and other abilities, namely, those of auditory comprehension, reading comprehension and writing. His spontaneous speech was effortful and consisted of nonsense utterances of 2 or 3 syllables at a slow speaking rate. Four months after onset, his speaking ability had improved to the extent that he sometimes uttered short sentences, where, however, errors of substitution, omission and distortion were still numerous.

Apparatus and Procedure

The X-ray microbeam system developed by Kiritani et al.[2) was used for observation of the articulatory movements. The movements of the articulators could be observed by tracking a few lead pellets attached to them. Pellets were attached to the lower lip, the lower incisors, the tongue tip, the tongue dorsum and the nasal surface of the velum of the subjects. The data output was read into the computer memory core through an X-ray detector and an A/D converter. The coordinate values for each pellet, synchronized with the speech signals, and the trajectories of the pellet movements could be displayed as time functions on an oscilloscope for off-line analyses.

The subjects were required to repeat Japanese nonsense monosyllables,/pe/ and /te/, and polysyllable /peteke/ respectively. They also uttered some meaningful Japanese test words embedded in a frame sentence "ii (or ee)____ desu" (that is good ____ or yes,that is ____). The test words are as follows:

makai,mikai,mikami,nakai,nikai,nikami,basha,washa,katamari

Results

I. nonsense syllable repetition

A. monosyllable repetition

The data of the two separate trials for continuous reputation of /pe/ or /te/ showed a quite similar tendency in all of the subjects. Fig.1 and Fig.2 shows examples of vertical and horizontal movements for each articulator when the patients of apraxia of speech and the normal subject are repeating monosyllables /pe/ and /te/. In case 1 general rate of the repetiton (the time required for each utterance of /pe/ or /te/), excluding that of the first and second utterance is about the same or rather faster than that of the normal subject. The range of displacements of the lip and the tongue,however, tends to be narrower than that of the normal subject indicating that the velocity of the articulators is not necessarily faster.

As for the patterns of the movements, other articulators that are not directly involved, i.e.the jaw and the tongue-tip in /pe/, and the jaw and the lip in /te/ move synchronously with the principal articulator,which is not seen in the normal subject. The synchronous elevation of the tongue-dorsum is seen only before the first utterance , being comparatively independent from the rest of the articulators. For example, a short and independent elevation of the tongue-dorsum is noticed in the prepatory period for the second utterance of /pe/. The exceptionally long prepatory period may be due to self-correction of the erroneous elevation.

In the monosyllable repetition of case 2 the repetition rate is considerably slower while the range of the displacements tend to be greater than that of the normal subject. The opening and closing movements of the lip or the tongue-tip are not so slow compared with those of the normal subject and the reduction of the rate is mainly due to delay in starting the following movements resulting in prolongation of vowels and silent period between sounds.

The movement pattern of the articulators in the repetition of /pe/ is similar to that of the normal subject, where the lip movement is predominant. On the other hand, clear lip elevation larger than that of the jaw movement synchronizing with the tongue-tip as well as slight elevation of the tongue-dorsum, both of which are not observed in the normal subject, are noticed in the repetition of /t/.

B. polysyllable repetition

The data for the polysyllable repetitions were obtained only in the case 1. While the rate of repetition of /pe/ and /te/ in case 1 was about the same or rather faster than that of the normal subject, the number of repeated syllables per second in /peteke/ resulted in less than half of the normal subject's, indicating that qualitative difference between repetition of /pe/ or /te/ and /peteke/ in terms of production process. Fig. 3 shows examples of the movement of each articulator in case 1 and the normal subject repeating /peteke/. The first utterance of /peteke/ in apractic speech takes markedly longer time than the others ,which is mainly due to exceptionally prolonged interval between /pe/ and /te/. The tendency of the longer interval between /pe/ and /te/ is observed in every utterance resulting in addition of /Q/ between them (i.e. /peQteke/) auditorily. The patterns of the articulation are deviated from those of the

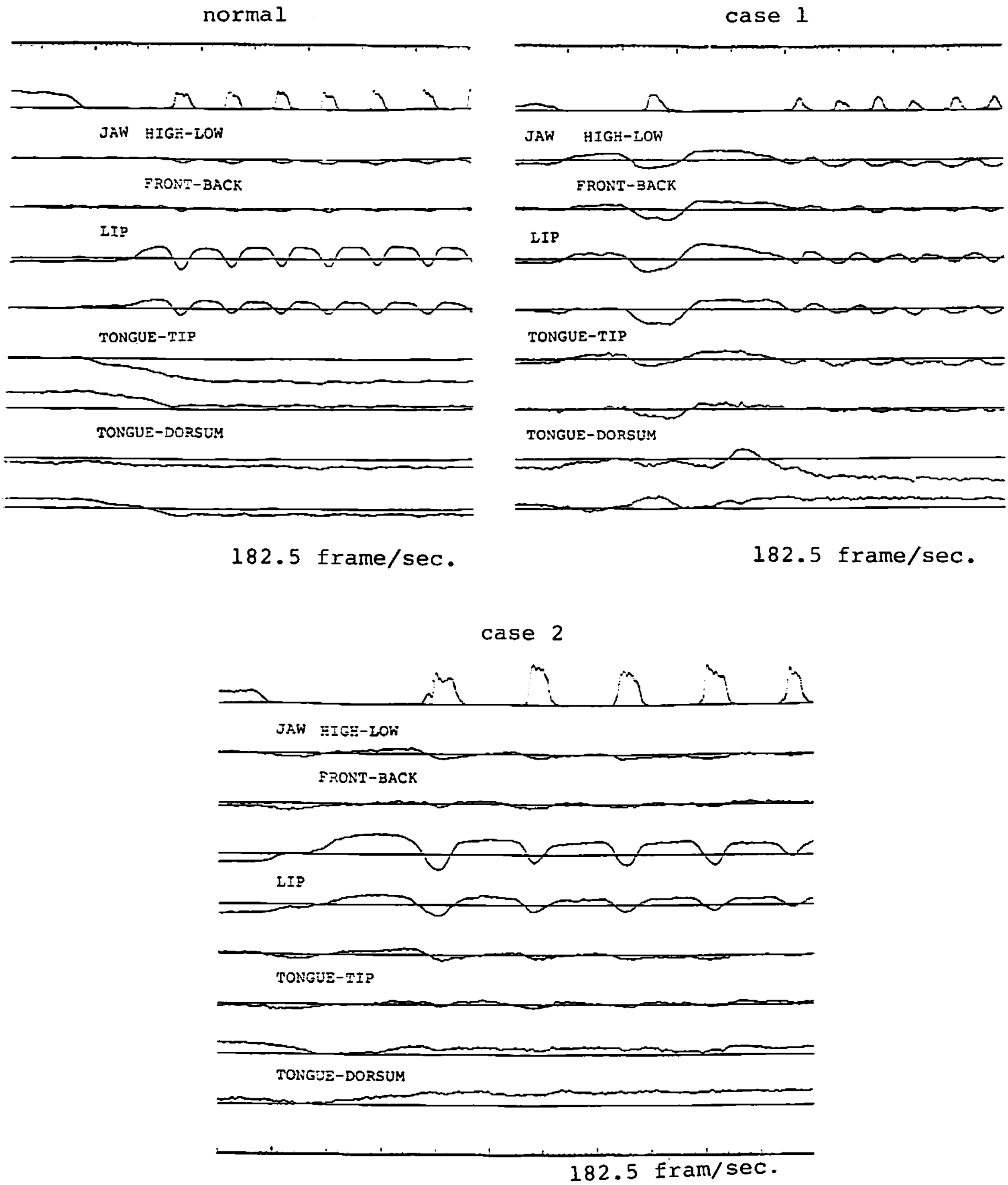


Fig.1. Vertical and horizontal movements of each articulator as a function of time in the normal subject and in the patients with apraxia of speech for repetitions of the monosyllable /pe/.

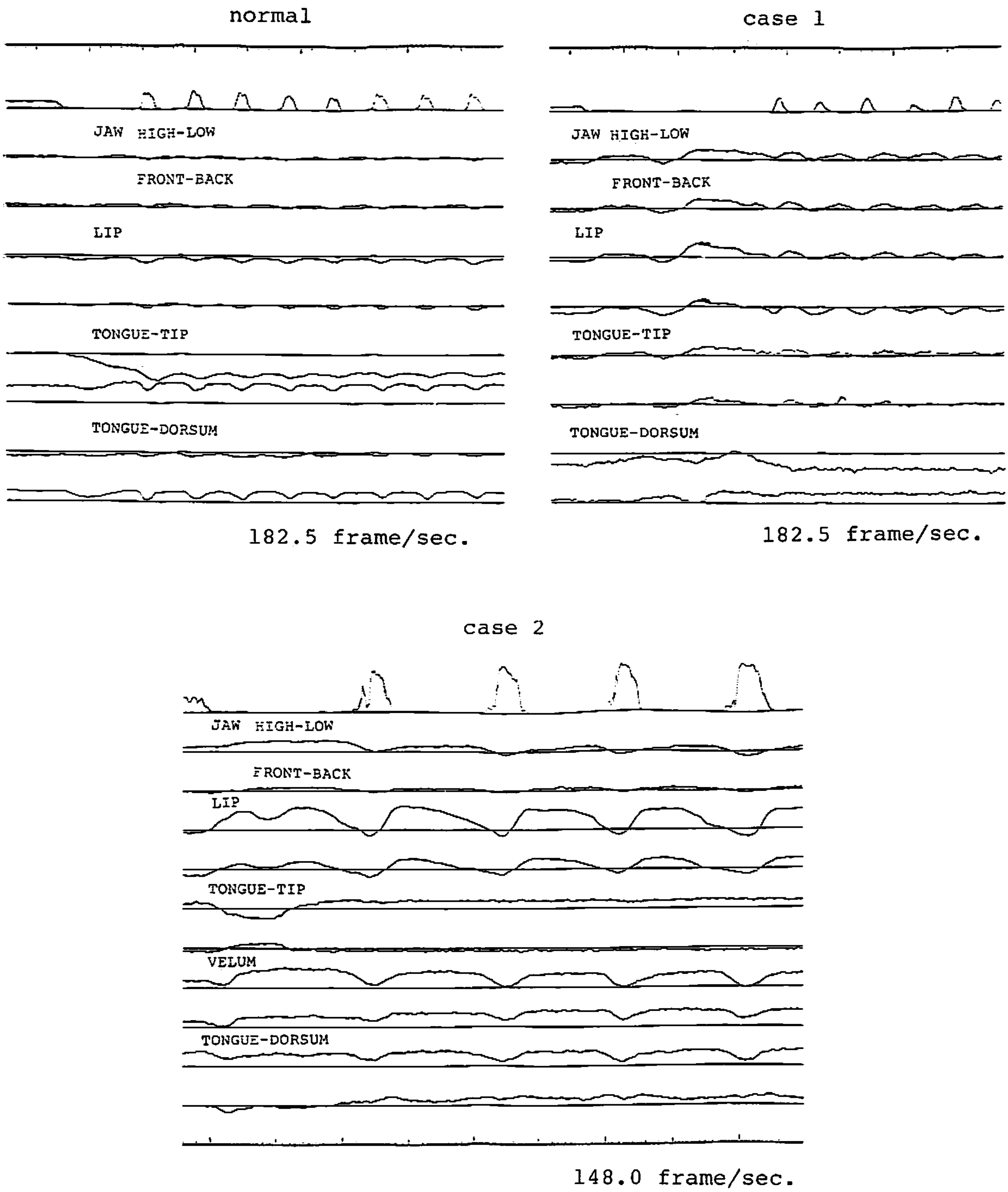


Fig.2. Vertical and horizontal movements of each articulator as a function of time in the normal subject and in the patients with apraxia of speech for repetitions of the monosyllable /te/.

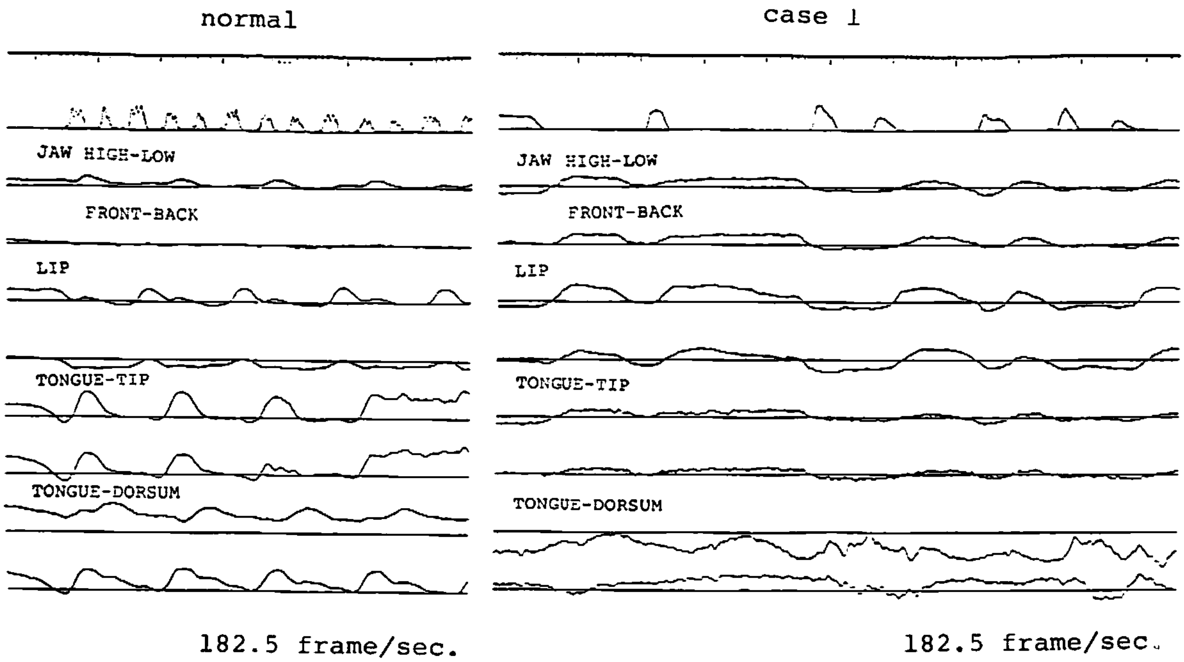


Fig. 3. Vertical and horizontal movements of each articulator as a function of time in the normal subject and in case 1 for repetitions of the polysyllable /peteke/.

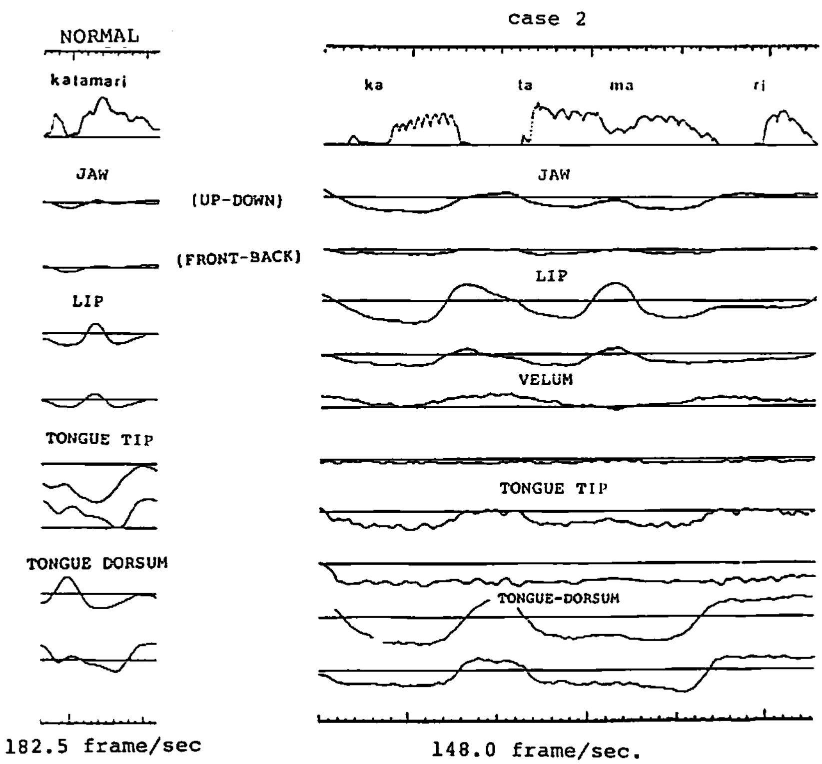


Fig. 4. Vertical horizontal movements of each articulator as a function of time in the normal subject and in case 2 for /katamari/.

normal subject. In the normal subject, each of the lip, tongue-tip and tongue-dorsum elevates independently for the target consonant /p/, /t/ and /k/ though the jaw tends to synchronize with the tongue-tip. In case 1, however, all the articulators but the tongue-dorsum tend to move together. For the first /pe/ the tongue-dorsum also elevates synchronously but it generally shows rather independent movements. Notice the isolate elevation of the tongue dorsum between the first /pe/ and /te/ which may again cause the prolongation of the interval between them. The produced sounds reflect these movement patterns in that /pe/ are often distorted as /pte/ while all of the /ke/ are correct.

Fig.4 indicates examples of /katamari/ (a mass) which contains /k/,/t/ and a bilabial sound /m/ in case 2 and the normal subject. It is noticed that the movements of case 2 are extremely slow relative to those of the normal subject. In addition, all of the articulator elevate together when the target sound is tongue-tip /t/, while the lip elevation for /m/ occurs isolately. These tendencies are consistent with the result of monosyllable repetition. For the tongue-flap sound /ri/, erroneous but marked elevation of tongue-dorsum as well as tongue-tip occurs resulting in substitution of /ki/ for /ri/ as a sound.

II. Data of minimal-pair words

A. /m/ vs. /n/

Coarticulational effect was revealed in case 2 among the data of minimal-pair words. All of the initial /m/ and /n/ were perceived as correct sounds when the following vowel was /a/, while followed by a high vowel /i/ they were perceived as distorted or substituted. This tendency was not apparent in case 1 partly because of the small number of errors (Table 1). The initial /m/ and medial /m/ showed a similar tendency in terms of the error rate and the pattern of the movements in both cases.

As a sound, /m/ was more correctly produced than /n/ in case 1 while for /mi/ in case 2, /ni/ or other lingua-palatal sounds were more often substituted. The data of the movements revealed individual difference between the patients in the tendency of the articulation. In case 1, the elevation of the lip occurs when the target sound is /m/ or /n/, while there is no tongue elevation for /m/, indicating that suppression of the elevation is lacking in the lip for the tongue-tip sounds. Therefore, most /m/s are correctly articulated. In contrast produced sounds for /n/ vary with the timing and degree of the tongue-tip elevation. That is, when the tongue-tip elevates high enough to make complete closure, /n/ is correctly produced. If the elevation is incomplete or omitted or it ceases before the release of the unnecessary lip elevation, the sound changes to /m/ or is distorted as /mn/(Fig.5).

A omission error is observed in one of /ma/, where the lip elevation occurred ahead of the VO(Fig.6).

Table 1

Number of Correct Sounds for /m/ and /n/ Based on Auditory Inpressein in Patients with Apraxia of Speech

	case	1		Total
m	makai	mikai	mikami	
	2/3	3/3	2/3	7/9
n	nakai	nikai	nikami	
	2/3	1/3	1/3	4/9

	case 2			Total
m	makai	mikai	mikami	
	3/3	0/3	0/3	3/9
n	nakai	nikai	nikami	
	3/3	2/3	1/3	6/9

Table 2

Sounds Added to Carrier Word /i:/ in Case 2

g	d	dʒ	n	m	tʃ	∅	Total
10	4	2	1	1	1	1	20

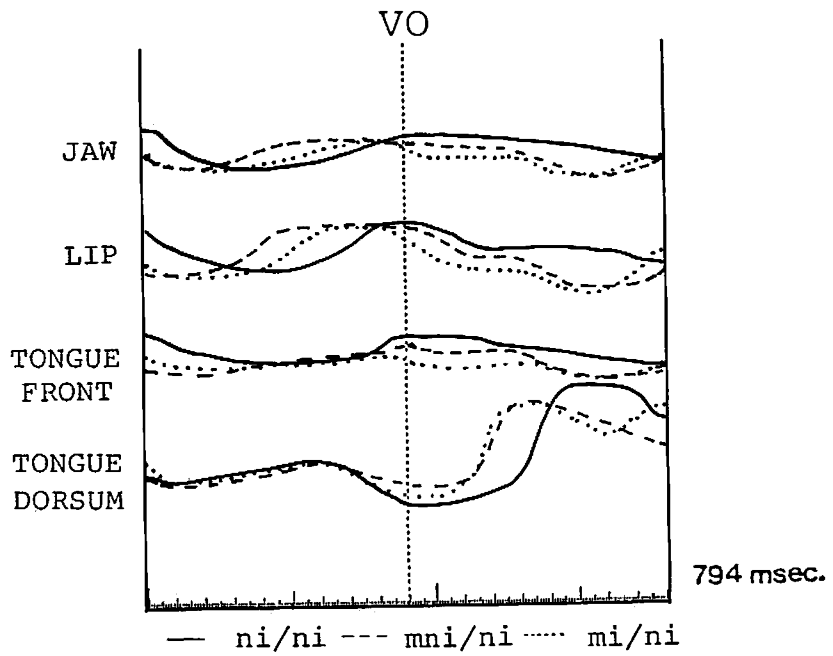


Fig.5. Examples of vertical movements as a function of time in correct, distorted and substituted /ni/ in case 1.

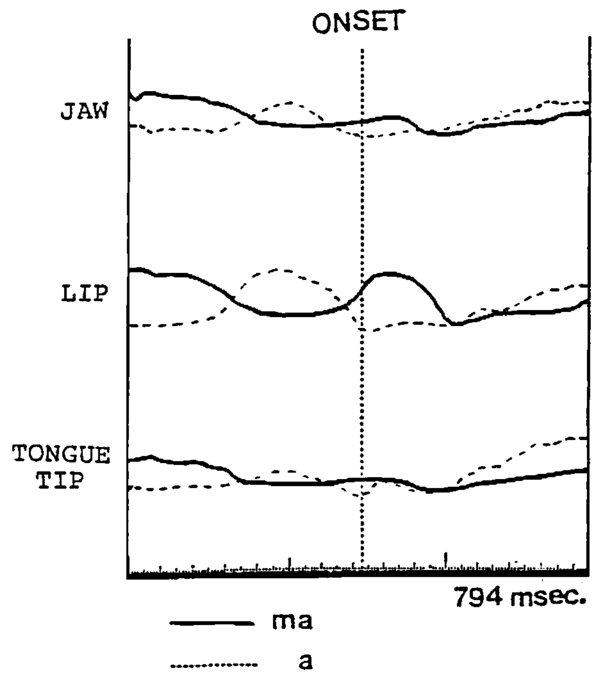


Fig.6. Examples of vertical movements as a function of time in correct /ma/ and omission of /ma/ of case 1.

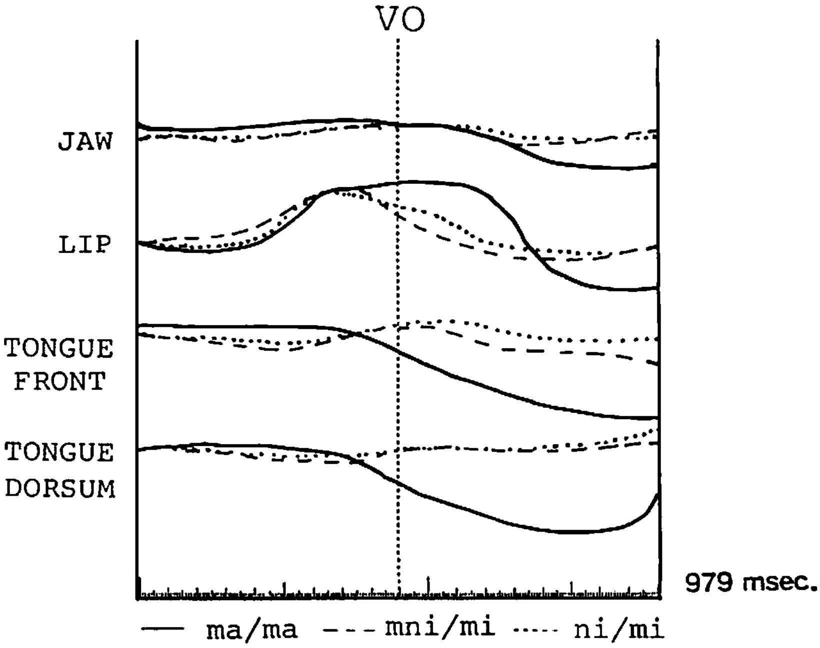
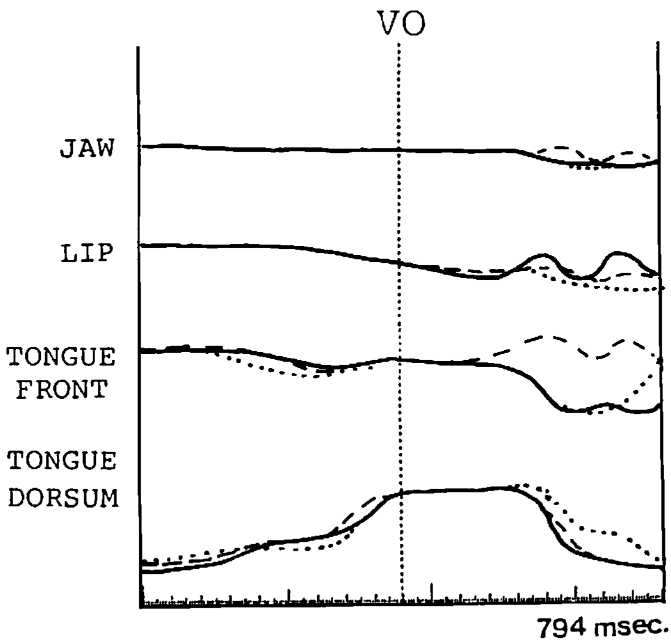


Fig.7. Examples of vertical movements as a function of time in correct /ma/, distorted and substituted /mi/ in case 2.

NORMAL



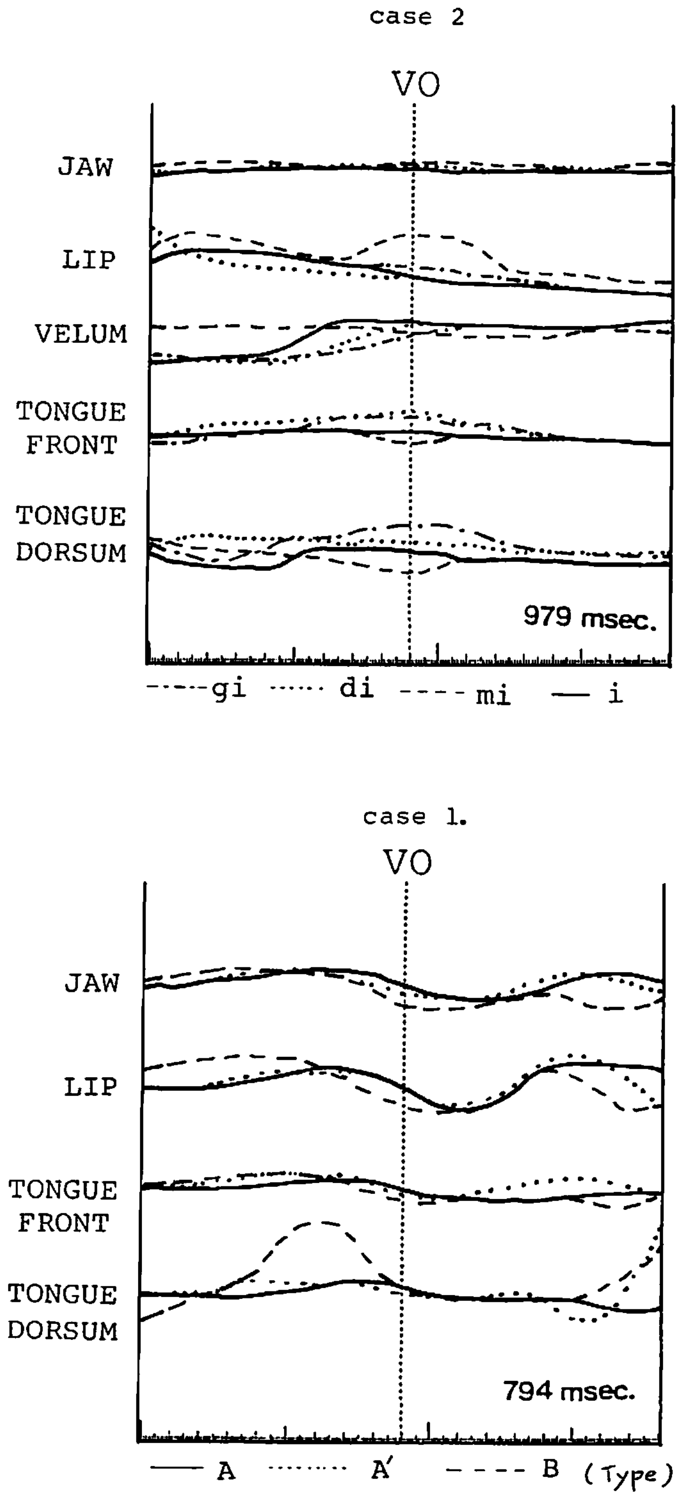


Fig. 8. Examples of vertical movements as a function of time in correct /i:/ and addition errors of /gi/, /d i/ and /mi/ of case 2 and those of case 1 in /e:/ compared with the normal subject.

In case 2, on the contrary, the lip elevation occurs most of the time, though the timing relation to VO(voice onset) varies greatly except in the sound /ma/. On the other hand, the tongue-tip also elevates around the VO excepting /ma/. When the tongue elevation is high enough at the VO the utterances are perceived auditorily as /n/ or other lingua-palatal sounds such as /t /, regardless of the lip movement. When the low vowel /a/ follows, the tongue-tip elevation does not occur while the lip elevation lasts longer beyond the VO resulting in the correct sound /ma/(Fig.7).

B. Data from carrier word /i:/

Numerous addition errors were observed in carrier word /i:/ (good) of case 2. The table shows the sound added to /i:/. While various kinds of sounds are added, certain tendencies of errors are noticed. In half of the total utterances, /g/ is added followed by partially omitted non-nasal lingua-palatal sounds(Table 2).

Fig.8 illustrates examples of the vertical movements of each articulator in case 2 and the normal subject. In the normal subject the movement pattern is constant in every trial and only the tongue-tip (or tongue-blade) elevates for /i/. On the contrary, most of the time the synchronous elevation of the lip and the tongue-tip often accompanied with that of the tongue-dorsum was observed before the VO. The lip elevation usually finishes ahead of the VO while the downward movements of the tongue-tip and the tongue-dorsum start at or beyond the VO influencing the sound produced. When /g/ is perceived auditorily, the tongue-dorsum elevation lasts beyond the VO. As for addition of partially omitted lingua-palatal sounds such as/d /, quick drop of the tongue-tip elevation is observed shortly after the VO. When /m/ is perceived as added, the lip elevation occurs at the VO while the tongue and the velar are kept low. It is interesting that there was only one addition error among middle /i/ in /makai/ and /nakai/. Elevation of the lip and tongue was not observed in the correctly produced middle /i/.

Although there was no addition errors for carrier word /e:/ (yes) in case 1, the patterns of the movements were considerably different from those of the normal subject. First of all, irrelevant articulators such as the jaw and the lip elevate synchronously with the tongue-tip. Half of the time the tongue-dorsum also elevates together and in the rest its elevation occurs independently shortly after the elevation of the rest of the articulators, though all of the elevation finishes before or at the VO. Fig.8 illustrates the variability of the movements for /i:/.

Discussion

Our data of the articulatory movements in the patients with apraxia of speech revealed abnormalities as follows:

1) lack of suppressing upward movements of irrelevant articulator(s) for a target sound.
2) Timing errors among articulators, especially between laryngeal and supralaryngeal movements.
3) Inaccurate or incomplete movements of the adequate articulator for a target sound.
4) slowness in starting movements.

As for lack of suppression, several characteristics are observed:

a) some articulators tend to move together while others do not: for example the lip and the tongue-tip elevate together compared with the tongue-dorsum or the velar (or vocal folds). For example, the elevation of the lip occurs more often when the target sound is a tongue-tip sound such as /n/ than in /k/.
b) Errors of suppression occur most in the lip followed by the tongue-tip, tongue-dorsum and the velar in this order.
c) The occurrence and the pattern of the associated unnecessary movements change according to the type of the target sound or following vowels: for example, high vowel /i/ elicits the elevation of the tongue-tip in /m/ more often than low vowel /a/ in case 2.
d) The associated movements tend to occurred more often at the beginning of an utterance.

Itoh et al.[4] studied velar movements by fiber scopic observation in a patient with pure apraxia of speech 6 years after the onset. Based on the observation they concluded that the general successive pattern of velar gestures for a given phonetic context was preserved well, though repeated utterances of the same word showed a marked variability in the velar movements.

They[5] also used an X-ray microbeam system for simultaneous observation of several articulators in apractic talk of the same patient. It was found that the timing of the velar lowering for /n/ did not always correspond well with that of the tongue movement for the apical closure, and concluded that the patient suffered from an apparent disorganization of timing among the several articulators. They suggested, based on these results, that apraxic errors are more often distortion than substitutions[6].

As mentioned above, additional abnormalities to timing errors were revealed in the present study. The articulatory pattern for a target sound is not merely one for different sound but rather an abnormal one which does not exist in the normal articulation in Japanese. It is therefore not just distortion of correct patterns where the height of elevation is incomplete, or the lowering of the velar slightly delayed, or simple substitution where correct movement pattern for different sound occurs that is more characteristic of apraxia of speech in our patients.

There are several differences between Itoh et al 's study and ours which may affect the results. First of all the severity of the disorder in their patient appears to be only slight. He made only 4 substitution errors out of 298 words. More than 6 years of speech therapy could also affect the symptom of his disorder. On the other hand, both of our patients were examined within a year after onset and showed numerous substitution errors as well as distortion, and addition errors.

Secondly, unfortunately the tongue-tip movement which is the target articulator for /n/ was not directly observed in Itoh's study. They inferred the movement of the tongue-tip from the movement pattern of the tongue-dorsum and the lower lip. However our results showed that the movement pattern of each articulator in apractic patients markedly differed from those of normal subjects. Therefore it is difficult to infer the apractic movements from normal patterns. Our data indicated relatively independent movement of the tongue-dorsum from the rest of the articulators.

On the other hand, the abnormal elevation of the lower lip shown in their data of the apractic subject, which is not observed in the normal subjects, seems to show the lack of suppression of unnecessary articulators. This possibility was not discussed in their paper, probably because there was only one subject and they could not differentiate it from individual difference.

If recovery from apraxia of speech is the result of relearning skilled movements such as movement pattern of phonemes, the period from the onset or its recovery stage as well as characteristics of motor impairment will be an important variable for the syndrome. For example, when discoordination between laryngeal function causes gross delay of air flow, initial sounds are often perceived as omitted. Other errors of movements are masked by the lack of air flow as shown in our previous study (Sugishita et al.). Electropalatographic analysis revealed that linguapalatal contact existed even for sounds perceived as omitted auditorily, and the patterns were those for correct sounds, substitution or distortion errors with air flow. Otherwise many kinds of spatio-temporal errors, which are severe at an early stage, may be perceived as substitution or addition errors. As correct movement patterns are relearned the errors become increasingly slighter and perceived as distortion errors. In fact, case 1 showed numerous omission errors at the early recovery stage, then replaced by substitution errors. But in the final stage distortion errors were predominant. On the other hand in case 2, whose omission errors were minor from the early stage, substitution and addition errors were predominant. These, however, also were replaced by distortion errors in the later stage. Therefore core symptom of apraxia of speech may differ according to at the stage the patients are examined.

Hirose et al[7)] studied articulatory movements of dysarthric patients using the X-ray microbeam system. In their paper they discuss the difference in the patterns of slowness between their ALS and normal subjects. The velocity of lip is consistently low in the ALS subjects. On the other hand, no remarkable decrease in the velocity of displacement of the lip was observed in the normal subjects with slower speech rate when compared with that in the case of quick repetition. However, the duration of the closure period is prolonged. The pattern of slowness in our apractic patients is similar to that of normal subject, in that prolongation of the closure period as well as vowel duration contribute more to slowness than decrease of the velocity. The decisive differences between apractic speech and dysarthria are deterioration of general movement pattern of apractic speech due to the wrong choice of articulators and synchronous movements of unnecessary articulators except jaw-lip one, which is also observed in dysarthoric speech.

There are some individual differences. For example, case 1 showed numerous omission errors in the early period while case 2 did not. Lack of suppression in tongue-elevation caused many substitution errors in case 2. On the other hand lack of suppression in lip-elevation in /n/ as well as incomplete elevation of tongue-tip, which might be due to excess of suppression, were the main problem in case 1. Both of our patients made less nasal-oral errors than that of Itoh et al suggesting that velar control is comparatively preserved.

References

1) Broca,P: Remarques sur le siege de la faculte du langge articulae survies d'une observation d'aphemie. Bulletin de la Societe de Anatomie, 2e serie, 6, 330-357,1861.
2) Kiritani,S.,Itoh,K. and O.Fujimura: Tongue-pellet tracking by a computer-controlled X-ray microbeam system. J. Acous. Soc. America, 57,1516-1520,1975.
3) Sugishita,M., Konno,K.,Kabe,S.,Yunoki,K.,Tohashi,O. and M.Kawamura: Electropalatographic analysis of apraxia of speech in a left hander and in a right hander. Brain in press.
4) Itoh,M.,Sasanuma,S. and T.Ushijima: Velar movements during speech in a patient with spraxia of speech. Brain Lang.,7,227-239,1979.
5) Itoh,M., Sasanuma,S., Hirose,H., Yoshioka,H. and T.Ushijima: Abnormal articulatory dynamics in a patient with apraxia of speech: X-ray microbeam observation. Brain Lang.,11,66-75,1980.
6) Itoh,M. and S. Sasanuma: Articulatory movements in apraxia of speech.Apraxia of speech. College-Hill press, California,1984.
7) Hirose, H., Kiritani, S., Yoshioka, H., Sawashima, M. and T.Ushijima: Astudy of articulatory dynamics in the dysarthria Part I: Cerebellar Degeneration. Ann.Bull.RILP, 11,57-66,1977.