Ann.Bull.RILP(1986)No.20, 169-204

PATHOPHYSIOLOGY OF MOTOR SPEECH DISORDERS (DYSARTHRIA)*

Hajime Hirose

Introduction

Speech is an extremely important and unique human activity which sets us apart from other animals and is closely related to our ability to reason. The activity of speech is realized by the articulatory movements of the speech organs, which are complex, purposive movements for generating acoustic signals pertinent to the codes of each language. It must be emphasized that articulatory movements are exclusively under neuromuscular control. Thus, even the simplest peripheral motor pattern should reflect the coordinated function of the central nervous system (CNS).

It is possible to compare the pattern of movements for speech production with that of the fine movements of the extremities as in playing musical instruments. It follows that the speech process can be viewed as a fine motor skill which must be regulated in terms of sequence and duration with great accuracy, speed and rhythmicity. The fine motor skill of speech develops quickly during the period of childhood through continuous learning based on innate human linguistic ability, as well as on neural and musculoskeletal development. As a result, after the proper acquisition of one's native language, the motor patterns in adult speech processes seem to be under automatic control and freed from any conscious motor planning.

If, however, any damage occurs in the neuromuscular system regulating speech, the fine motor control of speech production can be disrupted. This would result in articulatory disturbance generally associated with abnormal acoustic patterns of speech perceptually recognizable for listeners. The type of speech disorder in these cases is generally classified as dysarthria.

The term dysarthria has been traditionally defined as "disorders of oral speech resulting from lesions within the nervous system" [Arnold, 1965]. Recently, the concept of dysarthria has become more comprehensive and refined [Darley et al., 1975; Rosenbeck and LaPointe, 1978; Netsell, 1982]. For example, Darley et al. state that dysarthria comprises a group of speech disorders resulting from disturbances in muscular control due to impairment of any of the basic motor processes involved in the execution of speech. Based upon the above concept, the term "motor speech disorders" has been used

---

* Paper to appear in Folia phoniatrica vol. 38, 1986. A version of this paper will be presented at the XXth Congress of International Association of Logopedics and Phoniatrics, Tokyo, August 1986.

synonymously with dysarthria. By definition, then, dysarthria must be distinguished from language disorders or more broadly based cognitive disorders. Also, the definition of dysarthria does not cover speech disorders of a organic or psychological origin.

The diagnosis of dysarthria is usually straightforward, if we are concerned solely with the presence or absence of speech problems in each clinical case. However, a more precise description of dysarthric symptoms is often quite difficult, since they include a variety of signs as diverse as those reported in the literature on speech pathology and neurology, which have been based essentially on the acoustic impression.

It is needless to say that perceptual judgments on the characteristics of dysarthric speech are clinically significant and helpful for diagnostic purposes. Darley et al. [1969, a; b] have reported extensive perceptual studies on various types of dysarthria and attempted to establish the concept of clusters of deviant speech dimensions being characteristic for different categories of neuromuscular abnormality. In Japan, Hirose [1973] has reported a similar attempt at a perceptual analysis of the dysarthric speech of Japanese, using specially designed evaluation items for Japanese speech samples. Later, additional studies [Fujibayashi et al., 1977; Fukusako et al., 1983] have also reported on Japanese dysarthric cases, and it has been concluded that a perceptual study is applicable to the differential diagnosis of different types of dysarthria. Thus, it is clear that these perceptual studies provide new scope for the study of dysarthria.

However, since dysarthric speech is the end product of the pathological dynamics of the articulators, its perceptual characteristics must depend on the motor characteristics of the articulators. Therefore, the analysis of the motor patterns of the articulators in dysarthric subjects seems to be a more direct approach to disclose the nature of dysarthric speech. In this sense, objective analyses of the motor patterns of the pathological dynamics in dysarthric speech have received a great deal of attention.

In recent years, we have developed various kinds of observational techniques for the assessment and analysis of the dynamic patterns of human speech movements. By applying these techniques, we have been attempting to describe the temporal and spacial aspects of articulatory movements in normal and dysarthric subjects. The principal aims of this presentation are to introduce some representative methods of assessment of articulatory dynamics and to report the preliminary results of the analysis with reference to the role of the nervous system regulating human speech activity.

Assessments of articulatory movements

1. Description of systems applicable to clinical data assessment

The following are brief descriptions of systems for the assessment of articulatory dynamics presently available at the author's research institute. Most of these systems have been developed for physiological studies in the field of experimental phonetics. Though the application of each system in clinical cases is still in a preliminary stage, we have been able to obtain some insights into the underlying neuromuscular mechanism of dysarthric speech behavior.

1) Cineradiography and X-ray microbeam system

For the observation of articulatory movements, cineradiography appears to be one of the most useful methods. As has been reported, even with a film speed as slow as 24 frames per second, cineradiographic assessment can provide information on articulatory dynamics in the dysarthrias [Kent and Netsell, 1975; Kent et al., 1975; Netsell and Kent, 1976]. How-ever, acquisition of necessary information on the pattern of articulatory movmements is generally restricted by the radiation dosage problem in the conventional cineradiographic technique.

In order to overcome the dosage problem, a new radiographic technique was developed at our institute in which a computer-controlled X-ray microbeam system is used. The present X-ray microbeam system has made it possible to collect and analyze a large set of X-ray data. A fairly good recording of the speech signal is also obtainable simultaneously for combined data analyses.

In the present method, several lead pellets are attached at selected positions on the speech organs, and their movements are automatically tracked by the X-ray microbeam under the on-line computer control of the X-ray beam deflection [Kiritani et al., 1975].

The overall principle of the X-ray microbeam system is depicted in Figure 1. The system employs a high-voltage, flying-spot type X-ray microbeam generator with a rating of 150 Kv-2mA controlled by a computer (PDP 11/34). The deflection system is electro-magnetic, and the effective band width of the frequency response is about 1 MHz. The object plane is 70 cm away from the target, and the usable image field is 16 cm in diameter. Sample points on the object plane are located by 9-bit x- and y-coordinates. Resolution on the object plane is approximately 1 mm.

Through the use of this system, the movement of the articulators can be observed by tracking several lead pellets attached, for example, to the dorsal surface of the tongue, the lower incisors, and the upper or lower lips (or both), using a biomedical adhesive (allon-alpha) before the recording session. In selected cases, a strip of thin plastic film with a lead pellet attached to its end has been passed through a nostril placing the pellet on the nasal surface of the velum. The location of this pellet was examined and adjusted under anterior as well as posterior rhinoscopy, and then the front end of the strip was secured by a piece of adhesive tape at the skin anterior to the nostril.

At each time frame, exposures are made of the sample points on a horizontal line segment centered at the current pellet position predicted from its past positions, and the point of the minimum intensity of the transmitted X-rays is detected to determine the x-coordinate of the current position. Using this x-coordinate value, a similar procedure is applied vertically to determine the y-coordinate value. Then, the program proceeds to the next frame repeating the same procedures. At present, up to 6 pellets can be tracked at a rate of 130 frames/sec. The effective exposure area per frame is 1 cm^2, and the radiation exposure rate within the area is approximately 100 milliroentgens (mR)/min. The data output is read into the computer memory core through an X-ray detector and an analog-to-digital (A/D) convertor.

For the purpose of off-line observation, the X-ray image can be displayed on a monitor oscilloscope using a hardware scan-signal generator. Additional computer programs are also available for displaying the image data digitally stored in this mode of observation. For example, the trajectories of the pellet movements can be displayed in real time. As an alternative, the coordinate values for each pellet can also be displayed as time functions. Through the use of a pertinent program for differentiation, the velocity of the pellet movements is also obtainable.

2) Fiberoptic observation and photoglottographic recording

Since the introduction of the flexible fiberscope for the observation of the larynx [Sawashima and Hirose, 1968], it has become possible to observe and record laryngeal views in normal and pathological subjects quite easily.

The laryngeal fiberscope can also be used to illuminate the larynx under direct vision for photoglottography in which the light modulated by the glottal gesture is sensed by a photosensor attached to the anterior neck on the trachea [Lofqvist and Yoshioka, 1980]. Figure 2 shows a blockdiagram of the photoglottographic procedure. Using this system, laryngeal articulatory dynamics can be investigated in different types of dysarthrias [Hirose et al., 1984].

3) Ultrasonic technique

The physical principles of ultrasonic examination have been treated extensively in many reference works on medical ultra-

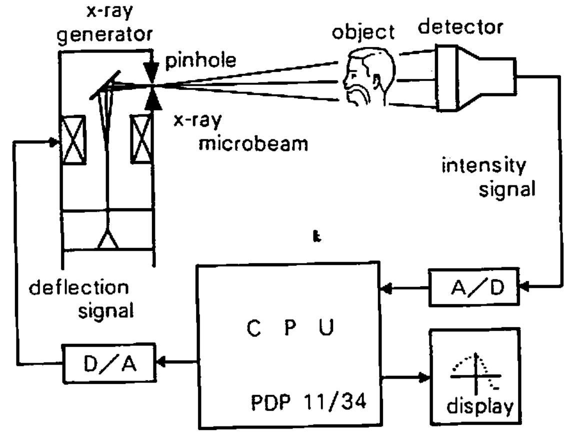

Figure 1. A block diagram of the X-ray microbeam system.

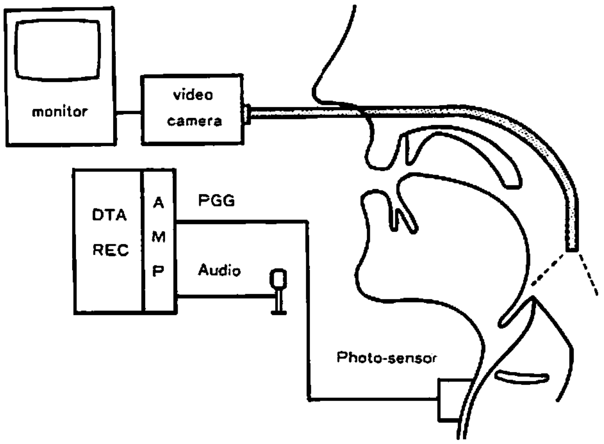

Figure 2. A block diagram of the photoglottography procedure with video-image monitoring.

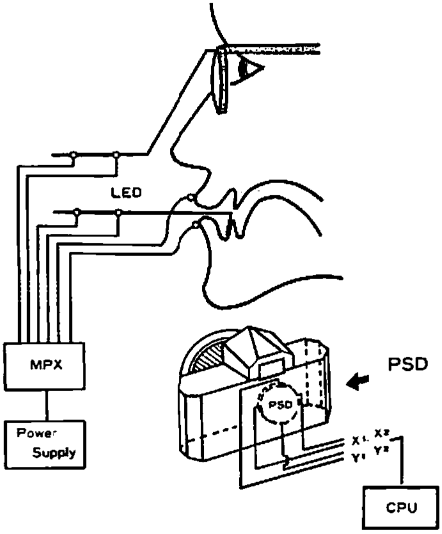

Figure 3. A block diagram of the PSD recording system.

sonics [Kelsey et al, 1969; Watkin and Zagzebski, 1973; Hamlet, 1981; Keller and Ostry, 1983].

Body tissues, fluids and sorrounding air differ in acoustic properties due to their physical components. When an ultrasonic wave is transmitted into the body, sound reflection occurs from the boundary between objects or substances with a different specific acoustic impedance, which is the numerical product of the density of the material and the speed of sound within it.

For example, the boundary between the surface of the tongue and the air within the oral cavity is clearly demonstrated if the ultrasound beams are transmitted through the skin surface underneath the chin.

Ultrasound is produced by electrically driving a piezoelectric crystal at a resonant frequency. Detection of the reflected ultrasound is made with a piezoelectric element also. In our experience on a detecting the tongue configuration, ultrasound in a frequency range between 2.5 and 3.5 MHz provided by a sector-scan type probe appears to be most useful. In order to monitor the sagittal configuration of the tongue, the probe is located on the midsagittal line under the subject's submandibular triangle.

In addition to the above method of obtaining the sagittal configuration of the tongue dorsum using the so-called B-mode of an ultrasonic system, there is another way of detecting tongue dynamics along selected axes approximately perpendicular to the surface of the tongue (M-mode). The latter technique is adequate for illustrating characteristic movements of the tongue in dysarthric cases on the time axis.

Since the ultrasonic apparatuses used for speech study were originally designed for clinical purposes in different specialities, there are certain limitations in trying to detect precise articulatory dynamics. For example, there is a difficulty in visualizing the palatal contour simultaneously, and the frame rate is relatively low. However, the application of this system to the research of dysarthria seems promising due to its safety and ease of applicability. In particular, this technique is quite valuable for obtaining a large amount of data quite safely from each subject. Also, the ultrasonic apparatus can be used as a bio-feedback system for the speech training of patients.

4) Position sensitive detector (PSD)

It is possible to record the movement of the jaw and lip using a PSD (optical spot position sensitive detector). In this system (Figure 3), two infrared light emitting diodes (LEDs) are attached to a solid steel wire which is attached to the lower front teeth, and led out from the mouth. Two additional LEDs are attached to another solid wire fixed to the frame of glasses worn by the subject. The latter are used to monitor the possible movement of the head during the recording session and to calculate the movements of the lower jaw relative to the upper jaw. Two other LEDs can also be attached to the upper and lower lips to record their movements when necessary. A PSD is located within a camera body on which the image of the LEDs is formed through the lens. From the PSD, the electrical signals are obtained in reference to the x- and y-coordinates of each LED from which the coordinate values are calculated by an analog function circuit. The coordinate signals are sampled by a computer, at a frame rate of 100 per second, together with the speech signal.

Although this system can be used only for detecting the dynamics of the jaw or lips, it is adequate for obtaining a large amount of data due to its safety.

5) Electromyographic assessment

Electromyography (EMG) is a technique for providing graphic information about the time course of the electrical activity of the muscle fibers which accompanies muscle contraction and subsequent effects such as tension development. Since EMG was established as a scientific technique, it has been widely used in various fields for studying muscular function and coordination.

In clinical situations, the significance of EMG as a diagnostic procedure for neuromuscular disorders has been generally recognized. In particular, EMG is quite effective for the differentiation of peripheral neurogenic paralysis from myogenic disorders, and, for this purpose, an inspection of the discharge pattern of the neuromuscular units (NMU) is most important. EMG can also provide significant information on the abnormality of the articulatory organs at the peripheral neuromuscular level.

Recently, EMG has further been applied to the analysis of pathological kinesiology related to speech production. For this purpose, the hooked-wire electrode technique has been developed and it has enabled us to obtain necessary information without affecting natural speech performance. Also, progress in the computer processing of EMG data has led to better analyses of the temporal patterns of the activity of a pertinent muscle as a whole with reference to speech signals [Hirose, 1977].

2. Test batteries for data acquisition

In order to analyze articulatory dynamics in normal and dysarthric subjects, appropriate articulatory tasks must be given to the subjects.

In most of our assessments of articulatory movement in the present study, each subject was requested to repeat Japanese monosyllables at his or her fastest rate of speech. In some cases, repetition of the monosyllables was made at different

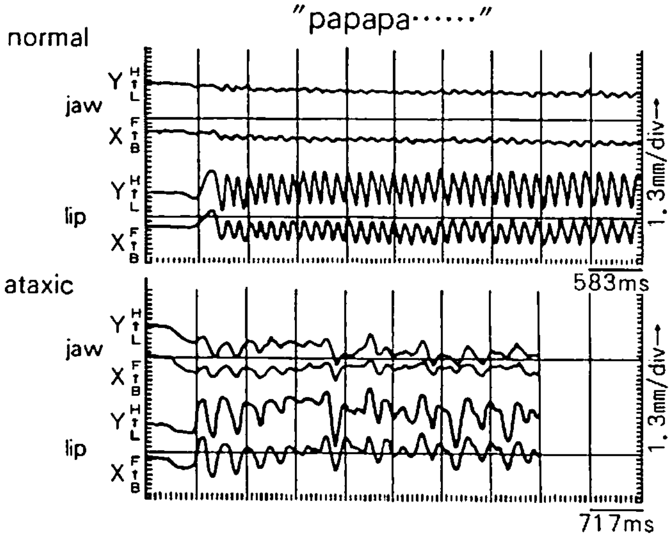

Figure 4. Patterns of the movements of the jaw and lower lip in a normal subject (upper) and in an ataxic subject (lower) for repetitions of the monosyllable /pa/ displayed as time functions of the x- (back [B] to front [F]) and y- (low [L] to high [H]) coordinates.

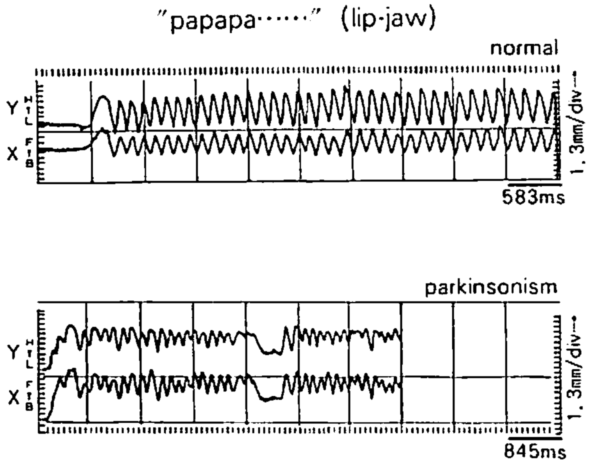

Figure 5. Patterns of the movements of the lower lip in the normal subject (upper) and in a parkinson subject (lower) for repetitions of the monosyllable /pa/ displayed as time functions. In this figure, the coordinate values for the jaw are subtracted from those of the lip so as to yield the values for the displacement of the lip itself. 1.3 mm/div. = 1.3 mm per division.

rates. The repetitive production of monosyllables requires the rhythmic actions of the articulatory organs, which are relatively simple but can readily reveal a characteristic pattern of abnormal movements in each type of dysarthric speech.

In addition, specially designed short sentences containing meaningful words were also uttered at a normal speaking rate.

Results of an analysis of articulatory dynamics in different types of dysarthric subjects

1. Repetitions of monosyllables

1) Patterns of movements of the articulatory organs

In this chapter, representative patterns of the movements of the articulatory organs in normal and dysarthric subjects analyzed mainly by the X-ray microbeam system are presented.

Figure 4 illustrates the patterns of movements of the jaw and the lower lip for repetition of the monosyllable /pa/ with maximum utterance speed, comparing a normal subject (44-year-old male) with a patient having ataxic dysarthria of cerebellar origin (53-year-old male). In this figure, the x- and y-coordinates of the pellets attached to the lower incisors and the lower lip are displayed as functions of time. It is apparent in the ataxic subject that the range and velocity of the movement of each pellet are markedly inconsistent, and that the alternation of the direction of movement is often sluggish when compared to the normal subject.

It can also be seen that displacement of the jaw in the production of the sequence of /pa/ is very small in the normal subject, and the articulatory movement is more or less confined to the lip. On the other hand, the jaw movement is fairly large for the sequence of /pa/s in the ataxic subject, where the displacement of the lip depends, to a considerable extent, on that of the jaw. It is interesting to note that there is an apparent synchronism between the jaw and lip even in the ataxic subject [Hirose et al., 1978].

In Figure 5, the patterns of the lip movements for the repetition of the monosyllable /pa/ are compared for the normal subject and a parkinson subject (59-year-old male). In this figure, the coordinate values for the jaw are subtracted from those of the lip in order to observe the pattern of the lip movements independently of the jaw. It can be seen that the frequency of repetition is similar in both cases (7.7 Hz on average in the parkinson subject and 7.4 Hz in the normal), but the range of movements is smaller, particularly in the y-coordinate value in the parkinson subject. It can also be seen that the range gradually decreases throughout the repetition series until the movement finally ceases.

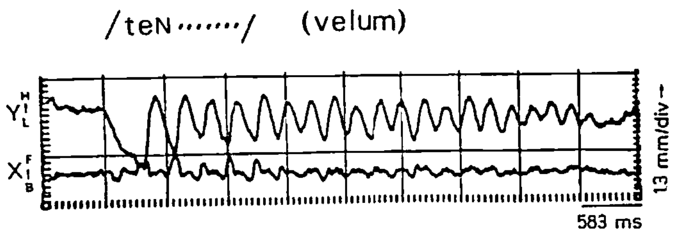

Figure 6. Patterns of the velum movement in the parkinson subject while producing sequences of /teN/ at his fastest rate of speech.

A similar tendency of gradual decrease in the degree of displacement is also shown in Figure 6, in which the time course of the movement of a pellet attached to the nasal surface of the velum is illustrated for repetition of the monosyllable /teN/ with the fastest possible repetition rate in another case of parkinsonism (68-year-old male). The rate of repetition is 4.6 Hz on the average. As the degree of velar displacement decreases gradually, the velum lowering for the word-final, Japanese nasal consonant /N/, and its elevation for non-nasal consonant /t/, are both incomplete towards the end of the repetition task.

The patterns of the lip and velum displacement in the latter case of parkinsonism for repetitions of the syllable /paN/ are shown in Figure 7, in which two separate attempts made at a slow rate (3.4 Hz on average) and a fast rate (6.9 Hz) are compared. It can be seen here that the velar movements are fairly consistent in both rate and displacement at the slower rate of repetition, whereas in the faster repetition rate, the velar displacement becomes quite limited and irregular and, as a result, the velum stays at an elevated position throughout the procedure. Perceptually, the utterance sounded like repetitions of /pa/ instead of /paN/ [Hirose et al., 1981].

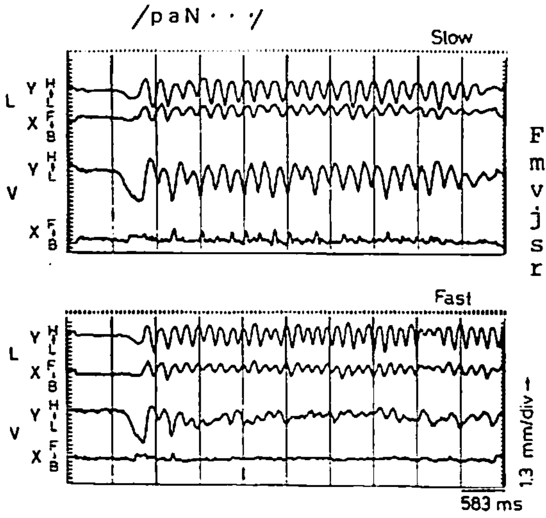

Figure 7. Patterns of the movements of the lower lip (L) and velum (V) in the parkinson subject for repetitions of /paN/ at slow (upper) and fast (lower) rates.

It is generally observed in clinical cases with amyotrophic lateral sclerosis (ALS) and pseudobulbar palsy (PBP) that single as well as repetitive articulatory movements are very slow, and that the range of movement is limited, while regularity of repetition is usually well maintained.

Figure 8 shows the patterns of the lower lip and jaw movements for repetition of the monosyllable /pa/ at a maximum repetition rate, comparing the normal subject with a patient with ALS (53-year-old male). It can be seen that the rate of repetition is very slow in the ALS subject (3.5 Hz on average) compared with that of the normal (7.2 Hz on average). It is also apparent that the jaw displacement in the production of the sequence of /pa/s is minimal in the normal subject, whereas there is a considerable jaw displacement in the ALS subject.

Figure 9 compares the patterns of the lower lip movements for the repetition of /pa/ in the ALS subject and in a patient with PBP (64-year-old male), with the normal subject who made two separate attempts at the fast and the slow rates of repetitions. In this figure, the x- and y-coordinate values for the jaw are subtracted from those of the lip.

The rate of the repetition of the lip movements in the two pathological cases (3.5 Hz in the ALS subject, and 2.1 Hz in the PBP subject, on average) is as slow as that of the slow repetition of the normal subject (3.8 Hz on average). However, the general patterns of repetitive movements in the pathological cases are quite different from those of the slow repetition in the normal. That is, the patterns of slow repetition in the normal subject are characterized by a prolongation of the labial closure period, and the slope of the lip displacement curve

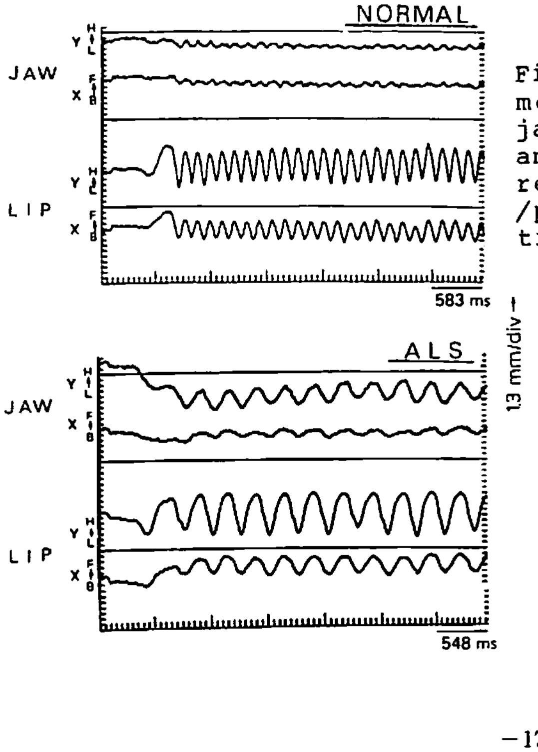

Figure 8. Patterns of the movements of the lower lip and the jaw in the normal subject (upper) and in an ALS subject (lower) for repetitions of the monosyllable /pa/ displayed as time functions.

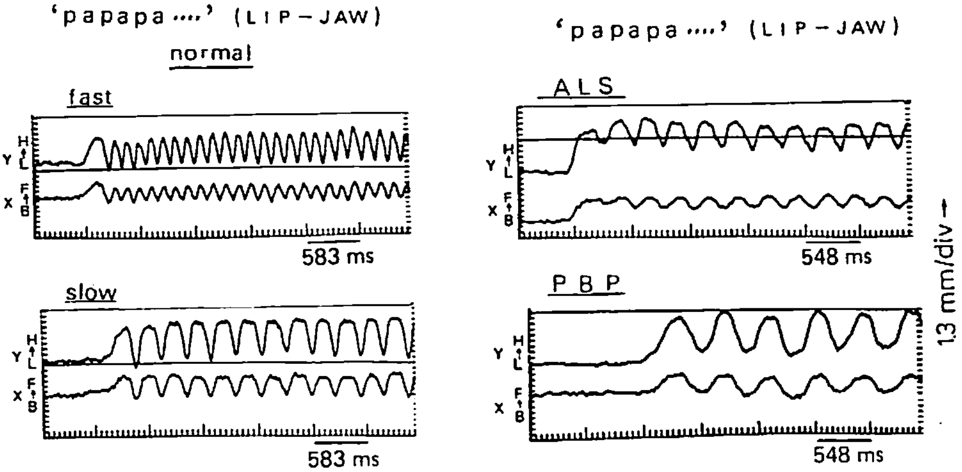

Figure 9. Patterns of the movements of the lower lip in the normal subject repeating the monosyllable /pa/ at a fast rate (left-upper) and at a slow rate (left-lower); in the ALS subject (right upper); and in a PBP subject (right-lower). In this figure, the coordinate values for the jaw are subtracted from those of the lower lip.

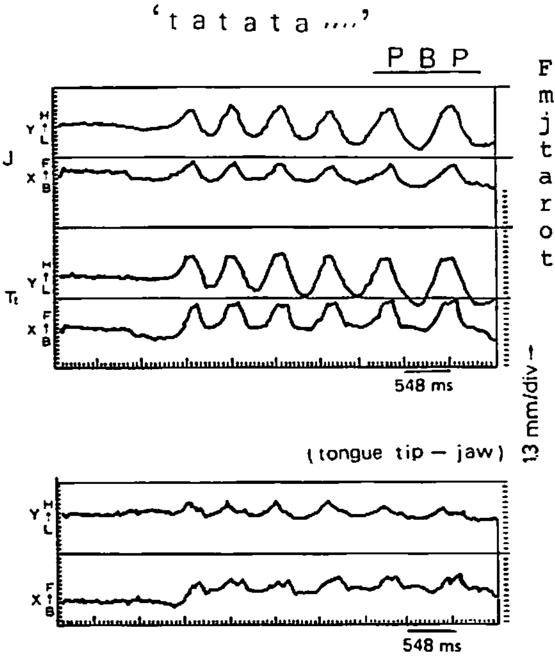

Figure 10. Patterns of the movements of the tongue tip and the jaw in the PBP subject repeating the monosyllable /ta/ (upper), and the same recording illustrated after subtracting the coordinate values for the jaw from those of the lower lip (lower).

indicating lip velocity appears to be unchanged from that of fast repetition. On the other hand, there is a generalized slowness of displacement in the two pathological cases.

The tendency toward "jaw dependency" is also noted in tongue articulation in pathological cases. For example, Figure 10-a shows the patterns of the tongue tip and jaw movements of the patient with PBP in repetition of the monosyllable /ta/. When the x- and y-coordinate values for the jaw are subtracted from those of the tongue tip, it is apparent that the range of the independent tongue tip movement is extremely limited, as shown in Figure 10-b.

Figure 11 illustrates the patterns of the movement of the tongue dorsum, velum and jaw for repetition of the monosyllable /ka/ at a maximum repetition rate, and comparing the normal subject with the ALS subject. It can again be seen that the rate of repetition is much faster and the jaw displacement is unremarkable in the normal subject. It can also be seen in the normal subject that the velum elevates at the onset of a series of /ka/s and stays at the same level thereafter. It appears that each /k/ closure is accomplished by a simple upward displacement of the tongue dorsum in the normal subject, while in the ALS case, the upward displacement is accompanied by a forward shift of the tongue dorsum. This finding would seem to indicate that the tongue dorsum moves not only upward but also forward for /k/ closure in this case, and returns in the opposite direction for the following vowel /a/. It can also be seen in the ALS subject that the velum shows up-and-down movements for /ka/ production. In other words, the velum cannot maintain the elevated level for each postconsonantal vowel period. In this particular record, the ALS subject repeats /ka/ only six times, after which the velum falls to the resting level presumably for inspiration, and the repetition is started again. This finding can be taken as an indication of increasing nasality during the successive production of monosyllables in ALS cases [Hirose et al., 1982].

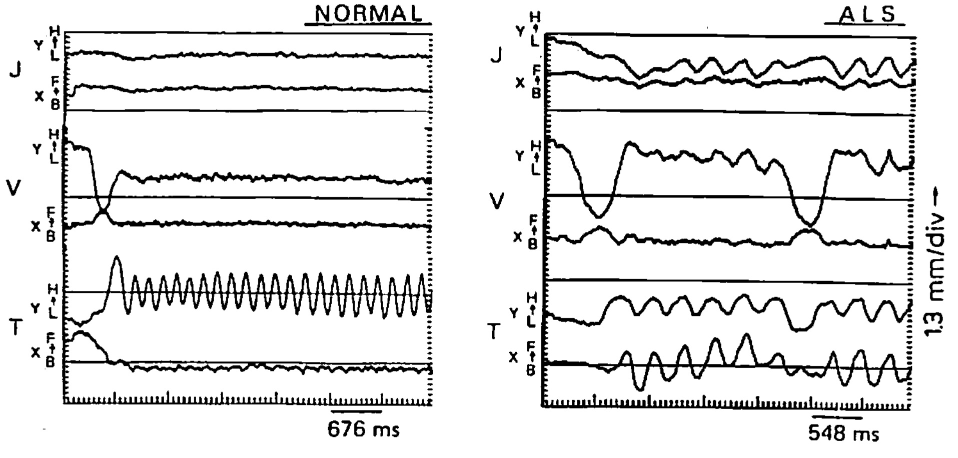

Figure 11. Patterns of the movements of the tongue dorsum, velum and jaw for repetitions of the monosyllable /ka/ in the normal subject (left) and in the ALS subject (right).

Using of other methods for the assessment of articulatory behavior, such as the ultrasonic system or PSD system, essentially similar patterns of abnormality have been demonstrated in clinical cases with the different types of dysarthrias described above.

2) Electromyographic findings

The pattern of the articulatory movements in the production of monosyllables described in the preceding section is realized by a voluntary contraction of the muscles related to the pertinent articulators such as the lip, tongue, jaw, velum and larynx. Therefore, electromyographic (EMG) examination of these muscles is clinically significant particularly for the purpose of a definitive diagnosis of motor neuron disease (MND), including the bulbar form of ALS. In most cases of MND, a decrease in NMU discharges associated with abnormal wave forms, such as high

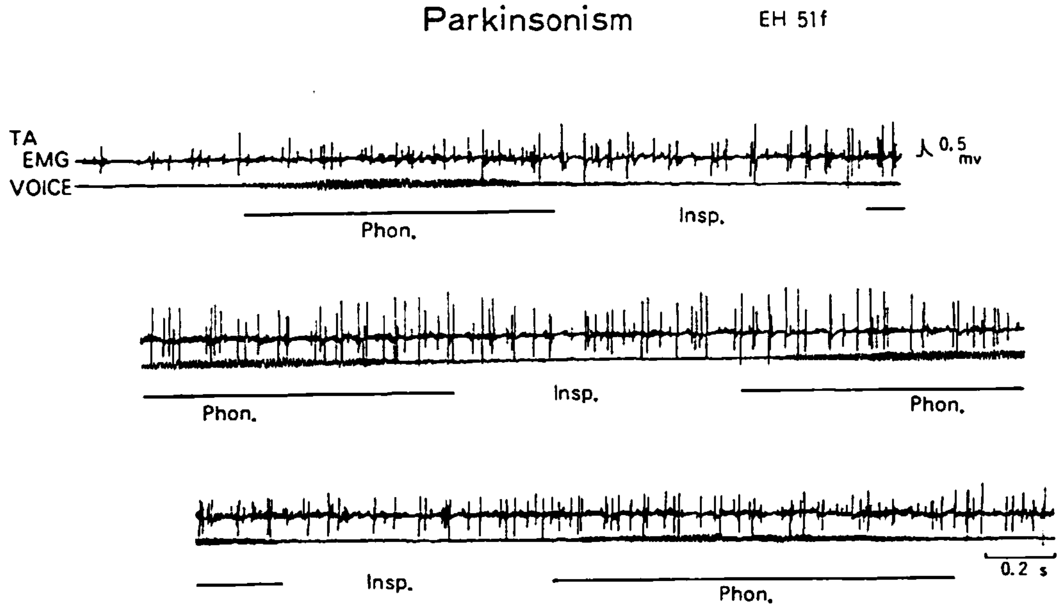

Figure 12. EMG patterns for the thyroarytenoid obtained from a subject with parkinsonism for a series of alternating inspiration and phonation.

amplitude voltage, is confirmed in the pertinent muscles.

It has been reported in the literature that parkinson subjects may develop laryngeal paralysis in the course of their disease [Vas et al., 1965; Plasse and Lieberman, 1981]. In these reports, however, the diagnosis of laryngeal paralysis was simply made by observation under conventional laryngoscopy. Although it is often the case that parkinson subjects present a very weak, breathy voice associated with the apparently limited movements of the vocal folds, a definite diagnosis of paralysis can only be made by EMG examination.

Figure 12 demonstrates EMG patterns for the thyroarytenoid obtained from a case of parkinsonism who showed very limited vocal fold movements under indirect laryngoscopy. The EMG was recorded during a series of alternating inspiration and phonation. It appears that the number of NMU discharges for phonation, or for the concomitant vocal fold adduction, is not reduced, and that there are no pathological discharge patterns such as polyphasic or high-amplitude voltages. On the other hand, persistent firing is seen even during the period of inspiration in which thyroarytenoid activity is suppressed in normal cases. These findings would seem to indicate that there is no evidence of neurogenic paralysis in this case, but that there is a loss of the reciprocal suppression of the thyroarytenoid during inspiration.

The pathological kinesiology of the articulators can also be described in EMG terms, particularly in the temporal domain. Examples of the temporal pattern of muscle activity during the course of repetitive production of the monosyllable /pa/ in the normal subject and different types of dysarthric subjects are shown in Figure 13, in which rectified and integrated EMG signals of the anterior digastric (AD) and the mentalis (MENT) are illustrated.

In the normal subject, the AD is active for the jaw opening for the /a/ gesture and suppressed for the jaw closing in the stop production. In contrast, the MENT shows activity for the lip gesture in the /p/ production and is suppressed for the vowel segment /a/. Both muscles thus show quick activation and suppression quite regularly, and there are apparent reciprocal patterns between the two, which must be a prerequisite to the coordinated articulatory movement in the repetition of the monsyllable /pa/.

In the ataxic subject, the EMG patterns of the two muscles are irregular both in shape and timing, and there is generally a plateau during the period of suppression which indicates the tendency toward a disturbance in the initiation of muscle activation in repetitive movement. However, the apparent reciprocity between the two muscles is somehow preserved.

In the parkinson subject, both muscles show quick activation and suppression in a regular fashion. However, the temporal reciprocity between the two muscles is not maintained throughout

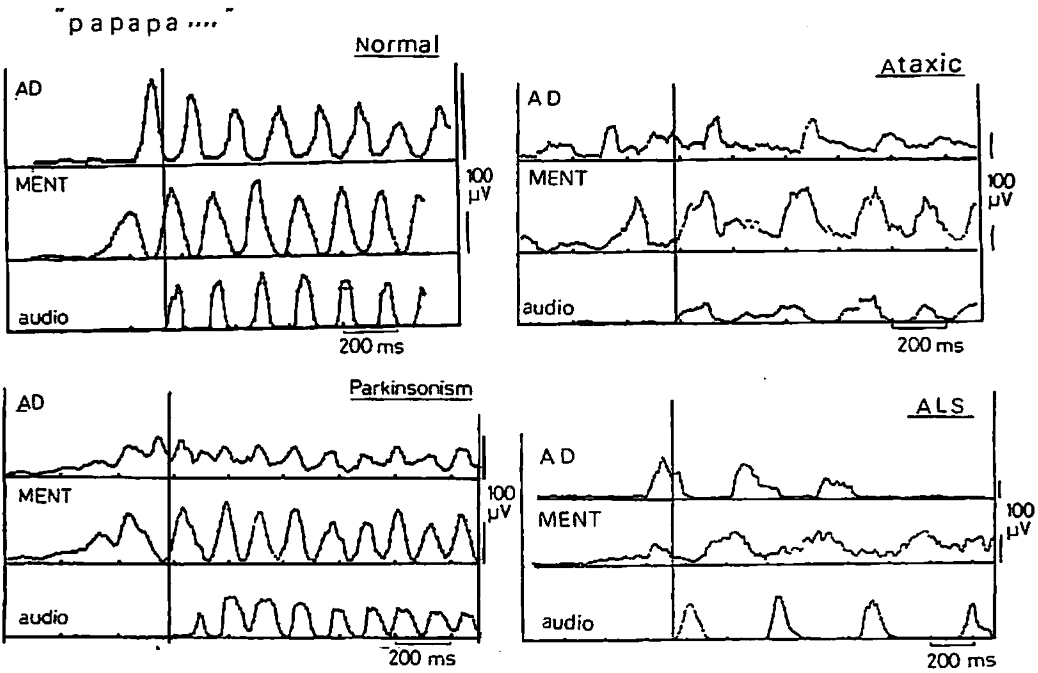

Figure 13. Computer processed EMG curves of the anterior digastric (AD) and the mentalis (MENT) for repetitions of /pa/ in the normal subject and in dysarthric cases of different types.

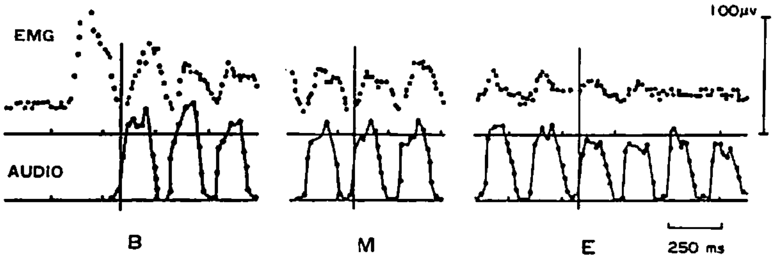

Figure 14. Integrated EMG patterns of the levator veli palatini of a case of myasthenia gravis during the production of successive sequences of the monosyllable /teN/. The three sections above represent the activity pattern at the beginning (B), middle (M) and end (E) of the sequence.

the series of repetitions, but both muscles are activated and suppressed synchronously in fast rate repetition.

In the ALS subject, the frequency of repetition is much lower than in the normal subject, but the reciprocity between the two muscles is fairly well maintained for each segment, in that the AD activity starts to increase at the time point where the MENT activity reaches its peak. However, the timing of the increase in the activity of the MENT is delayed as compared to the normal subject. Namely, the MENT activity does not start to increase until the AD activity completely ceases in the ALS subject.

An abnormal pattern of muscle activity is also well demonstrated in the case of myasthenia gravis as shown in Figure 14. In this figure, rectified and integrated EMG activity of the levator veli palatini muscle of a 22-year-old patient with myasthenia gravis is shown for the repetitive production of the monosyllable /teN/. Here, there is a tendency toward easy fatigability of the muscle for the velum elevation for /t/ after the nasal sound toward the end of a string of repetitions, where the peak of the EMG activity is much lower compared to that recorded at the beginning of the repetition. It can also be noted that suppression of the EMG activity appears to be incomplete at the end of the repetition. Thus, in the case of myasthenia gravis, both quick contraction and relaxation may become difficult toward the end of repetitive movements.

3) Velocity of the articulatory movements

Estimation of the velocity of the articulators in the production of certain speech sounds is important for the analysis of articulatory kinesiology [Hirose et al., 1982]. In the present study, the velocity was obtained from the X-ray microbeam data through use of a pertinent computer program in which a linear approximation was made for seven consecutive frames to represent the trajectory of the pellet within that very short period. Thus, the velocity could be obtained either in a digital form or as a time curve.

Figure 15 shows the time course of the lip velocity for the repetitive production of the monosyllable /pa/ in the normal subject and in dysarthric cases of different types. In this figure, each positive peak indicates the maximum velocity in both labial closure and release, consecutively. In the normal subject, the velocity values are quite consistent and high in the direction of both closure and release.

The velocity values are extremely inconsistent in the ataxic subject, and there is an occasional standstill where the velocity of the lip is 0 and the apparent lip displacement must entirely depend on the jaw movement. In the parkinson subject, the velocity declines quickly as the same syllables are produced repeatedly. On the other hand, the value is low but relatively consistent

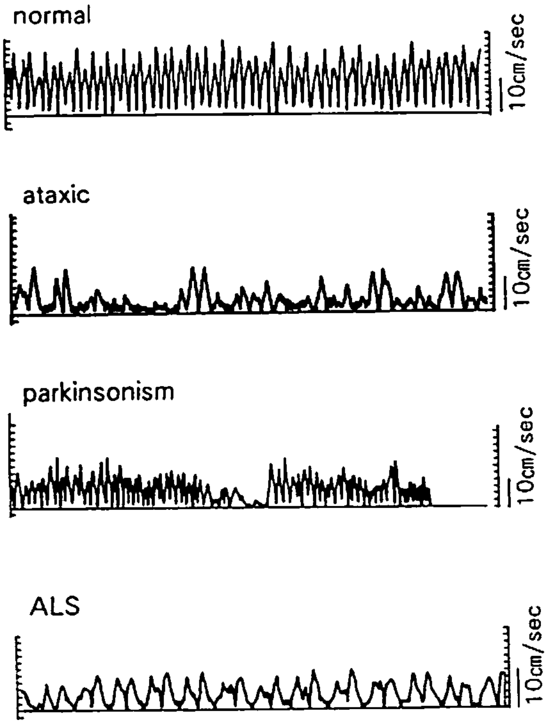

Figure 15. Comparison of the velocity of the lip displacement in the normal subject and in dysarthric cases of different types.

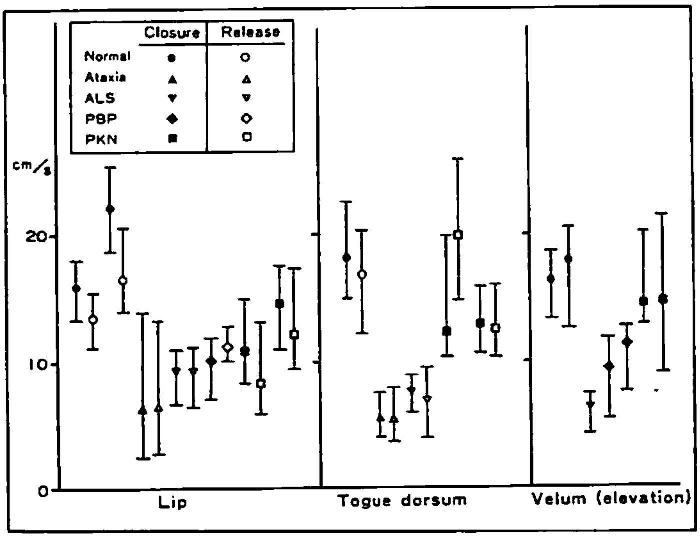

Figure 16. The mean value and the range of velocity of the lip and the dorsum of the tongue (for consonant closure and release) and the velum (for elevation) in the normal and dysarthric subjects.

in the ALS subject.

Figure 16 summarizes the means and ranges of velocity for the pertinent articulators in the repetitive production of the monosyllables for the normal and dysarthirc subjects. The order of magnitude of articulatory velocity in all subjects was found to be in a range from several centimeters per second (cm/s) to more than 20 cm/s. The velocity value is generally low in cases of so-called paralystic types (ALS and PBP) and cerebellar ataxia for all the articulators examined. Incidentally, it was found that the change in repetition rate within a conversational range did not appear to affect the velocity value significantly.

4) Examination of other kinesiological parameters

In the study of limb dynamics, it has been reported that the interval from the onset of movement to the point of maximum velocity appears to be independent of a difference in the extent of the movement for rapid elbow and finger flexions [Freund and Budingen, 1978]. For articulatory movement, Ostry and his colleagues [1983] examined the kinematics of the tongue dorsum using a pulsed ultrasonic system during articulatory movements and found that at each stress level the interval from the initiation of the movement to the point of maximum velocity was relatively constant. In the present study, the correlation between the time interval from the initiation of labial movement to the point of its maximum velocity was investigated in normal subjects and in different types of dysarthric cases.

In Figure 17-a, the relationship between the time interval from the initiation of the labial articulatory movement in the repetitive production of the monosyllable /pa/ to the point of the maximum velocity and the extent of the labial displacement is shown for two normal subjects, the data from which are combined. It can be seen that the time interval from the initiation of movement to the point of the maximum velocity is relatively invariable regardless of the difference in the extent of the movement. In this figure, the 95% range for the distribution of the data is circled by an elipse showing a flat contour with a long horizontal axis.

The interval from the initiation of movement to the point of the maximum velocity, relative to the labial articulatory displacement, was also obtained for three ataxic subjects for the production of each monsyllable, and the results are plotted in Figure 17-b, on which an eliptic area corresponding to the normal data distribution is superimposed. It can be seen that a significant number of data plots are out of the normal range, and that there is a tendency for the interval from the initiation of movement to the maximum velocity, relative to the articulatory displacement to be elongated.

In contrast, a preliminary analysis of the relationship between the above mentioned two parameters for ALS and PBP cases

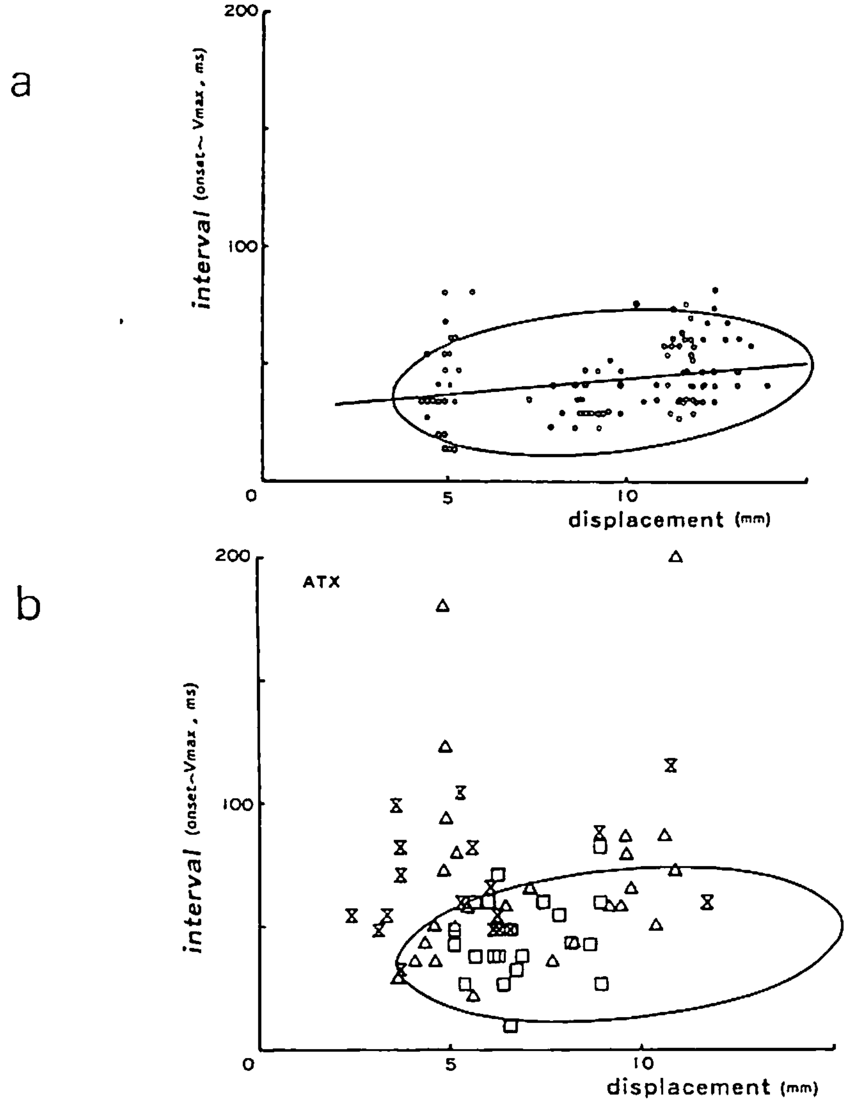

Figure 17. The relationship between the time interval from the initiation of the labial movement to the point of the maximum velocity and the extent of the labial displacementin the normal subjects, with the 95 % range for the distribution is circled by an elipse (a). The relationship is examined and plotted for the ataxic subjects on which the elipse obtained from the normal subjects is superimposed (b).

revealed that the distribution of the data was mostly within the range obtained from the normal subjects.

2. Articulatory dynamics in the production of a short sentence containing meaningful words

The repetition of monosyllables, the results of which have been documented in the preceding section, may require a different type of articulatory control from normal conversation or reading. On the other hand, the task of uttering selected sentences containing meaningful words should be more appropriate for examining an articulatory behavior similar to that used in ordinary conversational speech, although the selection of the test sentences and data interpretation may become more difficult than in the case of monosyllable repetitions. In the present study, a Japanese sentence /ii kakato desu/ (It is a good ankle) was uttered several times by the normal and dysarthric subjects, and the articulatory movements were analyzed using the X-ray microbeam system.

Figure 18 shows pairs of time curves for the x- and y-coordinates of pellets attached to the articulators in the production of the above mentioned test sentence uttered twice.

In the case of the normal subject (Figure 18-a), the pattern of the articulatory movements is quite consistent in the two separate utterances. The duration of corresponding segments in the two utterances is also very similar.

In the ataxic subject (Figure 18-b), considerable inconsistency is observed between the two utterances. For example, the segment duration of the first syllable /ka/, the consonantal portion of which became a voiced [g] in utterance 2, is longer in utterance 1 than in utternce 2, and the displacement of the back of the tongue (T(B)) and that of the mid-portion of the tongue (T(M)) are also larger in utterance 1. The pattern of the tongue tip (T(F)) movement is more different between the two utterances in that the tongue tip shows a transient shift to the postero-inferior direction immediately before the production of [t] in utterance 1. There is no such shift in utterance 2. In both utternces, the jaw displacement is generally more marked, and the utterance speed is slower compared to the normal subject.

The inconsistency between sentences is more marked in the case of a parkinson subject (Figure 18-c). The entire duration of the three-syllable word /kakato/ is much shorter in utterance 2, in which the displacement of the back of the tongue (T(B)) for /a/ in the first syllable and the following /k/ in the second syllable is unclear. The initiation of the tongue tip (T(F)) displacement toward the postero-inferior direction preceding the release of [t] appears to start earlier in utterance 1 than in utterance 2.

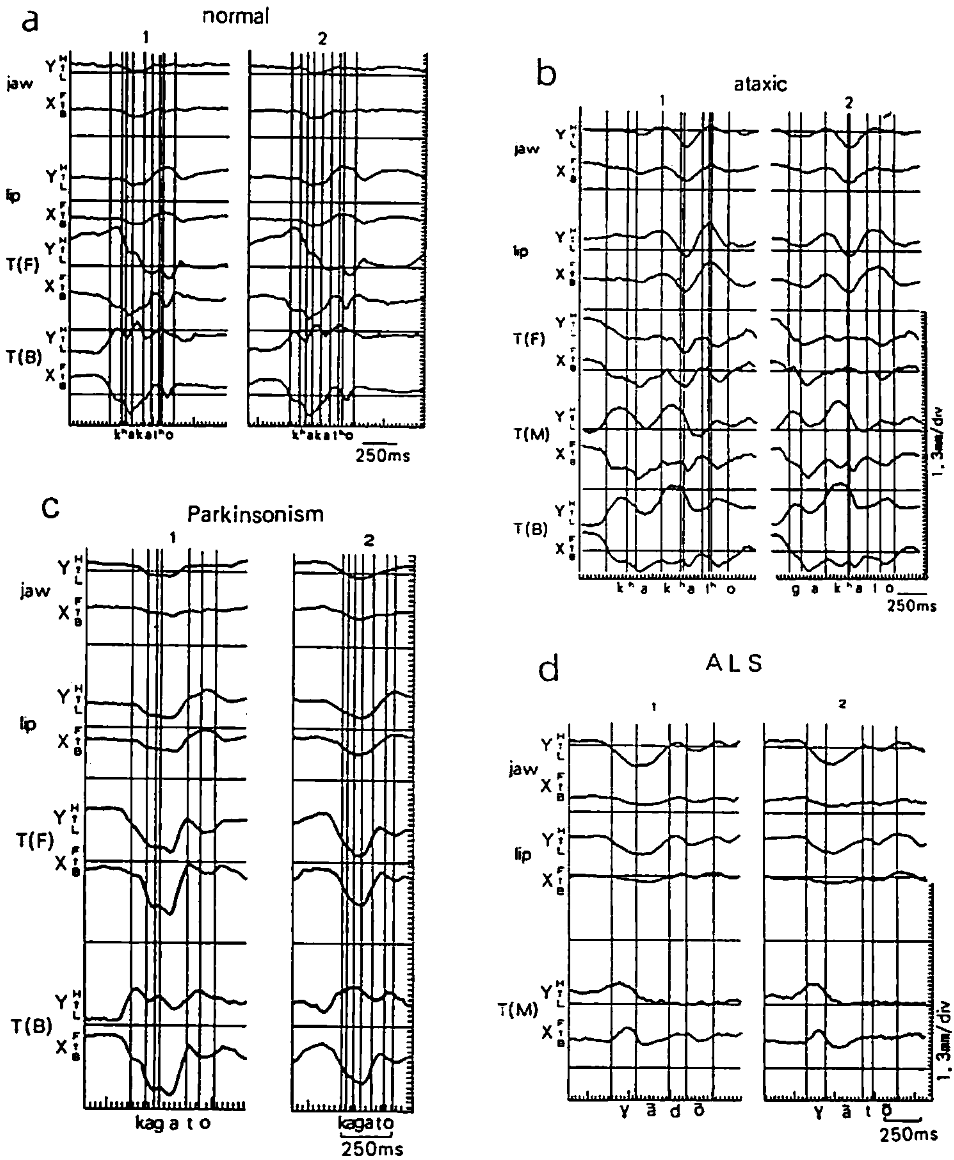

Figure 18. Pairs of time curves for the x- and y- coordinates of pellets attached to the articulators in the production of a short meaningful sentence uttered twice by the normal subject and dysarthric subjects of different types.

In the ALS subject, the articulatory pattern for the same sentence is preserved, but the tongue displacement is generally limited (Figure 18-d). Perceptually, the [k] sound of the second syllable is very weak and can be heard as a palatal fricative. For the production of the [t] sound, the displacement of the tongue is minimal and apparently compensated for by jaw displacement.

3. Laryngeal articulatory dynamics

The analysis of laryngeal dynamics related to the articulatory and phonatory functions of dysarthric subjects is an important approach in the clinical evaluation of dysarthrias. In the present study, photoglottographic recordings were made in two cases of parkinsonism and three cases of ALS. As a control, a normal speaker also served as a subject.

Figure 19-a shows a photoglottogram (PGG) obtained from the normal subject during repetition of the monosyllable /se/. The upward shift of the curve indicates the glottal opening gesture. It is apparent that the glottis opens and closes regularly for the rhythmical repetition of the monosyllable, which consisted of a voiceless consonant and a vowel. The degree of glottal opening represented by the height of the upward shift appears to be consistent. Figure 19-b shows another PGG obtained from the same normal subject repetitively producing the monosyllabale /he/. A regular rhythm of glottal opening and closing is also maintained here, although the degree of glottal opening gradually decreases towards the end of the series of repetitions.

A PGG obtained from the ALS case during repetition of the monosyllable /he/ is shown in Figure 19-c . As compared to the pattern obtained from the normal subject in Figure 19-b, the pattern of the repetitive gesture of the glottis quickly becomes irregular. The glottal opening also becomes smaller, and the voiceless /h/ appears to be replaced by a voiced /h/. The fifth repetition is preceded by an interval of glottal opening associated with an abrupt air intake and followed by a choking gesture associated with an outbreak of coughing, shown by an arrow in the figure. The choking gesture seems to be the result of a tight reflex closure of the glottis corresponding to increasing spasticity.

It has often been noted that parkinson subjects tend to automatically repeat the same articulatory gesture, or to "stutter", during speech. Figure 20 shows a PGG of a parkinson subject during production of the test word "kisee" embedded in the carrier phrase "soreo __to yuu" (we call it __). The subject appears to repeat the articulatory gesture for the production of /k/, but the laryngeal gesture for the consonantal opening is not produced. The glottis appears to be nearly closed. This pattern is quite similar to that observed in the case of developmental stuttering [Yoshioka and Lofqvist, 1981].

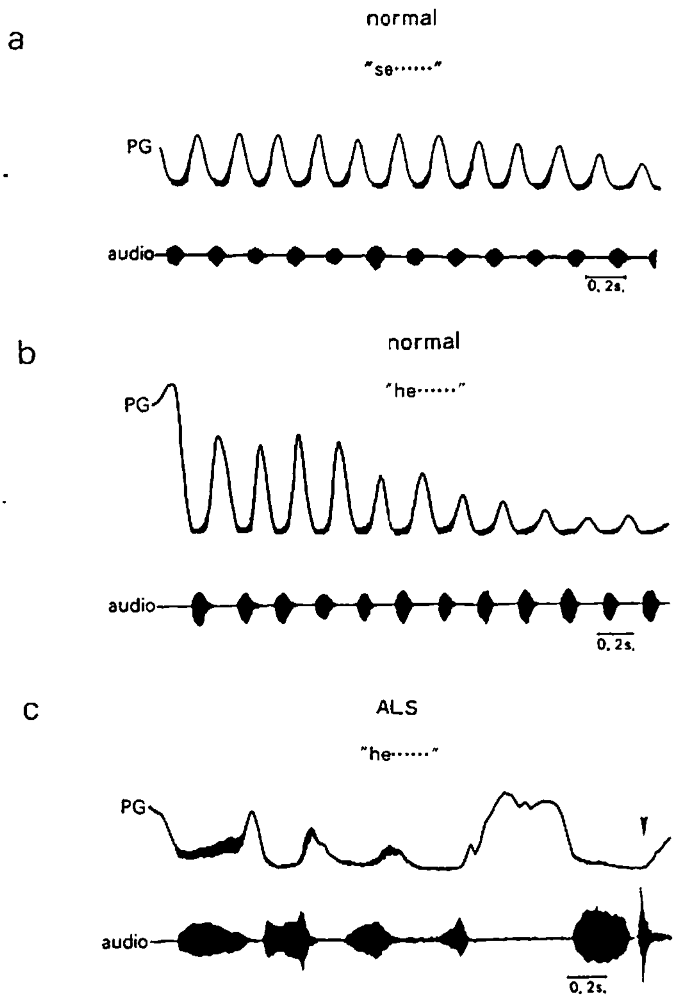

Figure 19. Photoglottograms obtained from a normal subject for repetitions of the monosyllable /se/ (a) and /he/ (b) and from a subject with ALS for repetitions of the monosyllable /he/ (c).

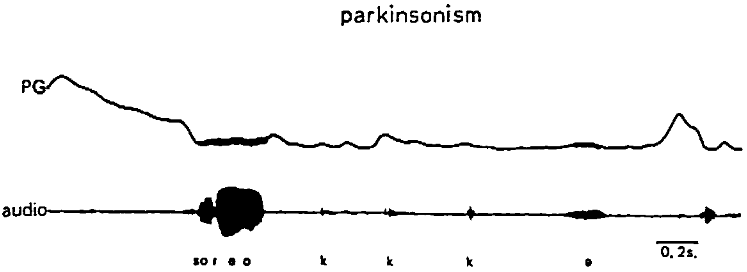

Figure 20. Photoglottogram obtained from a subject with parkinsonism for the production of a test sentence containing meaningful words.

Comments

1. The role of the central nervous system in the control of voluntary movement

As stated in the introductory chapter, speech is a complex voluntary movement specific to human beings. The execution of voluntary movements is believed to be depending on the activity of the network in the CNS which can be divided into several subsystems, although the exact role of each subsystem of the CNS has not yet been fully understood.

Allen and Tsukahara [1974] proposed a scheme illustrating possible contribution of different subsystems of the CNS and postulated that the association cortex of the brain plays an important role in initiation of voluntary movements with the help of the cerebellum and the basal ganglia (Figure 21-a). Active participation of the cerebellum in the execution of movements was also emphasized in their scheme and this point will be discussed in the later part of this chapter.

More recently, their original scheme has been modified by several authors and one of the examples is shown in Figure 21-b [Kubota, 1984]. In this figure, the motor cortex (Brodmann's Area 4) is directly connected with the premotor area and the supplementary motor area (Area 6) as well as with the lateral cerebellum. Association cotex is divided into 3 areas; the parietal (Area 5, 7), temporal (Area 21, 22) and frontal (Area 8, 9, 10). The basal ganglia complex is related directly to the thalamus which is connected with the motor cortex.

It is believed that the premotor and supplementary motor areas are quite important at the level of planning and programming of the voluntary movement in terms of spacio-temporal structuring of behavior. Pathological changes at this higher level of the neural network for motor control may be related mainly to clinical entities other than dysarthrias and, therefore, they are beyond the scope of the present report.

At the level of the execution of the voluntary movement, a flow of nerve impulses is coming down along the pyramidal pathway in accordance with the motor plans and programs to achieve a final goal. During this process, elaborate contributions of the subsystems of the CNS, those of the so-called extrapyramidal system in particular, are required.

Although most of the concept on the motor control system are based mainly on the experimental results on the movements of the limbs, the basic principle should also be common to speech articulation. Pathophysiological manifestations of the dysarthric subjects described in the preceding chapter can be interpreted as examples of disturbances in the process of execution of skilled movements. In the followings, the neurophysiological background of the representative types of dysarthrias will be discussed.

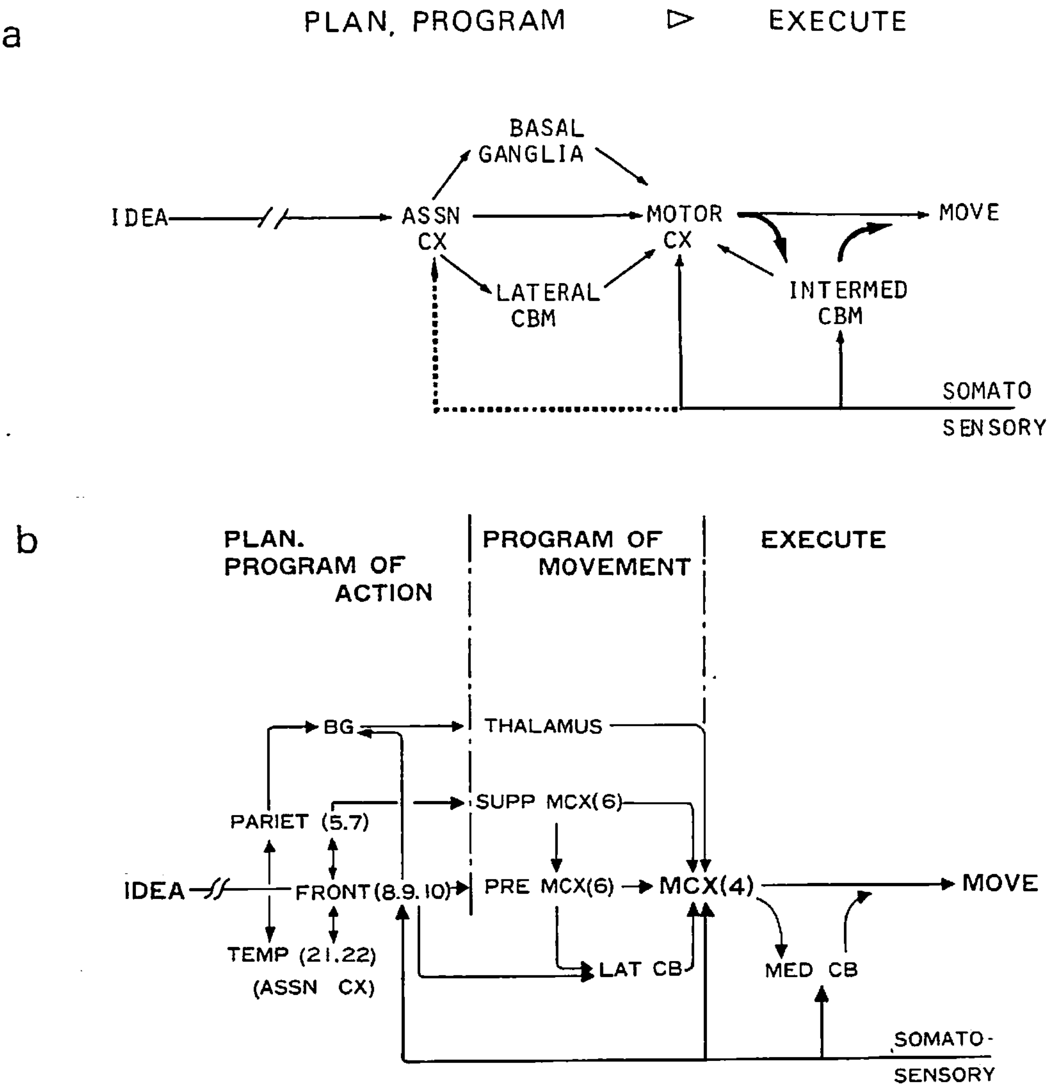

Figure 21. (a) A scheme showing the proposed roles of several brain structures in the execution of movement. Broken lines represent pathways of unknown importance.
CBM: cerebellum ASSN CX: association cortex (from Allen and Tsukahara).
(b) A modified version of the scheme.
MCX: motor cortex BG: basal ganglia Supp MCX: supplementary motor cortex (from Kubota).

2. Ataxic dysarthria and the function of the cerebellum

Analysis of articulatory patterns of the ataxic subject indicated that it is characterized by inconsistency in both range and velocity of movement particularly in sequences of repeated monosyllables, while the maximum velocity is not much less than that of the normal subject. In EMG analysis, the patterns of rhythmical activation and suppression are generally distorted and irregular, and there is a tendency toward disturbance of the initiation of movement, although an apparent reciprocity between the anterior digastric and the mentalis is maintained. It has been reported that the speech pattern of the ataxic subject is characterized by irregular articulatory breakdown. This patterns seems to be compatible with the above-mentioned physiological evidence of inconsistency in the articulatory movement.

It has been postulated that the lateral cerebellum participates in the programming or long-range planning of the movement. Its function is largely anticipatory, based on learning and previous experience and also on preliminary, highly digested sensory information that some of the association areas receive. Once the movement has been planned within the association cortex, with the help of the cerebellar hemisphere and basal ganglia, the motor cortex issues the command for movement.

At this point the pars intermedia of the cerebellum makes an important contribution by updating the movement based on the sensory description of the position of the effector and velocity on which the intended movement is to be superimposed. Namely, the cerebellum receives precise and immediate information of the discharge coming down the pyramidal tract and, as a consequence, it can return appropriate corrective information to the cerebral motor areas before the pyramidal tract discharge has caused any muscle contraction. Considerably later, there will be the feedback to the cerebrum along the spinocerebral pathways of information from skin, joint and muscle that results from the muscle contractions evoked by pyramidal tract discharge. Thus it can be said that all pyramidal tract discharge are provisional and are unceasingly subject to revision both by the feedback from the periphery as a consequence of the evolving movement, and more expeditiously via the cerebro-cerebellar loop [Eccles, 1973]. For learned movement, in particular, the cerebellum is considered to provide an internal substitute for the external world, and the operation of the cerebellum eliminates the need for peripheral sensory input and allows one to increase the speed of the learned movement by preprogramming.

If we take into consideration of the above concepts, the clinical symptoms of cerebellar ataxia can be explained, to a considerable extent, by the failure of the continual revisory control by the cerebellum. The voluntary commands from the motor cortex give imprecise and merely provisional signals down the pyramidal tract, and all refined control is exercised via the continuously operating cerebro-cerebellar loops. Thus, it can be said that the cerebellar function is essentially equivalent to that of a computer in its guidance of all voluntary movements.

More recently, Ito [1984] states that three major principles have now been raised regarding the characteristics of the cerebellar control mechanism: open-loop, multivariable, and adaptive-learning. He also claims that, among the ataxic symptoms which are clinically characteristic of cerebellar dysfunction, dysmetria and delayed movement initiation could be related to the failure of an open-loop motor control, whereas incoordination should represent a disturbance in the multivariable control.

According to Ito, dysmetria represents inaccuracy of a goal-directed movement to be performed in the predictive manner without feedback correction, whereas delayed movement initiation characteristic of an open-loop control for which there is no time for feedback correction. His idea is that there should be a "spacial map" of the body within the cerebral cortex relative to the external world being formulated by multisensory information. On the other hand, the cerebral cortex also has a "motor map" on which an equilibrium point of the muscle-load system for each part of the body is represented. The role of the cerebellum is to calibrated the correspondence between the two maps and, if the translation from the spacial map to the motor map contains an error, dysmetria can occur.

Thus, abnormal patterns of articulatory movement in cerebellar disorders must also be explained as impairments of the programming and updating functions of the cerebellum. In particular, fine control of skilled movement such as speech articulation must be affected by loss of the updating or revisory function and, as a result, quick change in the direction of movement can be disturbed. It seems reasonable to conclude that deterioration in speech or in the pattern of artculatory breakdown in the case of cerebellar ataxia is mainly caused by impairment of the updating-revisory function of the cerebellum. It can also be argued that the disturbance in muscular force development in the temporal domain often observed in the ataxic pattern of movement (cf. Fig. 18) is related to a disturbance in the open-loop control mechanism in cerebellar dysfunction. The EMG result that an apparent reciprocity between the anterior digastric and the mentalis was preserved in the ataxic subject (cf. Fig. 13) confirms that there is no serious impairment in the preprogramming at the cortical level, although further studies must be needed for a definite interpretation of the present experimental results.

3. Parkinsonian dysarthria related to the function of the basal ganglia

Since the first description by Parkinson, it has been known that parkinsonism is characterized by a mask-like facial expression, persistent tremor generally found in the extremities and limitation of movements. Clinically, parkinsonism has long been regarded as a classical example of a dysfunction of the basal ganglia, notably the striatum (caudate nucleus and putamen) and pallidum (globus pallidus). At present, the lesion most specific for parkinsonism is considered to be the degeneration of the melanin-containing neurons in the compact zone of the substantia nigra and, to a lesser degree, other melanin-containing brain stem nuclei, such as the locus coeruleus [Hornykiewicz, 1975].

The exact role of the substantia nigra for the functioning basal ganglia is not yet fully understood. However, the substantia nigra may be regarded as a nodal point for the extrapyramidal motor system, probably exerting a modulating influence on the activity of higher strial control centers. More recently, much has been disclosed about the biochemical properties of the extrapyramidal system and it is now known that the most prominent biochemical features of the basal ganglia is their conspicuously high content of neurotransmitters of the monoamine group. In particular, the dopamine has been demonstrated in high concentration in the nigrostrial dopamine pathway which originates from the compact zone of the substantia nigra and ends synaptically in the striatum [Anden, et al. 1964].

Further, it has been confirmed that the depletion of dopamine produces akinesia, rigidity of the skeletal muscles, and tremor, all of which are characteristic to parkinsonism. This conclusion has been further attested by effective results of the administration of l-dopa to patients with parkinsonism, and a good number of clinical reports on the use of l-dopa have been accumulated in many countries [Cotzias et al., 1967].

In the present study, it is revealed that abnormal patterns in the articulatory movements of parkinson subjects are evidenced by a disturbance in rhythmic performance in the repetitive production of monosyllables. It is also revealed that the parkinson subject shows marked temporal variation in segmental adjustment in the repeated production of the same short sentence.

It has generally been assumed that, in parkinsonism, articulation becomes imprecise. It has also been claimed that some individuals may present an abnormally rapid rate of speech [Canter, 1967]. The result obtained in the present study seems to be to compatible to the latter description.

Similar results have often been observed in finger-tapping examination [Nakamura et al., 1976]. This tendency of gradual increase in the repetition rate has been called as a "hastening phenomenon" and taken to be comparable to the festination gait which is common and characteristic in parkinsonism. The hastening phenomenon may be based on an abnormal release of the intrinsic oscillation mechanism in the CNS. In the case of finger-tapping, even the tapping is initiated with a frequency of as low as 2 Hz, the frequency quickly increases up to 5 - 5.5 Hz, the value of which has been regarded as a ratio of the intrinsic oscillation. This phenomenon is called "freezing" and known to be resistant to l-dopa therapy [Narabayashi et al., 1976].

Although the function of the basal ganglia has not been completely clarified in humans, Yoshida [1977] suggested its significance as an inhibitory system closely connected to the different areas of the cerebral cortex. It might be reasonable to conclude that the hastening phenomenon in parkinson subjects becomes manifested by a disturbance in the inhibitory function of the extrapyramidal system, if Yoshida's suggestion is acceptable.

Marsden [1982] suggested that the basal ganglia are involved in ongoing movement control, particularly in overall control of a motor act rather than a specification of the precise details of the movement, the latter function being performed by the precentral motor cortex and corticospinal system. It is further suggested that the difficulty in organizing ongoing movements may explain some of the subtle disabilities seen in parkinson subjects such as difficulty in performing concurrent or sequential movements [Dick and Marsden, 1985].

Hypokinetic patterns in parkinsonism in terms of reduction in the range of movements can be related to a deterioration in the reciprocal adjustment of the antagonistic muscles. Leanderson et al. [1972] recorded EMG activities from several facial muscles in parkinson subjects and found that there were persistent EMG discharge in the facial muscles indicating the loss of the reciprocal suppression between the functionally antagonistic muscle pairs. They also found that the persistent muscle contraction was effectively relieved by administration of l-dopa.

The persistent discharge pattern obtained from the thyroarytenoid muscle (cf. Fig. 12) should be comparable to the data given by Leanderson et al. indicating the loss of reciprocity between the agonist and antagonist, although EMG activity of the functionally anatagonistic muscle, the posterior-cricoarytenoid in this case, was not recorded simultaneously. It follows that the apparent limitation in the vocal fold movement in parkinson subjects should not simply be taken as neurogenic paralysis of the larynx unless EMG reslut confirms the existence of paralysis.

The synchronous discharge pattern observed in the present study between the anterior digastric and mentalis in the parkinson subject (cf. Fig. 13) must also be taken to indicate the loss of reciprocity which results in the reduction in the range of movements. Further, the apparent limitation in velar lowering in the repetitions of the monosyllable containing a nasal consonant with fast rate would also indicate that there was a persistent contraction of the levator veli palatini, even though its activity was not monitored electromyographically. Thus, the physiological mechanism of hypokinesia or rigidity in parkinsonism is generally considered to be based on the abnormal muscle contraction in a persistent fashion.

The question remains whether the abnormally persistent muscle contraction would indicate an increase in the stretch reflex secondary to the hyperfunction of the gamma system.

Although the mechanism and significance of the gamma motor control on the muscles innervated by the cranial nerves are still open to discussion, the analysis of the articulatory dynamics of pathological cases, particularly parkinson subjects, may further provide a clue to the understanding of the central motor control of the cranial nerve regions.

4. Paralytic dysarthria and its pathophysiological background

Dysarthric manifestation associated with pathologies along the pyramidal pathway down to the peripheral system are generally classified as paralytic dysarthria. Motor control problems in this type of pathologies can be viewed as disturbances of muscle forcing function. Even the disorders at the most peripheral level such as motor nerve paralysis or myasthenia gravis (cf. Fig. 14) can be included in this category. At the CNS level, PBP is a clinical entity of involvement of the primary motoneuron, whereas in ALS both primary and secondary motoneurons are known to be involved.

Dysarthria associated with ALS and PBP is relatively straightforward in terms of the speech pattern and presumed motor control problem. The speech is perceived as slow, hypernasal and breathy with reduced loudness and monopitch. Darley et al. [1975] refers to them as flaccid dysarthria.

In the ALS and PBP subjects, a reduced range of articulatory movement and slow-down in the rate of speech are the most manifest signs of the pathological condition, although in some cases, full range of movement is reached if sufficient force is applied slowly to the individual muscles.

On the other hand, consistency of the dynamic pattern in articulatory gestures is generally preserved, as seen in the repetition of the monosyllables. The values of the maximum velocity of the articulators are also fairly consistent. This feature is clearly different from that of ataxic subjects, who often present slow movements associated with marked inconsistency of dynamic patterns of articulatory gestures.

It is also noted that lip and tongue articulations are often accompanied by jaw displacement which is rather atypical in the normal subjects. This is probably an evidence of compensatory articulation in which tongue or lip gesture is compensated by jaw movements. Clinically, it is usually the case that jaw movement is well preserved even in advanced cases of ALS or PBP. The finding of "jaw dependency" in the present series may indicate the presence of voluntary effort of compensation in the pathological cases.

The gradual shift of tongue position and the tendency toward the lowering of the velum during the repetitive production of the monosyllables (cf. Fig. 11) are likely to be due to easy fatigability of the articulatory muscles, often described as progressive weakness during movements.

These dynamic features can be considered as the causes of imprecise consonant articulation, vowel distortion, bradylalia, hypernasal voice quality and nasal emission, all of which are described to characterize the clinical profiles of the case with ALS or PBP. It must be noted here that these clinical patterns and articulatory characteristics are common in these two neurological categories of ALS and PBP. In other words, although the two pathological groups must be and can be distinguished on a neurological basis, at least the articulatory dynamics are very similar. In this sense, these two groups may be combined as paralytic dysarthria only for simplification in describing their articulatory characteristics.

Concluding remarks

In the present paper, the results of analysis of articulatory dynamics in the normal and dysarhtric subjects were reported and discussed. The dysarthric subjects were selected cases with characteristic neurological symptoms for representative clinical entities, a definite diagnosis for whom was made by neurologists prior to the analysis. For the purpose of the precise analysis of the dynamics, different types of recently developed methods for the assessment of motor patterns were employed.

It has generally been revealed that the patterns of abnormal articulatory dynamics in the dysarthric cases reflects the neuromotor characteristics of the pertinent disease, which have been documented for the limbs. In other words, there are similarities in the control of the articulators and the limbs in neurological terms. The result would suggest that our approaches to the study of speech neuromotor mechanism leads to finer documentations of the basic nature of pertinent neurological disorders and to the progress in both qualitative and quantitative evaluations of neuromotor diseases. Further, as Moll et al. [1977] pointed out, observations of spacial and temporal properties of speech movements and their electrophysiological correlates eventually may lead us to units of neuromotor coding that correspond to some of our present constructs of human speech.

It must be mentioned that the discussion made in the preceding chapter is based on the results obtained from a limited number of subjects examined in the present study. Even though the subjects were representative for each category of the normal and pathologic groups, there may exist some individual variations in the motor patterns of speech articulation which have not been disclosed through the present approaches. Thus, we admit that further continuing studies on additional numbers of subjects must be definitely needed. In particular, experimental studies on normal subjects using some form of disturbance to the normal speech mechanism such as application of transient loads to the articulators seem to be important [Netsell and Abbs, 1977].

Also, other types of dysathrias including developmental dysarthrias must be investigated as well.

It should be realized, however, an essential aim of this report was to fully describe and discuss the motor patterns of speech in those selected cases analyzed throughout the present study. In this sense, the aim was achieved and the usefulness of the data assessment methods was proved. It is hoped that further neurophysiological approaches to the analysis of the articulatory dynamics of normal and dysarthric subjects will provide more important information for a better understanding of the central control mechanism of speech production.

Summary

By means of recently developed techniques for physiological data assessment including the X-ray microbeam system, motor dynamics of articulatory movement were analyzed in normal subjects and in selected dysarthric cases with different types of disorders of the central nervous system. The result indicated that the pattern of articulatory movements generally refected the neuromotor characteristics of the pertinent disease which have been documented for the limbs in the past literature. It was also indicated that there was a certain correlate between the perceptual characteristics of dysarthric speech and the underlying articulatory dynamics. The significance of neurophysiological approachs to the analysis of speech motor dynamics was emphasized.

Acknowledgment

The author wishes to extend to his gratitude to the staff of Research Institute of Logopedics and Phoniatrics, Faculty of Medicine, University of Tokyo. The present study was supported in part by the Grant in Aid for Scientific Research, Ministry of Education, Science and Culture, the Japanese Government.

References

Allen, G.I. and N. Tsukahara: Cerebrocerebeller communication system. Physiol. Rev. 54: 957-1006, 1974.

Anden,N.E., A. Carlsson, and A. Dahlstrom: Fuxe, K.: Demonstrating and mapping of nigrostriatal dopamine neurons. Life Sci. 3: 523-530, 1964.

Arnold, G.E.: Central nervous disorders of speaking :dysarthria; in Luchsinger and Arnold Voice-speech-language , Wadsworth, Belmont, 1965.

Canter, G.J.: Neuromotor pathologies of speech. Am. Jour. Physical Med. 46: 659-666, 1967.

Cotzias, G.C., M.H. van Woert, and L.M. Schiffer: Aromatic amino acid and modification of parkinsonism. New Engl. J. Med. 276: 374-379, 1967.

Darley, F., A. Aronson and J. Brown: Motor speech disorders, W.B. Saunders, Philadelphia, 1975.

Darley, F., A. Aronson and J. Brown: Differential diagnostic patterns of dysarthria. J. Speech Hearing Res. 12: 246-269, 1969(a).

Darley, F., A. Aronson,J. Brown: Clusters of deviant speech dimensions in dysarthrias. J. Speech Hearing Res. 12: 462-496, 1969(b).

Dick, J.P.R. and C.D. Marsden: The role of the basal ganglia in movement. Advances in Neurolog. Sci. 29: 299-315, 1985.

Eccles, J.C.: A re-evaluation of cerebellar function in man; in Desmedt New developments in electromyography and clinical neurophysiology, pp. 209-224, Karger, Basel, 1973.

Freund, H.J. and H.J. Budingen: The relationship between speed and amplitude of the fastest voluntary contractions of human arm muscles. Exp. Brain Res. 31: 1-12, 1978.

Fujibayashi, M., Y. Fukusako, H. Monoi, N. Kobayashi, I. Tatsumi, and H. Hirose: Characteristics of speech due to cerebellar disorders, pseudobulbar palsy and amyotrophic lateral sclerosis. Jpn. J. Logop. Phoniatr. 18: 101-109, 1977.

Fukusako, Y., H. Monoi, I.F. Tatsumi, K. Kumai, N. Hijikata and H. Hirose: Analysis of characteristics of dysarthric speech based on auditory impressions. Jpn. J. Logop. Phoniatr. 24: 149-164, 1983.

Hamlet, S.: Ultrasound assessment of phonatroy function; in Ludlow, O'Connell Proceedings of the conference on the assessment of vocal pathology, ASHA Report 11, pp. 128-140 ASHA, Rockville, 1981.

Hirose, H.: Toward differential diagnosis of dysarthrias; in Kirikae Approaches to the disorders of the central nervous system, pp. 214-232, Kanehara, Tokyo, 1973.

Hirose, H.: Electromyography of the larynx and other speech organs. In Dynamic Aspects of Speech Production (Eds. Sawashima, M. and F.S. Cooper), pp. 49-67, University of Tokyo Press, Tokyo, 1977.

Hirose, H., S. Kiritani, T. Ushijima, and M. Sawashima: Analysis of articulatory dynamics in two dysarthric patients. J. Speech Hearing Dis. 43: 96-105, 1978.

Hirose, H., S. Kiritani, T. Ushijima, H. Yoshioka and M. Sawashima, : Patterns of dysarthric movements in patients with parkinsonism. Folia phoniat. 33: 204-215, 1981.

Hirose, H., S. Kiritani and M. Sawashima : Patterns of dysarthric movement in patients with amyotrophic lateral sclerosis and pseudobulbar palsy. Folia phoniat. 34: 106-112, 1982.

Hirose, H., S. Kiritani and M. Sawashima: Velocity of articulatory movements in normal and dysarthric subjects. Folia phoniat. 34: 210-215, 1982.

Hirose, H., S. Niimi and M. Sawashima: Laryngeal dynamics in dysarthric speech. New Dimensions in Otorhinolaryngology-Head and Neck Surgery, vol.2 (Ed. E. Meyers) pp.411-412, Elsevier Science Publisher B.V., Amsterdam, 1985.

Hornykiewicz, O.: Parkinson's disease and its chemotherapy. Biochem. Pharmacol. 24: 1061-1065, 1975.

Ito, M.: The cerebellum and neural control. Raven Press, New York, 1984.

Keller, E. and D.J. Ostry: Computerized measurement of tongue dorsum movements with pulse-echo ultrasound. J. Acoust. Soc. Am. 73: 1309-1315, 1983.

Kelsey, C.A., F.D. Minifie and T. Hixon: Applications of ultrasound in speech research. J. Speech Hearing Res. 12: 564-575, 1969.

Kiritani, S., K. Ito and O. Fujimura: Tongue-pellet tracking by a computer-controlled x-ray microbeam system. J. Acoust. Soc. Am. 57: 1516-1520, 1975.

Kubota, K.: An introduction to "voluntary movement and the brain". Advances in Neurolog. Sci. 28: 3-6, 1984.

Leanderson, R., B.A. Meyerson and A. Persson: Lip muscle function in Parkinsonian dysarthria. Acta otolaryng. 74: 354-357, 1972.

Lofqvist, A. and H. Yoshioka: Laryngel activity in Swedish obstruent production. J. Acoust. Soc. Am. 63: 792-801 1980.

Marsden, C.D.: The mysterious motor function of the basal ganglia. Neurology 32: 514-539, 1982.

Moll, K.L., G.N. Zimmerman and A. Smith.: The study of speech production as a human neuromoter system. In Dynamic Aspects of Speech Production (Eds. Sawashima, M. and F.S. Cooper), pp. 107-127, University of Tokyo Press, Tokyo, 1977.

Nakamura, R., R. Hagaseki and H. Narabayashi: Arythmokinesia in parkinsonism. In Advances in Parkinsonism (Eds. Birkmayer, B. and O. Hornykiewicz), Roche, Basel, 1976.

Narabayashi, H., H. Imai, M. Yokochi, M., K. Hirayama, K. and R. Nakamura: Cases of pure akinesia without rigidity and tremor and with no effect by L-Dopa therapy. In Advances in Parkinsonism (Eds. Birkmayer, B. and O. Hornykiewicz), pp. 335-342, Roche, Basel, 1976.

Netsell, R.: Speech motor control and selected neurologic disorders. In Speech Motor Control (Eds. Grillner, S., B. Lindblom, J. Lubker and A. Persson), pp. 247-261, Pergamon Press, Oxford, 1982.

Netsell, R., Abbs, J.: Some possible uses of neuromotor speech disturbances in understanding the normal mechanism. In Dynamic Aspects of Speech Production (Eds. Sawashima, M. and F.S. Cooper), pp. 369-392, Tokyo University Press, Tokyo, 1977.

Ostry, D.J., E. Keller and A. Parush: Similarities in the control of the speech articulations and the limbs: kinematics of tongue dorsum movement in speech. Jour. Exp. Psychol. 9: 622-636, 1983.

Plasse, H.M. and A. N. Lieberman: Bilateral vocal cord paralysis in Parkinson's disease. Arch. Otolaryngol. 107: 252-253, 1981.

Rosenbeck, J. and L. LaPointe: The dysarthrias: description, diagnosis and treatment. In Clinical Management of Neurogenic Communication Disorders. (Ed. D.F. Johns), pp. 251-310 Little Brown, Boston, 1978.

Sawashima, M. and H. Hirose: New laryngoscopic technique by use of fiber-optics. J. Acoust. Soc. Am. 43: 168-169, 1968.

Vas, C.J., M. Parsonage and O.C. Lord: Parkinsonism associated with laryngeal spasm. J. Neurol. Neurosurg. Psychiat. 28: 401-403, 1965.

Watkin, K.L. and J.A. Zagzebski: On-line ultrasonic technique for monitoring tongue displacement. J. Acoust. Soc. Am. 54: 544-547, 1973.

Yoshida, M.: The basal ganglia. Advances in Neurolog. Sci. 21: 777-783, 1977.

Yoshioka, H. and A. Lofqvist: Laryngeal involvement in stuttering-a glottographic observation using a reaction time paradigm. Folia phoniat. 33: 348-357, 1981.