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ANALYSIS OF ABNORMAL ARTICULATORY DYNAMICS IN THE DYSARTHRIAS

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Abstract

By means of pellet tracking techniques using an x-ray microbeam system, observations of the articulatory movements of various types of dysarthric subjects were conducted. In some selected cases, electromyographic (EMG) studies were also performed. The data were specifically examined with special reference to the range, velocity and consistency (reproducibility) of the movements of the articulators as well as to the pattern of coordination of the different articulators involved. It was found in the case of ataxic dysarthria of cerebellar origin, for example, that the dynamic patterns were best represented as a difficulty in the initiation of purposive movements and an inconsistency of articulatory movements, particularly in the repetitive production of a monosyllable. On EMG, breakdown of the rhythmical patterns in the articulatory muscles was quite obvious in the repetition of a monosyllable. In the case of ALS, decrease in the range and velocity of movements was noted ; this seemed to result from reduced NMU activities manifested in clinical EMG. It was suggested that analysis of the dynamic aspects of the dysarthrias is a promising approach for elucidating the nature of central problems of speech production and for a differential diagnosis of various types of dysarthrias.

Introduction

The principal purpose of the present study is to investigate the dynamic aspect of speech production in clinical cases with articulatory disorders of neuromuscular origin. The type of speech disorders in these cases is generally classified as dysarthria. 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, more precise description of dysarthric symptoms is often quite difficult, since they include a variety of signs as diverse as those reported in the past literature in speech pathology and neurology, which were based essentially upon the acoustic impression.

In 1969, Darley and his colleagues reported extensive perceptual studies on various types of dysarthrias and attempted to establish the concept of clusters of deviant speech dimensions being characteristic for different categories of neuromuscular abnormality (Darley, et al., 1969 a, b). In Japan, one of the present authors reported on an attempt at a perceptual analysis of the dysarthric speech of Japanese, using a similar strategy to that of Darley and others (Hirose, 1973). More recently, additional studies were also reported on Japanese patients (Kobayashi, et al., 1976; Fujibayashi, et al., 1977) and it was concluded that perceptual study was applicable to the differential diagnosis of different types of dysarthrias. Although these studies opened a new scope for the study of dysarthria, different approaches are still needed in order to investigate the motor pattern of pathological dynamics in dysarthric speech.

Application of x-ray cinematography has been attempted at different institutions for this purpose, but acquisition of necessary information on the pattern of articulatory movement is generally restricted by the dosage problem in the conventional x-ray cinematographic technique. Recently, a new radiological technique has been developed in the authors' institute in which a computer-controlled x-ray microbeam system is in use. (Kiritani, et al., 1975) This system has, to a large extent, solved the dosage problem, while greatly reducing the time required for data analysis.

In the present paper, preliminary results of an analysis of abnormal articulatory dynamics in dysarthric patients are reported based on observations using the computer-controlled x-ray microbeam system. In addition, the results of an EMG analysis of the pathological articulatory movements are also presented.

Procedures

The general description of the x-ray system and the strategy for the automatic tracking of the pellet on the moving articulator, such as the tongue, have been reported elsewhere. Briefly, the system employs a high-voltage flying-spot type x-ray microbeam generatory with the rating of 150Kv-2mA controlled by a computer (PDP-9). Through use of this system, movement of the articulator can be observed by tracking a few lead pellets attached to it. Before x-ray recording, several lead pellets are attached to the dorsal surface of the tongue, the lower incisor, and the upper and/or lower lips, using a type of biomedical adhesive (allonalpha). In some cases, a strip of thin film with a lead pellet attached to its end was passed through the nostril so as to place the pellet on the nasal surface of the velum. The location of the 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 to the skin anterior to the nostril. At present, up to 6 pellets can be tracked at the rate of 120 frames/sec. The effective exposure area per frame is $1cm^2$ and the exposure rate within the area is appproximately 100 mR/min. The data output is read into the computer memory core through an x-ray detector and an A/D convertor.

For the purpose of off-line observations, the x-ray image can be displayed on a monitor oscilloscope by using a hard-ware scan signal generator. Some additional computer programs are also available for displaying the image data which are digitally stored in this mode of observation. For example, 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.

For EMG analysis, one to several pairs of hooked-wire electrodes are placed in the pertinent articulatory muscles (Hirose, 1971) and the obtained data are subjected to computer-processing to obtain a graphic representation of the muscle activities as a function of time (Sawashima, 1976).

In the present series, articulatory patterns were analyzed for a case of cerebellar degeneration [case #1] and a case of amyotrophic lateral sclerosis (ALS) [case #2]. As a control, a normal adult male also served as a subject.

Case #1 is a 53 year-old male who suffered gradually aggravating disturbance in the movement of the extremities and in speech for over

4 years. Neurological examinations at the Department of Neurology revealed ataxic movements and marked adiadokokinesis in the extremities, particularly in both arms. In an eye tracking test, disturbance in smooth pursuit movement with inconcistant saccadation was noted. Based on the clinical signs, a diagnosis of spinocerebellar degeneration was made.

Case #2 is a 34 year-old female who noted increasing difficulty in articulation for the past two years. Neurological examinations showed atrophy of the tongue with fibrillatory twitches. Gag reflex was markedly diminished and incomplete velopharyngeal closure was noted in articulation and other tasks such as swallowing and blowing. Clinical EMG examinations revealed neurogenic patterns of high amplitude spikes in the intrinsic and extrinsic muscles of the tongue, facial muscles and levator veli palatini muscle. The movement of the larynx appeared to be intact. Other neurological examinations were essentially unremarkable and the patient was diagnosed as having a bulbar type of ALS.

The subjects were required to repeat Japanese monosyllables, /pa/, /ta/, /ka/,/ma/ and /teN/ separately at their fastest rate of speech. In addition, they uttered some meaningful Japanese test words embedded in a frame sentence "ii ______ desu" (that is good ______). In this paper, the data on the syllable repetitions will be presented.

Results

Figure 1 exemplifies the patterns of movements of the jaw and the

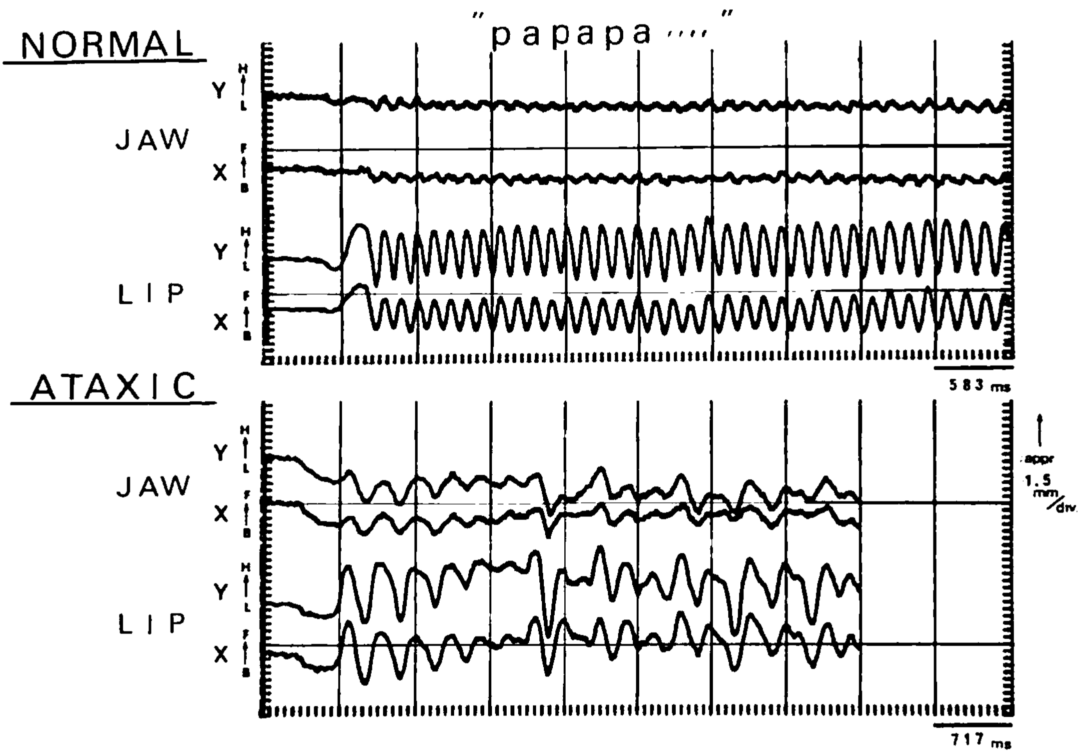

Fig. 1. Patterns of movements of the jaw and the lower lip in the normal subject (upper) and in the ataxic subject (lower) for repetitions of the monosyllable /pa/ displayed as time functions of X (back [B] to front [F]) and Y (low [L] to high [H]) coordinates.

lower lip for the repetition of the monosyllable /pa/ with maximum utterance speed, comparing a normal subject with case #1, a case of ataxic dysarthria of cerebellar origin. In this figure, the X and Y coordinates of the pellets attached to the lower incisor 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 the alteration of the direction of movement is often imprompt when compared to the normal subject.

Displacement of the jaw in the production of the sequence of /pa/ is very small in the normal subject and his articulatory movement is more or less confined to the lip. On the other hand, jaw movement is fairly large for the sequence of /pa/ in the ataxic case, 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.

In Figure 2, the patterns of lip and jaw movements are compared between the ataxic and ALS subjects. In this figure, the coordinate values

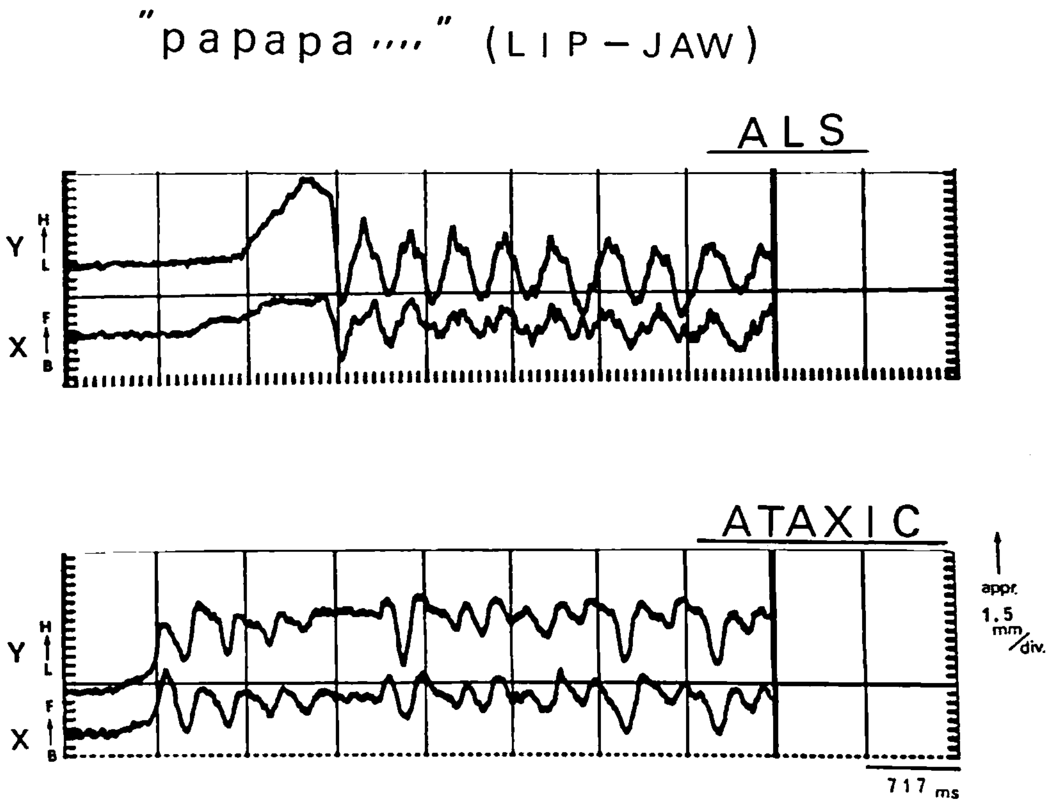

Fig. 2. Patterns of movements of the lower lip in the ALS subject (upper) and in the ataxic subject (lower) for repetitions of /pa/. In this figure, the coordinate values for the jaw are subtracted from those of the lower lip so as to obtain absolute values for the displacement of the lip.

for the jaw are subtracted from those of the lip in order to observe the pattern of lip movements independently of the jaw. It appears that in the ALS subject the range and velocity of displacement were relatively consistent although the velocity is slow in general.

Figure 3 compares the velocity of lip displacement in the production of the sequence of /pa/ among the three subjects. In the normal subject, the values are quite consistent and high in both directions of opening and closing. They are approximately 190 mm/sec (172 - 206 mm/sec in range) in lip opening and 250 mm/sec (234 - 261 mm/sec) in lip closing. The values are extremely inconsistent in the ataxic case and there is an occasional standstill where the velocity of the lip is 0 and the apparent lip displacement must entirely depend on jaw movement. It should be noted, however, that the maximum velocity of lip displacement is about 180 mm/sec, and the value is not much less than the normal value. On the other hand, the velocity is consistently low in the ALS case and the value is approximately 135 mm/sec.

When the normal subject attempts to produce the same sequences at a slower speed, the pattern of lip movement is different from that of ALS, in that there is no remarkable decrease in the velocity of displacement of the

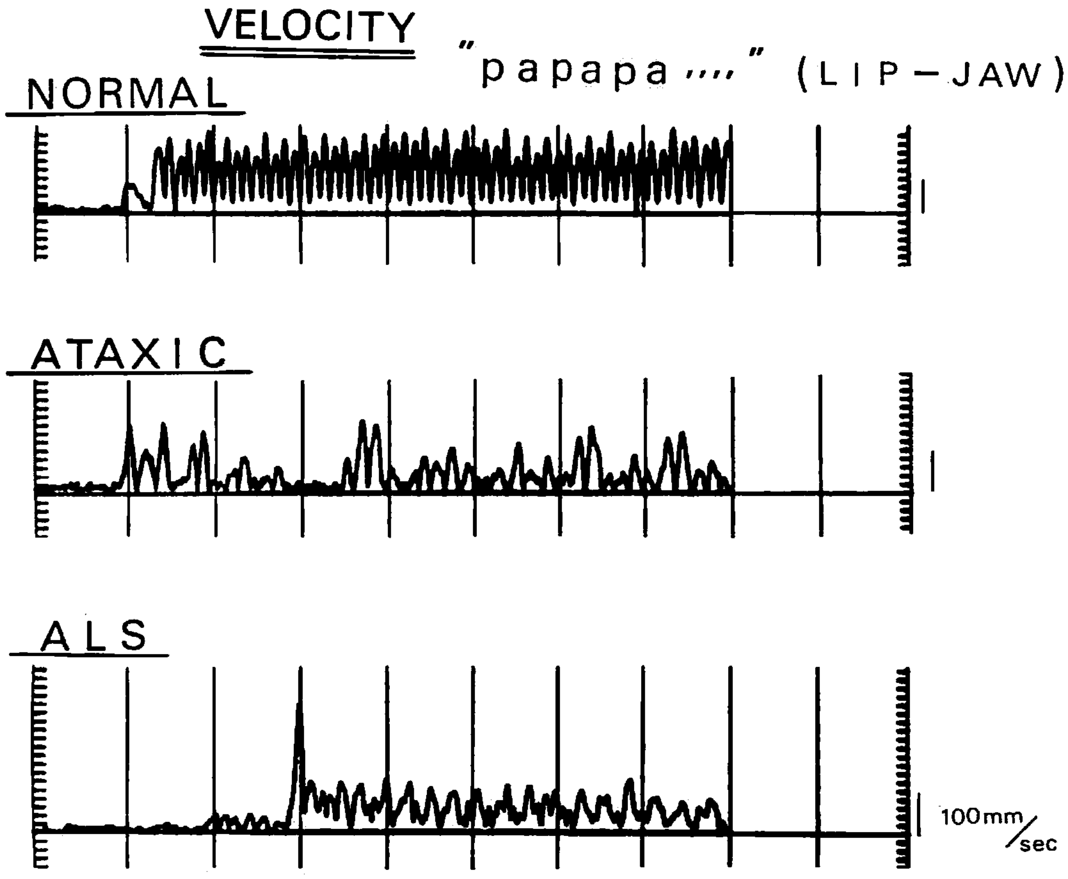

Fig. 3. Comparison of velocity of lip displacement in the normal subject (upper), the ataxic subject (middle), and the ALS subject (lower) for repetitions of /pa/. Velocity was obtained through use of a pertinent computer program for differentiation.

lip when compared with that in the case of quick repetition, but the duration of the closure period is simply prolonged (Fig. 4). This would suggest that the pattern of "slowness" in the ALS subject is different from that of slow articulation in the normal subject.

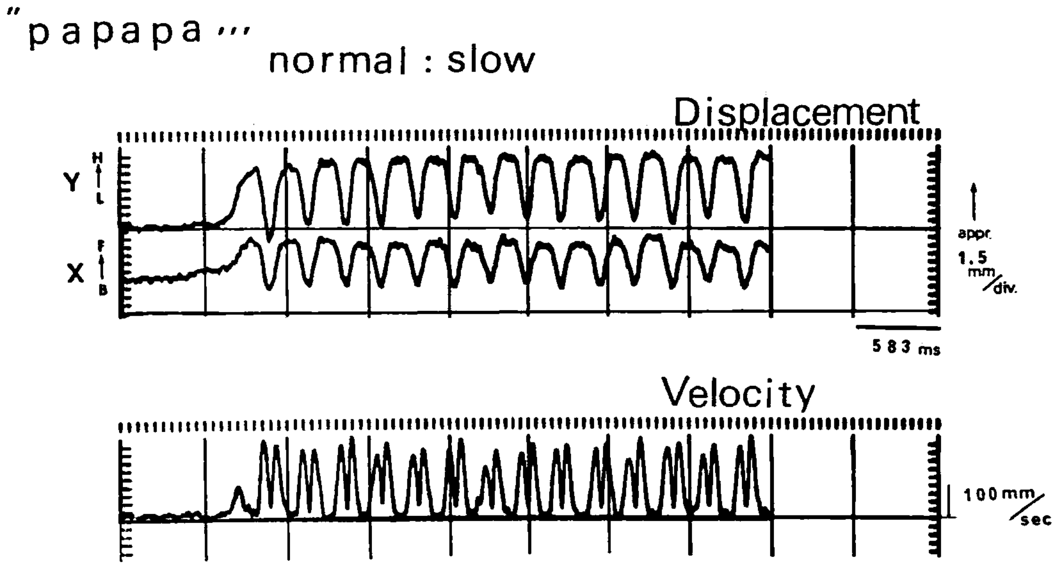

Fig. 4. Pattern of lip movements and its velocity in the normal subject attempting to produce sequences of /pa/ at a slow rate.

Figure 5 illustrates rectified and integrated EMG signals of the anterior digastric and the mentalis for the production of sequences of /pa/ in the normal subject and the ataxic subject [case #1]. As clearly seen in the normal subject, the anterior digastric is active for jaw opening for /a/ gesture and suppressed for jaw closing in the stop production. On the contrary, the mentalis shows activity for the lip gesture in /p/ production and 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 prerequisite to the coordinated articulatory movement in the repetition of the monosyllable /pa/. In the ataxic case, 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 may indicate the tendency toward the disturbance of initiation of muscle activation in repetitive movement. However, apparent reciprocity between the two muscles is somehow preserved.

In the ALS subject, clinical EMG examinations revealed reduced NMU activity with typical high amplitude voltages in the extrinsic and intrinsic lingual muscles, levator palatini, facial muscles and intrinsic laryngeal muscles.

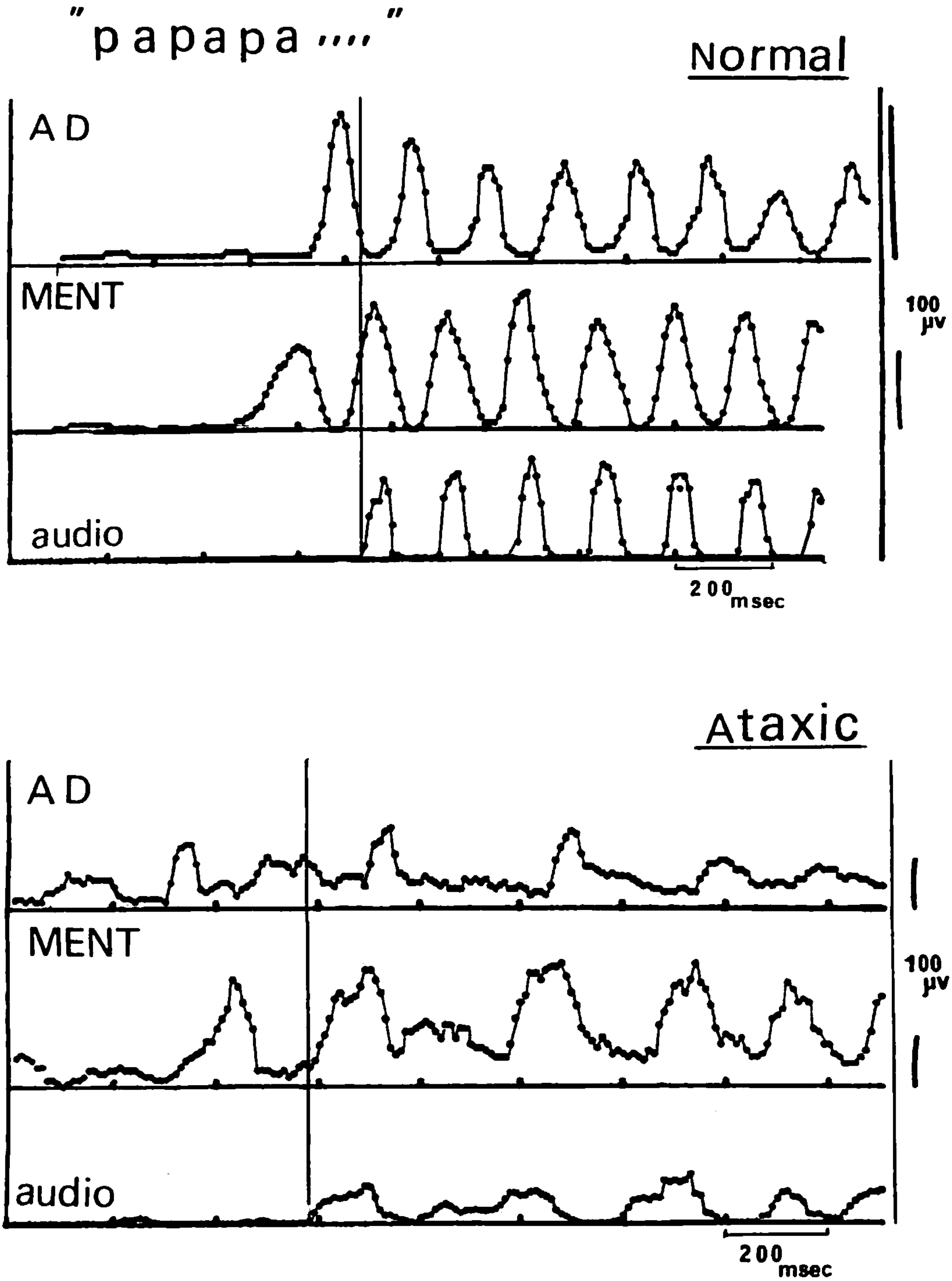

Fig. 5. Processed EMG curves of the anterior digastic and the mentalis for repetitions of /pa/ in the normal subject (upper) and in the ataxic subject (lower).

Comments

The present study reveals that the articulatory pattern of the ataxic subject 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. Electromyographically, 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 somehow maintained. It has been reported that the speech pattern of the ataxic is characterized by irregular articulatory breakdown. This pattern seems to be compatible with the above-mentioned physiological evidence of inconsistency in the articulatory movement.

In the ALS subject, a reduced range of articulatory movement and slowdown in the rate of speech are the most manifest signs of the pathological condition. In clinical electromyography, it has been reported that neurogenic patterns of reduced NMU discharges with high amplitude voltage are usually observed in ALS, and these patterns were confirmed in this particular case. The abnormal articulatory movements in the ALS subject must be based on these neuromuscular changes.

The role of each subsystem of the central nervous system in normal voluntary movement is not yet fully understood. In particular, very little is known about the neurophysiological mechanisms of skilled movements such as speech. Recently, Allen and Tsukahara (1974) discussed the participation of the cerebellum in the planning and carrying out of a voluntary movement in their extensive review on the cerebrocerebellar communication systems. According to them, the most reasonable possibility for the lateral cerebellum is, as suggested in Figure 6, that it 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. For learned movements, the cerebellum is considered to provide an internal substitute for the external world, and this operation of the cerebellum eliminates the need for peripheral sensory input and allows one to increase the speed of the learned movement by preprogramming. Although most of these concepts on the motor control system are based on the experimental results on the movement of the limbs, the basic principle might also be common to speech articulation.

Abnormal patterns of movement in cerebellar disorders must be explained as impairments of the programming and updating functions of the cerebellum. In particular, fine control of skilled movement must be affected by loss of the updating function and, as a result, quick change in the direction of movement must be disturbed. It seems reasonable to conclude that deterioration in speech or the pattern of articulatory breakdown in the case of cerebellar ataxia is mainly due to impairment of the updating

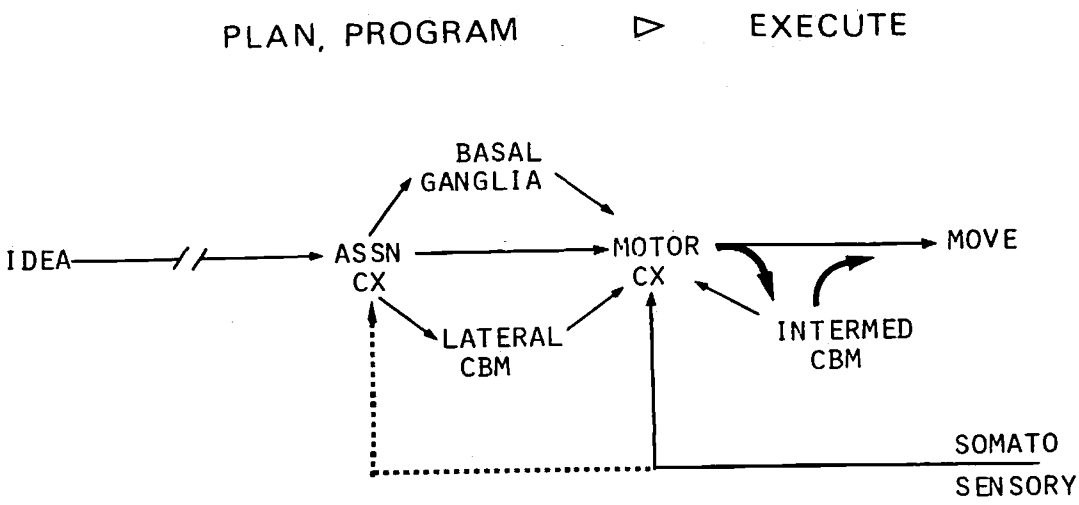

Fig. 6. Scheme showing proposed roles of several brain structures in the execution of movement. Broken lines represent pathways of unknown importance. CBM: cerebellum. ASSN CX: Association cortex. (From Allen and Tsukahara, 1974).

function of the cerebellum. The fact that an apparent reciprocity between the anterior digastric and the mentalis was preserved in the ataxic subject would suggest that there might not be serious impairment in the pre-programming at the cortical level, although further studies must be undertaken for a definite interpretation of the present experimental results. It is hoped that neurophysiological approaches to the analysis of the articulatory movements of dysarthric subjects will provide important information for a better understanding of the central control mechanism of speech articulation.

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