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VELOCITY OF ARTICULATORY MOVEMENTS IN NORMAL AND DYSARTHRIC SUBJECTS

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Introduction

In the study of articulatory dynamics, the velocity of the articulators in the production of certain speech sounds is a topic of great academic interest. Until recently, however, a very limited number of reports have been available on the velocity of articulators mainly because of methodological difficulties. For example, Cooker (1974) studied the kinetics of the lower lip and claimed that comparison of the EMG with various movement parameters suggested a velocity-based system of articulatory control, however no comprehensive data presentation has been made since this report. Abbs and Netsell (1973) recorded jaw movement and calculated velocity and acceleration but again the data was almost entirely limited to jaw movement. Lehiste (1970) pointed out that it might be useful to establish the upper limits of the speed of which the articulatory organs are capable, but what she referred to was simply the rate of repetitive productions of certain syllables by different articulators. She confirmed the earlier observation made by Hudgins and Stetson (1937) that the maximum rate of tongue movements for articulations of a train of [tə] syllables was 8 syllables per second. She commented that the maximum rate of 8 syllables per second might not be completely determined by the physical properties of the articulator, in this case the tip of the tongue, since the [r] oscillations in trill were almost three times faster than the [t] articulations. In any case, it is conceivable that the velocity of the articulator is an independent parameter of speaking rate and should be investigated separately.

The introduction of the x-ray microbeam system (Kiritani, Itoh and Fujimura, 1975) has opened up new possibilities in speech research and has enabled us to track the movements of pellets attached to several portions of the articulators at the frame rate of 120-160 per second. This system, at the same time, has solved the problem of the subject's x-ray exposure dosage to a large extent while greatly reducing the time required for data analysis. By using this system, it is possible to plot the excursion of the specific portions of the articulators and to calculate its velocity.

In the present report, results of an analysis of the normal and abnormal dynamics of the articulators as obtained by the use of the computer-controlled microbeam system will be presented in terms of the velocity of the movements.

Procedures

In the present study, the movements of several lead pellets attached to the pertinent articulators were tracked and analyzed using the x-ray microbeam system.

The description of the computer-controlled x-ray microbeam system and the strategy for the automatic tracking of a pellet on a moving articulator has been reported elsewhere (Kiritani, et al., ibid.). The pellets were attached to several portions of the selected articulators such as the tongue, using a biomedical adhesive. Detailed description of the method of placing the pellet on the nasal side of the velum has been given by Hirose, Kiritani, Ushijima and Sawashima (1978). The data output was read into a computer memory core through an x-ray detector and an analog to digital (A/D) convertor.

For the purpose of off-line observations, the x-ray image can be displayed on a monitor oscilloscope by using a hardware scan-signal generator. The velocity was obtained by differentiating through use of a pertinent computer program in which linear approximation was made for seven consecutive frames to represent the trajectory of the pellet within that very short period of time.

Since the lip and tongue movements depend, to a certain extent, on the movement of the jaw, the corrdinate values for the jaw have been subtracted from those of the lip and tongue in order to obtain new coordinate values representing independent movement parameters for these two articulators. The calculation of the velocity was also made using the obtained coordinate values.

In the present study, the velocity data was obtained from two normal subjects and six dysarthric cases (Table I). The diagnosis of neurological disorders of each dysarthric case was made at the Department of Neurology, the University of Tokyo Hospital.

Table I

Subjects of the present study

		Age	Sex	Condition
1.	TU	39	M	normal
2.	HH	44	M	normal
3.	HN	53	M	cerebellar ataxia
4.	SK	58	M	cerebellar ataxia
5.	YA	34	F	amyotrophic lateral sclerosis
6.	CK	55	M	pseudobulbar palsy
7.	SY	59	M	Parkinsonism
8.	KS	68	M	Parkinsonism

The subjects were required to repeat each of the following Japanese monosyllables, /pa/, /ta/, /ka/, //teN/ and /paN/, separately at different rates of speech. In addition, several kinds of meaningful Japanese words were uttered with or without carrier phrases.

Results

Figure 1-a shows the patterns of movements of the lower lip for repetition of the monosyllable /pa/ at a medium utterance speed. In this figure, the coordinate values for the jaw have been subtracted from those of the lip, and the X and Y coordinates thus obtained are displayed as functions of time.

The velocity of lip movements given in Figure 1-a was calculated and displayed in Figure 1-b. Each consecutive peak corresponds to the closing and opening velocity of the lower lip for /p/ production. The peak values were also given in digitized form and, from these values, the average velocity and its standard deviation (SD) were calculated.

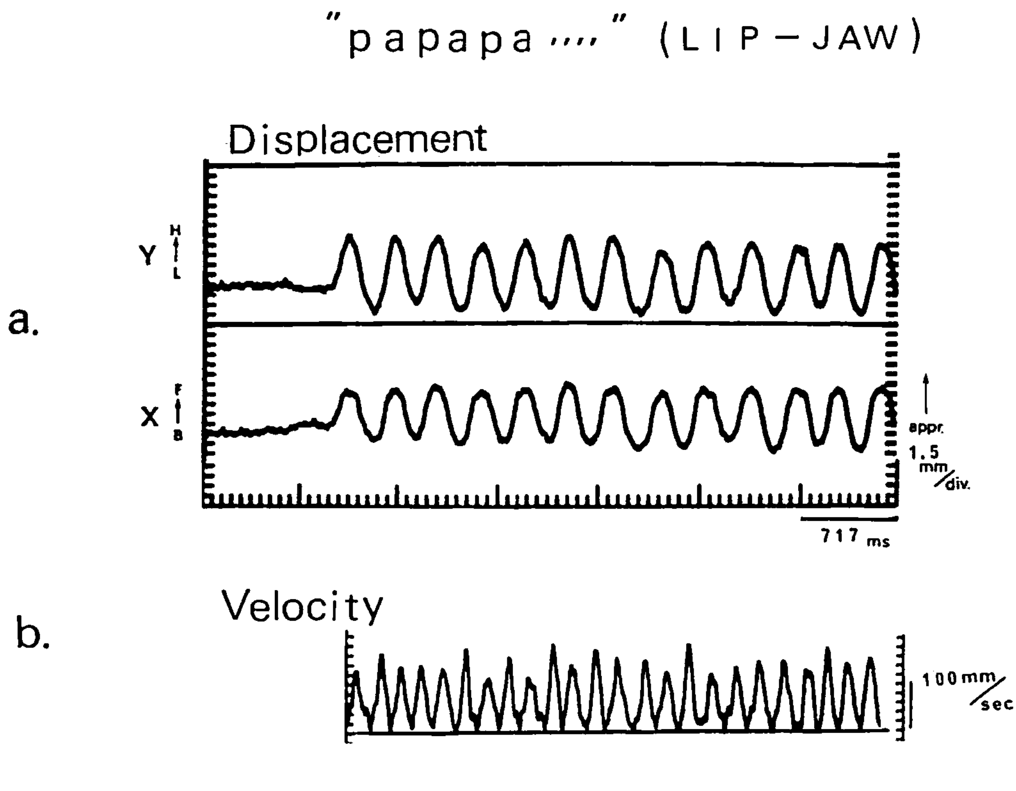

Fig. 1: An example of lip movement patterns (a) and velocity (b) in a normal subject producing sequences of the monosyllable /pa/ at a moderate rate of speech. The displacements are displayed as time functions of X (back [B] to front [F]) and Y (low [L] to high [H]) coordinates. In this figure, the coordinate values for the jaw are subtracted from those of the lip so as to obtain the values for the lip itself.

Table II summarizes the values of velocity and the SD for the pertinent articulators in the repetitive production of the monosyllables for the normal and dysarthric subjects. As mentioned above, some subjects were required to produce meaningful words such as /papa/ or /kakato/, for which

TABLE II

organ & subject	task (number of repetitions)	direction of movements	range of velocity(cm/sec)	average velocity	SD	% SD
lip	repet. of /pa/	closure	13.4 - 18.1	16.0	1.5	9.2
TU (N)	medium rate (n=14)	release	11.2 - 15.7	13.4	1.4	10.4
lip	repet. of /pa/	closure	18.1 - 22.6	20.4	1.7	8.5
HH (N)	medium rate (n=10)	release	14.0 - 22.9	18.7	2.5	13.6
lip	repet. of /pa/	closure	18.8 - 25.4	22.2	1.9	8.5
HH (N)	fast rate (n=20)	release	14.0 - 20.7	16.5	2.6	15.9
lip	repet. of /pa/	closure	2.5 - 14.1	6.3	4.1	65.0
HN (A)	fast rate (n=10)	release	2.8 - 13.3	6.5	3.0	45.4
lip	repet. of /pa/	closure	6.7 - 11.0	9.3	1.6	16.9
YA (ALS)	fast rate (n=8)	release	6.5 - 11.2	9.3	1.3	14.2
lip	repet. of /pa/	closure	5.4 - 14.5	8.4	3.4	40.4
SY (PKN)	medium rate (n=25)	release	3.6 - 12.2	8.0	2.4	30.1
lip	repet. of /pa/	closure	8.3 - 15.0	11.0	2.1	18.7
SY (PKN)	fast rate (n=16)	release	5.9 - 13.1	8.3	2.8	34.3
lip	repet. of /pa/	closure	11.0 - 17.7	14.7	2.0	13.5
KS (PKN)	fast rate (n=16)	release	9.4 - 17.4	12.2	2.6	20.9
velum	repet. of /teN/	elevation	5.5 - 8.3	6.4	1.1	16.4
TU (N)	(n=14)					

velum YA (ALS)	repet. of /teN/ (n=7)	elevation	4.3 - 7.4	6.1	1.1	17.5
velum SY (PKN)	repet. of /paN/ (n=16)	elevation	12.8 - 20.0	14.4	2.2	15.4
velum KS (PKN)	repet. of /paN/ (n=21)	elevation	8.9 - 21.2	14.6	3.6	24.8
velum CK (PBP)	repet. of /paN/ (n=16)	elevation	5.4 - 11.8	9.4	2.0	21.4
tongue dorsum HH (N)	repet. of /ka/ (n=16)	closure	12.6 - 17.9	15.1	1.6	10.7
		release	12.7 - 20.5	16.4	1.8	10.8
tongue dorsum KS (PKN)	repet. of /ka/ (n=13)	closure	10.4 - 20.0	12.3	4.4	35.4
		release	14.9 - 25.8	20.0	3.3	16.7
tongue tip HN (A)	repet. of /ta/ (n=10)	closure	3.1 - 9.2	6.0	1.9	31.9
		release	3.1 - 9.0	5.0	1.6	31.9
tongue tip SK (A)	repet. of /ta/ (n=16)	closure	5.0 - 10.2	6.9	1.4	20.6
		release	3.1 - 9.0	6.1	2.7	43.6
tongue tip SY (PKN)	repet. of /ta/ (n=16)	closure	5.0 - 12.0	8.2	2.9	35.0
		release	4.1 - 11.2	7.2	2.0	27.7

Table II Values of velocity and their standard deviation (SD) of the articulators examined in the present study.

(N: normal, A: ataxia, PKN: Parkinsonism, ALS: amyotrophic lateral sclerosis PBP: pseudobulbar palsy) the velocity of either the lip or tongue was calculated. The results indicated that the velocity of these articulators in the production of these meaningful words was not significantly different from, but was within the range of the velocity values obtained in the repetitive production of similar monosyllables; in this case /pa/ or /ka/.

It has been predicted that the velocity will increase with greater displacement of the articulator. In order to test this assumption, 36 samples were taken and the degree of displacement on the X-Y coordinates and the maximum velocity during the period required for the displacement were compared. These samples were selected from the data obtained from the normal subjects for the production of meaningful words. As can be seen in Figure 2, a high positive correlation between the degree of displacement and the maximum velocity (r = 0.81) was found.

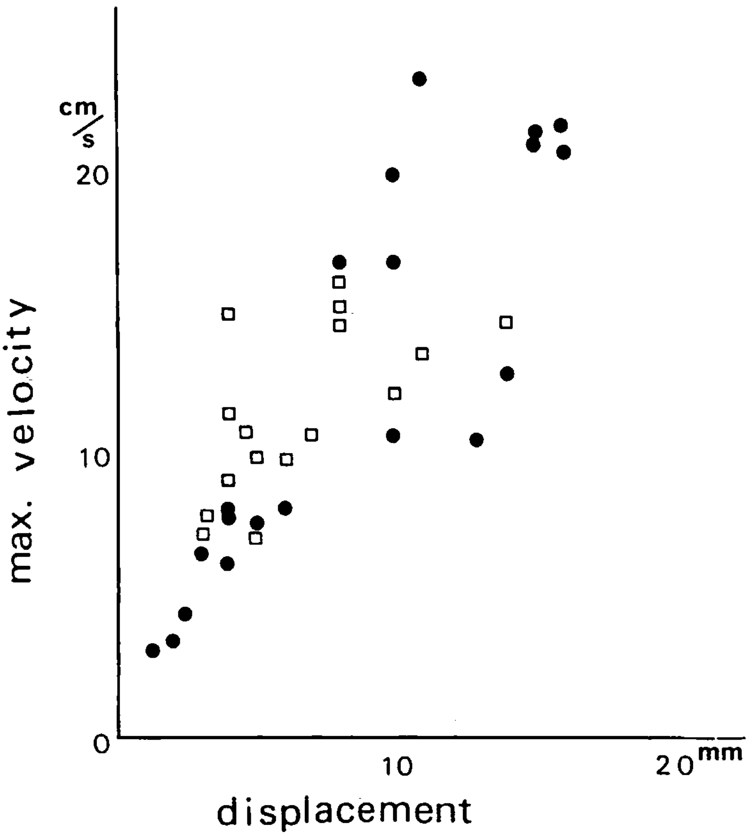

Fig. 2: Relationship between the maximum velocity of the articulators and the values of their displacement. These values were obtained from the normal subjects producing meaningful Japanese words at various speaking rates (lip: ●, dorsum of tongue: □)

Comment

In the present study, the order of magnitude of articulatory velocity was found to be in the range from several to more than 20 cm per second. The values are generally higher in normal subjects particularly for lip articulation, while the velocity of the velum is relatively low at least for the present samples.

It must be taken into consideration, however, that the velocity should depend, to a certain extent, on the distance which the articulator has to travel during the pertinent articulatory gesture. Therefore, if the pellet is attached to the point on an articulator where the degree of displacement is not maximum for its articulatory movement, the obtained value may not represent the maximum velocity of the articulator. Since the placement of the pellet on the nasal side of the velum is technically difficult, the pellet might not in some cases, be attached to the point which becomes highest for a given utterance. This may be the reason for apparently low values of velar velocity in the normal subject in the present experiment.

In the repetitive production of monosyllables, the position of the articulator preceding the consonant closure must be consistent for each repetition and, therefore, the obtained values of velocity must not be affected by the difference in the articulatory distance between consecutive syllables. In fact, in the normal subjects and in subject YA (ALS), the velocity is more or less consistent and the SD value is low. On the other hand, in cerebellar ataxia and in Parkinsonism, the SD values are high in most samples. These results would indicate that the velocity of articulatory movements is inconsistent in these two types of dysarthrias. However, closer observations also indicate that there is a certain difference in the general pattern of the inconsistency between the two pathological conditions. As shown in Figure 3, the velocity of lip movements for each consecutive syllable is quite variable and inconsistent in cerebellar ataxia, while in Parkinsonism, the velocity declines quickly as the same syllables are produced repeatedly. The latter pattern can be interpreted as a kind of "hastening" - or "short rashes" - type phenomenon which is characteristic for Parkinsonism. The inconsistent pattern in cerebellar ataxia, on the other hand, can be referred to as a random articulatory breakdown in this type of pathology.

In the present samples, the velocity of lip closure generally tended to be faster than that of the release except for the cases of cerebellar ataxia (8 out of 9 pairs), while a similar tendency was not confirmed for tongue gestures. More data is needed to clarify the significance of the velocity of the articulators in articulatory dynamics.

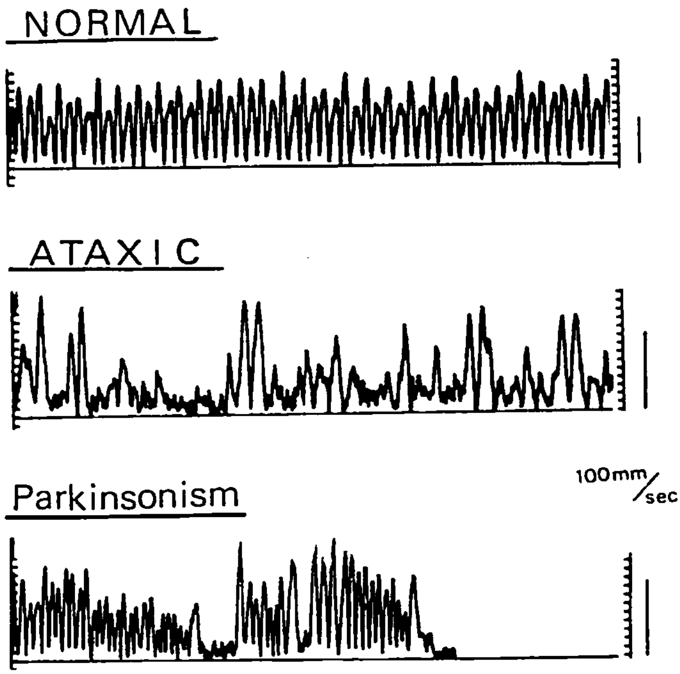

Fig. 3: Comparison of velocity of lip displacement in the normal subject (top), the ataxic subject (middle) and the Parkinsonian subject (bottom) for repetition of /pa/.

Acknowledgement

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