A computational approach to arm movement on the sagittal plane performed by parietal lobe damaged patients: An attempt to examine a computational model for handwriting for its neurobiological plausibility from a neuropsychological symptom.

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Abstract

We measured arm movement on the sagittal plane of parietal lobe damaged patients and control subjects. In neurological patients, (1) the hand height did not become lower as the motion duration became shorter; (2) the hand jerk of measured trajectory increased when motion duration lengthened. These results suggested that the parietal lobe is involved with realizing smooth arm movement. The performance of patients with parietal lobe lesions may reflect their difficulties in planning a trajectory with smooth movement.

Key words: Parietal lobe damaged patients; Sagittal plane movement; Hand height

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1 Introduction

Wada and Kawato [5] proposed a computational models on handwriting and reaching movement based on the minimum commanded torque change model

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where we plan an arm trajectory minimizing the time integral of the square of the rate of the commanded torque change.

The object function of the minimum commanded torque change model is expressed as follows.

$$C_{CTC} = \frac{1}{2} \int_0^{t_f} \sum_{i=1}^{N} \left(\frac{d\tau_i}{dt} \right)^2 dt \tag{1}$$

Here, t_f indicates the motion duration. N is the number of joints, and τ_i is the commanded torque generated in joint i. The following two facts are mathematically deduced from the model. (1) when movement distance is constant, the time integral of the square of the rate of the commanded torque change becomes larger as the motion duration becomes shorter. (2) when movement distance is constant, the time integral of the square of the rate of the commanded torque change becomes smaller as the hand height becomes lower.

The minimum commanded torque change model reproduces smooth arm movement during reaching movement well [4,3,2]. Wada et al [4,3] measured hand trajectory of the arm movement in control subjects on the sagittal plane and confirmed that hand height varies as motion duration varies. They also demonstrated that the minimum commanded torque change model explains the relationship between hand height and motion duration.

In the present study, we first measured and quantitatively compared arm movements on the sagittal plane in the parietal lobe damaged patients with agraphia and the control subject. We also attempted to explain the differences in arm movement of control subjects and the parietal lobe damaged patients using the minimum commanded torque change model.

2 Purpose

The purposes of the present study are as follows. 1) To quantitatively analyze and compare arm movements on the sagittal plane in the neurological patients with agraphia and the control subjects. 2) To investigate the functional role of the parietal lobe in arm movement.

3 Methods

3.1 subjects

Seven neurological patients: They had the left parietal lobe lesions accompanying agraphia. Table 1 shows lesions of the patients. Control subjects: Seven normal males, five of which also served as subjects in Wada et al.'s studies [4,3] served as control subjects. All subjects were right-handed.

Table 1
Lesions of the patients

Patients	Age	Lesions
K	77	Left angular gyrus.
H	74	Right parietal lobe lesion extending into the superior portion of the parietal lobe, left lateral of occipital lobe lesion extending into the angular gyrus, prietooccipital lesion extending into left lateral horn of the ventricle.
Y	60	Superior parietal lobule, postcentral gyrus, precentral gyrus area.
S	41	Left angular gyrus, left temporal lobe.
M	26	Subcortical area of left parietal lobe.
T1	57	Extensive parietal lobe lesion.
T2	53	Parietal lobe.

3.2 Procedure and apparatus

The subjects were required to move their hands back and forth between the starting point and the final point marked on a desk along a board placed at a right angle to a horizontal plane. They were asked to raise their hands in the air during the movement except that they were asked to touch the two points. Each trial consisted of seven back and forth movements. The subjects repeated about sixty trials with three different distances (0.200, 0.175 and 0.150m) and three different speeds (control, fast and slow). The position of the subject's shoulder and hand were magnetically measured using FASTRAK (Polhemus Inc.) with a sampling frequency of about 60Hz. The apparatus used in this study was described in detail in Wada et al.[3]

3.3 Data analysis

We analyzed the obtained data of hand position using following three ways.

3.3.1 Position Data

We extracted the data of hand position in the Z direction (= hand height data) from the obtained position data. We represented hand height data as the exponential function of motion duration, then, we calculated the correlation coefficient between the exponential function and the hand height data of measured trajectory.

3.3.2 Hand Jerk

We calculated hand jerk [1] (an index of movement smoothness) of a measured trajectory. Then, we calculated standardized hand jerk which is the hand jerk

[1] We employed hand jerk model [1] to analyze the data obtained in the present study for mathematically simplicity.

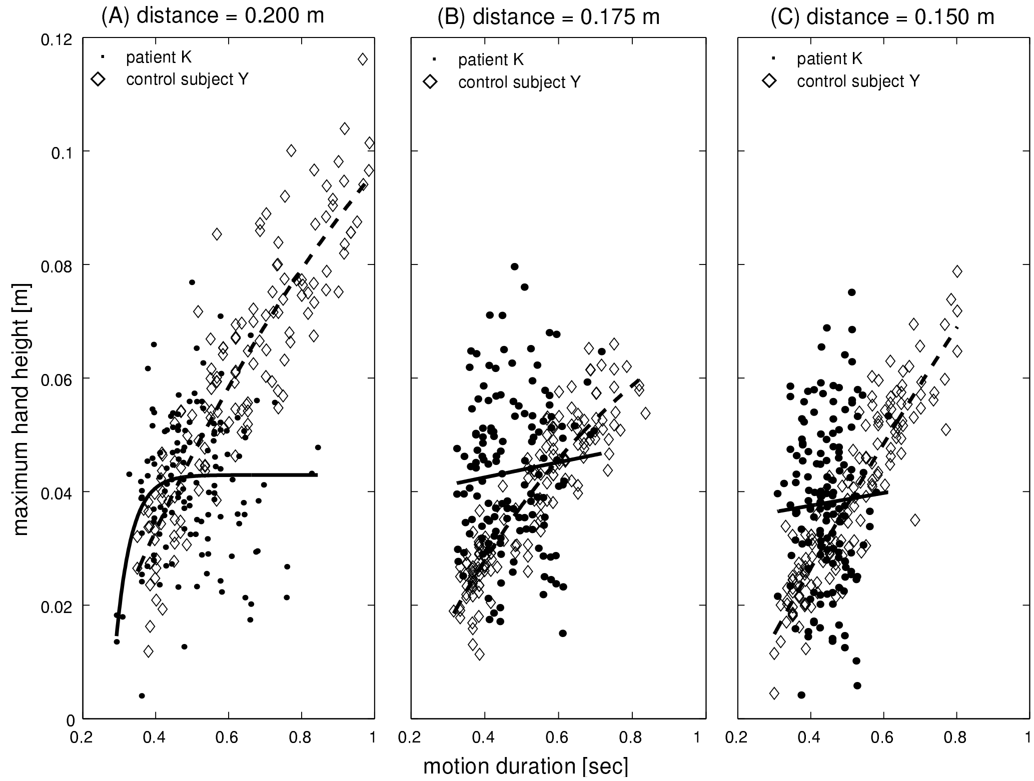

Fig. 1. Maximum hand height data and approximated exponential curve in (A) distance=0.200m, (B) distance=0.175m and (C) distance=1.150m. In control Y (diamonds and dashed lines), hand height tended to become lower as the motion duration became shorter in all movement distances. However, in pattient K(dots and lines), hand height did not become lower as the function of the motion duration.

of the measured trajectory divided by the hand jerk of the minimum hand jerk trajectory. The equation of the standardized hand jerk is given by

$$\frac{C_{data}}{C_{mj}} = \frac{\frac{1}{2}\int_0^{t_f}\left\{\left(\frac{d^3 y_{data}}{dt^3}\right)^2 + \left(\frac{d^3 z_{data}}{dt^3}\right)^2\right\} dt}{\frac{1}{2}\int_0^{t_f}\left\{\left(\frac{d^3 y_{mj}}{dt^3}\right)^2 + \left(\frac{d^3 z_{mj}}{dt^3}\right)^2\right\} dt} \tag{2}$$

where $data$ is measured trajectory, mj is minimum hand jerk trajectory, t_f is movement time and x, y, z shows hand position.

4 Result and discussion

4.1 Prediction of C_{CTC} and the relationship between hand height and motion duration

In the measured trajectory of control subjects, hand height tended to become lower as the motion duration became shorter in all movement distances

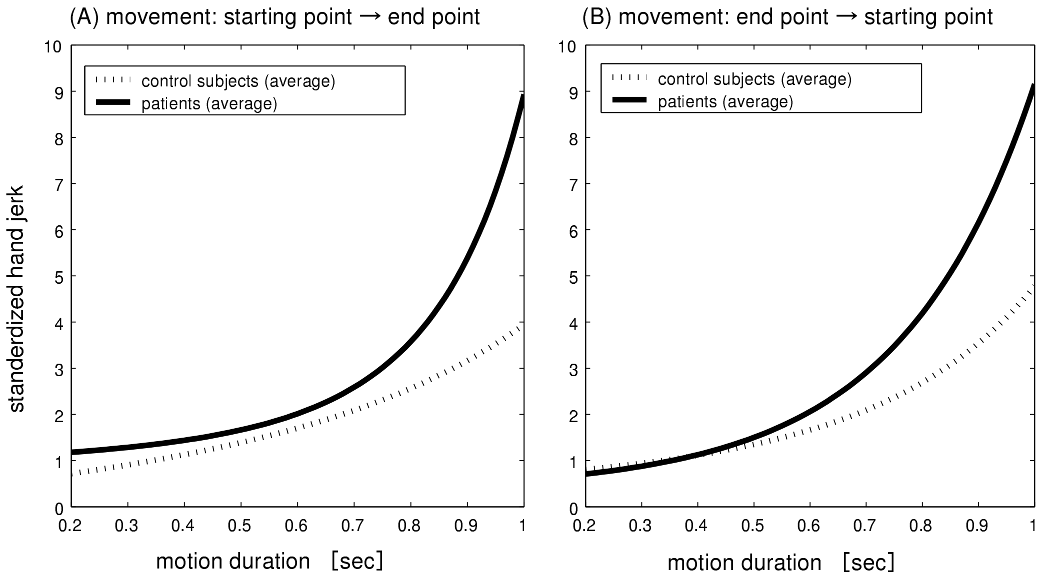

Fig. 2. Comparison between the standardized hand jerk of the control subjects and that of the patients in (A) movement from starting point to end point, (B) movement from end point to starting point. The standardized hand jerk in the neurological patients increased when motion duration became longer. On the other hand, he standardized hand jerk of the normal subjects was rather small in longer motion duration.

(Fig. 1). In neurological patients, however, hand height did not become lower as the function of the motion duration. In control subjects the correlation coefficient between the exponential function and the measured proved to be high while that of the neurological patients proved to be low. The low correlation coefficient in the neurological patients suggests that they could not minimize the commanded torque which is produced as motion duration became shorter.

4.2 Movement smoothness

We analyzed the relationship between standardized hand jerk and motion duration to examine movement smoothness. The standardized hand jerk (an index of movement smoothness) in the neurological patients became larger when motion duration became longer (Fig. 2). On the other hand, he standardized hand jerk of the normal subjects was smaller than that of the neurological patients. Furthermore, the hand jerk of measured trajectory of normal subjects varied only slightly when motion duration became longer.

The results suggest that the movement of the neurological patients was not as smooth as in control subjects when the motion duration became longer assuming that the value of standardized hand jerk is an index of movement smoothness.

5 Conclusion

The result of the present study suggests that the control subjects can realize the smooth arm movement on the sagittal plane by lowering hand height as motion duration became longer. On the other hand, it is suggested that the neurological subjects cannot move their hands like the control subjects. It is further suggested that the parietal lobe is involved in realizing smooth arm movement.

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