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Matsumoto, Yuji

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博　士　論　文

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（脳卒中患者の回復段階における手関節運動機能の客観的評価の確立：
ブルンストロームステージとの比較）

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Establishment of a quantitative evaluation of wrist motor function recovery stages in stroke patients: Comparison with the Brunnstrom stages

Authors' information

Yuji Matsumoto[1], Jung-ho Lee[4], Takatoshi Baba[2], Shinji Kakei[4], Yasuhiro Okada[3], Hiroshi Ando[1]

[1]Kobe University Graduate School of Health Sciences

[2]Junshin Rehabilitation Hospital

[3]Rehabilitation Research Center of Kakogawa

[4]Tokyo Metropolitan Institute of Medical Science

Running Title

QUANTITATIVE EVALUATION OF THE WRIST MOVEMENT OF STROKE PATIENTS

Key Words:

Stroke, Brunnstrom recovery stage, Quantitative evaluation

Abstract

Purpose: This study establishes an objective quantitative evaluation method for the wrist movement of stroke patients with a newly developed system and apply the method for evaluation of stroke patients at Brunnstrom stages V or VI and normal healthy participants.

Methods: Fifteen stroke patients at Brunnstrom stage V or VI and ten healthy participants performed a four-way step-tracking wrist movement task. This task required quick and accurate movements of the wrist joint in four directions. The movements were digitalized and analyzed for movement time, maximum velocity, reaction time, and path variation.

Results: The movement time of the patients at Brunnstrom stage V was significantly different from that of healthy participants. The healthy participants and stage V patients showed a significantly different maximum velocity. In contrast, there was no significant difference in reaction time among the three groups. In terms of motion accuracy, the stage V patients showed more erratic variation and fluctuation in the trajectory path than the healthy participants.

Conclusion: Evaluations using the present system can objectively assess multiple factors of stroke-related movement dysfunction.

I. Introduction

Stroke is one of the common movement disorders affecting the elderly. After a stroke, a patient may lose motor function in their legs, arms, feet, or hands. With appropriate treatment, the patient may regain voluntary and deliberately controlled movements. As motor recovery is an incremental process, Brunnstrom defined six motor recovery stages in an approach that is now widely used to evaluate the motor recovery process and rehabilitation outcome of stroke patients [1]. The Brunnstrom recovery stage (BS) classification is based on subjective evaluation of recovery progress in, for example, the arm or hand. Stage I (BS I) applies to the period of muscle flaccidity immediately following the stroke. BS II is defined as the emergence of synergic movement or elements of this. In BS III, synergic movement patterns emerge and spasticity is most strongly exhibited. In BS IV, the spasticity begins to abate and movement that deviates from basic synergic movement emerges. In BS V, spasticity declines further, and the ability to move independently from synergic movement emerges. In the hand, awkward palmar prehension, and cylindrical and spherical grasp become possible at this stage. Finally, in BS VI, spasticity is almost entirely absent and coordinated movements can be performed almost normally [2].

These definitions of stages allow a synopsis of clinical dysfunction to be concisely expressed. However, recovery from dysfunction is gradual and continuous, and the boundaries between the stages are indistinct. Recent advances in technology have made it possible to make quantitative measurements of motor dysfunction in stroke patients. There have been several reports of the use of accelerometers for quantitative evaluation of arm motor function; for a review, see Noorkõiv *et al.* [3]. In one study, the arm movements of elderly stroke patients were monitored by attaching an accelerometer [4], and in another, researchers attempted to quantitatively evaluate the arm movements of stroke patients using accelerometers [5, 6]. Evaluations such as these target the motor function of multiple joints. However, when isolated movement becomes possible in the course of stroke recovery (at BS V and later), an assessment of the movement around a single joint may be required. Such an assessment was attempted in one study by quantitatively evaluating elbow movements while adding various loads [7]. However, elbow joint movement is uniaxial, consisting only of flexion and extension; thus, evaluation and analysis of isolated movements are limited. We have devised a quantitative motor command analysis system for wrist movement that enables continuous measurement with two degrees of freedom (flexion/extension and radial/ulnar deviation). This system can be expanded to evaluate the controlled and deliberate movements of stroke patients [8]. In this study we quantitatively evaluated the wrist motor function of patients with stroke classified as BS V or VI, and compared this with the function of healthy individuals.

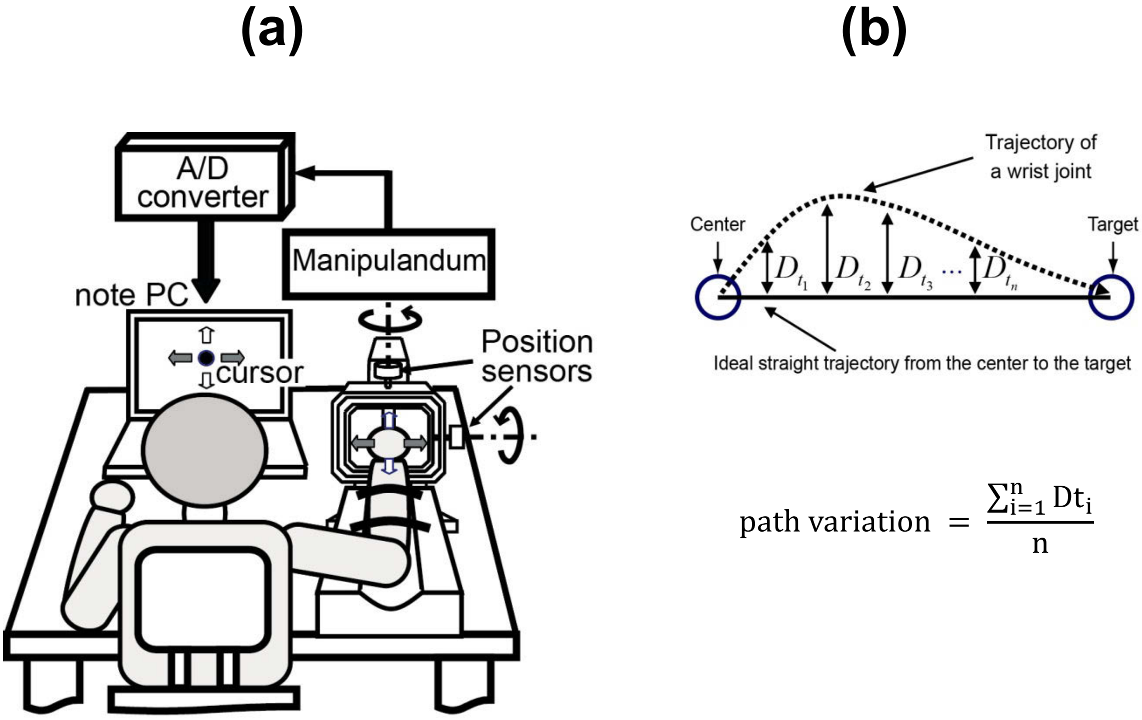
II. Materials and Methods

1. Participants

The study included eight patients at BS V (aged 69.4 ± 6.5 years), seven patients at BS VI (68.6 ± 8.2 years), and ten age-matched healthy participants with no history of neurological disorders (69.2 ± 4.6 years) as a control group. All participants were right handed. The participants in the patient group had no prior history of ailment directly affecting arm motor function, and at the time of this study presented hemiparesis due to a first-time attack of stroke. They also had no visual and cognitive dysfunction. The classification of the Brunnstrom stage of the patients was made by experienced physiotherapists. All participants provided written informed consent prior to participation. The protocol was approved by the ethics committees of Junshin Rehabilitation Hospital and was implemented in accordance with the ethical standards of the Declaration of Helsinki.

2. Measurement of wrist movement

Wrist movement was recorded using a wrist movement evaluation system[8]. The participant sat on a chair in front of a computer display and grasped a Strick-Hoffman type manipulandum [9] (Hoyo Elemec Co., Ltd., Sendai, Japan) with his/her right hand. The forearm was comfortably supported with an armrest (Fig. 1a). The handle of the manipulandum could be rotated freely about the horizontal and vertical axes with low friction. The manipulandum measured movement of the wrist with two degrees of freedom (flexion–extension and radial–ulnar deviation) using two position sensors, the output of which was digitized and transformed into wrist joint angle X (in the flexion–extension direction) and Y (in the radial–ulnar direction). These wrist joint angles were indicated on the computer display with a cursor, a black dot approximately 2 mm in diameter that moved in proportion to the participant's wrist movements. By using this system, various wrist movements could be assigned for experimental tasks. In this study we examined the results of step-tracking wrist movement (Fig. 2a).



$$\text{path variation} = \frac{\sum_{i=1}^{n} Dt_i}{n}$$

Figure 1. Experimental design.

(a) Experimental setup. Each subject sat about 60 cm in front of a computer screen that displayed a cursor and a target, and grasped a Strick-Hoffman type manipulandum with his/her right hand. Two position sensors were coupled to the device and measured the angle of the wrist in flexion-extension plane and radial-ulnar plane. (b) Path variation calculation. Measure distance angle (Dt) from the ideal straight trajectory every 50 ms and sum all the values. Then divide the summed value by number of data and get the normalized path variation value.

3. The task

A 1-cm circle was displayed at the center of the PC screen, and the participant was instructed to move the cursor into the circle and keep it there. After 500–1000 ms, a new target circle appeared in one of four directions (flexion, extension, radial deviation, or ulnar deviation). The distance to the new target was equivalent to 18 degrees of wrist joint movement. The central circle then disappeared. This became the start cue, and the participant was instructed to move the cursor to the new target position as rapidly and accurately as possible. About 2000 ms after having placed the cursor in the target circle, the central circle was redisplayed, and the participant moved the cursor back into it. This was the end of one trial and the beginning of the next. Four trials (one trial for each direction) constituted one set of movements. Each participant performed one set (four trials) as practice followed by eight sets of the task (32 trials) continuously.

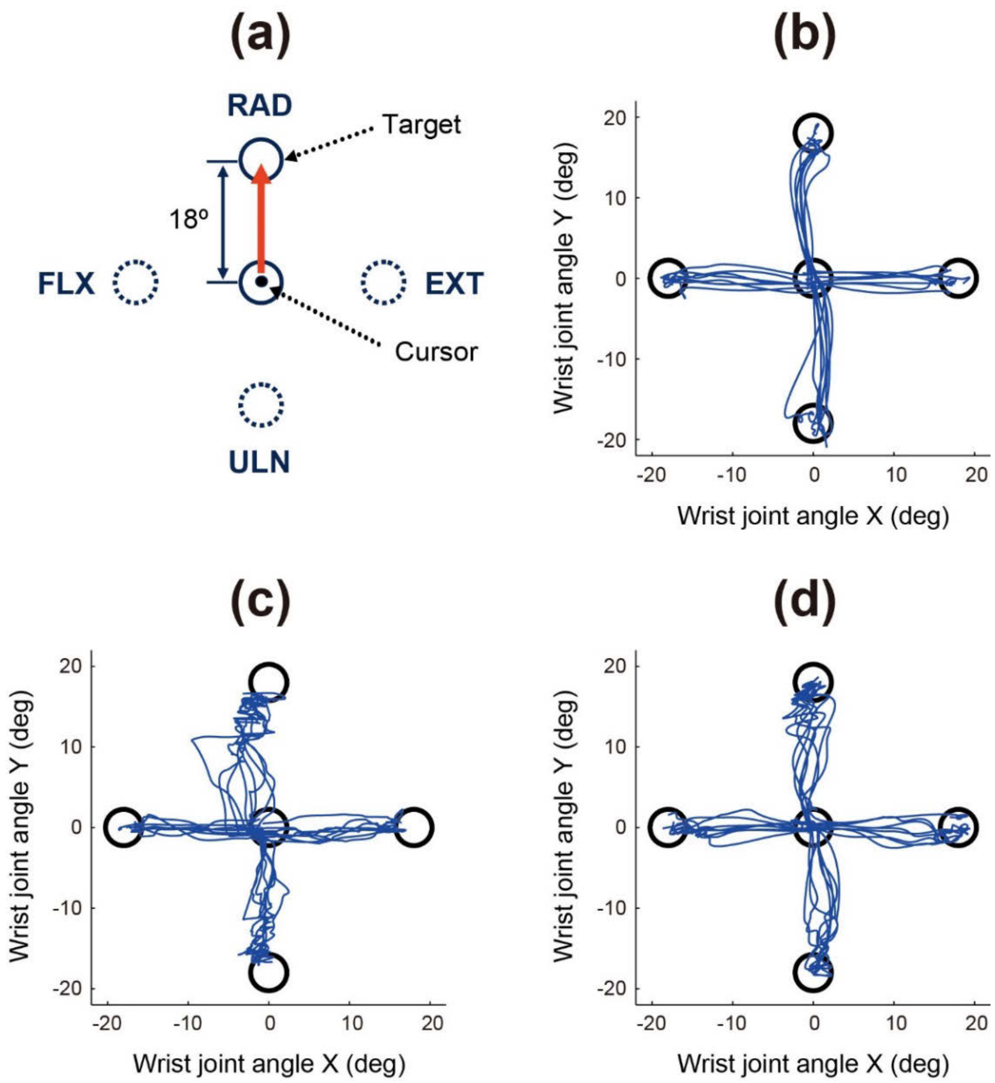


Figure 2. The four-way step-tracking task of the wrist joint.

(a) Diagram of the step-tracking task. The participant moves the cursor into the central 1 cm circle and keeps it there. A target circle appears in one of four directions. When the central circle disappears, the participant moves the cursor into the target as rapidly and accurately as possible. (b) Typical traces of trajectories recorded from one of the control group participants. (c) Typical traces of trajectories recorded from one Brunnstrom Stage (BS) V patient. (d) Typical traces of trajectories recorded from one BS VI patient.

4. Data analysis

While the participant performed the task, the wrist position expressed as the angle of rotation in the X and Y positions were recorded at a sampling rate of 1 kHz. The velocity components of the wrist movement (Vx, Vy) were determined by differentiation. From these data, we analyzed the following four parameters: 1) movement time (s), the time from the start cue (the disappearance of central circle) to the timing of the cursor entering the target circle; 2) maximum velocity (degrees/s); 3) reaction time (s); and 4) path variation (degrees), the normalized distance (i.e. error) between the ideal straight line and the actual trajectory of the wrist (Fig. 1b).

These four parameters were compared among the participant-groups using the Kruskal-Wallis test followed by multiple comparison using Tukey-Kramer method (the kruskalwallis function and the multcompare function in the statistics toolbox of Matlab, R2006b, The MathWorks, Natick, MA, USA). The threshold of statistical significance was set at 5%.

III. Results

Figures 2b, c, and d show typical traces of step-tracking movements recorded from a control group participant, a BS VI group patient, and a BS V group patient, respectively. The healthy control participants exhibited much straighter trajectories than the stroke patients. The trajectories of the BS V patients were more erratic than those of the BS VI patients, with this particularly pronounced in the radial–ulnar directions of the four-way step-tracking movement. The following analysis evaluated the quantitative differences in the step-tracking movements among the three groups based on the four parameters of movement time, maximum velocity, reaction time, and path variation.

1. Movement time

Figure 3 shows the box-and-whisker plot of the three groups' movement times for the step-tracking movement. Median of movement times were 2.02 s, 0.95 s and 0.65 s and interquartile range (IQR) were 1.24 s, 0.46 s and 0.07 s for the BS V, BS VI, and normal groups, respectively. Kruskal-Wallis test revealed significant differences among three groups ($p < 0.001$). Multiple comparison revealed significant differences between BS V group and normal group ($p < 0.001$).

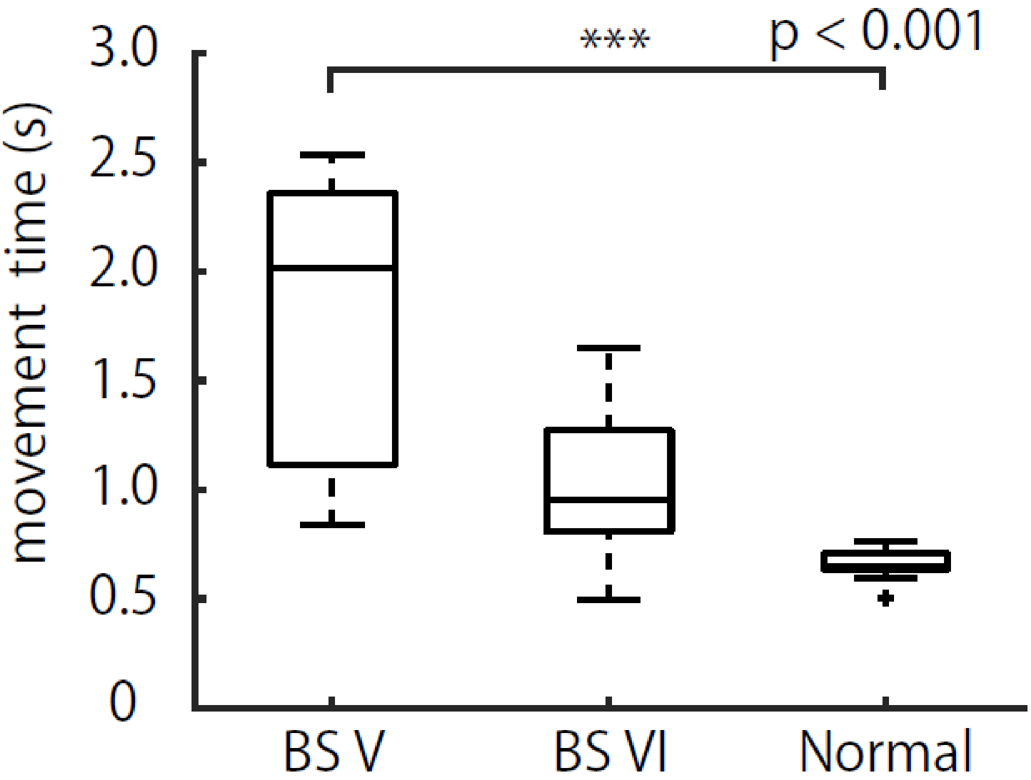


Figure 3. Movement times of the BS V group, the BS VI group and the control group. Kruskal-Wallis test revealed significant differences among three groups ($p < 0.001$). Multiple comparison revealed significant differences between BS V group and normal group ($p < 0.001$).

2. Maximum velocity

Figure 4 shows the maximum velocity of the step-tracking movements of the three groups. Median of maximum velocities were 44.5 degrees/s, 67.2 degrees/s and 86.1 degrees/s and IQR were 18.0 degrees/s, 23.3 degrees/s and 35.9 degrees/s for the BS V, BS VI, and normal groups, respectively. Kruskal-Wallis test revealed significant differences among three groups ($p < 0.001$). Multiple comparison revealed significant differences between BS V group and normal group ($p < 0.001$).

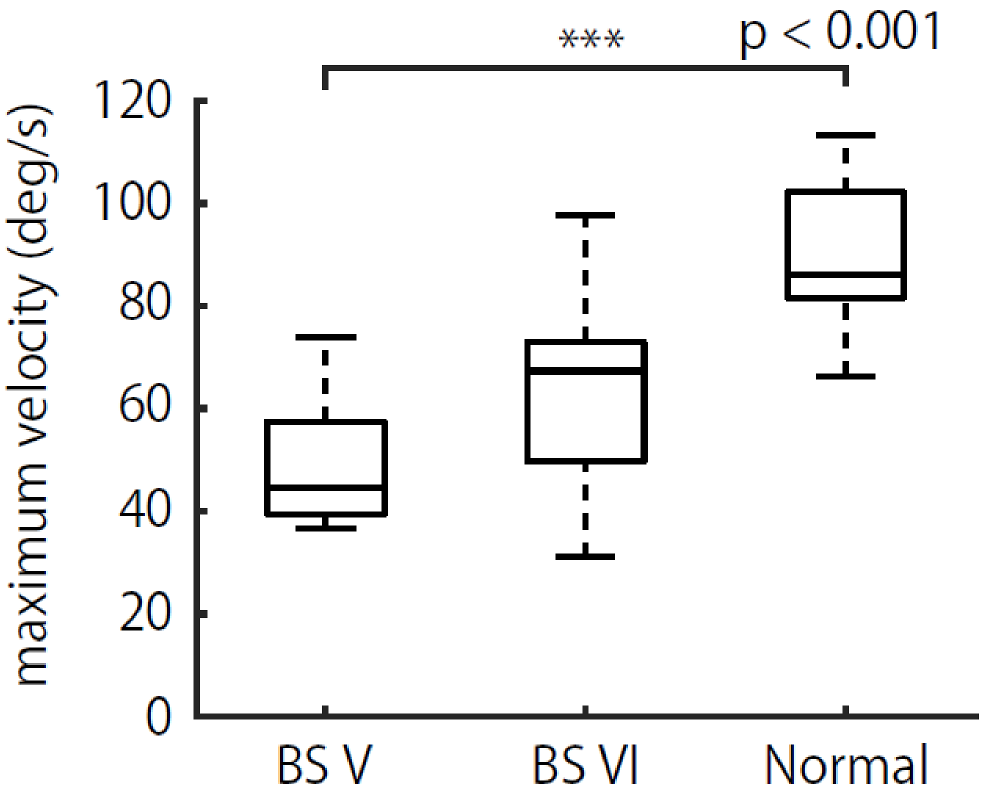


Figure 4. Maximum velocities of the BS V group, the BS VI group and the control group. Kruskal-Wallis test revealed significant differences among three groups ($p < 0.001$). Multiple comparison revealed significant differences between BS V group and normal group ($p < 0.001$).

3. Reaction time

Figure 5 shows the reaction times of the three groups. Median of reaction times were 0.32 s, 0.28 s and 0.28 s and IQR were 0.11 s, 0.11 s and 0.07 s for the BS V, BS VI, and normal groups, respectively. No significant differences were found by Kruskal-Wallis test.

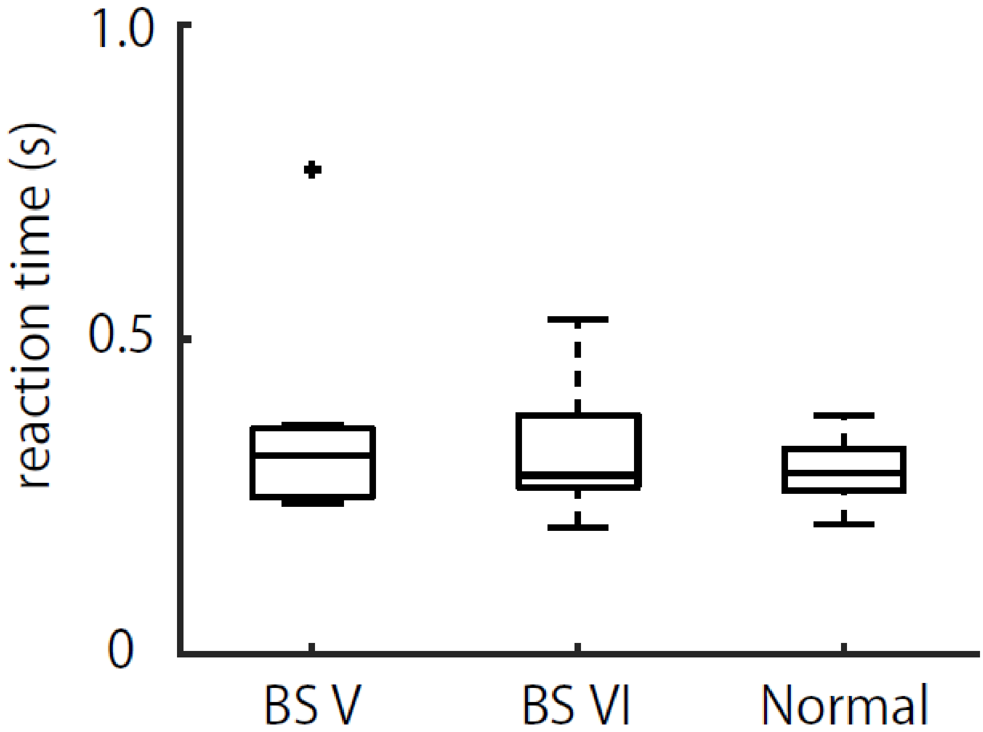


Figure 5.　Reaction times of the BS V group, the BS VI and the control group.
No significant differences were found.

4. Path variation

Figure 6 shows the path variation values of the three groups. Median of path variations were 1.10 degrees, 0.84 degrees and 0.73 degrees and IQR were 0.84 degrees, 0.26 degrees and 0.13 degrees for the BS V, BS VI, and normal groups, respectively. Kruskal-Wallis test revealed significant differences among three groups ($p < 0.05$). Multiple comparison revealed significant differences between BS V group and normal group ($p < 0.05$).

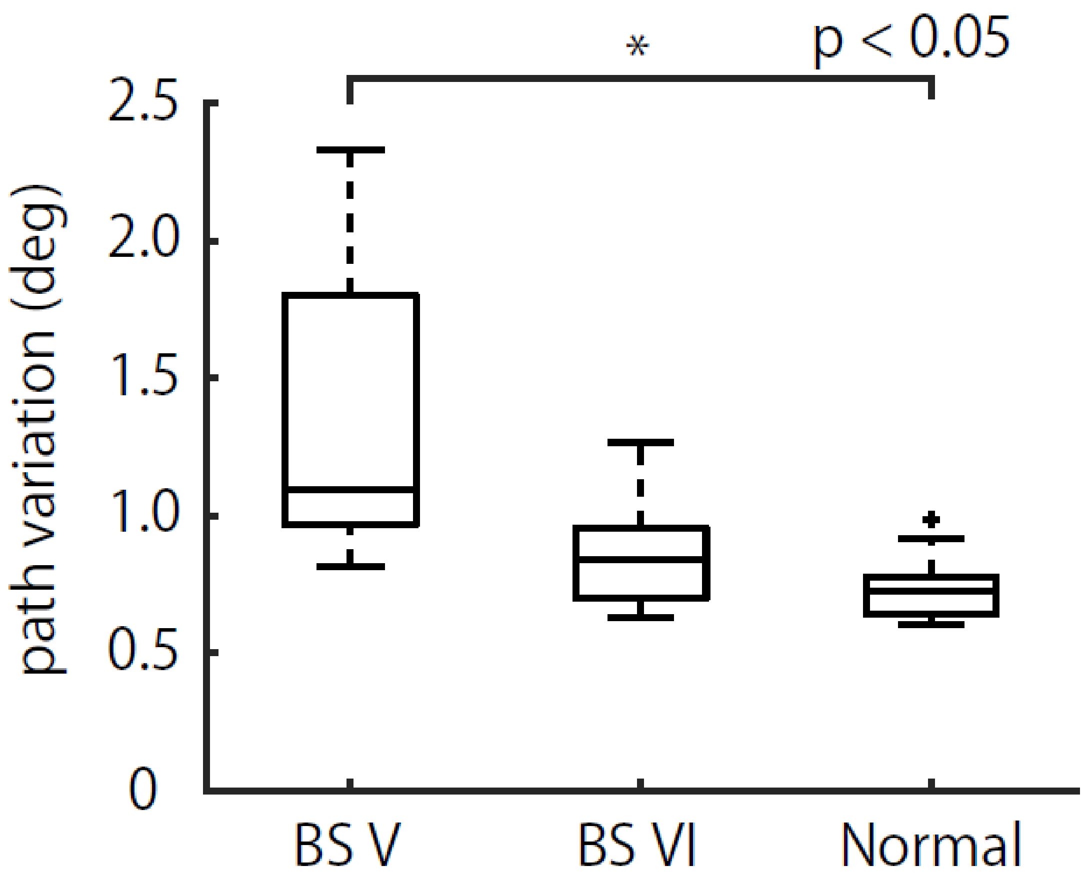


Figure 6. Path variations of the BS V group, the BS VI group, and the control group. Kruskal-Wallis test revealed significant differences among three groups ($p < 0.05$). Multiple comparison revealed significant differences between BS V group and normal group ($p < 0.05$).

IV. Discussion

Although their movements could be ungainly, the stroke patients at recovery stages V and VI were able to successfully complete the four-way step-tracking task. It is suggested that our result is consistent with the definition of BS V, which states that awkward palmar prehension, and cylindrical and spherical grasp become possible at this stage.

Movement time and maximum velocity for the four-way step-tracking task differed significantly among the groups. However, the reaction time for all groups was around 0.3 s, with no significant difference among the three groups. The reaction time includes the premotor time, i.e., the time from stimulus onset to initiation of muscle activities. There have been reports that indicate a longer premotor time with tasks that are unpredictable or require planning [10, 11]. However, in the present study, the participants confirmed their ability to move their wrist, and thus the cursor, in the four-way movement task during a practice session prior to the actual task implementation; they therefore had sufficient understanding of the task paradigm and started movement relying on their prediction. The extended movement time and lower maximum velocity of the stroke patients indicated that their movements were slower and more cautious. As shown in Figs. 1c and d, the trajectories of the patients were awkward and jolting. Together, these results indicate the patients' poor ability to coordinate synergic activities of muscles. Previous studies[12, 13] using three-dimensional movement analysis systems have also demonstrated non-cooperative and non-continuous movement in stroke hemiplegia patients. It suggests the usefulness of our system to evaluate the movement of stroke patients.

Path variation was greater in the BS V patients than normal participants. As path variation is an index of the awkwardness of wrist movements, our results suggests that awkward movements of BS V group will improve and become nearly normal if the patients recover to stage VI.

V. Conclusion

Using our novel wrist movement analysis system, we measured the movement speed and awkwardness of wrist movements. From these results, we were able to objectively and quantitatively demonstrate the recovery process of motor function from BS V to BS VI. We hope to expand this study to a greater number of cases.

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