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Quantitative evaluation of position sense in patients with parietal lesion

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Abstract

A position reproduction task was performed, in a controlled experimental environment, by seven patients with a parietal lobe lesion. We obtained mainly three findings: (a) even for patients who failed a thumb localization test, the accuracy of position reproduction was adequate and did not deviate from the range of error observed in healthy young participants, (b) the patients showed a centralizing tendency in localization, and (c) they initially moved in the wrong direction when reproducing the remembered positions. The study also indicated that patients whose lesion sites included the postcentral gyrus exhibited stronger exploratory movements than those who had no such lesions and lacked smoothness of movement. In patients without the lesion of the postcentral gyrus, a higher-order dysfunction, rather than the pure position sense problem, was suggested to contributed to their task performance. The present study provided fundamental data for sensorimotor skills of patients with parietal lesion, and these quantitative findings would also contribute to reconsideration of current assessments and rehabilitations for sensory deficits.

Keywords: parietal lobe, position sense, position reproduction task, thumb localization test

Introduction

Damage to the parietal lobe area causes disorders of position sense (e.g., Yamatori, 1985; Pause *et al.*, 1989; and Bassetti *et al.*, 1993). Although an accurate evaluation of the degree and nature of a patient's sensory disturbance is important for subsequent recovery of sensorimotor function, little is known about to what extent and how a patient's position sense is impaired in relevance to that of healthy population. This study therefore aims to identify, using a psychological experiment, the details of localization movements based on proprioception, which plays an important role both in the patients' daily lives as well as in clinical tests. In this paper, the sensation that relates specifically to position will be described as "position sense" and the sensation of joints, or joint sense, that is examined with conventional clinical tests, as "sense of position".

In Japan, a test called "thumb localization test" has been used to examine the position sense in clinical situations (Hirayama *et al.,* 1986, 1999; Fukutake, 1997). This test can be performed easily at the bedside and is reported to be an accurate and effective method for detecting abnormalities in the position sense of the limbs (Hirayama *et al.,* 1999; Fukutake 1997). However, some researchers claim the test has low reliability and sensitivity (Garraway *et al.,* 1976; Lincoln *et al.,* 1991; Dukelow *et al.,* 2010).

To evaluate patients' position sense more accurately, several methods with a more controlled environment have been proposed (e.g., Carey, 1996; Dukelow *et al.,* 2010). Although these studies provided quantitative scales to enable objective comparisons of healthy participants with stroke patients, the measures employed only reflect errors in angles or positions of "end point" but not include "movement" aspects. Moreover, these studies did not discuss the correspondence between lesions and damaged functions. We therefore aimed to quantify the abilities of position perception and reproduction in patients who had a parietal lobe area lesion, using various measures including motor factors that are rarely, if ever, reported.

In the experiment, we used the position reproduction task on a horizontal plane at shoulder level and employed healthy young individuals as controls. Position reproduction is a task performed by having the participants close their eyes, memorize the position of their fingertip, and then locate it with the finger (e.g., Laufer *et al.,* 2001). This task has an advantage of being able to quantitatively represent position perception and reproduction accuracy, using a continuous measure. Furthermore, in the position reproduction task, no obstacles are present on the workspace unlike the thumb localization test. That is, there is no feedback that would hinder the participants' final judgment and so they must rely solely on their own position sense. It appears, therefore, that this task can directly reflect the patient's position perception and reproduction abilities.

Materials and Methods

Participants

Seven patients (mean age: 57 ± 11.6 years), whose lesion sites included the parietal lobe, participated in our study. Of the seven participants, five presented with a sensory disturbance, all of whom failed the thumb localization test for their position sense. At the time of the tests, none of the participants exhibited motor deficits, muscle weakness, and/or memory impairment that would interfere with the movements necessary for performing the tasks. The demographic and clinical characteristics of the seven participants are presented in Table 1. Twelve healthy participants (21.6 ± 2.1 years) were used as the controls.

Patient K.K.-1 experienced the most severe sensory disturbance, having lost almost all of superficial and deep sensations. N.S. and T.H. had the next most serious sensory disturbances. Compared to these two patients, the degree of sensory deficits of H.F. and M.M. was mild. With T.O. and K.K.-2, no sensory deficits were reported in the clinical tests or self-reported forms. The sense of position was evaluated with passive joint movement, which is commonly used in clinical situations. Five to ten trials of the thumb localization test were also conducted. If repeated failures were observed in the test, we noted that the participant had deficits in performing the thumb localization test (Hirayama *et al.* 1999).

Table 1. Demographic and clinical characteristics of the patients. AVM: Surgery of arteriovenous malformation, SFG: Superior frontal gyrus, MFG: Middle frontal gyrus, PrG: Precentral gyrus, PoG: Postcentral gyrus, PO: Parietal operculum, BG: Basal ganglia, SPL: Superior parietal lobule, IPL: Inferior parietal lobule, STG: Superior temporal gyrus, MTG: Middle temporal gyrus, OL: Occipital lobe

	K.K.-1	N.S.	T.H.	M.M	H.F	K.K.-2	T.O.
Age	50	47	62	67	65	69	39
Sex	M	F	M	M	M	M	F
Duration of disease (months)	6	15	23	2	3	1	43
Etiology	Hemorrhage	Infarction	Infarction	Hemorrhage	Hemorrhage	Infarction	AVM
Lesions	Right PrG, PoG, IPL	Right SFG, MFG, PrG, PoG, PO, STG, BG	Left PoG, SPL, IPL	Left PoG, IPL	Left IPL, STG	Left IPL, MTG	Left IPL, OL
Preferred hand	Right	Right	Right	Right	Right	Right	Right
Neuropsychological symptoms at the experiment							
Sensory deficits	Right upper limb Total loss of superficial and deep sensation	Face, left side body Decrease of position, touch, and pain sensation	Distal parts of both upper limbs Decrease of position, touch, and pain sensation	Right upper limbs Decrease of position sensation	Both upper limbs Decrease of position sensation	-	-
Muscle weakness	-	Left upper limb	Right upper limb	-	-	-	-
Motor deficits	-	Deficits in skilled movements	Psuedoathetosis	-	-	-	-
Thumb-finding test	+	+	+	+	+	-	-

Procedures

Participants performed a position reproduction task on a shoulder-level flat surface[1]. They sat on a chair and closed their eyes in the experiment except for a rest. The task procedures were as follows: first, the experimenter brought the participant's fingertip to a target, and instructed him/her to memorize the location. Once the participant considered that he/she had memorized the location, he/she verbally signaled the experimenter. No time limit was set during this procedure. On receiving the verbal signal, the experimenter moved the participant's fingertip back to the starting point. The participant then asked to brring his/her fingertip to the position he/she had memorized as accurate as possible. The patients used their affected arm for the task. The control group participants, who were all right-handed, used their dominant arm.

The participants wore a support cradle with a bearing attached to their forearms and fingers. This enabled smooth movements in the horizontal direction on the surface. To restrict wrist movement, the participants wore a supporter around their wrists. When the experimenter moved the participants' fingertips either to the targets or to the starting position, they gripped the support cradle, not the hand or arm, so as to give as few extra cues as possible. To prevent from providing information on the location of the targets, the experimenter moved the participant's arms by drawing

[1] For details of the task, see Itaguchi and Fukuzawa (2012a, *Percept Mot Skills*; 2012b, *Exp Brain Res*)

a random trajectory.

A sensor for a three-dimensional position sensor (FASTRAK, Polhemas Inc.) was attached to the fingertip and its position was recorded. The targets were arranged at a distance of 15 cm from the center of the starting position, and in eight directions (Figure 1a). The closest position of the target on the median line was 10 cm from the participants. Since the location of the targets and starting position are not displayed on the actual experimental device, it was not possible for the participants to visually confirm these positions. The experimenters assigned the position of the fingertips to the target locations by monitoring the position of the sensor on the computer.

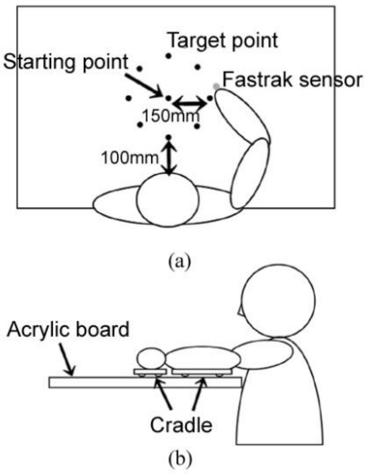

Figure 1. (a) Target arrangement. (b) Experimental apparatus.

The task was performed under two experimental conditions. In Condition 1, the participants wore a support cradle on their forearm during both perception and reproduction. In Condition 2, the participants did not wear the forearm support cradle during either perception or reproduction, and they used their own force to maintain the upper arm and the forearm to keep their arm horizontal to the experimental surface. The participants wore the support cradle at the fingertips in both conditions. Figure 1a illustrates the target arrangement viewed from the top, and Figure 1b shows the experimental apparatus viewed from the side.

For each target, the patients performed three trials, and control group performed five. The total number of trials was therefore 48 (8 targets × 3 trials × 2 conditions) and 80 (8 targets × 5 trials × 2 conditions) for the patients and controls, respectively. The targets were presented in random order. Since Condition 1 imposed required less effort than Condition 2, the patients always attempted Condition 1 first. The order of the conditions for the control group was counterbalanced among the participants. In the control group, we observed no influence of the order the conditions on the performance of the tasks; accordingly, the influence of the condition order was, if any, not likely to be large in the patients.

Analysis

We analyzed the position reproduction accuracy and the movements while reproducing the positions, using the following measures. 1) Absolute Error (AE): The distance between the targets and the position reproduction end points, representing the position reproduction accuracy to the targets. 2) Variable Error (VE): The distance between the average end point and the position reproduction end point, representing the variance in position reproduction. 3) Distance (D): The linear distance between the position reproduction end point and the start position. This measure reflects undershooting (centralizing) or overshooting of the reproduction. 4) Trajectory / Distance (TD): The product obtained by dividing the length of the movement path by the linear distance. This measure reflects exploratory tendencies of reproduction movement. 5) Initial Deviation (ID): The difference in the angle from the correct target direction at the time of the movement start (at a radius of 2 cm from the center of the starting position). This is an index of the directional accuracy of the reproduction.

In addition to the measures indicated above, we calculated the movement duration (MD), peak velocity (PV) of hand movement, and movement jerk (MJ, the rate of change of acceleration), which is known as a measure of motion smoothness. MJ was calculated in accordance with the study by Flash and Hogan (1985), using the following formula.

$$MJ = \frac{1}{2}\int_0^{t_f}\left\{\left(\frac{d^3x}{dt^3}\right)^2 + \left(\frac{d^3y}{dt^3}\right)^2\right\} dt$$

Multivariate analysis of variance (MANOVA , 8 variables × 2 conditions) was conducted to test the effects of the experimental conditions on the measures in the control group.

Results

Patients' execution of tasks

In the experiment, all patients reported that they did not feel their hand position, or that they had little confidence about whether they accurately located the position. However, with the exception of K.K.-1, no participants reproduced a position far distant from the correct target. Many of the healthy participants, as well as the patients, answered that they had little confidence in the sensation of their hand position. T.O. showed greater accuracy in position reproduction, even compared to the control group.

Performance according to each index

Figure 2 summarizes the results for each measure in all patients and the average of the healthy controls.

1) AE K.K.-1 made about twice as many errors with the targets than did the control group and other patients. The results of N.S., T.H., K.K.-2, and T.O. were within the range of the performance of the control group. Whereas M.M.'s AE did not largely differ from those of the control group in Condition 1, he had an approximately 3 cm greater error than the control's average in Condition 2. The AE in the control group were significantly smaller in Condition 2 than in Condition 1 [(F (1,11) = 21.04, p < .001)], and this pattern was observed in all patients except for T.O. and H.F.
2) VE VEs of all patients, except for K.K.-1 and H.F., were within the range of the control group. As with AE, the error was smaller in Condition 2 than Condition 1 in the control group [(F (1,11) = 54.26, p < .001)], and this pattern was observed in five of the seven patients.
3) D All patients, except for M.M., showed a centralizing tendency to locate the position near to the start point. The average D for the control group was 16.36 ± 2.08 cm and 16.04 ± 1.60 cm, in Conditions 1 and 2, respectively, whereas the average D for the patients was 13.86 ± 1.44 cm and 12.91 ± 2.69 cm, respectively. The pattern that D was smaller in Condition 2 than Condition 1 was most evident for K.K.-1.
4) TD As TD is obtained by dividing the length of the movement path by the linear distance between the target and start point, the value is 1 if the reproduction movement is completely straight and accurate. All TDs of the control participants, except for two individuals, were slightly higher than 1 (Condition 1: 1.30 ± 0.32; Condition 2: 1.21 ± 0.19). In contrast, although TDs of two patients were similar to the average of the control group, those of K.K.-1, N.S., and T.H were higher the range of the control group. TDs of K.K.-1 was markedly higher than the other participants, particularly in Condition 2.
5) ID IDs of the patients, except for those of T.O. and M.M. in Condition 1, were generally higher than those of the control group. Moreover, whereas the control group had a tendency to move their arms in the right direction in Condition 2 compared to Condition 1 [(F (1, 11) = 6.59, p < .026], three patients (T.H, M.M., and T.O) made greater ID errors in Condition 2 than Condition 1.
6) MD, PV, and MJ Six of the seven patients, except for K.K.-1, performed localization within 2-5 s, which was within the range of the control group. PVs of all patients including K.K.-1 were similar to that of the control group. MJs of the patients were within the range of the control group, with the exception for N.S., T.H., and K.K.-1 in Condition 2.

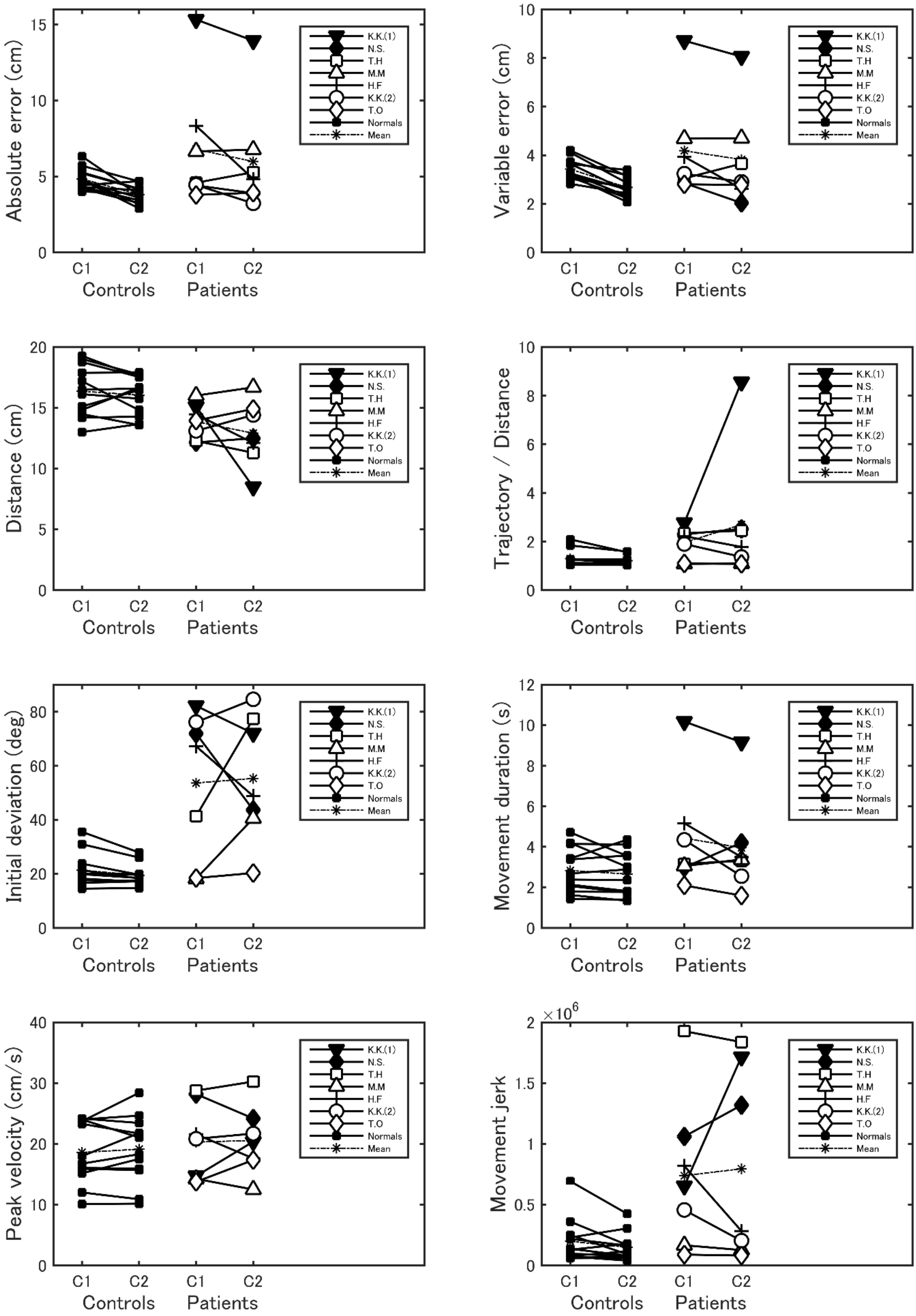

Figure 2. Performances of controls and patients. * *p*<.001, * *p*<.05**

Individual patient performances

Figure 3 provides the Z values (standardized using the mean values of control group and standard deviation) for the patients. The range of ± 3 can be regarded as the range of control group (if a normal distribution is assumed, approximately 60% of the control participants fall into the range of ± 1; approximately 95% fall into the range of ± 2; and 99.9% fall into the range of ± 3). Note that each Z value was standardized based on different magnitudes of standard deviation across conditions and measures. That is, a larger Z value in Condition 2 than Condition 1 does not necessarily imply that the actual error was greater in Condition 2 than Condition 1.

In Condition 1 (Figure 3, top-left), five patients showed large deviation from the control group in TD and ID. We also noted that AE and VE of K.K.-1, M.M., and H.F. were higher than the average for the control group. Z values in Condition 2 (Figure 3, top-right) generally followed the pattern for Condition 1, but the magnitude of the values was much larger. In both conditions, Ds for the patients were negative, except for one value, indicating general centralizing tendency in the patients.

MJs for three patients (K.K.-1, N.S., and T.H.) were relatively large, particularly in Condition 2 (Figure 3, bottom-right). In addition, MJ of H.F. slightly deviated from the range of the control group in Condition 1. None of patients' MD or PV exceeded the range of the control group.

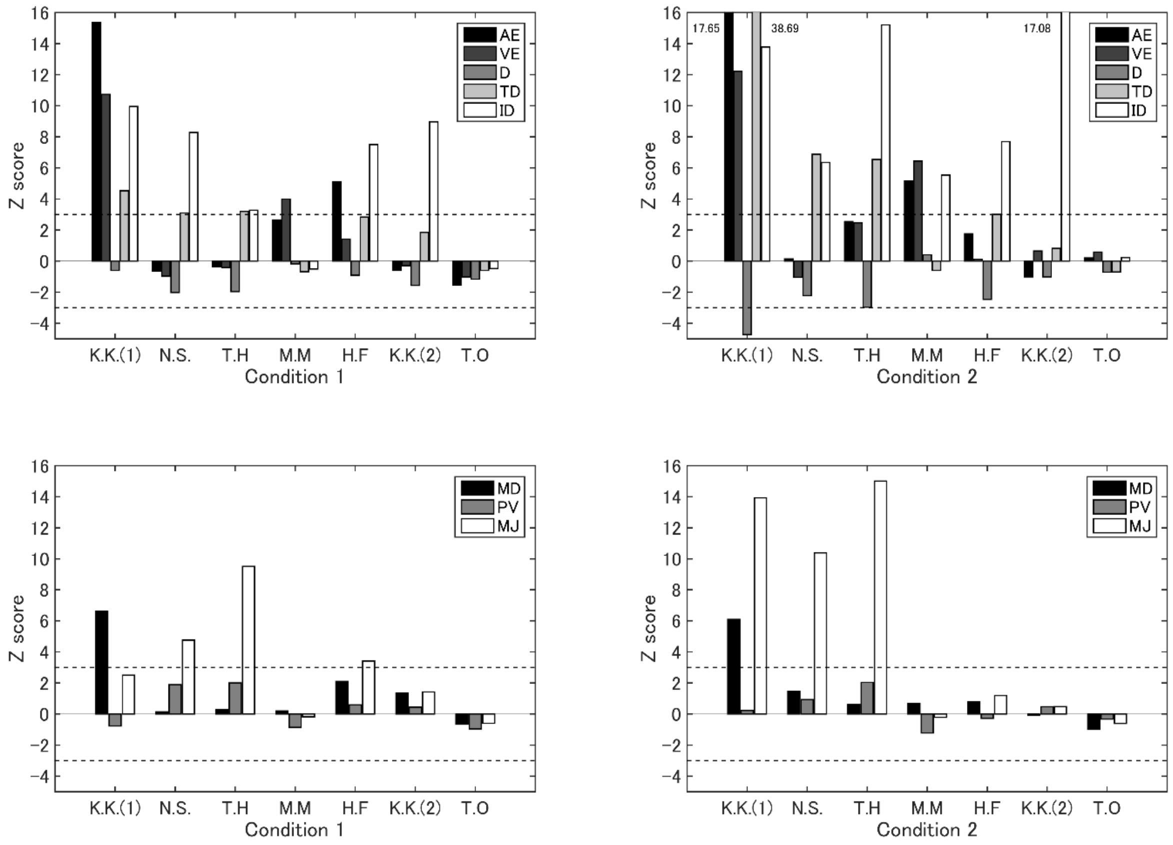

Figure 3. Standardized scores of performances in patients. All score is standardized by the mean and SD of the controls.

Discussion

This study used a total of eight quantitative measures to compare the performance of patients with parietal lobe damage to those of healthy younger individuals. The results are discussed in terms of following two points: the position perception and reproduction in the patients, and the correspondence between lesions and symptoms.

Before discussing the above points, we must first consider the influence of aging on the declined performance, since this study did not employ age-matched healthy controls. Adamo *et al.* (2009) compared the performance of healthy young individuals (22.1 ± 2.0 years old) and healthy old individuals (77.1 ± 3.5 years old) in a wrist (single-joint) position-matching task. The results revealed that AE in the older participants was significantly lower than those of the younger participants. All patients in our study were younger than the older participants in Adamo *et al.* (2009), and four patients were over 60 years old (T.H., M.M., H.F., and K.K.-2). AEs of T.H. and K.K.-2 were not deviated from the range of our younger control group, and VEs of the three patients, not including M.M., were also within the range of the control group. These results indicate no clear decline in performance due to age, at least in the 2-dimentilnal position reproduction task, and suggest that the patients' deterioration in the performance was likely attributed to their functional disorder in brain.

Characteristics of the patients' position perception and reproduction

As a characteristic pattern common in the patients, we found greater initial directional error in the reproduction movement and centralizing localization tendency. In addition, except for T.O., all patients exhibited stronger exploratory movements (TD). However, regarding AE and VE, which are measures related to the accuracy and precision of position reproduction, many patients did not deviate from the range of the control group. These findings indicate that the patients began moving their arms toward a direction that differed from the target, "searched" for the target positions in a trial and error-like manner modifying their movement paths, and then achieved relatively accurate and precise position reproduction. The average PV value of the patients, which is similar to that of the control group, indicates that the patients could control their arm movements at appropriate speed.

The effect of the experimental condition differed between the patients and the control group. In the control group, AE, VE, and ID in Condition 2 were significantly smaller than Condition 1. This pattern was observed in many patients for AE and VE, but not for ID. That is, in patients, endpoint errors decreased in the condition that required greater effort to control their movements by own effort, just like in the control group. In contrast, the movement errors at the beginning of position reproduction became larger at the Condition 2. These characteristics would be important and must be considered when evaluating a patient's position sense in clinical situations.

Another important finding in the present study is that multiple patients who failed in the thumb localization test showed moderate AEs which did not exceed the range of control group. The task in this study required the participants to use the same arm to conduct both target perception and localization on a two-dimensional surface, while the thumb localization test requires to use different arms for target perception and localization in a three-dimensional space. One, therefore, cannot easily compare these two tasks (thumb localization test and position reproduction task). Nevertheless, our task can be regarded as a task requiring minimal factors for proprioceptive localization, which is the essence of the thumb localization test. Notably, several patients in this study exhibited the same degree of positioning accuracy and precision as did young healthy participants, despite the lack of any cues other than their position sense. This result suggests that the failures in thumb localization test do not exclusively reflect the decline in “accuracy” of the position sense. Rather, they may be attributed to the centralizing or undershooting tendency in perceiving or reproducing positions, causing patients’ inconveniences experienced in daily life.

Measures for managing foci and symptoms

Pause *et al.* (1989) and Bassetti *et al.* (1993) reported that sensory deficits qualitatively varied according to the lesions in the parietal lobe area. Based on their criteria, we classify the participants according to whether or not the postcentral gyrus was included in the lesion sites. Of the patients in our study, four (K.K.-1, N.S., T.H., and M.M.) had lesions that included the postcentral gyrus, and three (K.K.-2, H.F., and T.O.) did not. T.O.’s lesion was located at the most anterior among the latter three patients. This patient performed outstandingly in the position reproduction task even when compared to healthy participants.

Of the four patients with lesions that included the postcentral gyrus, three, except for M.M., exhibited greater exploratory tendencies and more jerky movements than did patients with lesions that did not include the postcentral gyrus. Moreover, the values of these two measures were higher in Condition 2 than in Condition 1, indicating that the higher the degree of control of the arm with one’s own effort, the jerkier and more exploratory strategy patients used. Unlike the other three patients, M.M. did not show impairments of elementary sensation (touch, pain, temperature, and vibration: Bassetti *et al*., 1993). Therefore, although M.M. is classified as a case of inferior-anterior parietal lobe lesion according to Bassetti *et al*.’s (1993) criteria, it is possible that his symptoms may differ from the other patients with an inferior-anterior parietal stroke. The lack of smoothness of movement observed in the three patients can be largely attributable to exploratory movements. However, movement jerk is not necessarily proportional to exploratory movements (see Figure 3); impaired smoothness of movement cannot be explained only by increased exploratory movements. It is therefore suggested that other functional disturbances may cause increased jerkiness of the patients. Moreover, the correspondence between the patients’ symptoms and lesions indicates that exploratory movements are likely caused by sensory impairments other than “sense of position”.

The reproduction performance of patients with lesions that do not include the postcentral gyrus are characterized by two points: normal kinematic aspects (MD, PV, and MJ) similar to those of healthy control, and not-strong exploratory movements. Note that H.F. exhibited a larger Z value in AE in Condition 1. Since H.F.'s variance of the end points (VE) was either better or the same as the average for the control group, this large decline specific to AE may have not been caused by a simple reduction in the accuracy of position sense but rather other functional deficits at a higher level contribute to the disability.

In this study, we offered fundamental and quantitative data on the accuracy of position perception and reproduction in patients with a parietal lobe lesion. At clinical situations, mild impairments of position sense and subsequent motor disturbances do not often qualify for rehabilitation. As a result, many patients remain inconvenienced in their everyday lives. The comparisons of sensorimotor functions made in this study between patients and healthy young participants served an empirical support for conventional clinical tests and at the same time revealed some novel aspects of patients' profiles. Nevertheless, the correspondence between lesions and symptoms remains complex. To elucidate parietal lobe symptoms, it is important to continue to accumulate knowledge and information in a bottom-up fashion, and take theoretical approaches based on this acquired knowledge.

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