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Case Report

Verifying the Efficacy of a Tactile Perceptual Discrimination Stimulation Approach for Individuals with Finger Sensorimotor Dysfunction: A Case Report and Literature Review

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Abstract

Purpose: To investigate the effects of tactile discrimination feedback sensory compensatory system device training on finger sensory-based motor dysfunction after cervical cord injury.

Case Presentation: A patient with finger sensorimotor dysfunction following cervical cord injury underwent treatment using an ABB design, with each treatment period lasting 1 week. The patient performed daily pegboard, building block stacking, and material identification task tests over a 1-week period. The Purdue Pegboard Test, a behavioural measure, and the Numbness Numerical Rating Scale, a sensory function assessment tool, were administered daily. From these tests, the Tau-U, a statistical measure of the intervention effect size, was calculated. Additionally, as a physiological measure, an electroencephalogram was recorded daily for 1 min during the pegboard task. The coherence values of the electroencephalography frequency bands of the theta (4–8 Hz) and mu (8–12 Hz) waves of Pz–Fz, a sensorimotor information processing index, were calculated, and the mean value of each phase was calculated for comparison and validation.

Result: After the device intervention, the theta and mu waves in the sensorimotor domain were attenuated. Motor function and numbness of the right finger improved.

Conclusion: Training with a tactile discrimination feedback sensory compensatory system device may improve finger sensorimotor function and contribute to shortening treatment duration.

Keywords: Finger Sensorimotor Dysfunction; Tactile Discrimination Feedback; Sensory Compensatory System Device; EEG Frequency Analysis; Motor Learning.

Introduction

Injuries to the cervical spinal cord tend to cause motor dysfunction of the finger due to damage to the conduction pathways in the finger-controlled areas [1,2]. The hand and finger functions enable essential human processes, including eating and excretion, to survive in daily life. Therefore, improving upper limb motor function, including that of the fingers, is of the highest priority among physical functions in individuals with cervical spinal cord injuries [3]. According to Peckham et al. [4], finger function improves after cervical spinal cord injury, and the ability to perform activities of daily living contributes to a significant improvement in quality of life. Therefore, rehabilitation aimed at improving the finger motor function after cervical spinal cord injury is important.

Sensory dysfunction of the finger inhibits upper limb motor function from improving following cervical cord injury. Cervical cord injury causes numbness in the fingers in 82% of cases due to damage to sensory afferent pathways, and patients with such injuries are more likely to have finger sensory dysfunction [5,6]. To manipulate an object, fingers rely on sensory information from the finger pads to generate the muscle activity necessary to perform the action [7]. When finger sensory dysfunction occurs, obtaining friction information from the finger pads becomes impossible, making object manipulation difficult. This condition is known as finger sensorimotor dysfunction and greatly impairs a patient's ability to perform activities of daily living [8]. Therefore, improving sensorimotor function after cervical spinal cord injury (SCI) is essential.

Task-oriented approaches have been used to restore impaired motor functions. With this approach, patients actively perform the desired movements under the desired motor task conditions [9]. A task-oriented approach improves the motor function more easily as time progresses and the extent of rehabilitation increases [10]. Yang et al. [11] showed that the motor function of the upper limbs, including the fingers, can be improved by training for at least 6 h a week. Therefore, the quantitative aspects of this approach are important for motor function recovery. However, Taub et al. [12] reported that even if a person is able to actively and repeatedly perform a desired movement, their ability to learn the movement declines if the desired movement continues to fail owing to finger sensorimotor dysfunction. In addition, meta-analyses on task-oriented and high frequency approaches have often excluded patients who present with abnormal perceptions of the upper extremity or hand [13]. Thus, to regain motor function in cervical spinal cord injury, in addition to quantitative aspects such as the number of approaches and approach time, patients with sensorimotor dysfunction of the fingers must be made aware of how to perform movements correctly. Therefore, the qualitative aspects of this approach are important.

Hubbard et al. [14] reported that sensory feedback information accompanying movements improves the quality of the approach. This may be because the brain can synchronously process the motor intention and sensory feedback of the treated limb. When the motor intention and sensory feedback appropriate for the desired movement are processed synchronously (within 250 ms) in the brain, a sense of agency is created, whereby the person feels that they are performing the movement [15]. This sense of agency increases activity in the premotor cortex and corticospinal tract, thereby improving upper-limb performance [16]. These findings suggest that real-time feedback of the sensory information accompanying movements may improve the quality of the approach. Visual stimulation is generated as fingers move [17-19], electrical stimulation [20,21] and auditory stimulation [22]Real-time feedback approaches using compensatory sensory modalities have also been employed. Studies using these approaches have reported that real-time feedback stimulation that matches hand and finger movements enhances the sensorimotor areas in the brain that are important for motor learning, and improves hand and finger voluntariness [19-22].

The manipulation of an object is made possible by the continuous input of friction information generated between the finger abdomen and the object as sensory information, as well as by the generation of hand muscle activity in response to this friction information [7]. Considering this, the aforementioned sensory stimulation provides excellent feedback stimulation, indicating the direction of finger movement. However, providing continuous feedback stimulation corresponding to the kinetic friction that occurs between the finger pads and the target object is difficult.

In recent years, a tactile discrimination compensation system has been used for individuals with finger sensorimotor dysfunction to address this issue. This system has a sensing ability equivalent to that of sensory receptors on the fingers. Several approaches involving stimulators have been reported [23-26]. These reports suggest that, when performing fine movements, the sensorimotor cortex neurologically activates excitement and skilled movements, and improvements have been reported. Therefore, the aforementioned sensory feedback stimulation may be appropriate for individuals with finger sensorimotor dysfunction.

However, to improve the implementation of fine finger movements in actual movements in cervical spinal cord injury, two aspects require verification. In addition to verifying the sensorimotor area activation (early stage of motor learning) when fine movements are performed, the late motor learning stage, a phase in which the cognitive control necessary for sensorimotor information processing is available and efficient, needs to be verified [27]. Therefore, spatially capturing brain activity areas and confirming whether there is a transition to late motor learning after the implementation of an intervention is necessary. To do so, it is necessary to assess the ability to process sensorimotor information, exert cognitive control, and capture electroencephalogram (EEG) frequencies in the sensorimotor cortex, which are thought to reflect these abilities [28,29]. Therefore, we examined a patient with cervical spinal cord injury and finger sensorimotor dysfunction to determine whether an intervention using tactile discrimination stimuli affects the motor learning process for performing fine movements. Efficacy was verified using brainwave frequency analysis.

Case Presentation

Case Introduction

Three months before the intervention reported herein was conducted, the patient fell off a bicycle into a 1.5 m-deep ditch, subsequently presenting with muscle weakness and sensory dysfunction of the right finger as primary symptoms. The patient was urgently transported to Hospital A, where cervical spinal magnetic resonance imaging was performed. A C7 cervical spinal cord injury and C6/7 cervical disc herniation were diagnosed (Figure 1A, B). The patient had no history of brain or cervical spinal disease. The patient was able to get out of bed at Hospital A transferred to a convalescent hospital, Hospital B, for rehabilitation. The right-hand and finger rehabilitation approaches conducted at Hospital B included range-of-motion training, muscle strength training, and electrical stimulation therapy. The intervention was conducted daily for 40 minutes. Three months after the injury, the right-hand finger manual muscle test score improved from 3 to 4, and right-hand grip strength improved from 0 to 6 kg. The numbness of the right index finger was measured using a Numerical Rating Scale (NRS) ranging from 0 (not felt at all) to 10 (felt extremely strongly) [25,26]. Although the score improved from 9 to 4, numbness persisted. A Simple Test for Evaluating Hand Function [30] that objectively assessed the ability of the upper limbs, including the fingers, to perform fine movements was administered. The score improved from 86 to 93; however, the patient lost points when carrying a small pin. These findings indicate a residual loss of dexterity in the right fingers.

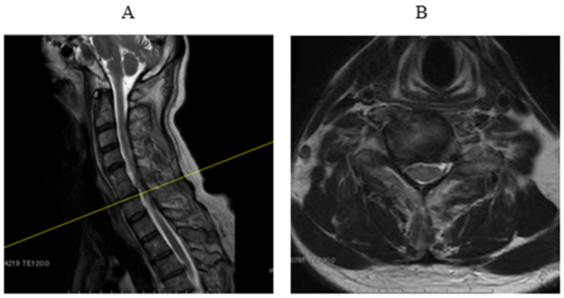


Figure 1: Cervical spine MRI image taken during hospitalization at Hospital B. A: Sagittal section at the C6/7 level. B: Horizontal section at the C6/7 level showing compression of the right nerve root. MRI, magnetic resonance imaging

Reason for selection

According to the Numbness NRS and Simple Test for Evaluating Hand Function scores, right index finger numbness and decreased fine motor skills persisted. Three months had passed since the onset of symptoms, meaning the optimal time for functional recovery had also passed. This suggested that the patient may have experienced sensorimotor dysfunction. Therefore, according to the patients' wishes, the intervention described in this study was administered. This study was approved by the Kyoto Tachibana University Ethics Review Committee (approval number, 23-27). The purpose, content, and procedures of the study were explained to the patients orally and in writing and informed consent was obtained.

Intervention

Although real-time feedback devices have been developed for gross finger movements, no device is capable of detecting and providing feedback on subtle differences in tactile modalities in areas sensitive to tactile discrimination, such as the fingers. Recently, the Yubi Recorder (Yubireco; Tech Gihan Co., Ltd., Kyoto, Japan) was developed to provide feedback. This device provides vibrational information that corresponds to the tactile modality of patients with sensorimotor disorders in the fingers resulting from central nervous system differentiation disorders, and interventional studies using this device have been reported [23-26]. The Yubireco device measures vibrational information by detecting the vibrations within the skin that occur when touching an object with the fingertips [31]. A vibration sensor was wrapped around the distal interphalangeal joint of the index finger, and vibrational information was presented via a vibrator by modulating the output from the sensor to a frequency that humans could feel. Therefore, in addition to synchronously matching the visual information accompanying finger movements, this approach provides real-time feedback on the vibrational information associated with the robot movements. In the present study, we used yubireco to conduct the intervention.

We aimed to compare the differences in intervention effects between using and not using yubireco during an exercise task. Moreover, we examined whether the length of the intervention period for B caused changes in the learning performance during skilled movements over time. As such, the intervention consisted of the first basic significance-level period A and the intervention introduction period B. The intervention was conducted using an ABB design for a period of 1–3 d. The intervention was performed without the patient wearing the yubireco during the motor tasks. B in periods 2 and 3 required moving the yubireco to the right index finger during motor tasks. The distal interphalangeal joint of the index finger was fitted. Each period lasted for one week for a total of 21 days. The motor task was based on the method described by Kitai et al. [25, 26] and consisted of using the right finger to stack the square building blocks used in the Box and Block Test [32] for 10 min, and discriminating between the five types of sandpaper using the ventral part of the right index finger for 10 min. Participants were also asked to vertically insert a peg (25 mm long, 3 mm in diameter) into a board with two rows of 25 holes, each with their right finger (Peg Test) for 10 min.

Evaluations included pre- and post-evaluations, as well as longitudinal evaluations. Pre- and post-evaluations were performed before and after the start of periods 1–3 to assess sensory and motor function and learning ability. During the longitudinal evaluation, neurophysiological, motor, and sensory function assessments were performed daily.

The pre- and post-evaluation Pain Catastrophizing Scale (PCS) evaluates the cognitive aspects of numbness as a sensory function evaluation [33], converting all questions regarding pain items in the questionnaire to numbness. The PCS consists of three sub-items: rumination, when a person cannot release the numbness from the mind; helplessness, when a person feels that they cannot do anything to relieve the numbness; and magnification, when a person perceives the numbness as stronger than it actually is; that is, an enlarged view of the state is considered to occur. The test consists of 14 items, and the evaluation is based on a 6-item scale (0 = not at all applicable to 5 = extremely applicable). Motor function was evaluated by measuring the grasping force using a GFD50-A grasp force meter (Tec Gihan Co., Ltd., Kyoto, Japan). This device measures the transportation time of the grasping force meter and acceleration that occurs during an action. The grasping force meter measured the generated vibration by dividing it into three axis components: X, Y, and Z. To standardize the movement distance of the grasping force meter, we used a box-and-block test to evaluate finger dexterity [32]. In this study, marks were placed at the midpoints of boxes 53.7 cm in width and 25.4 cm high, which were used in the box and block tests. The grasping force meter was set to move from the midpoint on the left side to that on the right side. During the measurement, a 62 g weight was attached to the grasping force meter, and the time and acceleration were measured three times. Hand and finger activities of daily living and the quality of life Motor Activity Log-14 (MAL-14) are useful tools for evaluating learning and the amount and quality of finger usage [34]. The MAL-14 is a 14-item evaluation of upper limb use in real life. The upper Amount of Use (AOU) was evaluated using a 6-point scale (0 = not used at all to 5 = used as much as before injury), and the quality of movement was evaluated using the QOM (0 = not able to do it at all to 5 = able do it as well as before injury). For each item of the MAL-14, the right-hand fingers measured the sense of agency (SoA) NRS [25,26], and the relationship between behavioural change and sense of agency was evaluated. This sense of agency was measured using the question, “How much do you feel that you are the one doing your own exercise?” The NRS score was measured on a scale from 0 (I do not feel it at all) to 10 (I feel it very strongly).

For longitudinal sensory function evaluation, the patient was interviewed once a day to administer the Numbness NRS to the right finger after completing motor tasks. For longitudinal motor function evaluation, the Peg Test was used to evaluate finger dexterity [35]. The Peg Test is an insertion test in which many iron pins (Sakai Medical Co., Ltd., Tokyo, Japan) are inserted into a board (Sakai Medical Co., Ltd.) with 25 holes arranged in two vertical rows within 30 s. Measurements were performed twice daily after the motor task. Neurophysiological evaluations were conducted after completion of the motor task.

EEG activity during the Peg Test was measured daily for 1 min. EEG measurements were obtained while the participants were seated in a relaxed and quiet environment. These measurements were performed once without the patient wearing the yubireco using a portable electroencephalograph (StEEG; Altaire) (Creact Co., Ltd.,Tokyo, Japan). Based on the international 10–20 method, the electroencephalogram was measured at eight sites, namely Fp1, Fp2, T7, T8, O1, O2, Fz, and Pz, using both earlobes as reference electrodes. The bandpass filter was set to 4–30 Hz, and the sampling frequency was set to 1,000 Hz.

Analysis Method

For the pre- and post-evaluations, the PCS was used to compare the scores of the sub-items and the total score of the sub-items between periods. The average values and standard deviations of the three tests were calculated during the evaluation of the grasping force using the total sum. Acceleration was evaluated by measuring the X-, Y-, and Z-axes, and calculating the average and standard deviation of the composite value (3-axis composite value) of the values (effective values) multiplied by the coefficients transmitted to the fingers at each frequency (3-axis composite value [m/s^2]). The values obtained by multiplying "a" with the coefficients transmitted to the fingers for each frequency of the three axes were set as ax, ay, and az, and the obtained data were input into the following formula: a=√ax2+ay2+az2.

The meter task was set as the average time required to complete the grasping force. The average value of the 3-axis composite was calculated three times, and the average value and standard deviation were calculated from the summation. In this task, the grasping force meter must be moved quickly to shorten task completion time. However, when the meter moved rapidly, the acceleration of the meter and fingers increased, thereby increasing the variation in the 3-axis composite value. Therefore, to perform the task quickly, the acceleration must be adjusted to avoid a decrease in the grasping force of the fingers. This control is achieved using a finger pad. Thus, the shorter the average time of the grasping force task, the more difficult it is to control the acceleration generated by the grasping dynamometer and fingers within the finger pads. This indicates that the upper limbs moved smoothly. The MAL-14 AOU and QOM were scored by dividing the total score on a 6-point scale from 0 to 5 by the number of items. The scores were compared between periods.

The Longitudinal evaluation was conducted as follows: Tau-U was calculated using the Numbness NRS score and the maximum value of the Peg Test. Tau U calculations were performed to determine the effect sizes of the statistical indices representing the size of the effect. Tau-U is characterized by the ability to correct baseline trends by combining the non-overlap between periods and trends in the intervention phase [36]. The Tau-U values were obtained for A versus B in period 1, A versus B in period 2, and B in period 2 versus B in period 3. The effect judgment of the results obtained when the Tau-U value is 0~0.20 is that the change is assumed to be small, when the value is 0.20–0.60, the change is assumed to be moderate, when the value is 0.60–0.80, the change is assumed to be large, and when the value is 0.80–1, the change is assumed to be very large [37]. Tau-U analysis was conducted using the web application software single-case research web-based calculators for SCR analysis (version 2.0) [38].

Independent Component Analysis (ICA) was performed to pre-process the EEG data. ICA represents a multidimensional random vector as a linear combination of non-Gaussian random variables that are as statistically independent as possible [39]. MATLAB (Matrix Laboratory) version R2023b with the EEGLAB toolbox [40] was used to implement the ICA. Infomax algorithms were implemented in EEGLAB [41], and their independent components were extracted from the EEG data. From the components separated by the ICA, the signal before mixing was estimated under the assumption that it was a linear sum of statistically independent components to extract clean EEG data. The noise-processed data were subjected to coherence analysis between the FZ and PZ. Furthermore, a custom script created in MATLAB was used to extract the average coherence values in the theta- and mu-wave bands. The theta- and mu-wave coherence values obtained for each period were summed, and the average and standard deviations were determined. The values were compared for each period.

Results

Except for the p-values, the data obtained in this study were expressed to two decimal places.

Regarding the evaluation of sensory function, the Numbness NRS scores were 3.71 ± 0.49 for A, 1.00 ± 0.58 and B in period 2, and 0.14 ± 0.38 for B in period 3. When comparing A and B in period 2, a Tau-U1 (very large change) was observed for B in period 2. Similarly, when comparing A and B in period 3, a Tau-U1 (very large change) was observed in B in period 3. A comparison of B in period 2 and B in period 3 indicated a change in Tau-U0.83 (a very large change) for B in period 3 (Figure 2; Table 1). The PCS score was 14 points for A, including 13 points for rumination, 1 point for helplessness, and 0 point for magnification. In period 2, the PCS scores improved to 7, 0, and 0 points for rumination, helplessness, and magnification, respectively, whereas in period 3, the PCS score was 0 (Table 2).

The assessment of motor function yielded the following results: The Peg Test scores were 12.00 ± 1.00 for A, 15.29 ± 0.76 for B in period 2, and 16.14 ± 0.69 for B in period 3. Comparing A and B in period 2, a Tau-U1 (very large change) was observed in period 2. When comparing periods A and B in period 3, Tau Tau-U1 (a very large change) was observed in period 3. A comparison of B in periods 2 and 3 showed a change of Tau-U0.67 (large change in) for B in period 3 (Figure 3; Table 3). In the grasping force meter evaluation, the task execution time was 4.50 ± 1.65 in the initial evaluation, 2.30 ± 0.78 for A, 2.07 ± 0.46 for B in period 2, and 1.60 ± 0.10 for B in period 3. Compared to A, B had shorter task performance times. The triaxial composite values were 8.06 ± 2.96 for the initial evaluation, 9.37 ± 0.16 for A, 7.73 ± 2.83 for B in period 2, and 9.10 ± 0.09 for B in period 3 (Figure 4A, B).

For MAL, the AOU, QOM, and SoA scores were 4.21, 4.21, and 122, respectively. In period 2, the AOU, QOM, and SoA scores for group B improved to 4.71, 4.71, and 132 points, respectively, and they further improved to 4.86, 4.86, and 136 points, respectively, in period 3 (Table 2).

The theta wave coherence values in the Fz–Pz region for A were 0.57 ± 0.19, and for B they were 0.56 ± 0.19 in period 2 and 0.46 ± 0.14 in period 3. The mu wave coherence values in the Fz–Pz region for A were 0.57 ± 0.19, and for B they were 0.57 ± 0.20 in period 2 and 0.45 ± 0.10 in period 3 (Figure 5A, B; Table 4).

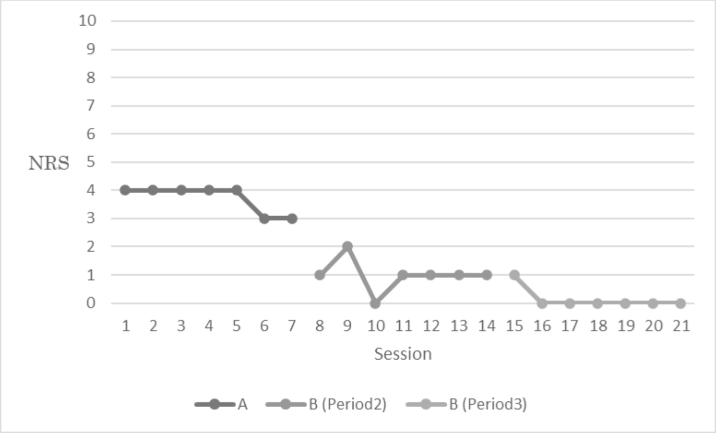


Figure 2: Numbness NRS.

	Numbness NRS	S	Tau-U	VARs	Z	P Value	CI90%	Effect Determination
A	3.71±0.49							
B (Period2)	1.00±0.58							
B (Period3)	0.14±0.38							
AvsB (Period2)		49	1.00	245	3.13	0.0017	0.48<>1	very large change
AvsB (Period3)		49	1.00	245	3.13	0.0017	0.48<>1	very large change
B (Period2) vsB (Period3)		36	0.83	245	2.30	0.0215	0.21<>1	very large change

Table 1: Numbness NRS results and Tau-U for each period. S, number of non-overlapping data points in the baseline and intervention periods; VARs, variance; Z, standard score; p-value, probability of realized value; CI90%, 90% confidence interval.

Assessment Description	Initial Evaluation	A	B (period2)	B (period3)
PCS (Point)	Total: 14/52 Rumination: 13/20 Helplessness: 1/20 Magnification: 0/12	Total: 14/52 Rumination: 13/20 Helplessness: 1/20 Magnification: 0/12	Total: 7/52 Rumination: 7/20 Helplessness: 0/20 Magnification: 0/12	Total: 0/52 Rumination: 0/20 Helplessness: 0/20 Magnification: 0/12
MAL-14				
AOU (Point)	4.07/5	4.21/5	4.71/5	4.86/5
QOM (Point)	4.07/5	4.21/5	4.71/5	4.86/5
SoA (NRS)	116/140	122/140	132/140	136/140

Table 2: Before and after evaluation. Pain Catastrophizing Scale: PCS, Motor Activity Log-14: MAL-14, Amount of Use: AOU, Quality of Movement: QOM, Sense of Agency: SoA.

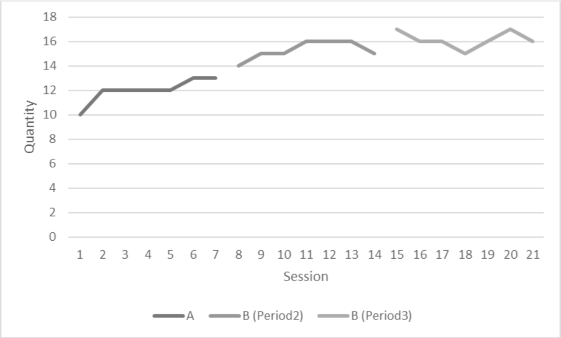
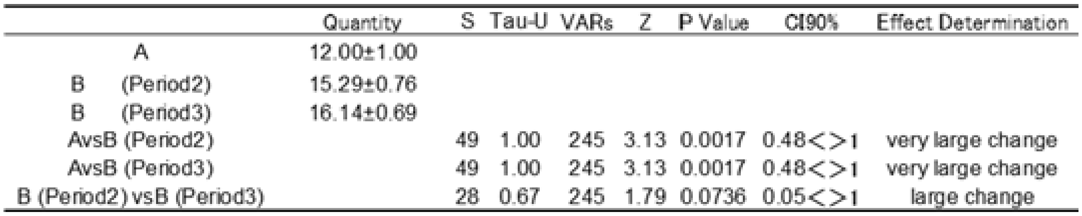


Figure 3: Peg test.



	Quantity	S	Tau-U	VARs	Z	P Value	CI90%	Effect Determination
A	12.00±1.00							
B (Period2)	15.29±0.76							
B (Period3)	16.14±0.69							
AvsB (Period2)		49	1.00	245	3.13	0.0017	0.48<>1	very large change
AvsB (Period3)		49	1.00	245	3.13	0.0017	0.48<>1	very large change
B (Period2) vsB (Period3)		28	0.67	245	1.79	0.0736	0.05<>1	large change

Table 3: Peg test results and Tau-U for each period.

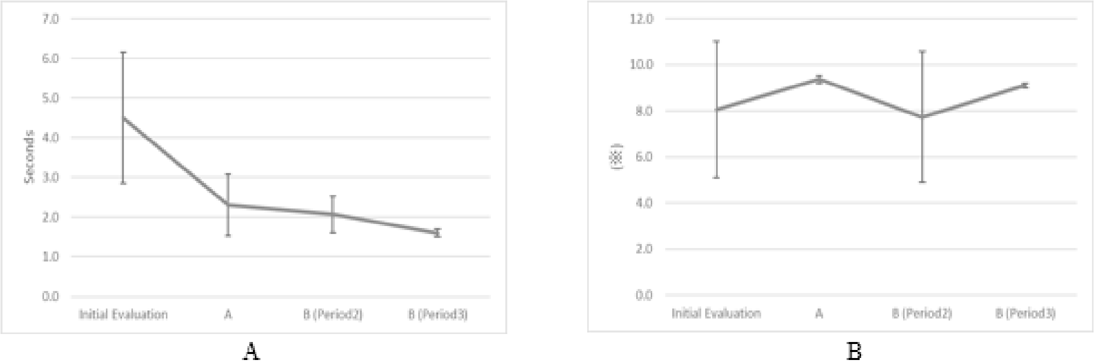


Figure 4: Grasping force measurement. A: Time required for the grasping force task; B: 3-axis composite value; * unit: m/s2

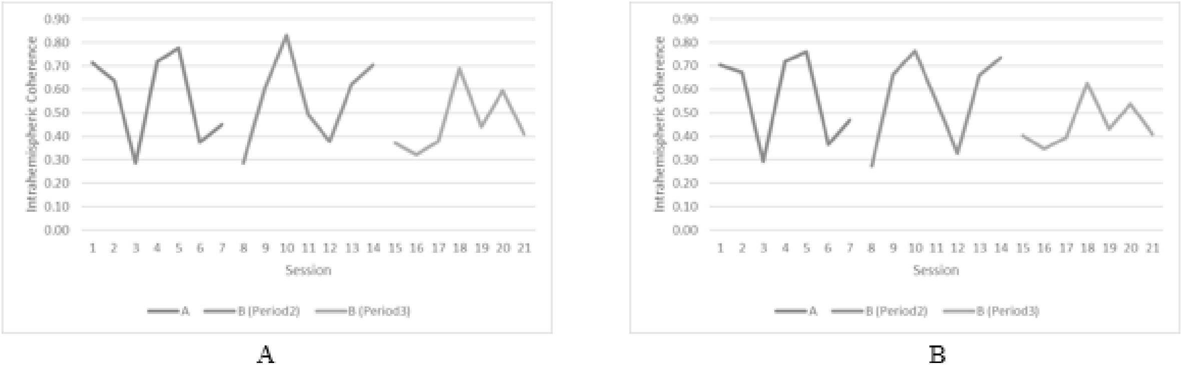
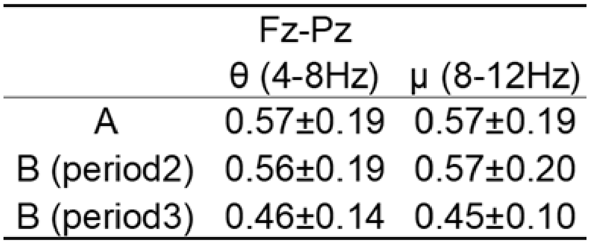


Figure 5: Fz-Pz coherence. A: θ wave coherence value, B: μ wave coherence value.



	Fz-Pz	
	θ (4-8Hz)	μ (8-12Hz)
A	0.57±0.19	0.57±0.19
B (period2)	0.56±0.19	0.57±0.20
B (period3)	0.46±0.14	0.45±0.10

Table 4: EEG frequency analysis results for each period.

Discussion

Herein, we present the case of a patient who fell off his bicycle approximately 3 months previously, incurring a cervical cord injury; rehabilitation was performed for numbness and loss of dexterity in the right hand and fingers. However, the numbness persisted in his right hand, causing motor dysfunction. Sensorimotor dysfunction in the right finger was suspected. To improve the right-hand finger sensorimotor function, in addition to synchronously matching the visual information associated with finger movements, an approach using the friction information generated when the fingers touch an object was implemented. This approach uses the real-time vibrational information feedback provided by a Yubireco device. We used EEG frequency analysis to verify whether the ABB design affects the motor learning process during fine movements.

Sensory function was evaluated using the Numbness NRS to calculate Tau-U. Compared with group A, the largest change was observed in group B during period 3. Numbness in the fingers of the right hand disappeared after B in period 3. When the sensorimotor area is activated through active movement, the brain eliminates unnecessary information for motor control and inputs only the necessary sensory information [42]. In this case, the coherence value of the front parietal region was the greatest for B in period 3, showing decay. The decay of mu waves enhances the sensorimotor processing ability during movement execution [28]. Therefore, using the Yubireco device may have enabled the suppression of unnecessary numbness during fine movements, because the patient could perform the movements more efficiently. Thereby The PCS score, which assesses the cognitive aspect of numbness, improved from 14 to 0 points as the numbness during exercise improved.

Motor function evaluation, assessed using the Peg Test, was based on the results of the Tau-U analysis. The comparison of the results for A and B showed that the largest change was observed for B during Period 3. In terms of the grasping force, the time required to complete the task was shorter and varied less for B in Period 3 than for A. When the ability to process sensorimotor information is strengthened, the sensory information at the fingertips predicts strengthened abilities, and the corresponding fine movements of the fingers become possible [43,44]. In the current case, the mu-wave coherence value of the Fz–Pz region [28], which enhances the sensory-motor information processing ability, showed the greatest decay in period 3. Therefore, after two weeks of intervention with yubireco, predicting the frictional information of the hands and fingers was possible, which may have enabled the patient to perform the fine movement task quickly. Additionally, theta waves are attenuated when the cognitive control necessary for sensorimotor information processing is efficiently performed (transitioning to the late stage of motor learning) [29]. In the current case, the theta-wave coherence showed the greatest decay for B in period 3 in the Fz–Pz region. This suggests that cognitive control during the skilled movements in Period 3 might have been more efficient in the frontoparietal region.

The AOU score for the MAL-14 showed an increasing trend from 4.21 to 4.86 points for B in period 3. In the AOU, the minimal clinically important difference (MCID) which can be interpreted as a beneficial change in the outcome when an intervention is implemented, was defined as 0.5 points [45]. In the present case, the MCID of the AOU was exceeded, suggesting that the frequency of finger use with the right hand improved in daily life. Compared with A, the QOM score showed an improving trend from 4.07 to 4.86 points for B in Period 3. Several factors may have contributed to the improvements in the AOU and QOM scores. If a person continues to fail in the intended movement because of finger sensorimotor dysfunction, their ability to learn that movement decreases [12]. The patient may also have right-hand finger sensory-motor dysfunction, which results in poor quality during right-hand finger movements and learning not to use the fingers. Behavioural changes to improve learned non-use require a sense of agency at the sensory level, where sensory feedback temporally matches motor predictions. Therefore, generating this information is important. In addition, motor learning occurs by generating a sense of motor subjectivity at the cognitive level, which allows the recall of the temporal coincidence of motor and sensory feedback [46]. Feedback stimulation, which corresponds to the friction information during object manipulation, is also important [47]. In this case, we considered that exercises using real-time feedback stimulation corresponding to friction information improved the sense of agency during the right-hand finger movements. We also consider that improving the sense of agency may improve the quality and quantity of use of the right-hand fingers. However, the MCID of the QOM score was 1.1 points [48], which is less than the MCID of the QOM. This was because the QOM score in this case exceeded four points at the time of implementing the intervention, making an intervention with a score higher than one point on the MCID difficult. The grip strength is involved in motor control during fine movements [49]. The fact that the patient's grip strength was only 6 kg may have been another factor contributing to the QOM not improving to the extent that it exceeded the MCID score.

In this case, the results of the neurophysiological evaluations showed that the theta and mu wave coherence values in the Fz–Pz region were the lowest for B in period 3. Therefore, motor learning during fine movements may have moved to a later stage in period 3. Skilled movements were performed more smoothly during Period 3 than during Period 1. In contrast, no difference was observed in the numerical values of the Fz–Pz theta and mu waves between A and B during Period 2. Thus, we considered that although the intervention using yubireco affected numbness of the fingers and motor function after 1 week of intervention, 2 weeks of intervention were required to affect brain wave frequency. The results of this study suggest the possibility of early improvement in finger sensorimotor function in patients with hand sensorimotor dysfunction after cervical cord injury.

This study has some limitations. First, the effects of sensory feedback devices cannot be separated from those of sustained exercise. Second, the cortical activation patterns recorded by EEG differ from those of cognitive and motor stimuli associated with intensive interventions and cannot be attributed to the specific effects of new rehabilitation techniques.

Conclusion

In the present case, the intervention was conducted using feedback through sensory compensation, a treatment strategy developed by Sharma et al. [16] as the basis for treating neurological disorders. These results suggest that yubireco mimics the motor learning process. We suggest that the recovery mechanism for finger sensorimotor dysfunction requires processing of active and real-time sensorimotor information during movement execution.

To date, a recovery time of at least 8 weeks of intervention is required, hindering the recovery of finger motor function caused by injury to the cervical cord [50]. Medical expenses for hospitalization and rehabilitation in cases of cervical spinal cord injury are approximately eight times greater than those in cases without injury [51]. Improving the quality of rehabilitation and shortening the length of hospitalization are urgent issues to reduce the socioeconomic burden on patients and their families. This study investigated the effects of finger sensorimotor dysfunction, a factor that lowers finger motor function. Using Yubireco, an improvement in fine motor skills was observed within 2 weeks of implementing the intervention. Thus, a compensatory real-time feedback approach for tactile sensory discrimination in cases of finger sensorimotor dysfunction after cervical spinal cord injury, reduces the duration of hospitalization and the number of hospital visits. In future, we plan to increase the number of cases and target diseases. We would also like to verify the effectiveness of this tool statistically.

Disclosures

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Institutional Review Board Statement: The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Kyoto Tachibana University Ethics Review Board (Protocol Code 23-27; Date of Approval July 21, 2023).

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

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Data Availability Statement: The data supporting the findings of this study are available from the corresponding author, T. K., upon reasonable request.

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