Effects of Searching Task on Spinal Cord Excitability for Finger Function Recovery Training with Robotic Device

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Abstract—There is an increasing need for patients affected by cerebrovascular diseases to receive continuous and proper rehabilitation support in his/her home. To this end, many robotic rehabilitation support devices for finger therapy have been proposed. However, there has been no consideration for treatment of “fingertips” with these finger therapy support devices. An active touch uses fingertip to discriminate the object in touch. It uses both sensational and motor control nerve systems. Therefore, there is a possibility that the active touch will improve the activities of a spinal cord, and therefore contribute to improve the effectiveness of a finger rehabilitation. A new robotic device that includes the active touch task with finger movements will provide an ideal home rehabilitation device. In this paper, we show that an active touch for pattern discrimination task will improve the activities of spinal cord. The measurement was performed by using F-waves and M-waves given by the evoked-EMG signals applied to healthy subjects. By the experiments, it was shown that the activity is significantly high for the cases of performing active touch tasks. We would like to utilize the results of this study for an exploitation of a robotic finger functional treatment machine used at home.

Index Terms — F-waves; active touch; rehabilitation supporting robot; cerebrovascular diseases

I. INTRODUCTION

Today, the number of affected individuals of the cerebrovascular diseases (CVD) in Japan is as high as 1,300,000. However, the number of hospitalization days and the duration of rehabilitation are insufficient because of the legal restriction by the Japanese medical care system. Therefore, rehabilitation support at home is a pressing need.

Disorders of upper motor neuron which is caused by central nervous system diseases, such as CVD, makes a symptom called “motor paralysis” which causes serious troubles in daily life. Especially, the motor paralysis of an upper limb has a direct effect on the activity of daily living (ADL) for which skill activities are needed.

A skeletal muscle at which a motor paralysis occurred cannot receive commands from upper motor neurons. The injured site of central nervous system (CNS) is hard to recover. Therefore, the recovery of purposive joint motion by voluntary contractions becomes difficult. By this, many examples will have motor dysfunction remaining as a sequel.

In Japan, most of patients who suffer CVD for over six months are judged by doctors as having reached the limit of functional recovery. However, it is widely known among many therapists that the motor function of a patient will recover in response to a suitable treatment even if a long duration has passed after his/her first onset of CVD. This means that a continuous and proper rehabilitation support in a patient’s home will be important.

In the present era, the rehabilitation programs based on a robotic support are studied as the therapeutic treatment (or intervention) strategy for various motor dysfunctions. However, most of such instruments are targeted to arm therapy by using such as robotic exoskeletons and glove type actuators. These are huge and expensive for use in patient’s homes, and their proper operation requires some special support by therapists or technicians.

In contrast to the arm support instruments, more compact robotic devices have been proposed in recent years that support physical exercise of fingers for therapeutic purposes [1]. These devices only require small actuators and mechanisms such as pneumatic drives and electric motors. Therefore, it will be suitable for a rehabilitation support system used at home.
Usually, these robotic finger exercise support systems work the same way as a finger stretching exercise operated by a human therapist. In most cases, the devices have only a basic functionality of moving up and down each finger. However, a sensation of touch, which is one of the most important functionalities of a finger that use a nerve system, is not taken care of these systems. Since an area of a sensation of touch at a finger is small, a hardware instrument that interact with a sensation of touch will be small enough to be attached on top of a robotic device for finger therapy.

**Figure 1** is an example of a prototype of a robotic finger therapy system which we are currently developing. It has motor driven levers to lift up each finger. Also at each fingertip it has a motor driven squared attachment (Fig.1 below). On the squared attachment, “tangible geometric patterns” are placed at each side. The patterns are simple triangles, circles, and lines which are drawn by small bumps. A patient places his/her hand on this machine and guesses which figure is presented by exploiting his/her active touch (Fig.1 upper right). During the active touch, a lever at the finger moves up or down for physical exercise. This scheme will be one of the typical pattern of combining active touch with physical therapy.

If this kind of interaction with touch of sensation is effective for CVD recovery, a robotic device that supports not only a movement of fingers but also interaction with touch sensations will be an ideal machine to be used at home.

**In this paper, we show that an active touch for pattern discrimination task will improve the activities of spinal cord.**

**III. MEASUREMENT DETAILS**

**A. Subjects**

Participants in this study were five men and five women (age 31±11.1 years, mean±S.E.). They were healthy and no subject had any previous history of diseases such as a peripheral neuropathy. A written consent to participate in this study was provided from each subject. This experimental protocols were approved by the Ethics Committee at Future University Hakodate, Japan (Permit No.2014004).
B. Measurement of F-wave

The experiments were carried out using an evoked EMG (NeuropacX1 MEB-2306, Nihon Koden, Tokyo, Japan) and standard electrodes. All electrophysiological examinations were performed in a quiet room as possible and the room temperature was 23-25°C. All subjects were resting for 5 min prior to examinations.

During measurement, each subject took a comfortable posture on a chair with a reclining backrest. The subjects were set their upper dominant limb on the desk with their elbow joint bending and their forearm rotating outward (Fig. 2).

For measurement of the median nerve, a surface disk electrode was placed on the belly of the abductor pollicis brevis muscle of the subject’s dominant hand for recording and on the tendon for reference (2 cm from the recording electrode).

Stimulation was applied at the palm side of the wrist. Stimulation intensities were set to little stronger than the value at which a maximum M-wave was appeared and a subject did not feel any pain.

Sixteen times consecutive stimuli were delivered at the intensity of 2.0 - 6.0 mA; Frequency 1 Hz; and duration 0.5 ms, to the median nerve during resting or searching behavior. The resulting F-waves were stored for subsequent analysis. The following parameters were obtained: F-wave occurrence; F-wave latency; F-wave amplitude; M-wave amplitude; and F/M amplitude ratio. Here, the F-wave occurrence is defined as the number of measurable F-wave responses divided by 16 times stimuli. The F-wave latency is defined as the mean latency from the time of stimulation to the onset of a measurable F-wave.

We define F/M amplitude ratio as the mean amplitude of all F-waves divided by the amplitude of the M-wave. This is a normalized intensity of an F-wave which is able to be compared with different subjects.

C. Searching task

We prepared a simple searching task that a subject is requested to discriminate between different tangible patterns assembled from bumps by stapler needles (Fig. 3-A). A subject is requested to use his/her fingertip of an index finger to classify the presented pattern without seeing on it. Searching motions are not restricted during this task. This searching task was performed using an easy instrument such as shown in Fig. 3-B.

The F-wave was measured while a subject was performing this searching task (Fig. 3-C) and while he/she was at rest and not performing it.

D. Statistical analysis

The F-wave occurrence and the F/M amplitude ratio during searching task were compared with those during rest. For statistical analysis, Wilcoxon signed-rank test was performed. P-values of less than 0.05 were considered to be statistically significant. All analysis were performed using SPSS Statistics software version 22 (IBM, Tokyo, Japan).

IV. RESULTS

We measured the evoked-EMG of the median nerve during rest and searching tasks (Fig. 6). The median of F-wave occurrence during rest was 34.5% (Fig.4). On the other hand, the median of F-wave occurrence during searching task was 22.0% (Fig.5). F-wave occurrence during searching task was significantly decreasing compared with that during rest ($p=0.029$). Furthermore, the median of F/M amplitude ratio during rest was 4.4%, and that during searching task was 6.1%. Unlike F-wave occurrence, F/M amplitude ratio during searching task was significantly increasing compared with that during rest ($p=0.016$). There was no significant difference between F-wave latencies during rest and searching task (Table 1).

V. DISCUSSION

F-wave latency is a time until an F-wave is derived from the stimulation. As mentioned above, an F-wave is an expression of antidromic activation in alpha motor neurons. It is thought that a fluctuation of F-wave latency is caused by diseases, such as peripheral neuropathies, and environmental changes, such as room temperature, etc. However, there was no those factors in this study. Therefore, it seemed that a
probability of fluctuating F-wave latency by subject’s postural changes is very low. Indeed, F-wave latency did not significantly change in this study. This result shows that stimulating electrode was applied at the same position in any posture, and indirectly demonstrates that the experimental procedures and methods in this study were accurate.

F-wave occurrence during searching task significantly decreased compared with that during rest. This result shows that, the muscle activity of the abductor pollicis brevis, which is a region where F-waves in this study were derived, was suppressed by upper motor neurons in brain, in accordance with the motions of index finger during searching actions. Furuya previously described that when a certain fingers are independently moved, such as by keyboard manipulations of a piano or a computer, the muscle activities of other fingers were suppressed[8]. It is regarded that our result is supported by this previous study. Accordingly, our result suggests that during a certain action, in order to increase the sensitivity of perceptions and motor systems related to the action, a mechanism which inhibits body activities unrelated to the action seems to exist.

Table 1: Data of F and M-waves

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>Searching</th>
</tr>
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<tbody>
<tr>
<td>F-wave occurrence (%)</td>
<td>44.5</td>
<td>26.83</td>
</tr>
<tr>
<td>F/M amplitude ratio (%)</td>
<td>4.3</td>
<td>24.95</td>
</tr>
<tr>
<td>F-wave latency (ms)</td>
<td>25.79</td>
<td>19.63</td>
</tr>
<tr>
<td>F amplitude (μV)</td>
<td>1113</td>
<td>1400</td>
</tr>
<tr>
<td>M amplitude (mV)</td>
<td>29.54</td>
<td>18.46</td>
</tr>
<tr>
<td>F-wave occurrence (%)</td>
<td>29.94</td>
<td>26.83</td>
</tr>
<tr>
<td>F/M amplitude ratio (%)</td>
<td>5.2</td>
<td>10.83</td>
</tr>
<tr>
<td>F-wave latency (ms)</td>
<td>19.07</td>
<td>19.63</td>
</tr>
<tr>
<td>F amplitude (μV)</td>
<td>960</td>
<td>1400</td>
</tr>
<tr>
<td>M amplitude (mV)</td>
<td>27.85</td>
<td>18.46</td>
</tr>
</tbody>
</table>

F/M amplitude ratio during a searching task was significantly high compared with that during rest. This result shows that the threshold of the alpha motor neuron’s activity was decreased by the motion program of upper motor neurons in brain. The activity of an alpha motor neuron is facilitated or inhibited by the upper motor neurons, thereby resulting in maintaining a certain threshold of the activity. It is previously reported that a slight muscle contraction reduces the threshold of the activity and increases the amplitude of an F-wave[9]. Consequently, our result suggests that during the active
searching tasks of fingers, the muscles which participates in those action are selected. Moreover, our result also suggests that the mechanism controlled by the upper motor neurons which decrease the threshold of the activity of the nervous system which innervates these agonist muscles exists.

Unlike a passive touch, an active touch can more easily collect the surrounding information through sensing a sensation on a skin[10]. It is previously reported that the cognitive process which integrates the information acquired by searching tasks is active, and that a sensation reception and a cognitive process which integrates the information acquired by sensation on a skin[10]. It is previously reported that the active touch could more easily discriminate objects than the passive touch[13]. Other previous report have shown that not only the passive key which subjects felt but the power which a fingertip generates is important for discriminating objects, when a subject touched an edge of the object lightly with a finger[14]. These previous reports support the hypothesis suggested by our results in this study.

A hand is called an “external brain”[15] and there is a close relationship between the hand and the brain. In brain disorder, such as CVD, the symptom influences in upper limbs more strongly than trunk or lower limbs. It means that functional recovery of upper limbs is delayed compared with that of a trunk or lower limbs. There are positive signs and negative signs in the upper neuron syndrome which appears in CVD etc. The positive signs include muscle hypertonia and sthenia of tendon jerk. The spasticity is an expression of the positive signs of muscle hypertonia or sthenia of tendon jerk. The negative signs include palsy and muscle weakness. These symptoms cause disturb in a joint movement and interfere with ADL. The "spastic paralysis", which appears in an upper neuron trouble, is in the state that the spasticity (a positive sign) and the palsy (a negative sign) occur simultaneously[16]. However, with or without a joint movement, a little voluntary contractions are possible for most of the patients who has caused a spastic paralysis. Moreover, in the patients who have predominantly negative signs, the viscoelasticity of muscles in upper limbs and fingers decreases with flaccid paralysis, and voluntary contractions of these muscles are almost impossible. In any case, non-neurogenic symptoms, such as muscle stiffness, contracture and atrophy, are occurs by hypokinesia of muscles. Especially, in patients with flaccid paralysis, for whom the voluntary movements are impossible, recovery of the upper limb (especially fingers) is really late. In many cases, they have no sign of recovery and are advancing in severity. As known for the Brodmann areas, the regions of the movement and sensation related to fingers are wider than those related to other body parts. Even if the hemiplegia has occurred, a lower limb has much opportunity to participate in movements of rising, walking, etc. However, in comparison with a lower limb, the affected-side upper limb easily fall into disuse and there is a high probability that sensory inputs will extremely decrease. These clinical symptoms and living environments are considered to interfere the functional recovery of an upper limb. Therefore, early, active and continuous interventions in fingers are indispensable as therapeutic methods for disorders of upper motor neurons, such as CVD.

From these, we would like to conclude that the method using the "searching task" with finger exercise should be one of functionally interventional methods.

VI. CONCLUSION

This study revealed that an active searching behavior reduced the incidence of an F-wave. This result suggests that the abnormal muscle tonus of the patients, who have a disorder of upper motor neuron, can be controlled by this action. Moreover, it is also suggested that the alpha motor neurons required for this searching task are chosen and activated further. We would like to utilize the results of this study for an exploitation of a robotic finger functional treatment machine used at home.

REFERENCES