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Original Article

Comparison of cortical activation in an upper limb added-purpose task versus a single-purpose task: a near-infrared spectroscopy study

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Abstract. [Purpose] The purpose of this study was to compare prefrontal activations during an added-purpose task with those during a single-purpose task using functional near-infrared spectroscopy. [Subjects] Six healthy right-handed adults were included in this study. [Methods] The participants were instructed to complete both added-purpose and single-purpose activities separately with each hand. The near-infrared spectroscopy probes were placed on the scalp overlying the prefrontal cortex, according to the International 10–20 system (Fz). Changes in the oxygenated hemoglobin and deoxygenated hemoglobin concentrations in the prefrontal cortex were measured during performance of the activities. We then compared the number of activation channels with significant increase in oxygenated hemoglobin, during added-purpose activity to single-purpose activity using both hands separately. [Results] A greater number of widespread activations were observed in the prefrontal cortex during the added-purpose task than during the single-purpose task. These results were noted with both right and left hands. [Conclusion] According to our findings, added-purpose activity can bring about more activation in the prefrontal cortex, which may provide occupational therapists with effective guides in therapeutic practice.
Key words: Purposeful activity, Functional near-infrared spectroscopy (fNIRS), Prefrontal cortex

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INTRODUCTION

Purposeful activities, commonly used as a treatment modality in occupational therapy practice, play an important role in the health insurance system. Various added-purpose activities are employed by occupational therapists for patients at different stages of involvement during their treatment sessions. In the author's experience, recovery of the fingers on the hemiplegic side in cerebral vascular accident (CVA) patients differs depending on whether the patient participated in grasping objects with the affected side during occupational therapy. It was therefore unclear if the activity purpose influenced upper limb recovery. To investigate the changes among added-purpose activities, most previous studies measured heart rate, blood pressure, and perceived exertion rating[1–5)]. However, the relationship between the added-purpose activities and cerebral activation remains unclear.

A non-invasive measurement of the changes in oxygenated and deoxygenated hemoglobin concentrations (Oxy-Hb and Deoxy-Hb, respectively) in response to cerebral activities is provided by functional near-infrared spectroscopy (fNIRS)[6–9)]. In terms of temporal and spatial resolution, compared with other neuroimaging technologies, fNIRS is generally considered a less advanced technique. However, it is advantageous in that it represents a safer method and does not require strict restriction of motion; as a result of this, it can be used in natural environments[10, 11)]. These advantages specifically allow fNIRS to measure cerebral activities and stimuli in subjects carrying out tasks similar to those experienced in daily life[10–12)]. Therefore, subjects can perform pegboard tasks in the seated position and in a relaxed environment.

As pegboard tasks are frequently used in occupational therapy for CVA patients, we defined "an added-purpose task" and "a single-purpose task" in terms of these tasks. The subjects were required to move a peg from one hole to another on the pegboard by pinching with the thumb and

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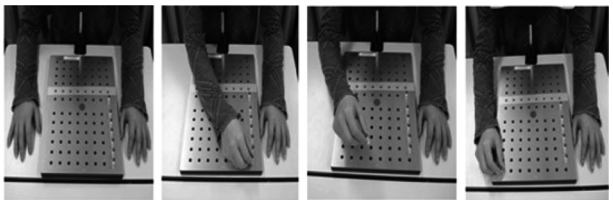

Fig. 1. An added-purpose task

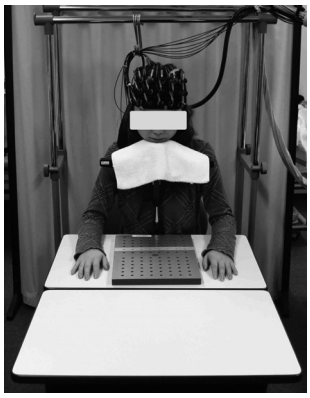

Fig. 2. Patient posture during the rest period

Table 1. Testing sequence in the subjects

Subjects	1st test	2nd test	3rd test	4th test
1	Task 1	Task 2	Task 3	Task 4
2	Task 1	Task 2	Task 4	Task 3
3	Task 2	Task 1	Task 3	Task 4
4	Task 4	Task 3	Task 1	Task 2
5	Task 3	Task 4	Task 1	Task 2
6	Task 3	Task 4	Task 2	Task 1

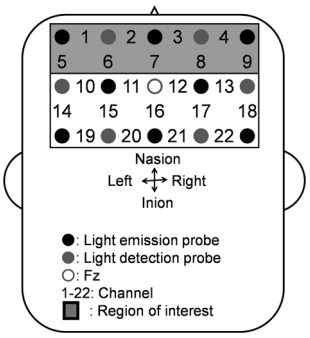

Fig. 3. fNIRS probe placement and ROI

index finger for the added-purpose task and perform the same movement without pegs for the single-purpose task.

Consequently, the purpose of this study was to identify the factors that affect functional recovery based on cortical activation during upper limb activities with different purposes.

SUBJECTS AND METHODS

Six healthy right-handed participants (5 women and 1 man; mean age: 19.7 ± 0.5 years; range: 19–20 years) who volunteered for this study were included. Handedness was assessed using the Edinburgh Inventory[13]. An added-purpose task and a single-purpose task had not been experienced previously by the participants. This study was approved by the institutional ethical committee of the China Rehabilitation Research Center (2015-K-070), and all participants were required to sign a written informed consent.

The subjects were required to move a peg from one hole to another on a pegboard using the pinch grasp with the thumb and index finger for the added-purpose task at the speed of 1 peg/s (Fig. 1) and perform the same motion of the added-purpose task without pegs for the single-purpose task. These tasks were carried out with the right and left hands at the rate of 1 peg/s.

Task 1: Added-purpose task with the right hand

Task 2: Added-purpose task with the left hand

Task 3: Single-purpose task with the right hand

Task 4: Single-purpose task with the left hand

Every task was repeated 5 times. During the rest period, the subjects stared at the red dot in the center of the pegboard under the seat (Fig. 2).

To avoid the influence of the test sequence on the results, the subjects were provided the tasks in a random sequence (Table 1).

We used the multichannel fNIRS optical topography system ETG-4000 (Hitachi Medical Corporation, Kashiwa, Japan) with 2 wavelengths of near-infrared light (695 and 830 nm). Optical data based on the modified Beer-Lambert law[12, 14, 15] was analyzed, as previously described[16]. This method allowed us to calculate signals that reflected changes in the Oxy-Hb and Deoxy-Hb concentrations in millimolar-millimeters (mM mm)[16, 17]. The sampling rate was set at 10 Hz.

According to the International 10–20 system (Fz), the NIRS probes were placed on the scalp overlying the prefrontal cortex[17, 18]. We used a set of 3 × 5 multichannel probe holders, consisting of 8 illuminating and 7 detecting probes arranged alternately at an inter-probe distance of 3 cm, resulting in 22 channels (CH).

We defined a set of 9 CH before Fz as a prefrontal area region of interest (ROI) (Fig. 3).

For every subject, the CH measurements showing a low signal-to-noise ratio were discarded.Linear trends of continuous Δ[Oxy-Hb] and Δ[Deoxy-Hb] fluctuations were also eliminated. Changes in the Δ[Oxy-Hb] and Δ[Deoxy-Hb] were smoothed with a 5 s moving average[12, 17]. We focused on Δ[Oxy-Hb], because Δ[Oxy-Hb] is the most sensitive parameter of cerebral blood flow[6, 17, 19, 20]. The standard deviation (SD) was calculated against 10 s resting periods just before the target task blocks in each channel and the significance level of Δ[Oxy-Hb] were evaluated, with SD × 3.053 as a threshold. The term "3.053" is the Z-score of the one-sided Bonferroni corrected significance level ($p < 0.05$) for multiple comparisons. A response of each channel was deemed significant when Δ[Oxy-Hb] was above the signifi-

Table 2. Number of activation channels in the prefrontal cortex (n = 6)

Task	Number of activation channels (M ± SD)
Task 1	6.83 ± 2.71
Task 2	7.50 ± 1.87
Task 3	4.50 ± 3.62
Task 4	5.00 ± 2.61

Value are presented as the mean±SD. The results of the number of activation channels are as follows (paired t-test): Significant changes were found between Task 1 and Task 3 ($p = 0.029 < 0.05$) in conditions with the right hand, and between Task 2 and Task 4 ($p = 0.007 < 0.05$) in conditions with the left hand.

cance level during the target stimulus block. To evaluate the activation areas, the number of channels with a significant increase in Δ[Oxy-Hb] was compared between the added-purpose task and single-purpose task[17]. These analyses were performed using Matlab 2010a (MathWorks, Natick, MA, USA).

RESULTS

The cortical activation areas in the prefrontal cortex and its surrounding areas, either left hand or right, the number of activation channels with the added-purpose task is much more. These results were demonstrated using the right hand (paired t-test, $p = 0.029 < 0.05$) and left hand ($p = 0.007 < 0.05$) (Table 2).

DISCUSSION

In this study, the author defined "an added-purpose task" and "a single-purpose task". The subjects were required to move a peg from one hole to another on a pegboard by pinching with the thumb and index finger for the added-purpose task and perform the same motion of the added-purpose task without pegs for the single-purpose task. A comparison of prefrontal activation between added-purpose tasks and single-purpose tasks with the fNIRS revealed that in the prefrontal cortex and its surrounding areas, with both upper limbs, the added-purpose task brings about more activation in the prefrontal cortex. In other words, the number of activated channels is greater with the added-purpose task. Therefore, we think that the purpose of the activity may have an effect on the extent of cortical activation. Previous reports have shown that the prefrontal cortex is responsible for the synthetic control of action and attention[21, 22]. Several criteria should be taken into account during the pulling out, holding, moving, and inserting of pegs in this study, such as the location, size, and color of the pegs, and the proper position of the finger to guarantee smooth movement and correct insertion of the pegs. As this is an added-purpose task with pegs, attention should be paid to holding, moving, and inserting in order to achieve the goal[23]. In this moment, some sensory information of the flexion of finger arthrosis and the stretch of soft tissue like skin should be managed simultaneously. Introduction of pegs in the experiment may also help to heighten the motivation of the activity, since the fulfillment of this task requires concentration. Therefore, the author concluded that the cerebral activations during an added-purpose task are not the same as those during a single-purpose task.

This study involved only 6 subjects, and this small number may have affected the test results. A future study with a larger sample will be conducted. Application of these results to clinical occupational therapy will take a lot more time. Cerebral activation has been shown to be depressed in specific areas in CVA patients, in a few previously published studies in the literature[24]. Brain metabolism is also reduced in the prefrontal cortex in patients with vascular dementia, as the blood flow is reduced[25]. Our findings suggest that added-purpose activity can bring about more activation in the prefrontal cortex compared to single-purpose activity. Our findings may provide occupational therapists with an effective guide in therapeutic practice. Broadly speaking, more added-purpose tasks should be used for improving patient function and activitie daily living ability. Additionally, more time and effort is required to investigate specific activities and guidance method of added-purpose tasks to improve cortical activation.

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