Cortical Activation of Passive Hand Movement Using Haptic Knob: a Preliminary Multi-channel fNIRS Study

Juanhong Yu, Kai Keng Ang, Huijuan Yang, and Cuntai Guan

Abstract—**Several functional neuroimaging studies had been performed to explore the sensorimotor function for motor imagery and passive movement, but there is scanty work that investigated the cortical activation pattern for passive movement using functional Near-Infrared Spectroscopy (fNIRS). This study investigated the cortical activation pattern from fNIRS data of 8 healthy subjects performing motor imagery and passive movement tasks using a Haptic Knob robot. Group averaged contrasts were defined as motor imagery versus idle and passive movement versus idle. The cortical activations for motor imagery appeared on the contralateral sensorimotor area, whereas the cortical activations for passive movement appeared on both contralateral and ipsilateral sensorimotor area. This result suggests that the performance of passive movement has a wider cortical activation compared to the performance of motor imagery.**

I. Introduction

Sensorimotor functions are often impaired after a stroke. Brain structures and functions related to stroke injury can be reorganized and motor functions can be restored by neural plasticity. Haptic Knob (HK) is a robotic device that enables subjects to do the passive movement (PM) by opening or closing theirs hands [1]. The recent development of robot-assisted rehabilitation helps stroke patients to recover their hand functions; a HK with brain computer interface (BCI) is expected to explore new approaches in motor rehabilitation for stroke patients.

A brain computer interface allows direct communication and controls to the external devices by converting brain signals into commands [2]. Brain signal can be measured by electroencephalogram (EEG), near infrared spectroscopy (NIRS) and other modalities like functional magnetic resonance imaging (fMRI). Functional near infrared spectroscopy (fNIRS) is a non-invasive technique that measures the absorbed quantity of near-infrared light within 650-950nm wavelength to determine the concentration changes of oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR) in the superficial layers of human cortex [3]. fNIRS has better spatial resolution compared with EEG and higher temporal resolution and less constraint compared with fMRI. In a typical motor imagery (MI) BCI system, the signal acquired during the calibration phase is processed offline and used as the commands to control the external device in the evaluation phase. Study [4] shows evidence of the efficacy for stroke patients using EEG-based MI-BCI in restoring upper extremities motor function, and a large population of stroke patients can operate EEG-based MI-BCI [5].

Studies have shown that performing of motor imagery, passive movement and voluntary movement of the hand activate cortical activities in different patterns in the sensorimotor areas. An electrocorticography study [6] demonstrated the role of primary motor areas in movement imagery and the magnitude of imagery-induced cortical activity change was about 25% of that associated with actual movement. The study that used EEG to measure brain signal reveals that motor imagery involved greater neural activation compared to passive movement [7]. A fMRI study [8] demonstrated that the pattern of neural activation was best resembled by passive movement, followed by motor imagery, and lastly by movement observation. Study [9] focused on multimodal fNIRS and EEG-based BCI study and showed that the contrast of passive movement was significant different from motor imagery. Besides the above mentioned studies on multiple modalities, some fNIRS studies investigated the cortical activation as well. Study [10] investigated the cortical activation pattern for grasping when performing motor imagery, motor execution, action observation and passive movement by a functional electrical stimulation (FES) and the results demonstrated the considerable differences between these modes. Study [11] measured the hemodynamic evoked responses to voluntary finger movement and nonvoluntary electrical simulation applied on the fingers. The results showed that the observed hemodynamic evoked responses to voluntary motor task were larger in scale and amplitude compared to nonvoluntary sensory task.

In this study, we propose a novel experiment protocol to investigate the cortical neural activities from 8 healthy subjects performing motor imagery and passive movement using Haptic Knob in a multimodal NIRS and EEG setup (We only discuss NIRS data here). NIRS data is processed and statistical parametric mapping analysis is conducted using NIRS-SPM [12]. Group averaged brain activation changes are accessed based on the contrast defined as motor imagery versus idle and passive movement versus idle. Analysis of the time course of the interested channels is presented as well.

The remainder of this paper is organized as follows: Section II describes the experiment protocol, NIRS data collection, data processing and analysis. Section III presents the experimental results. Section IV presents the discussion and the future work.

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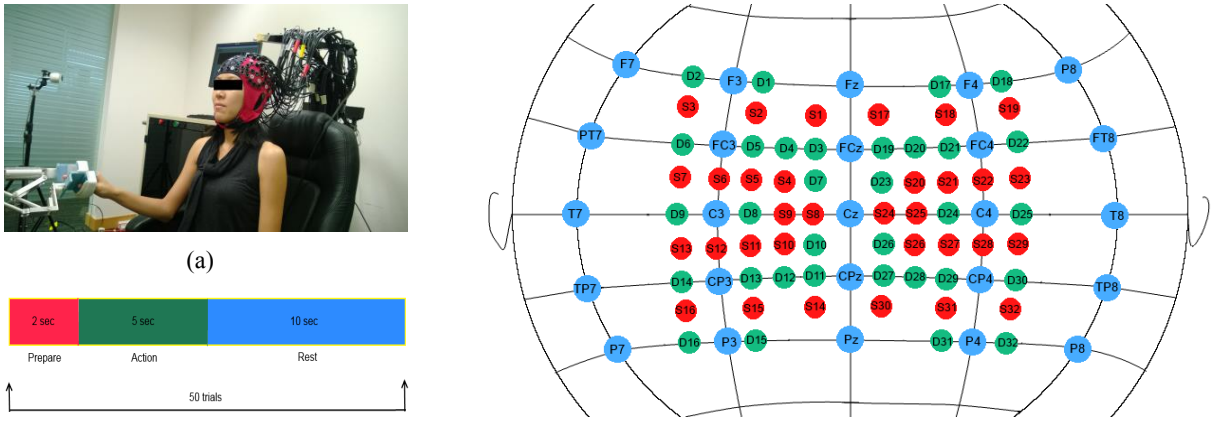

(a)

(b)

(c)

Figure 1. (a) Experiment setup for a subject performing motor imagery and passive movement using Haptic Knob. (b) Experimental protocol design. (c). NIRS optodes layout design. Blue circles represent EEG positions, green circles represent detectors while red cicles represent sources of the NIRS optodes.

II. Experiment and Method

A. Experiment protocol

8 healthy right-handed subjects were recruited from staffs and students in the Institute for Infocomm Research, Agency for Science, Technology and Research (A*STAR), 1 subject from outside. Ethics approval was obtained. All subjects signed on the consent form and were informed fully on the nature of the experiment.

Experiment was conducted in a room with normal lighting. Subjects sat on a comfortable chair with armrests and the right hand was fixed in the Haptic Knob during the whole experiment.

The experiment was conducted in two runs: motor imagery run and passive movement run. A total of 50 trials for each run were conducted. Each trial started from 2s of preparation cue, then 5s of action, and followed by 10s of rest. In the motor imagery run, actions referred to motor imagery (open / close hand) and idle, whereas in the passive movement run, action referred to passive movement and idle with the sequence of action being generated randomly. Each run had an initial 30 seconds for the signal to be stabilized and another 30 seconds before the run ended. Fig. 1 (a) and (b) show the experiment setup and protocol design of this study.

In the motor imagery run, subjects were instructed to do motor imagery only without actual movement while in the passive movement run, subjects were instructed to let the hand be opened and closed freely by the Haptic Knob without performing motor imagery. In both runs, subjects were instructed to look at the screen only without performing any movement or motor imagery during the idle trial. The idle trials were used as the baseline in the statistics analysis.

B. NIRS measurement

The experiment setup of this study included NIRS and EEG, and data were collected simultaneously. In this paper we only focused on analyzing the NIRS data. NIRS data were collected by a continuous wave NIRS instrument NIRx Dynamic Near-Infrared Optical Tomography (DYNOT) Imaging System at a sampling rate of 1.81 Hz using two wavelengths (760nm and 830 nm), with 64 optical fibers consisted of 32 sources and 32 detectors. The optodes of the NIRS machine were fixed in the motor area and centered at C3 and C4 according to the international 10-20 System used in the EEG. The arrangement of the optodes enabled the measurement of oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR) values from lateral and medial premotor cortices (Brodmann's area (BA) 6 and 44), primary motor areas (BA 4) to somatosensory cortices (BAs 1, 2, 3, 40) areas. Locations were detected using a 3D electrode digitizer system the Xensor digitizer. Since not all channels contained good quality data, only those channels with source and detector distances between 1.5 to 4.0 cm were used, yielding a total of 122 channels. Fig. 1 (c) shows the optodes layout where green circle represent detectors and red circles represent sources of the NIRS optodes.

C. Data processing

The hemoglobin changes of HbO and HbR were computed using the modified Beer-Lambert law [13] from the optical density changes. Data were then group averaged. Data were further processed using NIRS-SPM [12] to the correction of noise, signal distortion due to breathing or movement of the subject by applying high pass filter based on discrete cosine transform (DCT) with a cutoff frequency of 128 Hz and low-pass filtering using hrf (hemodynamic response function). A mass-univariate approach based on the general linear model (GLM) and Sun's tube formula [14-16] were applied to the data for the statistical analysis. Cortical activation maps were obtained from t-statistic values which illustrated the brain regions where increased or decreased HbO and HbR correlated with the stimulation protocol over time. Contrasts were defined as MI versus idle and PM versus idle with significant threshold set to $p < 0.05$.

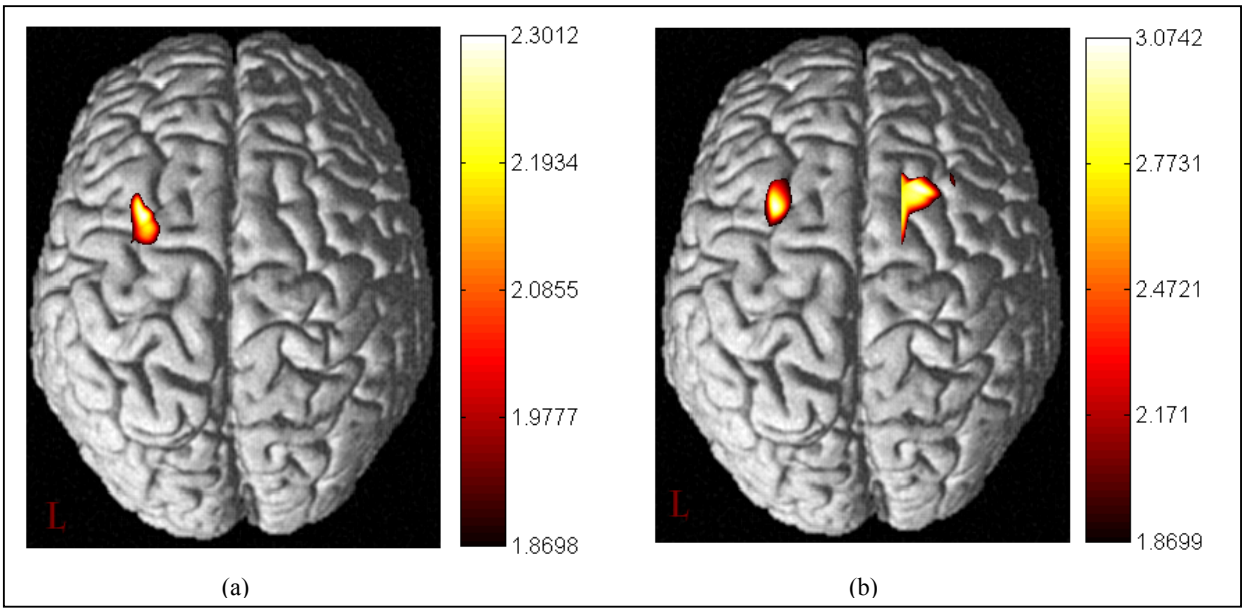

Figure 2. Activation maps of HbO with averaged trials. Each map depicts the significant difference between (a) motor imagery and idle state. (b) passive movement and idle state with threshold $p < 0.05$. Significant activation can be observed either ipsilaterally (a) or bilaterally (b) in the sensorimotor area.

III. RESULTS

NIRS technique utilizes changes in hemoglobin oxygenation as an index of neural activation [17]. Fig. 2 shows the cortical activations of HbO for group averaged based on single-trail during motor imagery and passive movement tasks. A significant increase of HbO can be observed for the left sensorimotor area when performing motor imagery (Fig. 2a) and both left and right sensorimotor areas when performing passive movement using Haptic Knob (Fig. 2b) (uncorrected, $p < 0.05$). Fig. 3 plots the time course for group averaged data for one task for optode pair (source 5, detector 8). The HbO values take some time to reach the peak values which show the time latency nature of NIRS signal.

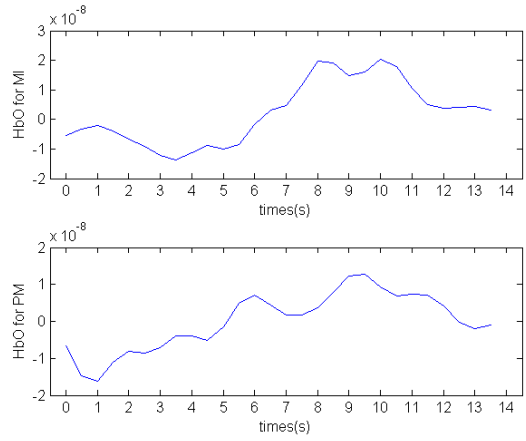

Figure 3. Time course for avearaged data trial for optode pair (source 5, detector 8).

IV. DISCUSSIONS

This present study investigated the changes of oxy-hemoglobin during performance of motor imagery and passive movement using Haptic Knob. The activation map of motor imagery versus idle in Fig. 2a revealed that the cortical activation happened in contralateral sensorimotor area. This is in agreement with several previous studies reported [18-20].

On the other hand, the cortical activation patterns for passive movement using different mechanisms were reported in several previous studies as well. Study [10] reported the passive movement conducted by FES activated an expected sensorimotor network of brain areas. Another study [21] reported the HbO values which indicated significant activation in the left primary sensory-motor cortex, left supplementary motor areas, left premotor cortex and left prefrontal cortex during execution of the rehabilitation robotic right hand finger movement. An fMRI study [22] showed the activation in the sensorimotor system for passive movement conducted by an examiner. From our result, the passive movement using Haptic Knob activated both the contralateral and ipsilateral sensorimotor area (Fig. 2b). This may be due to the reasons that the FES could not activate the actual hand movement like what Haptic Knob does. It is also noted that the activation for passive movement is stronger and wider compared with motor imagery shown in Fig. 2. One of the factors may be due to the noisiness of NIRS data. This would be further investigated in our future work.

The protocol design of this experiment was based on a typical BCI system which is different from some fNIRS studies reported in the literature. As NIRS signal has time latency, most of the NIRS study experiment designs are

block design, and have long action period (more than 20 seconds) and rest period. Fig. 3 shows time course for the group averaged single-trial. The changes in HbO for motor imagery and passive movement over the time course are consistent with the existing studies.

From the individual subject result analysis, difference was observed between experienced and novice subjects. In their passive movement run, the activation areas are more dominant for experienced subjects compared with those novices. This finding could be further investigated in more details and if verified, it would be helpful for stroke rehabilitation since this may imply that more motors would be involved after practicing passive movement rehabilitation trainings.

V. Conclusion

In this study, we investigated the cortical activations of performing passive movement versus idle using the Haptic Knob robot, which was compared to the cortical activations of performing motor imagery versus idle. The experimental results on 8 healthy subjects showed that the cortical activations occurred on the contralateral sensorimotor area for motor imagery versus idle, whereas the cortical activations for passive movements versus idle occurred on both the contralateral and ipsilateral sensorimotor area. This characterization of cortical activation patterns explored and the neural activities exposed in the time course will lay a good foundation for the future development work of BCI based rehabilitation.

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