NIRS STUDY ON THE CORTICAL CONTROL OF CYCLING EXERCISE IN STROKE PATIENTS

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INTRODUCTION

Stroke is one of the leading causes of disability in United States and other developed countries. Those survived from stroke may be left with physical impairments deeply affecting the activities of daily living and quality of life. Cycling exercise is a very common rehabilitation program in stroke patients with wild range of functional recovery. For patient with severe disability, with the symmetrical and reciprocal movement of lower extremities, it can be used as training prior to ambulation or for functional range of movement recovery in hip and knee joints.

A novel neuroimage technique, near-infrared spectroscopy (NIRS) or imaging (NIRI) has been utilized in the studies to detect cortical activation. NIRS optical recording technology measures changes in the concentrations of oxygen (HbO) and deoxygen hemoglobin (HbR) from the changes in the number of absorbed photons versus those scattered back to the surface of the scalp. NIRS technology is presently growing use world-wide to assess cortical activity during cognitive and motor tasks in healthy persons as well as in persons with central nerve system damage [1, 2]. Compared to the enclosed chamber used in fMRI, the cortical activity of participants can be assessed using NIRS while they are comfortably seated or move their limbs freely, which is more suitable for movement-related rehabilitation tasks.

The aim of this study is to investigate the effect of different types of training on brain plasticity observed from NIRS.

MATERIALS AND METHODS

Instrumentation

fNIRS recording of cortical activity

The optical signal recording system is a multi-channel frequency domain NIRS (FD-NIRS) system-Imagent (ISS Inc., Champaign, Illinois). The system is equipped with 16 paired of laser diodes with wavelengths of 690 nm and 830 nm and 4 detectors to emit and receive the NIR light. The light is emitted from diodes and conveyed to the head through multimode code glass optical fibers (P18855; OFS Inc., Norcross, Georgia) with a core diameter of 400 μm. Light scattered through the brain tissue was carried by detector optical fiber bundle to 4 photo-multiplier tubes (PMTs; R928 Hamamatsu Photonics). The concentration changes of oxygenation and deoxygenation hemoglobin were calculated base on the values of $\Delta\mu a$ at two wavelengths. [3] To detect the cortical activation during pedaling movement, 20 source-detector channels with 4 detectors and 14 paired of sources were used with a sampling rate of 19.8 Hz as shown in Figure 1(a). Each source location comprised two optical fibers for each wavelength. The interoptode distance was set at 3.0 cm. The optodes with custom-made connectors were screwed together with the custom-made cap. The cap comprised an external layer of glass fiber dyed with black to minimize the interference of environment light and an internal layer of soft foam to contact well with individual scalp (Figure. 1(b))

Figure 1(c) depicts the mapping of optode channels for sensorimotor cortices (SMC), supplementary motor area (SMA) and primary motor cortex (PMC) were measured. The concentration HbO changes of all channels within one area were averaged to represent the regional activation changes.

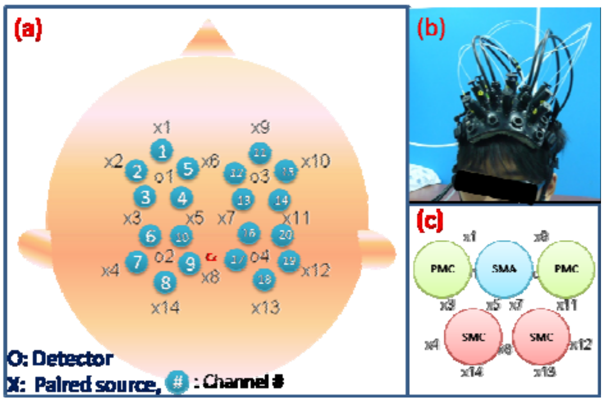


Figure 1. Schematic diagrams the optode locations. (a) The optical fibers were placed on the skull with holders on the custom-made cap (b), Cortical areas covered by the channels as shown in (c).

EMG recording of cortical activity

For kinesiological analysis of pedaling symmetry, the surface EMG of the rectus femoris (RF) was measured using active EMG electrodes (AMT-8; Brotec Biomedical Ltd, Canada). The EMG signal was amplifies at a gain of 375 and then was sampled at 2k Hz for further processing. For quantitatively measure the asymmetry of pedaling performance, the symmetry index (SI) was used [4]. The raw EMG was first processed with the band-pass filtering (Hamming window with cutoff frequency of 40 and 400 Hz) and rectified and smoothed by using a 10-Hz low-pass filter. Since the linear envelope (LE) of the EMG was the function of crank angle, the LE EMG sampled at 2k Hz was then decimated to obtain the same data points of crank angle sampled at 50 Hz for each cycle. Due to the reciprocal pedaling, a phase delay between the EMG LE of two legs was needed to correct by shifting about 180 degree of left axis. The EMG LEs after realignment can be calculated their normalized cross-correlation coefficient of the following equation:

$$SI_j = \frac{|c_{xy}(j)|}{\left[\sum_{n=0}^{N-1} x^2(n) \sum_{n=0}^{N-1} y^2(n)\right]^{1/2}}, \quad j = 1...360 \quad (1)$$

Where x and y are EMG LEs recorded from bilateral RF; $c_{xy}(j)$ denotes the circular cross-correlation function with the lag j between two LEs of one cycle.

The maximum of SI_j measured in one cycle was defined as the SI. The value of SI is between 0 and 1. The higher value represented the more symmetric pattern of EMG activities during pedaling movement.

Experimental design

Training protocol

Subjects were randomly assigned to three groups. The training intensity is 30 mins per day, two days per week for two month (totally 16 training sessions). The brain activity and cycling performance were measured 2 times, including pre-training (pre), and post monthtraining (post). For active cycling training, the subject was asked to pedal as asymmetrically as possible. The load would be adjusted depending on the subject's ability. During passive training, the subject would pedal passively without any active contraction of both legs. The training program of control group was upper limb training with the same frequency as the cycling groups.

To measure the cortical activation during pedaling exercises, the block designed trial was used. The trial, 440 s in total, was started with a 30-s rest block and followed by a 20-s task block with 30-s rest period for 8 repetition times as depicted in Figure 2. During the rest period, the cycling speed would be returned to zero and the subjects were asked to sit steadily without other hand or leg movement.

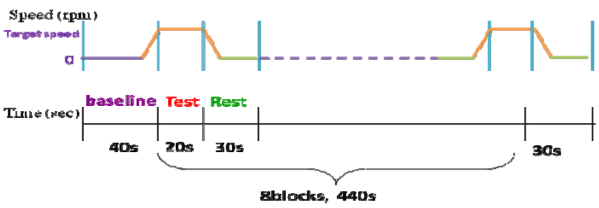


Figure 2. The designed pedaling tasks for studying cortical activation using NIRS. The subjects performed pedaling tasks with a 20-s task block with 30-s rest period for eight repetition times.

Subjects

There were 20 subjects recruited in this study (7 for active group; 7 for passive group;

and 6 for control group). The demographic data of subjects are illustrated in Table 1. from National Cheng Kung University hospital. The stroke subjects all met the criteria of first time unilateral stroke, no previous histories of other neurological or orthopedic problems known to affect pedaling performance and enable to follow verbal commands.

Table 1. The demographic data of recruited stroke patients in 3 groups.

	Active (n=7)	Passive (n=7)	Control (n=6)
Age (years)	57.4±6.1	63.3±12.7	59.2±14.2
Onset time (months)	13.2±20.2	18.3±14.7	27.4±31.8
Gender (M)	5	5	3
Hemiparetic side (R)	5	2	3
Lesion site (subcortical)	5	4	5

RESULTS AND DISCUSSION

Quantitative measurement of cycling performance

The SI of active and passive groups were increased after two month cycling training as figure 3. (Active, pre: 0.43±0.24; post: 0.53±0.19; Passive, pre: 0.49±0.27; post: 0.51± 0.2) On the other hand, the reduced SI was observed in the control group (pre: 0.39±0.25; post: 0.32±0.18). This indicated that the repetitive reciprocal bipedal movement can improved the symmetry of volitional EMG pattern whether the muscle contracts voluntarily or not. The results also proved that the potential benefits of sensory inputs from proprioceptive receptor of joints to motor recovery in stroke patients.

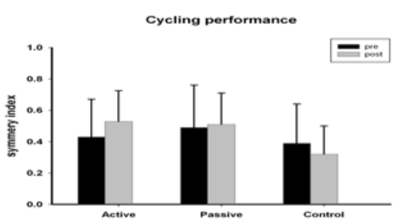


Figure 3. The symmetry index represents improved in active and passive groups after two months cycling training.

Brain activity during cycling

The represent cortical mappings based on the task-related increase of HbO in individual case are shown in Figure 5. The brain mappings in the subject with active cycling, the overall activations of SMC, SMA and PMC were increased indicating the active cycling training facilitates the general cortical activations in this subject. In patient with passive training, the cortical maps showed that the regional activity of SMC was more prominent than those of other regions. This also emphasized the important role of SMC in the cortical control of pedaling performance. Moreover, the asymmetrical activation pattern was improved in both cycling training. These preliminary results can provide insights of the potential efficiency of cycling training in the restoration of motor function as well as brain reorganization in hemiparesis after stroke.

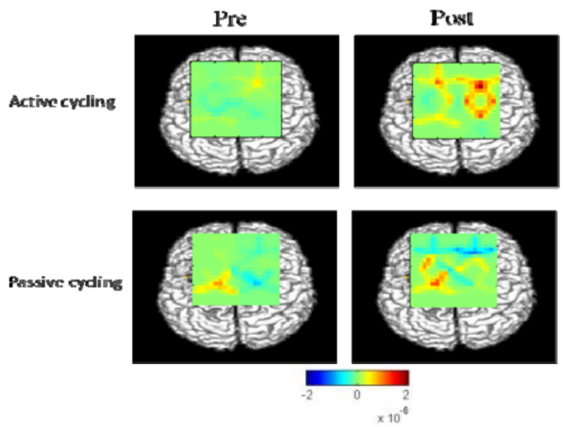
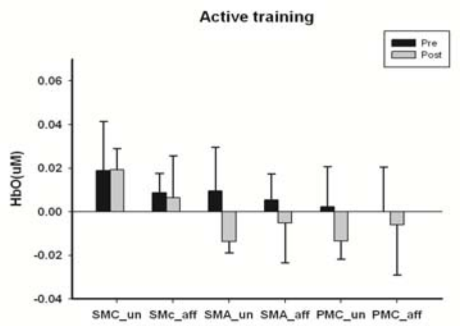
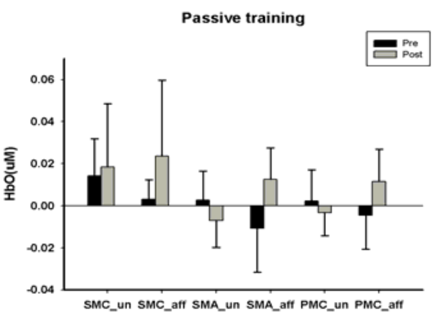


Figure 4. Cortical activities in three regions of cortex including sensorimotor cortices (SMCs), supplementary motor area (SMA), primary motor cortex (PMC) measured before and after 2 month active and passive cycling training.

Figure 5 showed the mean values of all cortical regions measured in stroke patients before and after training. The training effect showed that the SMC of the unaffected side was found to be activated prominently during cycling in the active group while increased activation of SMC of affected side was observed in both passive group. The strategy of each subject during cycling training may lead to altered brain activation patterns. Patients in active group may pedal asymmetrically, which could possible reduce the participation of the affected leg. This pedaling pattern may cause the more increased activation of the unaffected hemisphere. On the contrary, patients at the passive group received proprioceptive sensory input from both legs, could thus normalize the trend of activation patterns by increasing the brain activity of affected hemisphere. A previous study also reported that the movement of contralesional side may affect the brain activity of the ipislesional hemisphere [5].



(B)



(c)

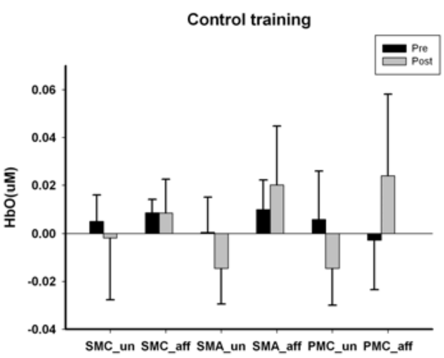


Figure 5. The mean regional activation of HbO changes in SMC, SMA and PMC of affected and unaffected side in active, passive and control groups before and after training.

CONCLUSION

Our preliminary results showed that the cycling performance improved under two month active or passive cycling training. However, distinct brain activation patterns during cycling after active, passive cycling were observed. The active training induced activation of SMC of unaffected hemisphere. The passive cycling training induced activations of SMC, SMA and PMC in affected side. It thus seems probable that different training strategy could result in different neural recovery.

ACKNOWLEDGEMENTS

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