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The Effect of Neurofeedback Training on Cortical Activity during Motor Imagery Revealed by NIRS and fMRI

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Abstract. To improve the performance of the brain-computer interface (BCI) to detect motor imagery from cerebrum hemodynamic data measured by NIRS (near-infrared spectroscopy), the cortical effects of the NIRS-based neurofeedback training for subjects were evaluated by NIRS and fMRI measurements. On three out of five subjects, the magnitude of the Oxy-hemoglobin signal elicited by the motor imagery increased and/or its spatial distribution was more focused on the right hand area by the 5-day neurofeedback training. And by fMRI experiment, it was shown that the brain activations of motor cortex were more focused after training.

Keywords: brain-computer interface (BCI), motor imagery, neurofeedback, motor cortex, NIRS, fMRI

1. Introduction

NIRS (near-infrared spectroscopy) is a measure of the metabolic rates of Oxy-and deOxyhemoglobin which are elicited by the regional activation of the brain. High spatial resolution of NIRS is suitable to realize the BCI system based on motor imagery, as the imagined limb is represented as a localized activation in the sensorimotor area (somatotopy). But the poor reproducibility and low S/N ratio of the NIRS signal have been the issue for the practical application of NIRS-based BCI.

In this study, the online neurofeedback training on motor imagery by using NIRS signal measured at the sensorimotor area was investigated, and the cortical effects of the neurofeedback training was evaluated by NIRS and fMRI measurements.

2. Material and Methods

Five volunteers (ages 19~24) took part in the experiment as subjects. Before taking part in the whole experiments, subjects were requested to practice the motor imagery of feet, left hand and right hand to exclude the factor of skill acquisition of motor imagery during experiments.

The NIRS neurofeedback training was conducted for 5 days. During sessions, 52-channel Oxyand deOxy-Hb concentration rates on sensorimotor cortex during motor imagery of right hand were measured (ETG-4000, Hitachi Medical Corporation, Japan). Before starting the neurofeedback training, the region of interest (ROI) was defined on the hand area of the left sensorimotor cortex (near location C3 of International 10-20 System), and for each subject, three channels were selected from the ROI. During experiments, the average value of these three Oxy-Hb channels was fed back to subjects as a length of the white bar which was displayed on the LCD display in front of the subject. The subject was instructed to control the length of the presented white bar as long as possible by the imagery of his/her own right hand movement during imagery period, and as short as possible during resting period. (For more details of NIRS neurofeedback training, see our preliminary report [Kanoh et al., 2009].)

Before and after the 5-day NIRS neurofeedback training experiments, the brain activities during imagery or execution of left, right and feet movement were measured by both NIRS (imagery only) and fMRI for evaluating the effect of the neurofeedback training. The fMRI measurement was performed using 3.0-Tesla Philips Achieva 3.0T TX. A T2*-weighted gradient-echo echo-planar

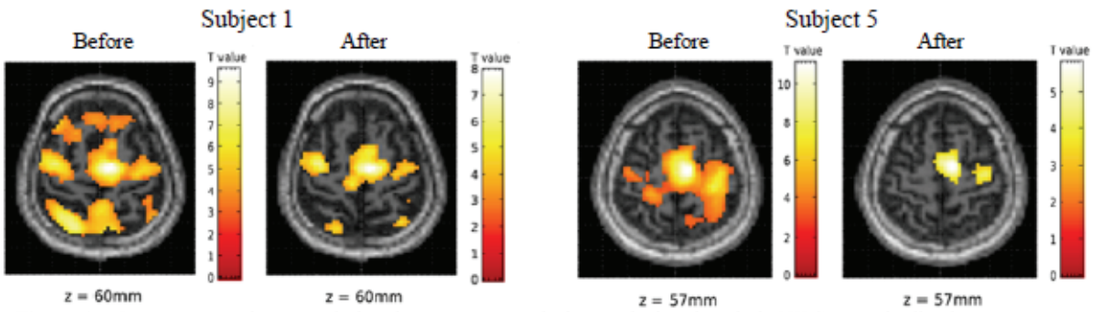

Figure 1. *Brain activity during right hand motor imagery before and after the whole NIRS neurofeedback training experiment ($p<0.001$, uncorrected). Right side denotes the left hemisphere.*

imaging (EPI) scan was performed to acquire functional images. Visual instruction and timing control during fMRI experiments was performed by the platform developed by the authors [Susila et al., 2010]. The acquired fMRI data was analyzed by SPM5 to identify the significant changes between conditions. And the time courses of mean BOLD MRI signal intensity in the following VOIs (volume of interests) were analyzed to observe the temporal change of the activations on each area: the feet, left hand and right hand area in the motor cortex, supplementary motor area (SMA: preSMA and SMA proper).

3. Results

By the NIRS experiments, it was shown that the Oxy-Hb values averaged over selected three channels increased on Subjects 1 and 3 by neurofeedback training (regression coefficients between training day and the Z-score (normalized by the Z-score on day 1): Sub. 1, 0.922 ($r = 0.971$), Sub. 2, −0.278 ($r = 0.211$), Sub. 3, 0.154 ($r = 0.267$), Sub. 4, −0.042 ($r = 0.122$), Sub. 5, −0.124 ($r = 0.331$)). And on Subjects 1 and 5, the localized activations on the contralateral and ipsilateral hand areas (near C3, C4, respectively, larger magnitude on contralateral area) and on the vertex area (near CZ) were more focused after completing the neurofeedback training. Thus, on three subjects out of five (Subjects 1, 3 and 5), the neurofeedback training showed the effects on the magnitude and/or the spatial distribution of the NIRS signal on the corresponding area in the motor cortex.

In the fMRI experiments, significant activations of motor cortex, SMA (preSMA and SMA proper) were observed on all subjects during right hand motor imagery. The brain activities before and after the whole neurofeedback training are shown in Fig. 1. On the motor cortex, contralateral hand area on left hemisphere was activated on four subjects, and both the contralateral and ipsilateral hand areas were activated on one subject. On four subjects, cerebellum was also activated during motor imagery. And on the three subjects mentioned above (Subjects 1, 3 and 5), the activations which were observed on the motor cortex, SMA and cerebellum were more focused after completing the whole neurofeedback training. And by the time course analysis of relative changes of BOLD signal intensities in five VOIs, it was shown that the magnitudes of BOLD activation on these VOIs after the neurofeedback training were smaller than before starting training on these subjects.

4. Discussion

In this study, it was shown that the neurofeedback training by NIRS could enhance and/or localize the regional neuronal activities during motor imagery, and such a neurofeedback could be a powerful tool to improve the accuracy of the present BCI based on motor imagery. As the measured NIRS signal contains excess drifts and noises, the performances and the evaluation results of neurofeedback training are affected by such variations of the signal. Noise reduction of NIRS signal should be improved for the detailed investigation and practical application of NIRS-based neurofeedback training. The experiments to verify the present results with more subjects, and more precise investigations by multimodal measurements (EEG/MEG, fMRI and NIRS) were left for the further study.

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