Cerebral Blood Flow Changes related to Motor Imagery, using Near-infrared Spectroscopy (NIRS)

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Abstract
Motor imagery and motor task execution has been shown to activate similar areas of the sensorimotor area of the cerebral cortex [Beisteiner et al.]. This has been studied using fMRI, PET and EEG. Four right-handed male subjects aged 25-45 participated in this study. The optical response was measured from the sensorimotor area of the cerebral hemisphere contra-lateral to hand movement. Cerebral blood volume changes, evident from a decrease in the detected light signal, were observed during the voluntary hand movement tasks and also from the imagined hand movement tasks. Not only do the results of this study further validate the theory that real and imagined movements activate similar cortical areas, but it also brings to light a novel approach to brain-computer interface development. Classification of EEG features during motor imagery has been applied to EEG-based brain-computer interfaces [Pfurtscheller et al]. Cerebral blood flow changes due to motor imagery detected using NIRS have potential use in an optical brain-computer interface.

Introduction
Motor imagery, i.e. imagined movement, is known to activate similar cortical areas as real executed movements. Initial studies investigating cortical activation due to motor imagery reported cerebral blood flow (CBF) changes mainly in the supplementary motor area (SMA), pre-frontal cortex and basal ganglia, but not in the primary sensorimotor cortex [Jeannerod 1995]. Recent studies using EEG [Pfurtscheller *et al* 2001, Beisteiner *et al* 1995, Pfurstscheller *et al* 1997] have demonstrated the activation of the primary sensorimotor area of the cortex, by taking measurements at positions C3 and C4 of the 10-20 system.

Motor imagery has been used in EEG-based BCIs for cursor control and also to control an electronic limb orthosis in tetraplegic patients [Pfurtscheller *et al* 2001]. The aim of this study is to examine the optical response of the primary sensorimotor area due to motor imagery. The next step will be to use the characteristics of this response to control a brain-computer interface (BCI).

This paper describes the instrumentation used and the experimental procedure that was followed. Results are presented and discussed along with details of the signal processing applied to the acquired waveforms. To conclude the implication and potential applications of these results are noted.

Method
The optode consisted of a light source and detector separated by 4cm. Studies have shown that the source-detector separation distance determines photonic penetration depth [Steinbrink *et al* 2001] and distances of 2-7cm are typically used in order to reach cerebral cortex depth [Steinbrink *et al* 2001, Villringer *et al* 1993, Benaron *et al* 2000]. The light source used, which was a NIR LED (peak wavelength 880nm, radiant output power 5mW), was placed in direct contact with the head. The LED was modulated at 6kHz. The detection

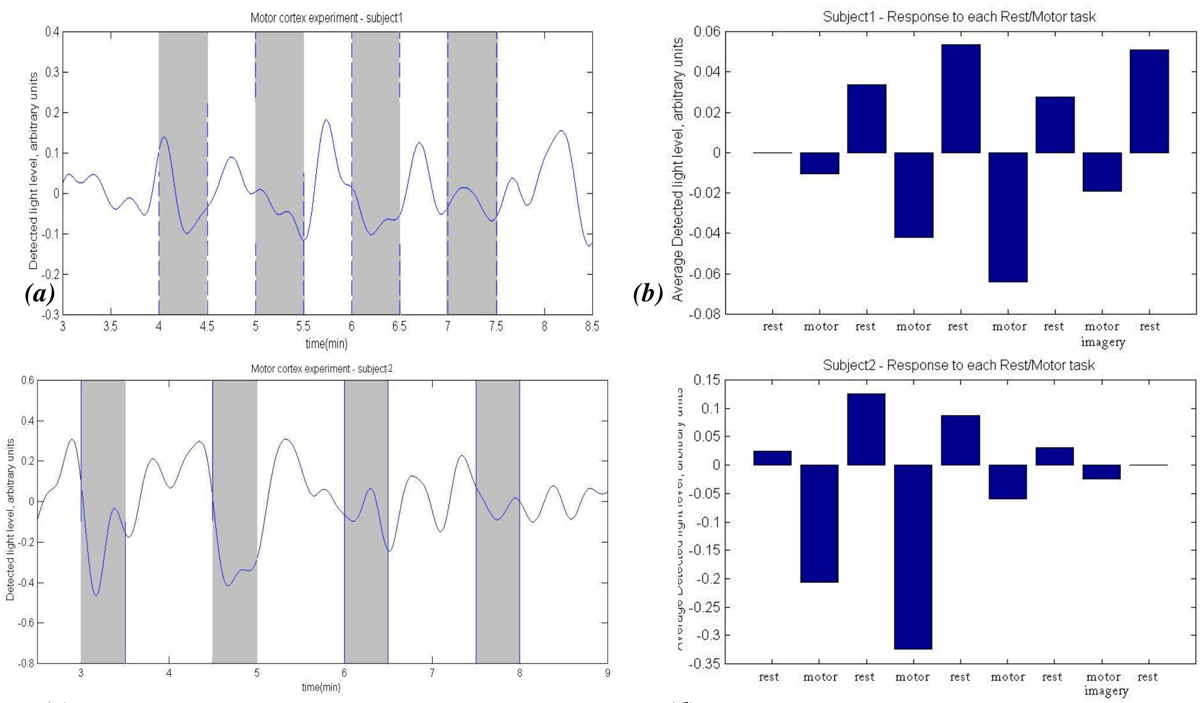
system consisted of an avalanche photodiode (Hamamatsu C5460-01) and lock-in amplifier (Ametek 5210). The avalanche photodiode (APD) was coupled to the head via a fibre optic bundle of 3mm diameter. A 16-bit A/D data acquisition card (Keithley PCMCIA16AI) was used to record the measurements at a sampling at a rate of 100Hz.

The optode was placed either on position C3 or C4 above the cerebral hemisphere contralateral to hand movement. Evidence suggests that this position is above to the cortical area related to the hand [Homan *et al* 1987].

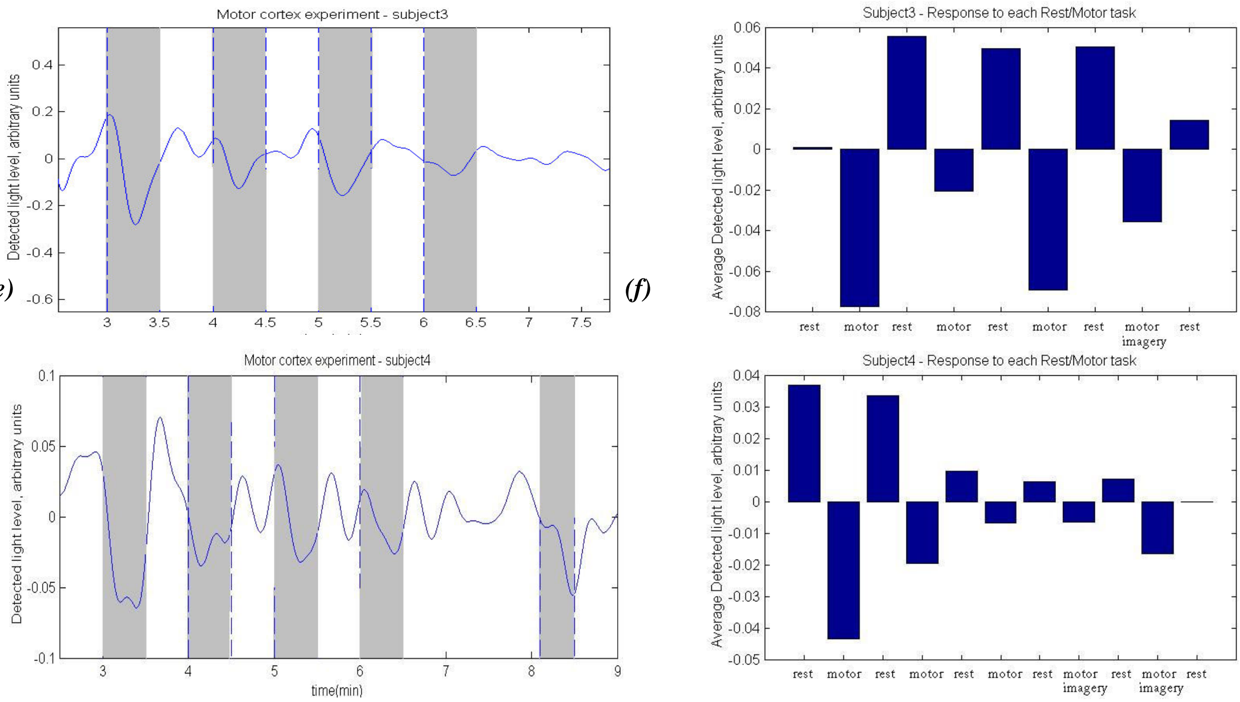
Subjects resided in an upright, seated position throughout the experiment. Five minutes rest was allowed at the start of the experiment in order to establish a baseline condition. The subject was then asked to perform three actual hand movement tasks, fist clenching or finger opposition tasks for a duration of 30 seconds. The tasks were separated by 30 seconds rest. Following real executed hand movement tasks, imagined hand movement was performed. The subject was asked to imagine clenching their hand for 30 seconds, using the mental image of clenching a tennis ball. The visualisation task was also followed by a rest period.

Results

The signal was linearly detrended and low-pass filtered using a fourth order Butterworth filter with a cut-off frequency of 0.5Hz. Forward and reverse filtering was applied in order to prevent phase distortion. The mean detected light intensity was calculated for each epoch of rest and motor tasks. Results for each subject are shown below.



(c) *(d)*



(e) *(f)* *(g)* *(h)*

Figure 1: - *(a,c,e,g)*Detrended and filtered optical response during motor and rest sequences. The first three shaded regions indicate periods of actual hand movement. Subsequent shaded regions indicate visualisation of hand movement, i.e. motor imagery. *(b,d,f,h)* The average of each rest and motor activity epoch.

Discussion

Changes in light absorbed are a result of changes in blood volume, an automatic mechanism related to cerebral metabolism [Roy, Sherrington 1890]. The slow haemodynamic changes due to actual motor activity is seen as a negative peak in the detected light intensity after 5-8 seconds following the start of the motor task, and a return to baseline conditions several seconds after rest, as has been shown by previous studies [Villringer *et al* 1993, Benaron *et al* 2000].

The optical response found is an indication of blood volume changes in the region of motor cortex associated with the hand. Our results show that the optical response due to real executed hand movements and imagined hand movements is similar.

The bar-charts shown above in Figure 1 clearly show decrease in detected light intensity during motor tasks – real and imagined.

Conclusions

Motor imagery was found to give a similar optical response as real executed movements. This signal has potential use in prosthesis control or control of communication devices. Motor imagery is currently used to elicit electric signals in EEG-based BCIs. This study suggests that the optical response due to motor imagery could be used to develop an optical BCI, using near-infrared techniques.

As a single wavelength of light was used in this study, the signal here is essentially photoplethysmographic in nature. Oxy-haemoglobin and deoxy-haemoglobin concentration changes has been shown to give a clearer indication of brain activity [Villringer *et al* 1993], which can be achieved by using a second wavelength of light. In order to develop a BCI using optical techniques a dual-wavelength system would be preferable. Cerebral blood flow changes indicating cortical activation have been investigated using PET and fMRI techniques, however these techniques are not viable options for brain-computer interfacing. Non-invasiveness and portability give NIRS the potential for use in BCI development.

References

Beisteiner R, Höllinger P, Lindinger G, Lang W, Berthoz A. Mental representations of movements. Brain potentials associated with imagination of hand movements, Electroencephalography and Clinical Neurophysiology 96: 183-193, 1995

Benaron D, Hintz S, Villringer A, Boas D, Kleinschmidt A, Frahm J, Hirth C, Obrig H, Houten J, Kermit E, Cheong W, Stevenson D. Non-invasive Functional Imaging of Human Brain Using Light, Journal of Cerebral Blood Flow and Metabolism 20:469-477, 2000

Homan R, Herman J, Purdy P. Cerebral location of international 10-20 system electrode placement, Electroenccephalography and Clinical Neurophysiology 66:376-382, 1987

Jeannerod M. Mental Imagery in the Motor Context, Neuropsychologia 33(11): 1419-32, 1995

Pfurstscheller G, Neuper C. Motor imagery activates primary sensorimotor area in humans, Neuroscience Letters 239:65-68, 1997

Pfurtscheller G, Neuper C. Motor Imagery and Direct Brain-Computer Communication, Proc. IEEE, 89(7): 1123-34, 2001

Roy C, Sherrington C. On the regulation of the blood-supply of the brain, Journal of Physiology 11:85-108, 1890

Steinbrink J, Wabnitz H, Obrig H, Villringer A, Rinneberg H. Determining Changes in NIR Absorption using a layered model of the human head, Physics in Medicine and Biology 46:879-896, 2001

Villringer A, Planck J, Hock C, Schleinkofer L, Dirnagl U. Near infrared spectroscopy (NIRS): a new tool to study hemodynamic changes during activation of brain function in human adults, Neuroscience Letters 154:101-104, 1993