STEADY-STATE VISUAL STIMULATION OF THE BRAIN: OPTICAL STUDY OF TASK-RELATED EFFECTS

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Near-infrared (NIR) and electroencephalography (EEG) systems were applied simultaneously to check a possibility of an optical brain-computer interface (BCI) based on visual protocol. A two-wavelength, two-channel NIR system using lock-in amplifiers to filter received signal was designed for monitoring of light absorption. An improved single photon-counting system based on NIR laser diodes and multichannel scaling was configured for fast one-wavelength capturing of the scatter changes in the area of the human brain corresponding to the task. Designed protocols consisted of the pattern reversed repeatedly at various frequencies. The stimulus repetition improves processing according to some behavioural measure as e.g. greater accuracy in identifying the stimulus or faster response times to make a decision about it, and often occurs under the same experimental conditions. Under certain conditions rather increased activity in the brain could be observed which results in a longer habituation time. Results of tests are presented in current article.

1. INTRODUCTION

Rapid development of novel, more application related diagnostic technologies in neuropsychological studies does not mean that their advantages and disadvantages are exploited properly and completely. A very important question, namely, does near-infrared spectroscopy function in functional activation studies of the adult brain, was answered recently [1]. Response of human brain to various stimuli investigated for last ten years could be improved and more information about processes on multi-time scales could be obtained [1].

Intrinsic activity-related changes in tissue arising due to functional physiological changes could be captured using semi- or non-invasive techniques, such as *positron emission tomography (PET), functional magnetic resonance imaging (fMRI)* and *in vivo near-infrared spectroscopy* (*iv*NIRS). Each of those techniques has different temporal or spatial resolution, penetration depth, measurement restrictions, etc., depending on the application to specific diagnostic purposes. While PET and fMRI techniques are very tempting technologies in the whole-body studies, optics find its application in brain-computer interface (BCI). NIRS operates in the wavelength range 700-1300 nm, which is non-invasive for the living tissue. NIRS imaging techniques can capture haemodynamic changes occurring within seconds after the stimulus onset. Those changes are based on the increased blood perfusion in the area of activated neurons due to neurovascular coupling. External stimulation increases oxygen consumption by active neurons which results in an increase in the blood flow. Monitoring Hb changes in human brain with NIR system was described in detail elsewhere [2]. Some not trivial application of time-resolved NIRS-based optical system was proposed recently in BCI design [3]. Another technique used in non-invasive neuropsychological studies and successfully applied in brain-computer interface is *electroencephalography (EEG)* [4, 5]. EEG has excellent temporal resolution, is simple to operate and can be used to measure the brain response to number of psychological variables. Electrical signals of the brain have a fast reactivity and co-variation with cognitive processes.

In the current study the system has to be designed for non-clinical applications which mean that portability, non-invasiveness and a high time-resolution play a key-role. Therefore, only two systems will be applied in current work: EEG and NIRS. Optical BCI based on a visual stimulation protocols are not sufficiently investigated. Signals obtained with EEG and with NIRS are not comparable since they reflect various processes but it is important to apply a reference technique which can check validity of stimulus protocol. This information might give some relation between neuronal signal and changes in Hb concentration [1, 6]. Especially interesting question is which output will be observed with optical system at the high-frequency stimulus? Which frequencies it can recognise / distinguish?

2. MONITORING EVENT-RELATED POTENTIALS (ERPS)

Event-related potentials (ERPs) are stimulus-locked transient features in the EEG. Early waves, like N100 and P200 are the result of the perception of sensory stimulus. Later waves, like P300, are thought to represent a brain processing corresponding to decision-making, cognitive processing.

One of signal acquisition approaches for BCI uses the steady state visual evoked potential (SSVEP). The SSVEP is characterised as an increase in EEG activity at the same frequency as visual stimulation. One protocol used naturally occurring SSVEPs to allow users to select one of two virtual buttons. Each button flashed at different frequencies, resulting in a SSVEP occurring at the frequency corresponding to the choice fixated by the user's gaze. This approach does not require training trials. The SSVEP approach has recently been applied to real-time gaming control [5]. The subject focussed their gaze on one of two checkerboards patterns presented to the left or right on the screen and in so doing the user can control the balance of a 3D animated character as it crosses a tight-rope.

The electrical activity of the brain is recorded by placing electrodes over the human scalp according to the agreed 10-20 International Placement System [7], or they could be fitted into an electrode cap. The acquired EEG signal is generated by the postsynaptic dendrites of millions of brain cells. The signal is very small and, therefore, has to be amplified and averaged if stimulus locked aspects of the EEG are to be acquired.

3. NEAR-INFRARED SYSTEM

The system configuration depends on the requirements of specific application field, e.g. on the kind of spatial resolution required, the size of the area to be monitored, whether qualitative measurements are sufficient and how many channels are to be used. Current system was developed for application as an optical BCI, where qualitative measurement over a small area of the cortex is required, a light wearable sensor has to be developed, high time-resolution, and improved signal-to-noise ratio are critical [3]. The typical configuration of a NIR system, as developed for the BCI application, is shown in Figure 1. Light sources, LEDs, are modulated at low reference frequencies (~ 3-5 kHz range) and phase sensitive detection techniques are used to recover the light signals at the reference frequencies.

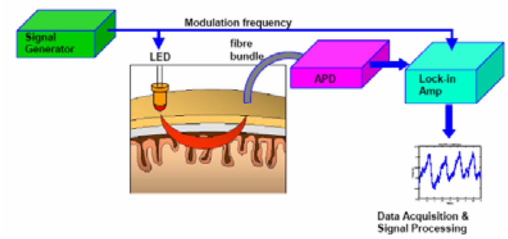

Figure 1: Components of a NIR system (*After: [3]*).

Applying NIR system in current study could be problematic due to higher sensitivity of optical system to the intrinsic processes inside various areas of the brain. Acquired signal might reflect a sum of brain responses instead of expected local response. Also, sufficient rest time between the stimuli should be allowed so that the brain activity will recover to the baseline and responses from various stimuli do not overlap. The choice of the activation detection algorithm is also an important consideration. The purpose of this study was to re-examine responses of the brain region involved in visual stimulus perception (O_1, O_z and O_2 positions) using localized brain coverage (visual cortex only) and a novel NIR system designed for BCI purposes.

4. PROTOCOLS AND TESTS

Healthy subjects were chosen for current investigations within the age range 25-35 years old. The task was focused mainly on the subject's perception of sensory stimulus and therefore only early waves will be expected and monitored. Visual evoked potentials appear due to a visual stimulus e.g. flashing light or checkerboard reversal pattern. An alternative signal acquisition approach to using single trial visual evoked potentials is to use the steady state visual evoked potential (SSVEP). The SSVEP is characterised as an increase in EEG activity at the same frequency as visual stimulation. It will detect them easily in healthy subjects with EEG and expectantly will influence NIRS signal as well.

A simple 6 x 6 black and white chequerboard pattern reversing black with white squares on the 17-inch flat-panel monitor was chosen as a stimulus.

Electrodes were placed over O_1 and/or O_2 positions. Optodes were placed ~ 1-2 cm higher from O_1 and O_2 positions. The checkerboard pattern was used to present stimuli to different parts of the visual fields. Protocol consisted of the chequerboard pattern generated by a simple program which was driving the reversals of white and black squares periodically at various frequencies 1-15 Hz. In the middle of the pattern was placed a red circle as a focusing point. Full-field stimulation or with other words, complete pattern stimulation was carried out, which simultaneously stimulated left and right visual fields. Subject was seated in front of the monitor ~ 1 m away. This protocol was described more in detail elsewhere [8].

Figure 2: Visual protocol. Electrode 10-20 Placement System (*After: [7]*).

Figure 2 shows schematic representation of experimental protocol when electrode cap is used and 10-20 system of EEG electrodes placement when electrode cap is not applicable. O_1 and O_2 positions were used in current studies. A_1 and A_2 positions were applied as reference points.

Haemodynamic changes in the brain: binocular and monocular study

Mono- and binocular tests at pattern reversing frequency of 9 Hz were done on the beginning to evaluate optical system. There were 10 s reversals period and after that there was embedded a 10 s rest period. One run was done for total 620 s. Results acquired from both hemispheres during binocular protocol. Hb changes from left side are represented in Figure 3.

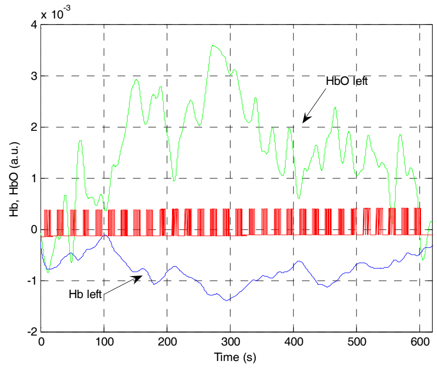

Figure 3: Haemodynamic response in visual cortex measured from left side during test when both eyes were opened.

Repetitious stimulation of the visual cortex showed approximately equal oxy-Hb increase from both hemispheres.

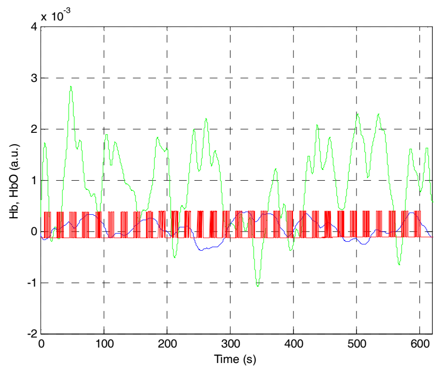

Figure 4: Haemodynamic response measured from left side during test when the right eye was closed.

Protocol where the right eye was closed (see Figure 4) showed smaller feedback from the left optodes which confirms that contralateral eye is transmitting more information. Therefore in this case less information arrived to the left part of the visual cortex from left eye. The oxy-Hb increase is still indicating some changes which occurs due to the crosstalk in the thalamus. When right eye is closed, small changes picked up with left eye are still delivered to the left part of the brain. Squares in Figures 3 and 4 showed stimulus signal.

Next, there were some trials done at different frequencies. In Figure 5 there are showed two samples of tests done at 6 and 10 Hz of pattern reversals. Fixed stimulus-rest period was 20 s. Measurement was done only from the left side of the visual cortex with both eyes opened.

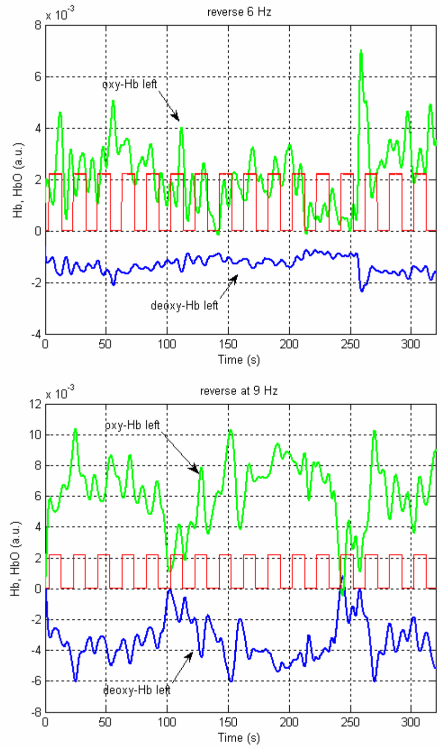

Figure 5: Haemodynamic response in the visual cortex measured from left side only during tests at reversing frequencies 6 (above) and 10 (below) Hz.

Oxy-Hb component increases evidently with increase of reversing frequency. Stimulus-rest period is evidently too short to allow the brain relaxation or habituation to the stimulus. Chosen stimulus continues to excite the visual cortex repeatedly and leads to an increase in the oxy-Hb concentration as well as longer brain response times. Pattern reversing frequency is high in comparison to trials done previously [1].

Combined EEG and NIRS studies

Summarising previous experience, for further investigations with EEG system protocols were chosen in which pattern reversing frequency increases at every stage, e.g. 5, 6, 7 Hz or 5, 10, and 15 Hz, and its duration does not exceed 10 s. It was also decided to build into the protocol a longer rest period ~ 60 s. Measurements were done over left hemisphere of the visual cortex only. These tests were supposed to answer the question of behaviour of the brain response acquired with NIRS-based optical measurement system. Increasing flashing frequency will reduce EEG response significantly. What will happen with NIR signal?

First protocol was generating 10 s of consecutively 5, 6 and 7 Hz reversals and built in between 60 s of rest period. Increasing reversing frequency at constant stimulus frequency results in decrease of Hb oxygenation level. Test done on the 25-year old subject showed these changes in Figure 6a. Observed brain response to the stimulus at increasing reversing pattern are showing oxy- and deoxy-Hb components return to the baseline after 60 s of test and does not reach the same magnitude if stimulus at higher frequency continues.

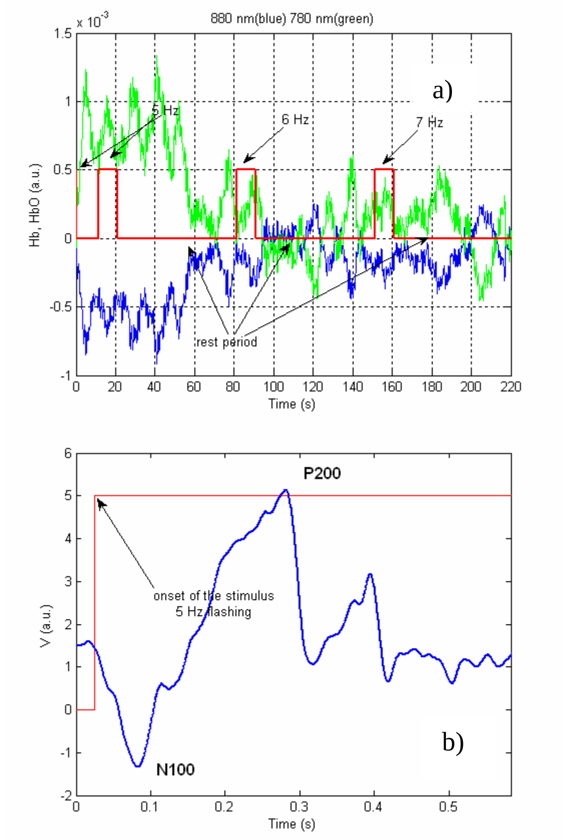

Figure 6: Haemodynamic response in the visual cortex measured from left side only during test at reversing frequencies 5, 6, and 7 Hz (left): Hb and HbO changes during test (a), visual evoked potential (b).

EEG data were examined for VEP immediately after the onset of the pattern. A wave with N100 and P200 was found immediately (see Figure 6b). However, constant increase in Oxy-Hb in the result of this stimulus protocol was observed in 4 of 7 tested subjects.

5. CONCLUSIONS

Currently designed systems for neuropsychological studies on human brain have their advantages and disadvantages, especially if system is designed to meet a large number of requirements to make its use more general. It is possible to create more sensitive or with higher temporal resolution system for specific conditions of application. The system that was tested in current study was designed specifically for application outside hospital conditions, where its sensitivity, resolution and mobility are critical. Previously it was investigated if this system could be applied as optical brain-computer interface in motor tasks with positive result. Details on those investigations are described elsewhere [3]. Current study was undertaken to see which changes would be required to apply it in visual tasks and what to be expected especially when operating on higher frequencies. The outcome of these investigations revealed predicted problems with optodes placement and further complications when optodes were applied together with EEG electrodes. This required isolation of metal parts of optodes or their replacement. System operation was satisfactory. Advantages of such design include high sampling rates applicable (up to 10 kHz), flexible hardware filtering of the unwanted noises depending on the test requirements, less strict requirements for the dark room conditions, and high NIR spectrum sensitivity.

Visual protocol applied for the investigation of the perception of sensory stimulus does evoke responses in visual cortex of the brain. The oxy- and deoxy- Hb levels change in dependence with applied stimulus frequency. Current studies registered higher oxy-Hb response to the higher frequency of displayed pattern reversing. Values were tested up to 15 Hz. Habituation periods vary depending on the repetition of the stimulus and particular investigated subject and his/hers concentration. Protocol in which stimulus periods were chosen with increasing frequencies showed rapid return of the Hb components to the baseline and decrease in response. Such results require more carefully undertaken study and are subject for further investigations.

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