Novel near infrared sensors for hybrid BCI applications

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ABSTRACT

This study's goal is to develop a low cost, portable, accurate and comfortable NIRS module that can be used simultaneously with EEG in a dual modality system for brain computer interface (BCI). The sensing modules consist of electroencephalography (EEG) electrodes (at the positions Fp1, Fpz and Fp2 in the international 10-20 system) with eight custom made functional near infrared spectroscopy (fNIRS) channels, positioned on the prefrontal cortex area with two extra channels to measure and eliminate extra-cranial oxygenation. The NIRS sensors were designed to guarantee good sensor-skin contact, without causing subject discomfort, using springs to press them to the skin instead of pressing them by cap fixture. Two open source software packages were modified to carry out dual modality hybrid BCI experiments. The experimental paradigm consisted of a mental task (arithmetic task or text reading) and a resting period. Both oxygenated hemoglobin concentration changes (HbO), and EEG signals showed an increase during the mental task, but the onset, period and amount of that increase depends on each modality's characteristics. The subject's degree of attention played an important role especially during online sessions. The sensors can be easily used to acquire brain signals from different cerebral cortex parts. The system serves as a simple technological test bed and will be used for stroke patient rehabilitation purposes.

Keywords: fNIRS sensor, Prefrontal cortex BCI, hybrid BCI

1. INTRODUCTION

fNIRS is emerging as a noninvasive, mobile, silent, low cost[1, 2, 3] and relatively easy to use signal acquisition method from the brain and was applied for BCI purposes as well[4, 5, 6]. Prefrontal brain cortex is a preferred target for NIRS studies to avoid signal attenuation caused by hair [2, 7, 8]. Prefrontal cortex fNIRS BCI tasks ranged from mental arithmetic[9, 10,11], working memory[12] to cursor control[13]. Using two independent modalities is thought to enhance the overall performance and information transfer rate in BCI usage[14, 15]. Various attempts have been made to combine fNIRS and EEG[16] as both systems are noninvasive, portable and inexpensive[17, 18, 19] and the hybrid NIRS-EEG BCI performance is thought to be superior to that of a single modality system[20, 21, 22]. To overcome the challenging and time consuming processes of placing dual modalities sensors accurately, especially on small areas of interest on the skull[23] – we present a dual modality sensor to provide a practical solution to those challenges.

2. METHODOLOGY

2.1 The sensor module

Ag/AgCl ring electrodes were connected to a g.Tec USBamp (Guger Technologies, Graz, Austria) to acquire EEG. The NIRS sensor was controlled by custom-built electronics[24] which were further optimized to a single miniaturized board. Two LED pairs, 770nm (Marktech MTE1077N1-R) and 850nm (Marktech MTE8560P), were located in the center of a neoprene sheet (see Figure 1(a, b)). Photodiode (PD) detectors (OSRAM BPW 34 B) were placed at the periphery of the sheet in 3cm distance to ensure sufficient penetration depth of light into the prefrontal cortex target area.

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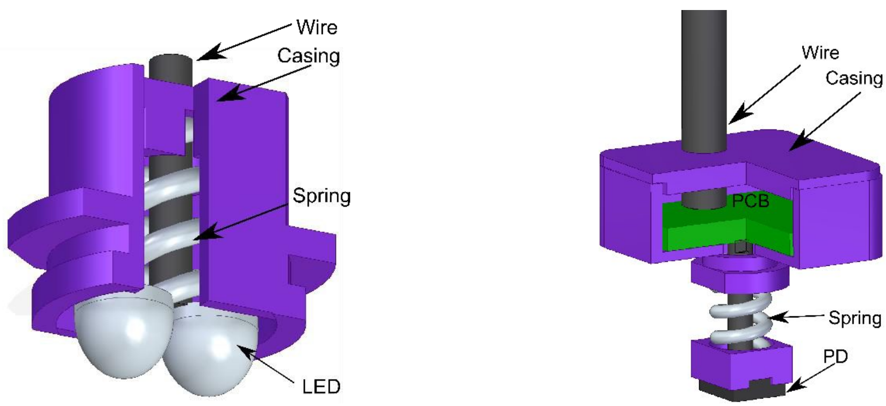
(a) (b)

Figure 1. (a) The EEG-NIRS sensors module (b) placement of the EEG electrodes and the NIRS sources and detectors on the subject.

A pair of PDs was located close by the LEDs to measure extra-cranial hemodynamic changes and eliminates their effect on other NIRS sensors. The NIRS sources and detectors were designed to ensure firm, comfortable coupling with subject skin by employing springs to press them to the skin (see Figure 2(a, b)). The NIRS sensors' casings and cap fixation rings were designed using Solid Edge 3D CAD software (Siemens Industry Software). They were manufactured from PLA by a 3D printer (Makerbot, Replicator2)



(a) (b)

Figure 2. (a) A 3D rendering of the NIRS source. (b) A 3D rendering of the NIRS sensor and the controlling circuit.

2.2 Experimental paradigm

Six healthy volunteers (3 males and 3 females, mean age: 29.6) participated in the study. All subjects except S6 were right handed. The experiment lasted approximately 3 h. Subjects were first informed of the experimental paradigm and consented to the experiment. They were seated in a comfortable chair in front of a computer monitor, located 1.2 meter from the subject, and preparation of the recording apparatus was initiated. A custom made NIRS headset was built for recording measurements from the prefrontal cortex of the brain.

Three EEG electrodes were attached to the module at the positions Fp1, Fpz and Fp2 in the international 10-20 system. A2 was used for reference while A1 was used for ground. The NIRS headset extracted intracranial hemodynamic responses using 770 nm and 850 nm NIR LED illumination.

The headset was fixed to the forehead by use of an elastic band wrapped around the subject's head. A dark colored elastic cap was placed over the headband in order to ensure optode contact with the forehead and minimize ambient light.

Each recording session began with a 15 second blank screen, followed by 7 prompts of 15 second mental task and 7 prompts of 15 second rest. The experimental paradigm consisted of a mental task (arithmetic task or text reading) and a rest task. In the mental arithmetic task, subjects were presented with a mathematical expression and instructed to evaluate it. The mathematical expressions consisted of a 2-4 length series of small numbers ranging from 1-20 subtracted from a three digit number. In the mental reading task, subjects were presented with a paragraph and instructed to read it quietly. The resting task was denoted by a light blue crosshair that appeared on the screen (replaced after the first experiment with a blank screen). In the resting task, subjects were instructed to clear their mind and look at the screen. Throughout the experiment, subjects were also instructed to refrain from movements and keep minimal eye blinks.

In each trial, there were 7 mental tasks and 7 resting tasks that lasted 15 seconds each. First, the resting task would appear. After 15 seconds, a one second pause would occur, and then the mental arithmetic or mental text reading task was presented followed by a 10 second baseline period. Mental text reading and mental arithmetic tasks were presented in a sequential order. There was a 3 minutes rest period between trails. There were seven trials in total. After seven offline trials, the resulting data was analyzed and a classifier was built from the data.

The following trials were performed online with the same mental and rest tasks. The online feedback apparatus consisted of a blue ball that oscillated between 0 and 1 positions on the computer screen, 0 represented rest and 1 represented task. This ball would give subjects an idea of their performance in the mental or resting tasks and allow them to adjust in a feedback loop.

2.3 Software and data analysis

Open source software OpenViBE[25] for real-time neurosciences was employed for our NIRS-EEG BCI experiment. The software collects EEG data and provides subject with feedback when the EEG was used as the BCI controlling signal. FieldTrip software[26] was modified to use NIRS as the BCI controlling signal.

For the first experiment EEG was used as the controlling signal while NIRS measurements were collected for offline analysis. After that the NIRS system and sensors performance was tested, the NIRS signals were used as the BCI controlling signal while EEG signals were collected for offline analysis.

Initially values for the oxygenated (HBO) and deoxygenated hemoglobin (HBR) concentration changes were calculated using the modified Beer-Lambert law[27]. Since there were 8 optodes recording data, this offered 10 channels of data.
The data was first linearly detrended, and then filtered using a 3rd order low pass Butterworth filter with a cutoff frequency 0.25 Hz. Once the data was filtered, we could extract features from it. The first feature used was the combinations of HBR and HBO, which was later combined with the first gradient and the second gradient of the data providing for a grand total of 48 features. The data was trained using the Matlab classify function, which makes use of a linear discriminant analysis for machine learning purposes. The results were then fed to a GUI, which would move the ball to either 0 or 1 to give feedback to the user.

Offline data analysis included manual rejection of noisy channels. The detrended HBO, HBR signals were then band pass filtered between 0.01-0.5Hz. Signal slope (SS) was calculated as a feature for HBO, HBR task comparison.

3. RESULTS

Data was collected and compared for EEG and NIRS parameters HBO, HBR (see Figure 3). A noticeable difference could be seen between the SS HBO associated with task versus rest as shown in figure 4(a). The mental arithmetic and mental reading task contribution to the mental task is illustrated in figure 4(b) with overall SS HBO range slightly wider for mental arithmetic compared to mental text reading.

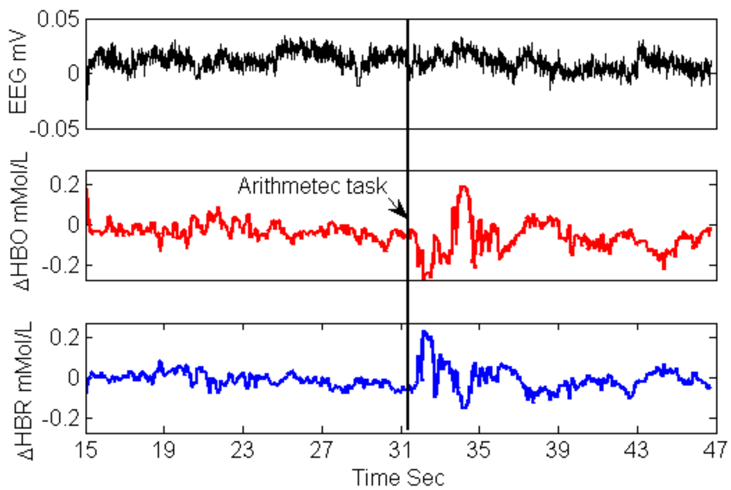
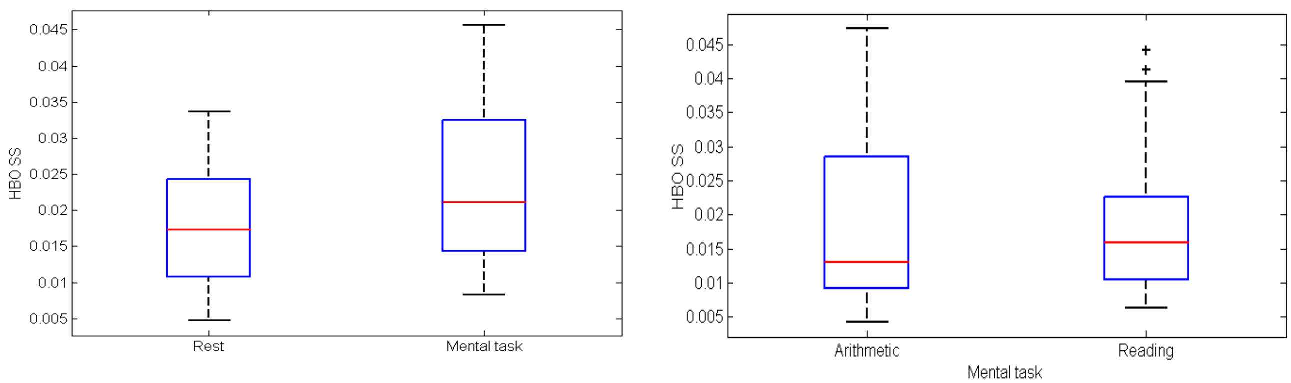
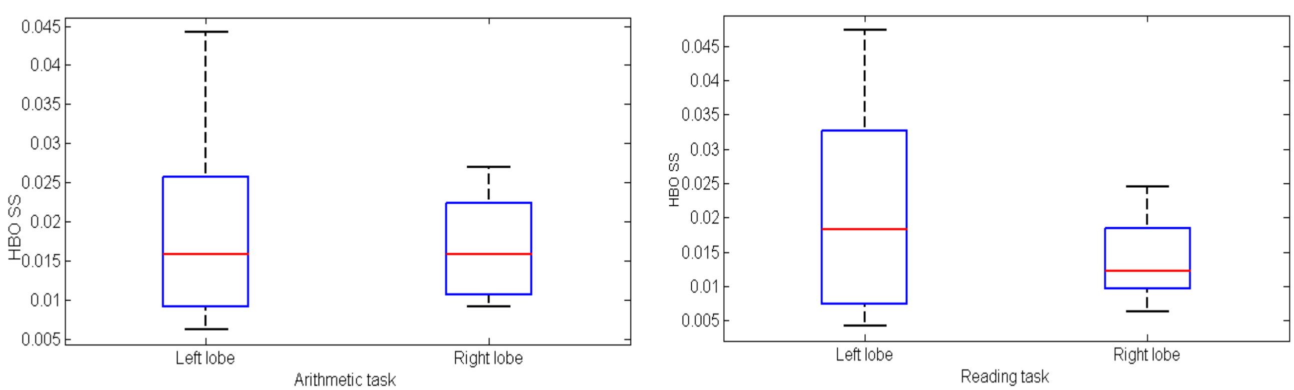


Figure 3. EEG and NIRS ΔHBO, ΔHR during rest and arithmetic tasks.



(a) (b)

Figure 4. (a) Boxplot of ΔHBO during rest and mental tasks. (b) Boxplot of ΔHBO during arithmetic and text reading mental tasks.



(a) (b)

Figure 5. (a) Boxplot of ΔHBO arithmetic mental tasks of right and left brain lobe. (b) Boxplot of ΔHBO during arithmetic and text reading mental tasks.

Figure 5 (a), (b) illustrate the mental arithmetic and mental reading task relation with right and left brain lobes. Signals measured from prefrontal cortex left side show higher values for both tasks, although the difference is insignificant for mental arithmetic task.

4. CONCLUSIONS

Both ΔHBO, and EEG signals showed an increase during the mental task, but the onset, period and amount of that increase depends on each signal characteristics. The subject's degree of attention played an important role especially during online sessions.

False positives were sometimes associated with the appearance of the crosshair on the screen, which denote the start of the resting task, probably because it stimulates the subject's attention after the baseline blank screen. This led to replacing it with a blank screen for both resting task and baseline. The subject level of concentration and training played an important role in the result's accuracy. The overall performance was improving with trial repetition, but it also depended on the subject concentration and comfort.

Power et al[28] tested the use of two mental task namely mental arithmetic and mental singing for BCI control. They indicated that the mental singing was less successful in controlling the BCI[28].

Our results also indicate a wider range of HBO SS and HR SS associated with mental arithmetic compared to mental reading. This could be interpreted as if mental reading requires a higher level of brain activity as compared to the resting state without reaching statistical significance. Mental arithmetic on the other hand requires sometimes brain activity close to resting level, probably due to low level of arithmetical challenge. Tanida et al investigated the asymmetry of prefrontal cortex activities during a mental arithmetic task. Their results suggested that the right prefrontal cortex activity during the mental arithmetic task has a greater role in cerebral regulation of HR[29]. Our results suggest left prefrontal lobe dominance on both mental arithmetic and mental reading, although to a lesser extent on mental arithmetic.

The NIRS sensors require firm but revisable coupling to the subject's skin to ensure accurate measurements and minimize ambient light and motion artifacts. This usually requires the usage of elastic caps to secure the sensors in their location. The pressure subjected by those caps may cause discomfort, interfere with the subject concentration and in some cases it becomes difficult for the subject to keep the sensors cap for long periods. Minimizing that pressure only to the actual sensors' points of skin contact, improved subject comfort, allowed longer experimental time and increased accuracy, especially at specific locations of the head where accomplishing a firm skin coupling using pressure from a cap is sometimes difficult. The system's sensors can be easily used to acquire brain signals from other cerebral cortex parts such as the motor cortex and will be used as a hybrid BCI to control a simple prosthetic hand[30].

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