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Brain Activations during Programming Tasks: TD-NIRS and EEG Study

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Abstract: Neural and cerebral hemodynamic activities of 16 programmers were monitored during programming tasks by simultaneous EEG and Time-Domain fNIRS measurements aiming at identifying cognitive and emotional states during code programming.

1. Introduction

Code programming is an extremely complex human task, it requires logical skills, symbol manipulation, mathematical problem solving, text comprehension and many other challenging functions. Even thus highly demanding and mature software development processes are used, the probability of including bugs is high [1]. A few studies demonstrated that bugs can be classified in a few categories that are independent from programming language, programming methodology and technical culture [2]. The possibility of bug classification paves the way for bug prediction. The Biofeedback Augmented Software Engineering (BASE) project aims to monitor cognitive and emotional programmer's states to predict errors in programming tasks using non-invasive sensors. In this work, we present the preliminary results by simultaneous electroencephalography (EEG) and time domain near infrared spectroscopy (TD-NIRS) measurements of neural and cerebral hemodynamic activities during three different programming tasks: neutral text reading, code snippets comprehension, and programming exercise.

2. Materials and Methods

2.1. The BASE protocol

Sixteen programmers were recruited in this study. All the subjects cooperated voluntarily and previously provided written informed consent to the procedures of the study, which was approved by the Ethics Committee of Politecnico di Milano. They were divided in two groups based on their level of proficiency in C programming, defined by a screening questionnaire. The protocol was divided in three sections: a baseline and two exercises. During the baseline (2 min) the subjects were asked to type the keyboard with their eyes closed. The two exercises were divided in three different tasks, before each task and at the end the exercises they were asked to watch (30 s) at a cross in the middle of the screen (fixation cross). The fixation cross was needed to have a neutral period between different tasks. The three tasks of each exercise were: one neutral text reading, one code snippets reading and one code programming. Each task was randomly selected based on the level of proficiency of the subject. Generally, a small break between the two exercises was required by the subjects. During this protocol, the subjects wear an elevated number of sensors to simultaneously measure EEG, TD-NIRS, electro dermal activity (EDA), respiratory signals, and electrocardiogram. Further, eye movements, facial and screen videos were recorded during all experiments. In this work we will focus on the results obtained from TD-NIRS and EEG signals, where TD-NIRS allows to retrieve cortical oxygenated (O_2Hb) and deoxygenated hemoglobin (HHb) concentrations [3], and EEG fast electric signals coming from neural activities.

2.2. Time-Domain NIRS

A TD-NIRS device with two injections and four detection channels previously developed at the Department of Physics, Politecnico di Milano [4] was employed. The optodes were positioned in the frontal region of the brain, near the Af2 and Af7 positions of the 10/20 international system of EEG electrode placement (precise position of the optodes are shown in Fig. 1). To allow simultaneous TD-NIRS and EEG measurements optodes were fixed on the EEG cap with a 3D printed tailored-designed housing. To enhance the depth sensitivity, TD-NIRS data were analyzed considering the probed area as a bilayer medium, made

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up of an extracerebral tissue and the cerebral cortex. An empirical model, which exploits the estimate of photon time-dependent pathlength in the two different domains, was employed [5], and the absorption coefficients (and then hemodynamic parameters) during programming tasks were retrieved separately for extracerebral tissue and brain.

2.3. EEG

EEG traces were recorded using a Micromed EEG acquisition system with a 64-channels EEG cap. Specifically, 29 channels placed according the 10/20 international system (Fp1, Fpz, Fp2, AF7, AF3, AF4, AF8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, Oz, O2) were acquired at a sampling frequency of 256 Hz. EEG traces were then pre-processed by means of the EEGLab Matlab Toolbox according to the following steps: i) 1-45 Hz pass-band filtering; ii) downsampling to 128 Hz; iii) common average rereferincing and iv) normalization to zero mean and variance one. Afterwards, for each task (i.e., text reading, code reading, and coding), the power content in the standard Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz) and Beta (13-22 Hz) EEG frequency bands was analyzed. For this purpose, power spectra of each EEG channel were computed on segments of 2 s length with 1 s overlap by means of the Welch’s method. Then, the time trend of the percentage power variation in the four frequency bands with respect to the previous 30 s fixation phase was extracted.

3. Results

The results obtained for one significant subject are shown and discussed in the following sections.

3.1. Time-Domain NIRS

The results, in terms of variations of O_2Hb and HHb, obtained in the four channels of a single subject are reported in Fig. 1. In the first three channels it is clearly visible a long activation for the overall task duration (higher in the third channel, panel c): increase of O_2Hb and simultaneous reduction of HHb, which starts from zero (at $t = 0$ s) and return to be close to zero at the end of the exercise. Moreover, during the single tasks it is possible to notice some task-related sub-activations, higher during code reading and programming, which are indeed the more demanding tasks, respect to the text reading. In the fourth channels no activations can be observed, probably due to a wrong postponement of the optodes.

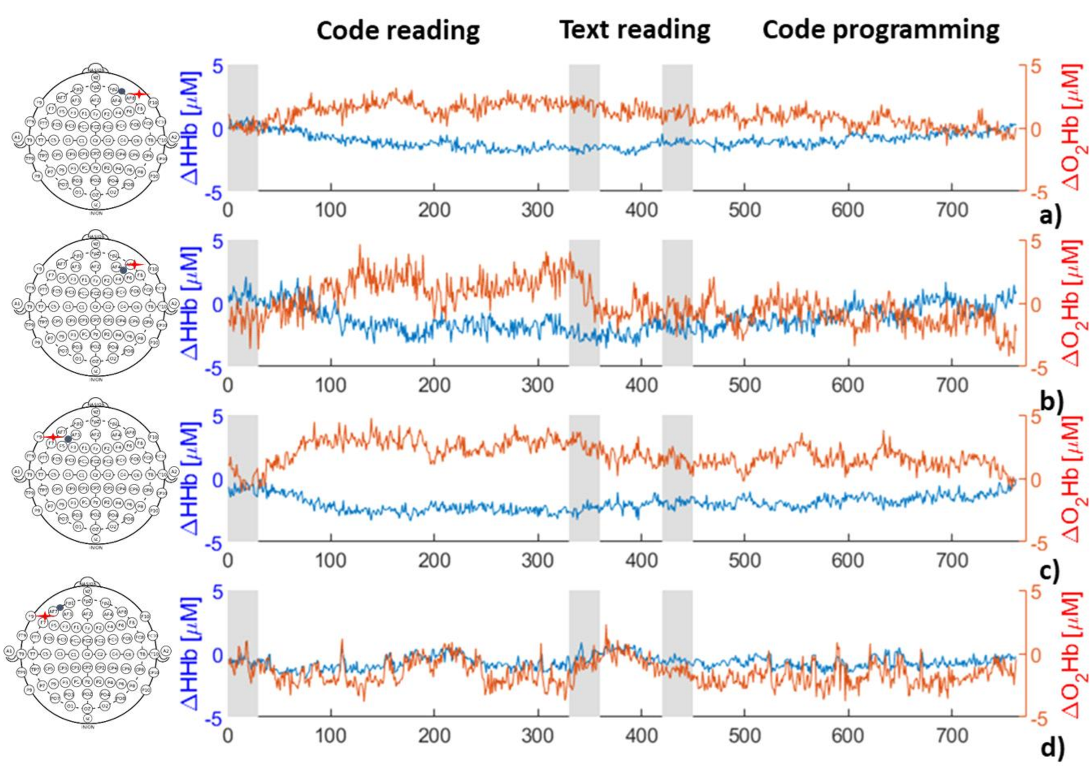

Fig. 1: Hemodynamic parameters retrieved for one subject during an entire exercise. The grey part of the graphs corresponds to the fixation cross periods.

3.2. EEG

Results obtained from the EEG spectral analysis, for the same subject, are summarized in Fig.2. Specifically, the topographical maps of the power variation (%) with respect to a resting condition in the four EEG frequency bands are shown. Five different phases of 1-min length are considered and compared: 1) text reading task; 2) first minute of the code reading task; 3) first minute of coding (window 1); 4) central minute of coding (window 2); 5) final minute of coding (window 3). Results presented in Fig. 2 mainly enhance an increase in Theta power (associated in literature to encoding and working memory tasks) passing from the text reading task to more demanding tasks, such as code reading and code programming. As in case of TD-NIRS, where higher activations were observed during code reading task, in this subject, the largest increase of Theta power in frontal region is observe during code reading. Theta power increase is mainly focused in the frontal and parieto-occipital regions, which can be associated to the cognitive and visual brain areas, respectively. These results are in accordance with a preliminary analysis performed on the average over all the subjects.

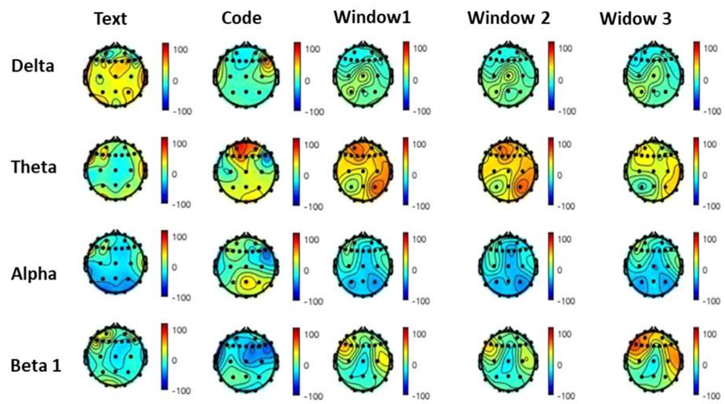

Fig. 2: Topographical maps for same subject presented in Fig. 1 of the power variation with respect to the baseline during five different conditions. Columns represents different tasks (i.e., text reading, code reading and three time windows of coding), while rows are associated to different frequency bands.

4. Conclusions

Experienced programmers were monitored during different programming tasks by simultaneous EEG and TD-NIRS measurements. The higher activations observed by TD-NIRS during code reading and programming tasks together with the significant increase in Theta power (in the frontal region) could be related to an increased attention level and to the involvement of working memory processes. Moreover, power content in the Theta band tends to decrease throughout the programming task, suggesting an increase of mental fatigue or a decrease of attention level during the final phases of the programming task. A similar result was also observed in the first channel of TD-NIRS signal, where the amplitude of the activations tends to decrease. Since the presented results are promising, more accurate group statistical analysis and also merged analysis among data coming from TD-NIRS, EEG, and all the other sensors used in the protocol are in progress.

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