Proof of concept platform of an electrotactile Brain Computer Interface

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***Abstract*—The aim of this paper is to present the concept and feasibility test of an electrotactile BCI platform consisted of EEG device, electrical stimulation device of nerves/muscles and custom software platform for device control. The developed application comprised GUI for device settings and synchronization of signal acquisition and stimulation control. Experiments for validation of the platform included trancutaneous electrical stimulation at 2 positions on the forearm for inducing somatosensory evoked potentials in the EEG signals in parallel with the tactile attention task performed by the subject. Initial results show that we were able to successfully acquire SEP with our system and that the tactile attention task modified SEP components in a physiologically congruent manner.**

***Index Terms*—Brain-computer interface; Event-related potentials; Somatosensory evoked potentials; Electrical stimulation.**

I. Introduction

BRAIN-computer interfaces (BCI) allow the direct link between a person's intentions and technical devices without the need for motor control. BCI devices are promising tools in the domain of assistive technologies for people with motor impairments due to neurodegenerative diseases, spinal cord injuries, stroke or brain trauma [1].

BCI control is based on brain signal measurements such as electroencephalography (EEG). Different EEG based control signals can be utilized for driving BCIs, such as event-related potentials, slow cortical potentials or brain oscillatory activity [2]. Those control modalities should enable the user to activate the function based on different mental strategies.

Event-related potentials (ERP) are commonly used BCI control signal and their features have been used for driving BCI based spellers and menus [2]. ERP based BCIs utilize synchronous BCI control where an ERP is elicited by an external stimuli and voluntary control of the device is based on mental strategy of selective attention towards a single stimulus which results in a mismatch in ERP between attended and unattended conditions which can be detected by BCI.

Since external stimuli for eliciting ERPs can be visual, auditory, and tactile, different types of stimuli have been previously tested for ERP-based BCI control. Most used is the visual modality while the auditory modality is not widely used because of its susceptibility to environmental interferences and relatively low accuracy [1]. The tactile BCIs are not as well-studied probably due to the need for a dedicated stimulation device for ERP eliciting which is more complicated than using a computer screen, light source or a speaker [3].

In this paper, we present an experimental, proof of concept platform of an (electro)tactile BCI based on EEG measurements of somatosensory evoked potentials (SEP) elicited by transcutaneous electrical stimulation (ES) of nerves/muscles.

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II. Methods

A. Subjects

One healthy male right-handed volunteer (aged 25) participated in this study. He was without a history of neuromuscular disease and with normal vision and had no previous experience with EEG measurements or proof of concept BCI platform. The study was approved by local ethical committee.

B. Instrumentation and experimental setup

The EEG signals were acquired using the g.USBamp amplifier (g.tec GmbH, Austria) in combination with active (g.GAMMAcap2 connected to g.GAMMAbox, g.tec GmbH) at six recording sites for EEG electrodes arranged according to the 10–20 system: FP1, C3, Cz, C4, CP5 and P3. The reference electrode was placed on the left earlobe and the ground was at the location AFz. FP1 location was used to register eye-movement artifacts. The signals were digitized with a 1200 Hz sampling rate and the amplifier was configured to use Notch embedded filtering with cut-off frequency of 50 Hz.

The electrical stimulation was delivered by an eight-channel electrical stimulator, MOTIMOVE (3F – Fit Fabricando Faber, Serbia). This stimulator is fully programmable and allows the change of stimulation parameters such as stimulus amplitude, pulse width and frequency of stimulation and in the case of our proof of concept BCI platform the parameter settings were made by sending commands from PC via USB. The stimulator has an internal battery power supply which allows mobility and isolation from the main supply.

In order to deliver necessary sensory stimuli, 2 stimulation channels were used. One channel is used for electrical stimulation of dorsal surface (stimulus location D), and the other of volar surface (stimulus location V) of the right forearm. Common indifferent electrode for both channels was round of 2.5 cm diameter and placed on the volar aspect of the right wrist. Two round active electrodes of 1 cm

diameter were placed over the extensor carpi radialis muscle (D location) and flexor carpi radialis (V location). The stimuli were single pulses (compensated biphasic with exponential discharge current) of 0.25 ms duration of the active phase. Inter-stimulus interval was set to 750 ms.

C. Experimental protocol

The participant was seated in a chair with a computer screen in front of him at a distance of approximately 1 m. To reduce ocular artifacts, the participant was instructed to fix his gaze at a fixation cross in the middle of the computer screen while right arm was resting on the table in front of the subject (Fig. 1).

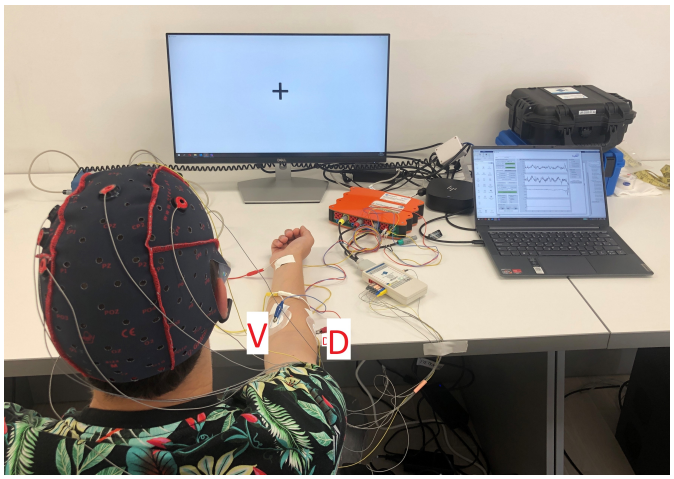

Fig. 1. Experimental setup.

Before the start of the experiment, individual motor threshold was found. Stimulus amplitude was set to 5 mA value and is increased with 1mA step until the contraction was achieved for both D and V locations. The amplitude was then reduced in order to produce the most intense sensation without inducing the contraction. In case of the subject tested those values were 11 mA for D and 10 mA for V.

Experimental protocol was consisted of 6 blocks. Within each block 300 stimuli were delivered in random order to locations D and V while the subject was instructed to attend the stimuli delivered to only one location (D or V) while trying to ignore the stimuli delivered to the other location. The mental strategy in order to maintain the attention was counting the number of stimuli delivered to target location per block. Within blocks 1, 3 and 5 the subject counted the stimuli delivered to location D while in blocks 2, 4 and 6, subject's attention was focused on location V. Therefore, within the duration of the experiment the total number of delivered stimuli was 1800, i.e. 900 per experimental condition (focus on D – F_D, and focus on V – F_V).

D. Software

Graphical user interface (GUI) for stimulation control and data acquisition was developed in MATLAB R2020a (MathWorks Inc., Natick, USA) programming environment (Fig. 2). The GUI consists of four sections.

1) Electrical stimulator control: In this section communication parameters were specified. When communication with stimulator was established, parameters for electrical stimulation were defined. The operator can set value of stimulus amplitude, pulse width and stimulation electrode for both location D and location V. These parameters could be changed during the experiment.

2) Data acquisition: In this section operator needed to set sampling rate and the buffering block size. Sample rate was set to 1200 Hz and buffering block size was set to 60. With these settings, and timer interrupt period, each timer epoch acquires 900 samples.

3) Experiment protocol settings: In this part of the interface operator had to set the parameters that define number of stimuli per block for both channels, number of blocks and duration of pause between blocks. Operator could also choose how the sequence of stimuli was generated. Five options were available: only D is stimulated, only V is stimulated, alternating stimulation between D and V, pseudo random manner with restriction that no more than two consecutive stimuli can be delivered on the same location, and pseudo random manner with restriction that no more than three consecutive stimuli can be delivered on the same location. Finally, operator initialized the session by clicking one of two buttons, depending on which stimulation location the subject has to focus on, so that the dataset was saved and named accordingly to the task (experimental condition).

4) Data visualization: Signals from all channels were shown on the GUI with one of three options. First option showed raw signals. Second one showed signals after filtering with Butterworth 2nd order bandpass filter in a range 1 - 30 Hz. Both first and second option showed signals in time interval of 0.75 s. Third option showed signals of longer duration which was used while preparing the subject for the test and inspecting the EEG signal quality.

E. Data processing

The collected EEG data was bandpass filtered using a 2nd order Butterworth filter in a range 0.1–25 Hz. EEG was segmented to 500 ms epochs (100 ms pre-stimulus baseline and 400 ms post-stimulus interval). Epochs containing artifacts were rejected, where epochs with high absolute amplitude potential shifts (at channels selected for further analysis) and eye-blink/movement artifacts (detected from the Fp1 channel) were selected for rejection. Noise-free epochs were baseline corrected and averaged to form 4 SEP waveforms derived from 2 experimental conditions: 1) focus attention on D while D was stimulated (F_DS_D), 2) focus attention on D while V was stimulated (F_DS_V), 3) focus attention on V while V was stimulated (F_VS_V) and 4) focus attention on V while D was stimulated (F_VS_D). The SEP difference waveforms were calculated by subtracting the SEPs of location D and V delivered within the same condition (task). Namely, difference waveform for FD condition was calculated as F_DS_D-F_DS_V while the difference waveform for F_V condition was calculated as F_VS_D-F_VS_V.

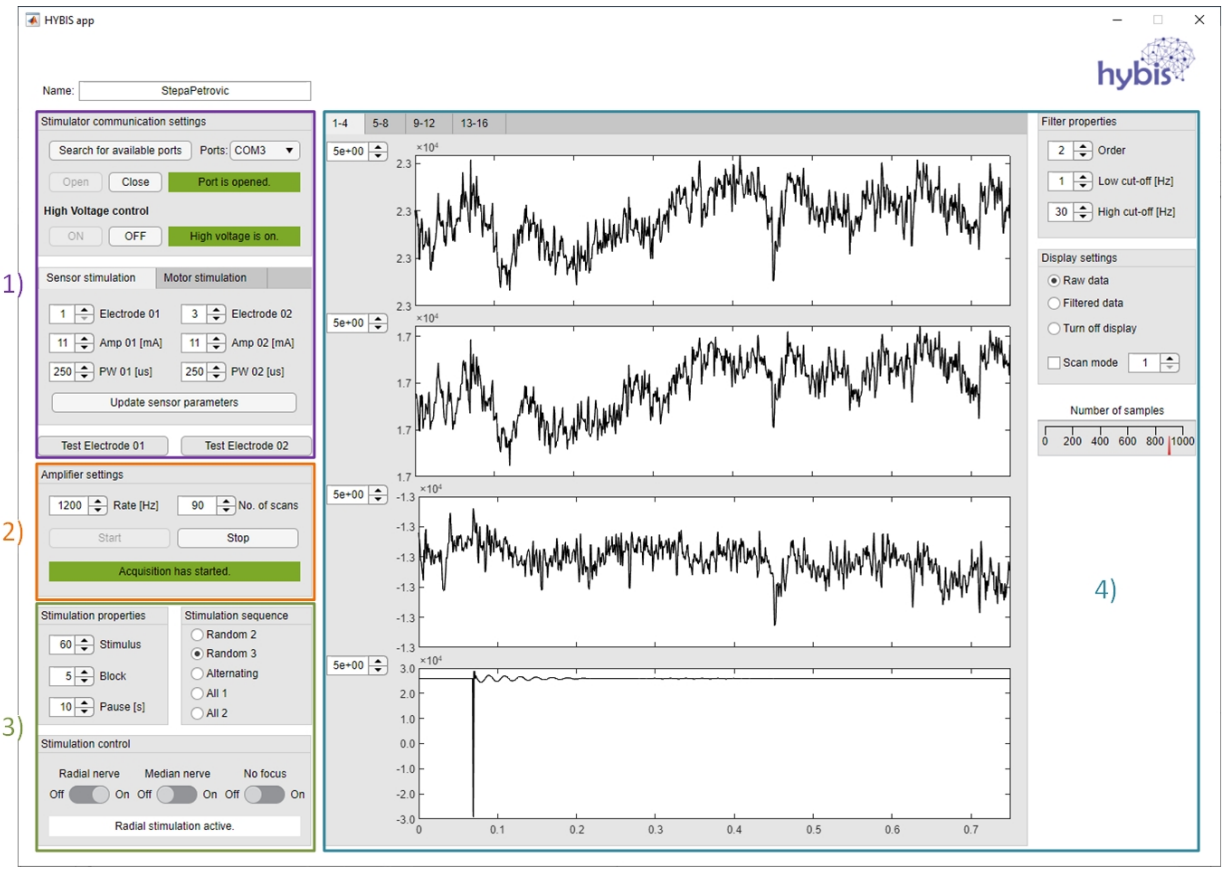

Fig. 2. Main window of the software application GUI during experiment. GUI is divided into four sections: 1) Setting the parameters for communication with electrical stimulator (com port) and stimulation parameters (stimulus amplitude, pulse width and stimulation electrode for both D and V locations), 2) Setting the parameters for data acquisition (sampling rate of acquisition and buffer block size), 3) Setting the parameters for experimental protocol (number of blocks, number of stimuli per block, pause duration and type of sequence), and 4) Data visualisation.

III. Results

SEP waveforms showed that attending the stimuli delivered at one location (D or V) modified the shape of the signal which was reflected in the SEP difference waveform. Representative data for P3 channel is shown in Fig. 3 and 4. Fig. 3 shows the average SEP waveforms when the attention focus was on

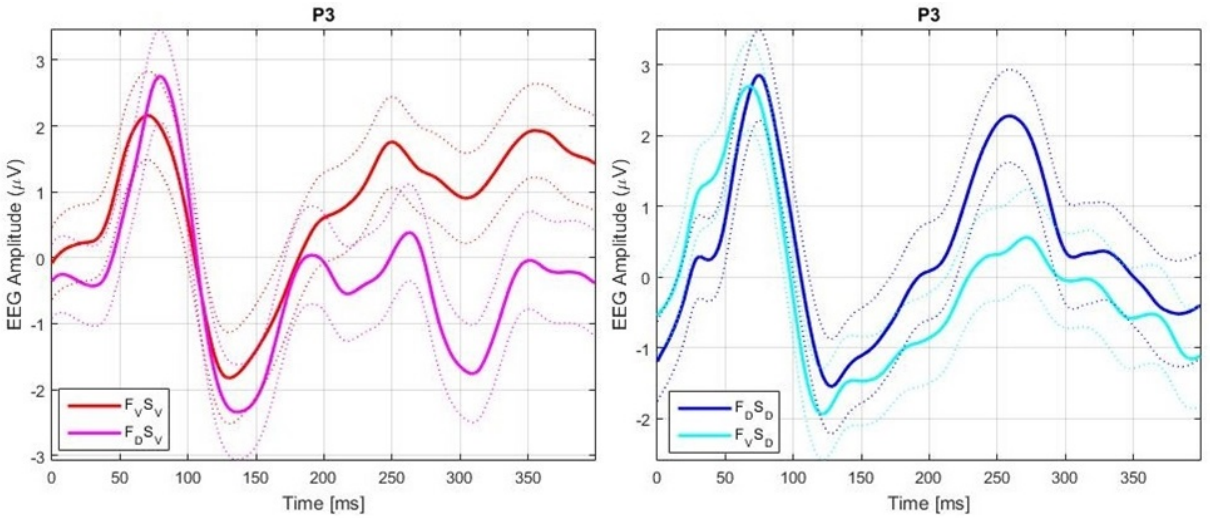

Fig. 3. Left graph shows 2 average SEP waveforms associated with stimulation of dorsal surface of the forearm (SD) while the subject was counting stimuli delivered on dorsal (focus dorsal – F_D, blue line) or volar (F_V , cyan line) surface. Right graph shows 2 average SEP waveforms associated with stimulation of volar surface of the forearm (S_V) while the subject was counting stimuli delivered on volar (focus dorsal – F_V, red line) or volar (F_D, magenda line) surface. Dotted lines present 95% confidence intervals. SEP graphs are presented for EEG channel P3.

the stimulated spot (blue line for D and red for V) or on the other spot (cyan and magenta lines, respectively).

Fig. 4 shows average difference wave between SEP associated with stimulation of dorsal (D) and volar (V) surface of the forearm while the attention focus was on the stimuli delivered to D (blue line) or V (red line).

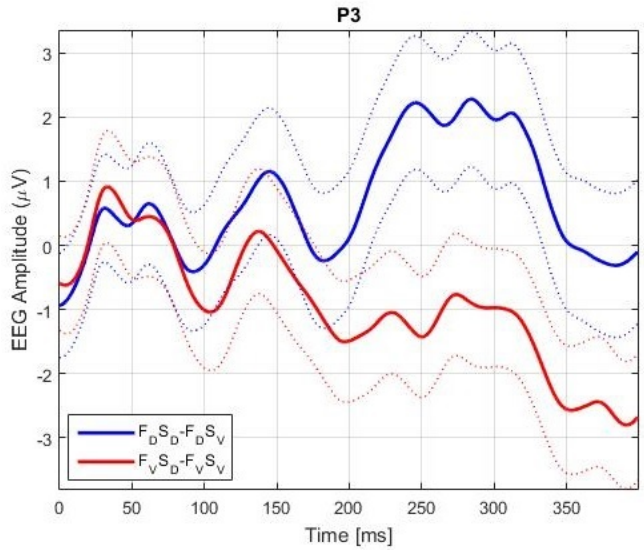

Fig. 4. Blue line represents average difference wave between SEP associated with stimulation of dorsal and volar surface of the forearm while the attention focus was on the stimuli delivered to dorsal surface. Red line represents average difference wave between SEP associated with stimulation of dorsal and volar surface of the forearm while the attention focus was on the stimuli delivered to volar surface. Dotted lines present 95% confidence intervals. SEP graphs are presented for EEG channel P3.

Results indicate significant increase in SEP amplitude of endogenous components, associated with attention focus in both stimulated locations.

IV. Discussion and conclusion

The presented SEP waveforms for both stimulated locations show similar morphology characterized with a first positive component between 50 and 100 ms and negative component between 100 and 150 ms post-stimulus.

Attention focus has resulted in increase of SEP amplitude peaking around 260 ms for SEP associated with D and around 310 ms for SEP associated with V (Fig. 3). The SEP difference waves reveal the window of significance in which the attention focus significantly impacts the processing of somatosensory stimuli in this subject between 210 and 350 ms (Fig. 4) which coincide with P300 ERP component, reflecting the processes involved in stimulus evaluation or categorization [4]. Therefore, our preliminary results validate the SEP recording using our platform and verify that the association of attention focus on SEP amplitude is in a physiologically congruent manner.

This proof of concept platform is a first step towards a novel BCI system for training of somatosensory functions.

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