 DOI:10.3217/978-3-85125-378-8-90

Online artifact reduction and sequential evidence accumulation enhances robustness of thought-based interaction

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Abstract

Electroencephalogram-based (EEG) brain-computer interface (BCI) technology should be able to robustly decode the users intent in the presence of artifacts. These requirements are particularly important for functionally disabled individuals with involuntary movements such as individuals with cerebral palsy (CP). In this paper we show that our novel online artifact reduction method in combination with a scanning mechanism that sequentially accumulates evidence for decision making enables able-bodied individuals to successfully operate a steady-state visual evoked potential (SSVEP) BCI on a Tablet computer while walking on a treadmill.

1 Introduction

Protocols used to calibrate and operate electroencephalogram-based (EEG) Brain-Computer Interfaces (BCIs) [3] generally demand from users the following, among others: Firstly, to carefully follow instructions and perform defined mental activity in response to a presented cue, and secondly, to avoid movements during periods of mental activity. The former allows labeling of EEG segments and thus the calibration of translation-rules. The latter aims at minimizing muscle artifact contamination. Artifacts are undesirable signals that may change EEG characteristics or even be mistakenly used as the source of control in BCI systems.

We are currently exploring the usefulness of BCI technology for users with cerebral palsy (CP). More precisely for individuals with dyskinetic forms of CP (DCP). Individuals with DCP have hypertonia and hypotonia mixed with involuntary movements and spasms. Hence, EEG will be heavily contaminated with artifacts and individuals, depending on affected muscles, may occasionally not be able to focus on and perceive cue information (e.g. look at screen).

To address the raised issues, we started working on both a novel artifact removal method for online processing of EEG data [1] and a scanning mechanism that sequentially accumulates evidence for decision making. In this paper, we introduce a steady-state visual evoked potential (SSVEP) BCI that incorporates both methods and report on first online control results.

2 Methods

2.1 Adapted online SSVEP-based BCI speller system

Conceptual design. The BCI is based upon a user-facing tablet with modules for both SSVEP and oscillatory activity (imagery) based communication. In the current manuscript only the SSVEP module is described. The user front-end of the system runs on an Android tablet, while

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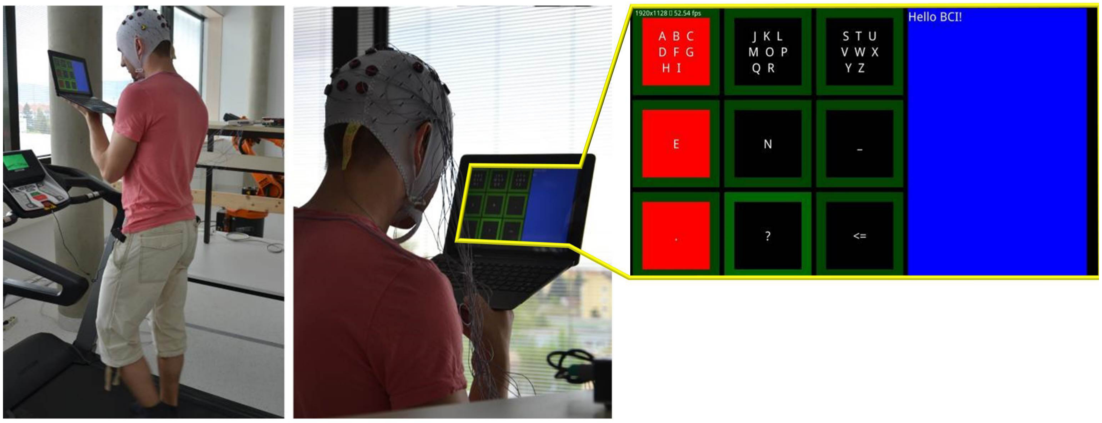

Figure 1: Participant walking on a treadmill while spelling with the SSVEP BCI system. The User Interface presented on an Android tablet (ASUS Transformer Pad TF700) is shown on the right side.

data acquisition and processing is performed on a Windows operating system computer. An operator computer can be used for monitoring and controlling experimental procedures.

Figure 1 shows the user front-end running on an Android tablet. The screen is split in two parts. The left side contains a 3x3 grid of stimulation targets, and to the right there is a speller where the participants see the letters they selected. One row or column flickers at a time in color red with a frequency of 7.5 Hz (SSVEP stimulation frequency). This frequency was selected after several tests with healthy subjects as working most robustly. The stimulation period, by default, is set to 4 seconds. The BCI evaluates data from seconds 2-4 to allow the SSVEPs to settle at a steady state. To provide feedback about target selection, target rows and columns on which the user is concentrating are highlighted with given intensity (green surrounding boxes are enhanced) while flickering. The SSVEP scanning paradigm allows the user to select any number of targets with only one single stimulation frequency. One row or column flickers at a time, switching to the next row or column after 4 seconds. This takes at least six steps to uniquely select one out of nine targets. The order of stimulation was random in this study. The current design of the system allows in a first step to select one out of three different menus representing certain groups of letters. By selecting one of these menus the user is then able to select the target letter in a second step.

Online Signal Processing and Analysis. Processing of the signals is performed with Matlab/Simulink (MathWorks, Natick, MA, USA). Many BCI users with CP exhibit high levels of spontaneous movement, therefore a fully automated method for the removal of artifacts such as electromyogram (EMG) was developed [1] and integrated in the online BCI system. EEG is first decomposed via Wavelet decomposition methods. Independent components are then derived from decompositions of the signal and removed from the signal in instances when they exceed pre-defined thresholds. In the SSVEP based BCI, classification is performed via the canonical correlation analysis (CCA) method described in [4] and applied in [2]. Correlations are found between EEG recorded over occipital cortex and the SSVEP stimulation frequency. The largest correlation coefficient was used to identify the stimuli the user is attending to. During the evaluation period (2-4 s) of a flickering target, the mean of the correlation coefficient for that target is adaptively updated. The mean for unfocused targets reaches a lower value

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than the mean of a focused target. A selection is made when the mean of a target reaches a threshold of 0.35 (determined empirically). Feedback about the progress towards selection is presented to the user in form of green colored frames around the target (Figure 1). Color black corresponds to a mean of 0, and color light green corresponds to a mean close to the threshold. The color is updated whenever the mean for that target changes by a certain step size.

The artifact correction method worked on blocks of one second of EEG data. The BCI system requires operation on smaller time steps. To ensure smooth operation and allow frequent updates of the feedback, artifact correction and BCI run as separate processes. Communication and data exchange was implemented through shared memory. Due to the block-wise cleaning of EEG, however, the BCI feedback presentation was delayed by 1 second.

2.2 Evaluation of the System

To evaluate the online system and test how the online artifact removal method affects the performance of the BCI we performed a study with four able-bodied male participants (27±3 yr). All participants had previous experience with SSVEP BCIs. In the experiment participants had to spell with the SSVEP BCI system during different conditions which were more or less prone to produce artifacts in the EEG. Participants were: (i) sitting in a shielded, shaded and sound-proof measurement cabin with the tablet placed about 70 cm in front of them on a table (condition CAB-SIT), (ii) standing in the measurement cabin holding the tablet in their hands (condition CAB-STND)), (iii) standing outside the measurement cabin on a treadmill in a room with daylight and holding the tablet in their hands (condition TRD-STND), and (iv) walking on a treadmill with slow speed (1.4-1.6 km/h) holding the tablet in their hands (see Figure 1). Condition (iv) was performed twice, once with the online artifact removal method (condition TRD-WLK, see Figure 1) and once without artifact correction (condition TRD-WLK-OFF). All other conditions were performed with artifact correction enabled. Before performing conditions (iv) participants trained spelling during walking on the treadmill for ten minutes. Conditions were randomized. Participants were asked to write one word of four letters (German words: Mund, Zaun, Auto, Haus, Werk, Baum) during each run. Participants had ten minutes respectively to complete the task.

EEG was recorded from 16 electrodes placed over cortical areas according to the international 10-20 system. Electrode positions included AFz, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, PO3, POz, PO4, O1, Oz, O2. Reference and ground were placed at position Pz and P5, respectively. The g.GAMMAsys system with g.LADYbird active electrodes (Guger Technolgies, Graz, Austria) and one g.USBamp biosignal amplifier was used to record EEG at a rate of 512 Hz (Notch 50 Hz, 0.5-100 Hz band pass).

3 Results

Results are summarized in Table 1. Arithmetic mean values, averaged over all participants for each condition individually, show that the the number of correct and erroneous selections are in a comparable range for conditions CAB-SIT, CAB-STND and TRD-STND. Also the selections per minute are in a comparable range over these conditions. When walking on the treadmill (TRD-WLK) there is a slight decrease in correct selections and in total 0.9 selections per minute. Disabling the artifact rejection method during treadmill walking (TRD-WLK-OFF) degrades the performance to 4.7 correct selections per run and 0.67 selections per minute. The average number of scan steps needed to correctly select an item was in the range 3.8-4.8 selections.

Table 1: Number of correct/erroneous selections and the number of selections per minute for each participant (P1-P4) and condition. Additionally the average number of scan steps needed to make a correct selection (Steps) for each condition is shown.

	CAB-SIT	CAB-STND	TRD-STND	TRD-WLK	TRD-WLK-OFF
P1	07/4, 1.0	09/1, 1.6	09/2, 1.5	10/5, 1.6	12/3, 1.6
P2	11/2, 1.6	10/1, 1.4	10/2, 1.2	09/1, 0.9	5/1, 0.7
P3	07/1, 0.7	08/2, 0.9	07/0, 1.3	07/3, 0.9	2/1, 0.4
P4	08/0, 1.9	08/0, 1.5	06/1, 0.6	01/0, 0.3	0/0, -.-
Mean	8.2/1.7, 1.30	8.7/1.0, 1.35	8.0/1.2, 1.15	6.7/2.2, 0.90	4.7/1.2, 0.67
Steps	4.5	3.8	4.6	4.8	4.4

4 Discussion

The preliminary results of our study show that when EEG data is contaminated by artifacts the performance of the BCI system improves when using the developed online artifact correction method. Participant P4 had problems to spell outside the box as the light in the room was very bright and dazzled him. In total for three of the participants (P2-P4) the system performed better with artifact correction method, and for one participant (P1) the system performed equally well with and without artifact correction.

The implemented scanning mechanism sequentially accumulates evidence until a decision can be made. Hence, providing user on-demand access is an intrinsic feature of this strategy. Robustness of detection can be enhanced by optimizing scanning time and selection threshold for each individual. Selection time can be enhanced by optimizing the scanning protocol.

One big issue when designing the experimental paradigm was to find a strategy to naturally elicit artifacts. As a first step, we asked participants to walk on a treadmill and hold the tablet in their hand. Since the results of the study suggest that the developed methods work at a fundamental level, in the next step we will explore their performance with CP users and adapt methods and scanning protocols following user-center design principles.

Acknowledgments

This work was supported by the FP7 Framework EU Research Project ABC (No. 287774). This paper only reflects the authors views and funding agencies are not liable for any use that may be made of the information contained herein.

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