Visual Motion Onset Brain-computer Interface

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Abstract. The paper presents a study of two novel visual motion onset stimulus-based brain-computer interfaces (vmoBCI). Two settings are compared with afferent and efferent to a computer screen center motion patterns. Online vmoBCI experiments are conducted in an oddball paradigm allowing for aha–responses decoding in EEG brainwaves. A subsequent stepwise linear discriminant analysis classification (swLDA) classification accuracies comparison is discussed based on two inter–stimulus-interval (ISI) settings of 700 and 150 ms in two online vmoBCI applications with six and eight command settings. A research hypothesis of classification accuracies nonsignificant differences with various ISIs is confirmed based on the two settings of 700 ms and 150 ms, as well as with various numbers of ERP response averaging scenarios. The efferent in respect to display center visual motion patterns allowed for faster interfacing and thus they are recommended as more suitable for the BCI.

Keywords: Brain-computer/machine interface (BCI/BMI); visual motion perception; neurotechnology application; EEG; online brain signal processing and classification.

1 Introduction

A brain–computer interface (BCI) is a neurotechnology that utilizes only central nervous system (CNS) signals (brainwaves) of a user to create a new communication channel with others or to control external devices without depending on any muscle activity [14]. The BCI technology has provided a support already to patients’ life improvement who suffer from severe paralysis due to diseases like an amyotrophic lateral sclerosis (ALS) [14][10]. The successful alternative options have been developed recently to utilize spatial auditory [49] or tactile (somatosensory) modes [12][8]. Meanwhile, the visual BCI seems to offer

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We present results of a novel study utilizing two strategies of the visual motion onset patterns [6,5] for BCI purposes. The vmoBCI patterns used in the presented experiments are shown in Figures 1a and 1b for afferent and efferent movements respectively. A goal of this study is to compare and test the performance (BCI classification accuracy) of the novel vmoBCI paradigm in function of two inter–stimulus interval (ISI) settings. Namely the ISI equal to 700 ms (a very easy case) and 150 ms (a harder case due to fast repetition of the presented visual movement patterns and larger overlap of the brainwave ERPs).

Results obtained with five healthy users in online BCI experiments with stepwise linear discriminant analysis (swLDA) classifier [7] and two different averaging settings are analyzed and discussed.

From now on the paper is organized as follows. In the next section we present methods used and developed in order to capture, process and classify the brainwave response in application to the proposed vmoBCI. Online EEG analysis results together with conclusions summarize the paper.

2 Materials and Methods

The visual motion onset stimuli were delivered as colored moving objects on a computer display in moving towards the center (afferent) and off–center (efferent) trajectories as presented in Figures 1a and 1b. The animations were programmed in Processing.org visual programming environment. There were six afferent and eight efferent patterns tested delivered in random order in order to elicit P300 brainwave responses in an oddball style paradigm [14]. The inter–stimulus intervals (ISIs) of 700 ms and 150 ms were chosen. The two different
ISI setups were tested in order to evaluate a possible impact of the fast stimulation repetitions on user’s BCI performance (the resulting BCI accuracy) in two different brainwave event related potential (ERP) averaging scenarios using ten or five responses. During the EEG experiments, the users were instructed to watch center of a computer screen and to minimize eye–movements as shown in Figures 1a and 1b as well as in online videos from the experiment [11,10]. The users responded mentally by confirming/counting only to the instructed visual motion patterns while ignoring the others. The EEG signals were captured with a portable EEG amplifier system g.USBamp from g.tec Medical Instruments, Austria. Eight active wet EEG electrodes were used to capture brainwaves with attentional modulation elucidated, within the event related potentials (ERPs), the so-called “aha-” or P300-responses [14]. The EEG electrodes were attached to the head locations CP3, CP4, POz, Pz, CPz, Cz, P3, and P4 as in 10/10 intentional system. A reference electrode was attached to a left earlobe and a ground electrode on the forehead at FPz position respectively. The details of the experimental procedures and the research targets of the tpBCI paradigm were explained in detail to the five human users, who agreed voluntarily to participate in the study. The electroencephalogram (EEG) vmoBCI experiments were conducted in accordance with The World Medical Association Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects.

The experimental procedures were approved and designed in agreement with the ethical committee guidelines of the Faculty of Engineering, Information and Systems at University of Tsukuba, Tsukuba, Japan (experimental permission no. 2013R7). The average age of the users was of 26.8 years old (standard deviation of 10.7 years old). The EEG signals were recorded and preprocessed online by an in–house extended BCI2000 application [13] and segmented (“epoched”) as features drawn from ERP intervals of 0 ∼ 700 ms. The sampling rate was set to 512 Hz, the high pass filter at 0.1 Hz, and the low pass filter at 40 Hz. The ISI were of 700 ms or 150 ms in two different experimental runs. Each user performed two sessions of selecting the six or eight patterns (a spelling of a sequence of digits associated with each tactile pressure pattern) in afferent and efferent visual motion settings, respectively. We performed offline analysis of the collected online EEG datasets in order to test a possible influence of the two ISI settings on the vmoBCI accuracy (compare ERP results in Figures 2a, 2b, 3a, and 3b depicting an impact of faster ISI on the ERP shapes). The swLDA [7] classifier was applied next, with features drawn from the 0 ∼ 700 ms ERP intervals, with removal of the least significant input features, having $p > 0.15$, and with the final discriminant function restricted to contain a maximum of 60 features.

3 Results

The results of brainwave ERPs have been summarized as simple grand mean averaged time series with standard error bars in Figures 2a, 2b, 3a, and 3b. Those results have clearly shown a very small impact of the two tested ISI of
700 ms and 150 ms, as well as the afferent and efferent visual motion settings summarized in Figures 2 and 3, respectively.

More interesting results have been elucidated with an area under curve (AUC) analysis for ERP feature distributions as reported in Figures 4 and 5. The AUC scores, visualizing the EEG features separability for a subsequent classification, were higher (AUC > 0.65) for the efferent motion cases depicted in Figures 5a and 5b for ISI of 700 ms and 150 ms, respectively. The AUC analysis results were confirmed also with vmoBCI classification accuracies summarized in Tables 1 and 2 for afferent and efferent vmoBCI online experiments using ten and five brainwave ERP averaging scenarios. The mean accuracies were non-significantly differing among the tested afferent and efferent cases with various ISI and averaging settings.

4 Conclusions

The aim of this study was to test the ISI variability impact on the vmoBCI classification accuracy results in various brainwave averaging scenarios of the proposed visual motion onset paradigm. The online results obtained with the swLDA classifier did not show significant differences for the both afferent and efferent motion scenarios.

The results are very promising for future online applications with patients suffering from LIS allowing for speeding up the BCI stimuli presentation without significant classification degradation.

The approach presented shall help, if not to reach the goal, to get closer to our objective of the more user friendly visual BCI design. Thus, we can expect that patients suffering from LIS, as well as healthy users, will be able to use
Fig. 3: Grand mean averaged brainwave ERP responses in efferent vmoBCI. The green traces depict the attended targets with P300 responses and blue the non-targets. The intervals surrounding the mean traces depict standard errors.

Although the statistical analysis did not yield significant differences between the tested afferent and efferent motion cases, the users preferred the efferent stimuli resulting with better speeds as shown in the example with single ERP classification documented in an online video available at [10].

Still there remains a long path to go before providing a natural and comfortable visual motion onset BCI end-user solution, yet our research has progressed toward this goal as presented in this paper.

Table 1: Afferent visual motion onset BCI accuracy results (a chance level of 16.7% due to six commands used)

| User number | ISI = 700 ms | ISI = 150 ms |
|-------------|--------------|--------------|
|             | 10 trials    | 5 trials     | 10 trials    | 5 trials     |
| #1          | 100.0%       | 83.3%        | 100.0%       | 100.0%       |
| #2          | 16.7%        | 50.0%        | 66.7%        | 83.3%        |
| #3          | 100.0%       | 83.3%        | 100.0%       | 66.7%        |
| #4          | 100.0%       | 100.0%       | 100.0%       | 66.7%        |
| #5          | 100.0%       | 100.0%       | 100.0%       | 66.7%        |
| **Average accuracy** | 83.3% | 83.3% | **93.3%** | **76.7%** |
| **Standard deviation** | 37.2% | 20.4% | 14.9% | 14.9% |
Fig. 4: AUC analysis of ERP responses in afferent vmoBCI. The left column head topographic plots depict the latencies with the best (maximum) and worse (minimum) of AUC scores. The right column summarizes the ERP responses in form of matrices of all channels and AUC traces at the bottom.

Fig. 5: AUC analysis of ERP responses in efferent vmoBCI. The left column head topographic plots depict the latencies with the best (maximum) and worse (minimum) of AUC scores. The right column summarizes the ERP responses in form of matrices of all channels and AUC traces at the bottom.

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Table 2: Efferent visual motion onset BCI accuracy results (a chance level of 12.5% due to eight commands used)

| User number | ISI = 700 ms | ISI = 150 ms |
|-------------|--------------|---------------|
|              | 10 trials | 5 trials | 10 trials | 5 trials |
| #1          | 100.0%   | 100.0% | 100.0%   | 100.0%   |
| #2          | 100.0%   | 75.0%  | 100.0%   | 87.5%    |
| #3          | 62.5%    | 50.0%  | 75.0%    | 75.0%    |
| #4          | 100.0%   | 100.0% | 100.0%   | 100.0%   |
| #5          | 87.5%    | 87.5%  | 87.5%    | 87.5%    |

Average accuracy

| ISI = 700 ms | ISI = 150 ms |
|--------------|--------------|
| 92.0%        | 92.5%        |

Standard deviation

| ISI = 700 ms | ISI = 150 ms |
|--------------|--------------|
| 16.5%        | 11.2%        |
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