BCI-based Game Control to Boost Focus and Attention in Students

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***Abstract*—This study presents a non-invasive Electroencephalogram (EEG) based Brain-Computer Interface (BCI) system to control games developed for the purpose of increasing focus and attention in students. For the study, data was collected from 6 subjects. Each subject played a focus game designed to evaluate their attention and focus before being trained through a P300-based speller. In order to evaluate the effect of training, subjects were asked to play the focus game again. The EEG data collected from the subjects during the P300-based Speller game training phase was analyzed to see the attentivity of the subjects. As per the classification accuracies obtained for all the subjects, the subjects were attentive and focused during the training phase. This training phase resulted in an improvement in their focus game performance metrics. P300-based BCI system can be effectively used to enhance focus and attention in students.**

***Index Terms*—BCI, EEG, ERP, P300-based Speller.**

I. Introduction

The phenomenon of diminished focus and attention among college students has garnered increasing attention in recent years due to its multifaceted implications on academic performance and overall well-being. This issue is closely linked to the pervasive use of digital technologies, particularly smart phones and laptops, which provide constant access to a multitude of distractions, including social media, instant messaging, and online entertainment. Research suggests that this constant connectivity and exposure to digital stimuli can lead to reduced cognitive control, making it increasingly challenging for college students to sustain their attention on academic tasks such as lectures, reading assignments, and studying. Furthermore, the demands of the college environment, including high-stress levels, irregular sleep patterns, and over commitment to extracurricular activities exacerbate this problem. Understanding the underlying factors contributing to the lack of focus and attention is pivotal for designing effective interventions and support systems aimed at enhancing the learning experience and academic outcomes for college students.

The main purpose of the study is to use a non-invasive Electroencephalogram (EEG) based BCI system to control games that are designed to improve focus and attention. Brain-Computer Interface (BCI) is a technology that enables communication between the human brain and a computer based external device [4] [5]. There are several ways in which a BCI can be implemented. BCI based training sessions have been used to enhance children's engagement in reading [9]. P300-based Speller is the most commonly used BCI system that is based on oddball paradigm [6]. P300-based Speller has been used to treat attention-deficit/hyperactive disorder in children [7]. For this study, P300-based Speller Game was utilized as a training tool to help enhance the cognitive abilities of students. The P300 response is a prominent positive deflection in the EEG signal, appearing approximately 300 ms after the presentation of the attended stimulus as shown in Figure 1. P300 deflection is widely considered to be an important indicator of attention and focus. In Figure 1, the target ERP (Event Related Potential) shown in blue shows a positive peak between 200 and 300 millisecond.

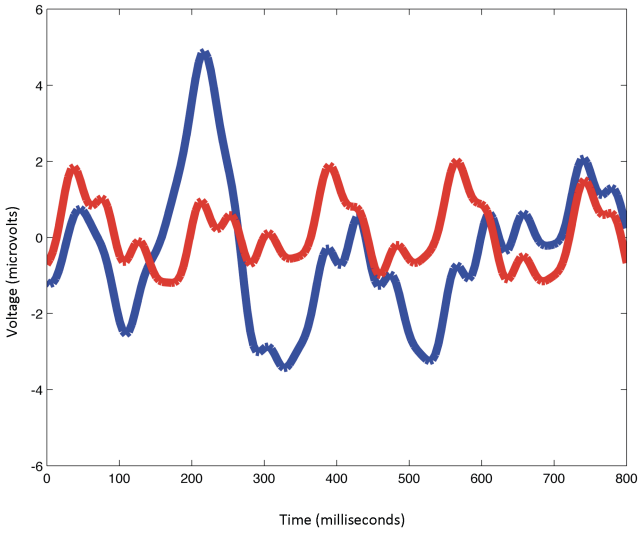

Fig. 1. Average P300 Response for Subject C. The blue waveform represents the Target ERP while the red corresponds to the Non-target ERP.

There are studies that have used BCI-based systems to improve the focus and attention in subjects. Authors in [1] [2] proposed an online EEG based neurofeedback game for enhancing attention and memory. In both the studies, subjects were asked to memorize a set of numbers in a matrix and later correctly fill the matrix. The focus of the study was mainly on

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memory of the subjects. The authors in [3] used a P300-based BCI Interface for improving attention. The game used in the study was challenging enough for the subjects to be attentive all the time.

The primary goal of this study is to explore the effect of P300-based Speller Game with and without feedback on enhancing the focus and attention of the subjects. The study is proposing a very simple, but monotonous game for the subjects to test their attention and focus.

The rest of the paper is organized as follows. Section II presents the materials and methodology used for this study. The section provides information about the subjects who participated in the study for data collection and the procedure used to collect the data. In Section III, preliminary results obtained from the EEG and the focus game data are presented. Section IV concludes the paper with the discussion of the current study and presents the future plan of action.

II. Materials and Methods

A. Subject Information

Since human subjects are a part of this study, the study was approved by the university's Institutional Review Board (IRB). After the approval, a number of emails were sent to all the students of the computer science department seeking volunteers for the study. Seven subjects from the department gave their formal consent to be a part of this study. To keep the study as unbiased as possible, the emails were not sent directly by the project investigators but by the department administrative assistant. One of the subjects, out of these seven, reported as being neurodivergent and thus was not considered for further study. This is to remove any biases. Only six subjects were thus considered for this study.

B. Procedure

The procedure used for the study is shown in Figure 2. All the three tasks were completed in a single session and it took around an hour for the subjects to finish all the tasks. During all the tasks, subjects sat in a comfortable chair approximately 75 cm from the monitor. EEG was collected using g.Nautlius Multipurpose 16-channel EEG cap. The headset has 16 electrodes (FP1, FP2, F3, FZ, T7, C3, CZ, C4, T8, P3, PZ, P4, PO7, PO8, and OZ) to record the data. All the electrodes were reference to the right ear and amplified, bandpass filtered from 0.5 - 500 Hz, and digitized at 1200 Hz.

- Pre-training Focus Game - A Focus Game was designed for the purpose of this study. The purpose of the Focus Game was for the subjects to play a game that was very monotonous and at the same time required attention and focus. In the Focus Game, subjects were asked to click on a moving target on the screen. The target could appear anywhere on the screen and at a variable rate. Figure 3 shows the Focus Game layout. The subjects had to click on a randomly appearing black box on a gray background on the screen. This box would disappear in a matter of 100 milliseconds so the subjects had to move their cursors quickly and click on the box before it disappeared and appeared somewhere else. The Focus Game lasted for five minutes and the moving target appeared 50 times in total.
- Training: P300-based Speller Game - As a part of the training phase, after completing the Focus Game task, subjects were asked to train via P300-based Speller Game. Each session of the P300-based Speller Game consisted of 4 experimental runs. Each run was composed of a 5 letter word. This set of characters that was consistent for all the subjects was from a 6×6 matrix displayed on the monitor, as shown in Figure 4. The rows and columns of the matrix were intensified for 100 ms with 25 ms between the intensifications [8]. There was a gap of 2 seconds between each run. A sequence of 12 row/column intensifications constituted one character epoch.

Words were presented on the top left corner of the mon-

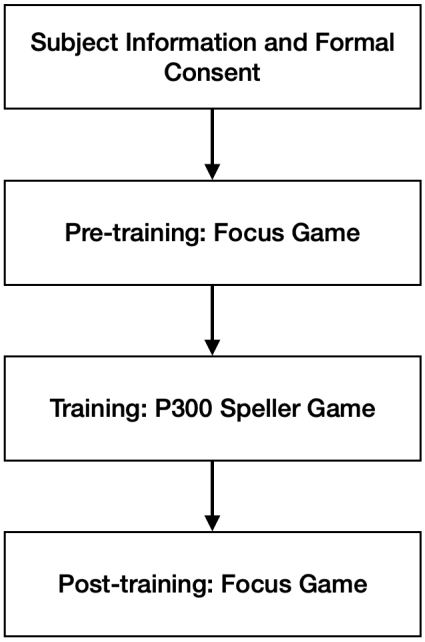

Fig. 2. Procedure used for this study.

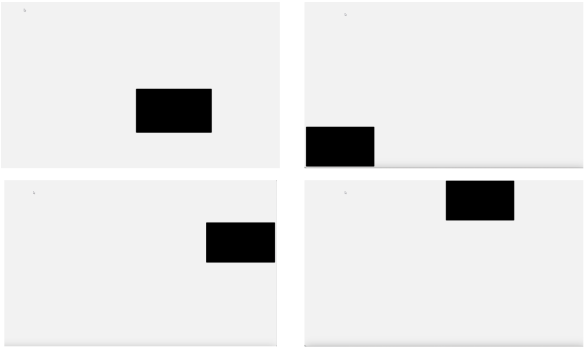

Fig. 3. Focus Game.

itor, and the character currently specified for selection was listed in parentheses at the end of the letter string. To better understand, for example, in Figure 4, D is the first letter of the word DICE. P300 response is generated for letter D when the fourth column and the first row of the matrix flashes.

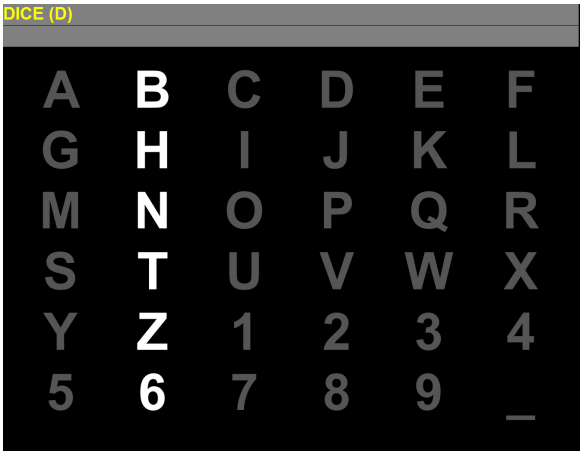

Fig. 4. The 6×6 matrix used in this study. A row or column intensifies for 100 ms every 175 ms. The letter in the parentheses at the top of the window is the current target letter "D". For this target, a P300 should be elicited when the fourth column or first row is intensified [8].

- Post-training Focus Game - After the training using P300-based Speller Game, subjects were asked to play the Focus Game again to see the impact of training.

III. Preliminary Results

A. EEG Analysis

The EEG data recorded during the training was analyzed to identify the P300 brain activity response and used to train a machine-learning model. To access the quality of the recorded EEG signal, offline P300-based Speller accuracy was computed. For each subject, an optimal classifier based on Random Forest (RF) was trained. For each channel of the data, 800 ms of the data segments were extracted following each flash for analysis. A feature vector corresponding to each stimuli was created by concatenating the extracted data segments by channel. All data were lowpass filtered to 20 Hz and decimated to 240 Hz, to smooth the data while retaining sufficient samples for classification model. A Random Forest classifier was trained using these features. In order to compute the classification accuracies, 80% of the data was used for training and the remaining 20% was used for testing. Table I reports the classification accuracies obtained for all the subjects.

The classification accuracies achieved for all the subjects are exceptionally high. This shows that the subjects were attentive and focused during the training phase.

B. Focus Game Score

To see the impact of P300-based Speller training, subjects played the Focus Game again. To determine whether the P300-based Speller Game contributed to enhanced motivation and focus of the subjects, the scores of the Focus Game were compared. Table II presents the improvement obtained in the Focus Game scores for all the subjects.

TABLE I
Training and Testing Classification accuracies for six subjects.

Subject	Training Accuracy (%)	Testing Accuracy(%)
A	99.9	99.7
B	99.5	99.4
C	99.6	99.6
D	99.6	99.8
E	99.4	99.4
F	99.8	99.9

TABLE II
Improvement in Focus Score for six subjects.

Subject	Improvement in Score (%)
A	20
B	2
C	2
D	10
E	4
F	7

In order to confirm if the improvement in the scores was statistically significant, the p-value was computed. The p-value of 0.03049 was obtained, which is much lower than 0.05, thus indicating the results obtained are statistically significant.

IV. Conclusion and Future Work

As can be seen from the results, training of the subjects via P300-based Speller Game helps improve their focus and attention. For all the subjects, there was an improvement in the Focus Game score after the training phase. The authors plan to consider three future directions, as follows.

- In this study, subjects were not given any feedback while they were training via the P300-based Speller Game. It is being anticipated that giving subjects neurofeedback while they are training, will have a very strong positive impact on the overall performance. The authors plan to implement neurofeedback as a part of the future work.
- The EEG data recorded during the focus game was not analyzed and thus is another potential candidate for the future work. With the analysis of this data, we may be able to find out what changes in the brain activity lead to such improvements.
- The EEG data recorded in this study does not specifically consider which brain areas were activated during EEG recordings. In our future work, we plan to record the brain areas that get activated during the focus activities. Let us say if only a few channels are being activated then instead of using all the 16 channels as done in this study, we only need to use those channels. This will reduce the setup time of data recording using EEG cap. Lesser data will make analysis quicker and comparatively easier and will allow for data collection from more subjects.

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This study has the potential to make significant contribution to the field of education and technology by providing insights on how the P300-based Speller Game can be effectively used to enhance students' focus and attention. The results of this study could lead to the development of new educational tools and methods that utilize BCI technology to improve student engagement and performance in the classroom. Ultimately, our goal is to make learning a more interactive and effective experience for students.

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