Design of an Online EEG based Neurofeedback Game for Enhancing Attention and Memory

Kavitha P Thomas, A. P. Vinod and Cuntai Guan

Abstract—**Brain-Computer Interface (BCI) is an alternate communication and control channel between brain and computer which even enables an individual to play computer games through thoughts. This paper proposes an Electroencephalogram (EEG) based neurofeedback game that allows the player to directly employ his attention based brain signals to control the game. The proposed game protocol requires the player to memorize a set of numbers in a matrix, and to correctly fill the matrix using his attention. The attention level of the player is quantified using sample entropy features of EEG. The statistically significant performance improvement of five healthy subjects after playing a number of game sessions demonstrates the effectiveness of the proposed game in enhancing their concentration and memory skills.**

I. INTRODUCTION

Brain-Computer Interface (BCI) establishes a direct communication channel between the brain and the computer, bypassing brain's normal communication pathway of nerves and muscles [1]. BCI is potentially an ultimate device to help people with motor disability as this technique can decode user's intention from brain signals. Among the many invasive and non-invasive brain signal measurement techniques developed so far, Electroencephalogram (EEG) is the most commonly adopted non-invasive method in BCI because of its high temporal resolution, ease of use, low cost and portability [2]. Though EEG based BCI systems have initially been targeting rehabilitation of disabled people, recently there is a widespread interest in its applications for healthy people as well, especially in the development of BCI based games [3]. Using BCI, the usage of keyboard, mouse or joystick in traditional videogames can be replaced by EEG signals.

BCI games depend on a neurofeedback strategy, which is the self-regulation of an individual's brain activity based on the real time visual/auditory feedback of his brain patterns [4]. This enables the individual to learn how to change his physiological activity for improving the performance. Neurofeedback utilizes operative conditioning principles by selectively enhancing or suppressing frequency, location, amplitude or duration of a specific EEG activity which allows subjects to maintain their brain state in a specific condition and to improve their cognitive function through training [5]. Several studies have revealed the therapeutic effect of neurofeedback training in treatment of neurophysiological disorders such as attention deficit hyper-active disorder (ADHD) [4, 5]. Improvement of certain cognitive aptitudes of healthy users has also been reported in [6] as a result of neurofeedback training. As attention is a key determinant for human cognition, most of the current neurofeedback games employ attention related EEG feature as the control parameter [3]. Attention level of an individual can be recognized using band power features in the theta (4-8 Hz), alpha (8-12 Hz) and beta (13-30 Hz) bands of EEG [1], fractal dimensional features [7] and entropy based features [8], which reveals complexity of brainy better than the spectral features.

In this paper, we propose a neurofeedback game where the player uses his attention to control the game and to win points. As reported in [8], the attention level of the player is identified by using sample entropy features of EEG signals. The proposed neurofeedback game is designed such that it requires player's selective attention, sustained attention and working memory to win the points. According to the study in [5], the behavioural indications of inattention not only correspond to a single psychological construct, but also combine features of sustained attention, selective attention and active working memory.

The rest of this paper is organized as follows. Section II describes the proposed methodology. The interface design and gaming protocol are given in Section III. Section IV depicts the experimental set up and Section V presents the results and analysis of the experiments done. Section VI concludes our paper.

II. PROPOSED METHODOLOGY

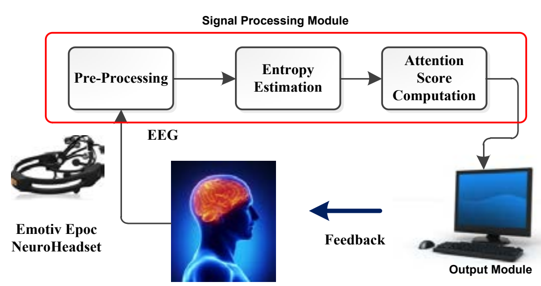

Fig. 1 Proposed neurofeedback BCI system.

The schematic of the proposed BCI system is shown in Fig. 1. It is composed of 4 modules named as (i) EEG acquisition module, (ii) Signal processing module that consists of preprocessing, entropy estimation and attention score computation stages, (iii) Output module and the (iv) System controller for integrating all the modules. The various modules are explained in this section.

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A. Data Acquisition Module

Data acquisition module consists of a wireless headset named as Emotiv Epoc Neuroheadset [2] for recording EEG as shown in Fig. 1, and a software package for the preliminary processing of data. This module is responsible for measuring EEG signal from scalp using electrodes, passing the signals to the computer software, preliminary filtering (notch filtering at 50 Hz and bandpass filtering of 0.2-45 Hz), and analog to digital conversion. The sampling frequency of signals is fixed as 128 Hz [2, 9].

B. Signal Processing Module

The signal processing module consists of 3 sub-modules named as pre-processing unit, entropy estimation unit and attention score computation unit.

(1) ***Pre-processing Stage***: The pre-processing unit is responsible for fine tuning the raw signal obtained from the headset for further processing. For every EEG channel recorded, the baseline correction of the incoming data is done by subtracting the mean of the signal just prior to the onset of any active attention task.

(2) ***Entropy Estimation***: EEG signal from the pre-processing unit then undergoes the entropy estimation stage. Entropy is the rate of information production [8]. It is the measure of complexity of a signal which increases with the degree of disorder. EEG activity during attention is slightly more complex than that in inattention task, and entropy of EEG signal during attention tasks are found to be greater than inattention task in [8]. Sample Entropy (*SampEn)* features have been used in [8] in order to quantify the attention during motor imagery. Hence, our work employs the *SampEn* features of EEG to measure the visual attention of subject and to play game. *SampEn* is the negative natural algorithm of the probability that 2 sequences for *m* points in a time series remain similar at the next point, where self matches are not included. The detailed procedure for computing entropy is provided in [8].

(3) ***Attention Score Estimation***: After estimating the *SampEn* features of all EEG channels, the attention score is computed as the average of *SampEn* values obtained from all channels as given in Eqn. (1) where P is the total number of channels.

$$AttentionScore = \frac{1}{P}\sum_{ich=1}^{P} SampEn^{ich} \qquad (1)$$

C. Output Module

The obtained attention score is fed as the control input of the Graphical User Interface (GUI) of the proposed neurofeedback game which forms the output module of the BCI system. Details of gaming protocol, the interface and control mechanisms are explained in Section III.

D. System Controller Module

The system controller integrates all the modules in the system by initializing and controlling the data acquisition, signal processing, data integration and transmission of messages from Emotiv to GUI in a synchronized manner. The output from the signal processing module is a quantified score value which is integrated with the GUI in real time using C#.

III. PROPOSED NEUROFEEDBACK GAME

The brain actuated GUI is the essential component of the proposed neurofeedback game. The GUI protocol is designed such that player has to focus on a set of numbers displayed in the form of a 3 x 3 matrix textbox, memorize them and to correctly re-fill the matrix. Subject is able to refill the matrix correctly only if his attention level crosses a specific threshold. This attention level; the control parameter of game is continuously provided in the form of a progress bar in the GUI which forms the core neurofeedback in the game. This information continuously helps the user to regulate his concentration to make its value greater than the threshold level. At first, a vacant 3 x 3 matrix textbox is presented to the player. The subsequent procedure is described in steps (a) to (d) as follows:

a. Based on the player's selection of Level-1, Level-2 or Level-3 button, the screen displays 3, 4 or 5 matrix elements (numerals) respectively. Level-1 is the least difficult level with the least number of elements (3), Level-2 is the medium difficult level with 4 elements and Level-3 is the most difficult level with highest number of elements (5). The difficulty level increases with the number of matrix elements displayed as the player has to memorize the numerals and correctly re-fill the matrix when the textboxes becomes empty after a few seconds. The 3 difficulty level buttons are shown on the left side of GUI and Fig. 2 is an example of the GUI snapshot corresponding to Level-3.

b. The button on the lower panel, labeled "click here to start the brain matrix game", is for requesting the system controller to initiate the communication between Emotiv Epoc headset and GUI. Attention scores are passed to GUI for game control when this button is activated.

Fig. 2 Proposed GUI during Level-3matrix display.

c. The matrix elements will be displayed for 2 sec during which the user has to memorize the numerals and their respective locations in the 3x3 matrix in order to correctly re-fill the matrix later. After the display period of 2 sec the textboxes will turn blank for a period of 4 sec.

d. At the end of the 4-sec blank display period, the system highlights the previously displayed textboxes one by one, by a dot at its center for a duration of 4 seconds as in Fig. 3. This stage requires active concentration of subject and for which he is requested to focus on a specific point on the screen. If the subject is able to raise the attention above a subject-specific threshold value which is computed during training phase before playing the game, two arrows will appear on the screen indicating the player that his attention is well enough and the answer selection can be done. The textboxes on the right and left side of the 3 x 3 matrix is meant for displaying the answer options ('8' and '5' respectively for the example shown in Fig. 3). One of the text boxes will display correct answer (left-side text box which displays '8') whereas wrong answer is placed on the other (right-side text box which displays '5'). The location of answer placement is randomly chosen.

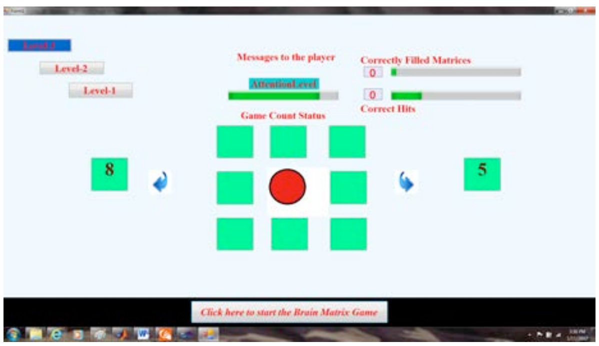

Fig. 3 Snapshot of GUI during answer selection process.

e. Answer selection in the left/right textbox is done by pressing left/right arrow button in the keyboard respectively. If he selects the correct answer, the game point is incremented by 1.

f. If the subject selects correct answer, a smiley appears on the textbox where the answer was placed. Then, the subject has to move the smiley by concentrating on the smiley or a specific point on screen, to the highlighted textbox. The game is designed such that speed of smiley is directly proportional to the attention of subject. If all the elements in the matrix are filled correctly, then the player wins that round of game and the numbers of correctly filled elements and matrices are also made visible to the player in form of progress bars as in Figs. 2 and 3.

g. If the attention level of the subject is not above the threshold, the arrow keys won't appear on the screen as in Fig. 3, and the subject will not be able to do the answer selection using keyboard. Subsequently the GUI will highlight the location of next element.

IV. EXPERIMENTAL SETUP

All the experiments were done in a silent room so that no other distractions were allowed while playing the game. Five healthy subjects have volunteered to play the game. During the experiments, the subject has been sitting in armchair, facing the computer monitor at about 60 cm apart. Ten EEG channels have been recorded from the scalp to compute the entropy of the attention tasks and they are AF3, F7, F3, P7, O1, O2, P8, F4, F8 and AF4 according to 10-20 international system of EEG electrode placement. The experiments consisted of 2 major sessions - training and testing sessions.

A. *Training session*

At first, every subject has to undergo a short training session of 10 trials for computing the subject-specific threshold which is used to assess his attention level while playing the game online. During this session, the subject wass requested to sit in an upright position wearing the Emotiv headset and to refrain from eye and muscle movements.

Each trial composed of 3 phases such as preparation, concentration and rest phases. Preparation phase lasted for 5 sec. It is the idle phase during which active concentration to any specified point on the screen is avoided. In the concentration phase, user actively concentrated at a specified location on the screen. This phase requires complete focus and attention of the subject regardless of the surrounding environment or objects. The time duration for this phase is 8 sec. Rest phase for duration of 5 sec is the relaxation phase during where the subjects are free to divert their focus from the point on the screen. Offline analysis of the data was done to estimate the entropy values of the EEG signal from all channels during the active concentration period. Then the average of all channels in 10 trials was taken as the subject-specific threshold.

B. *Online Testing sessions*

After determining the subject-specific threshold, the subject starts playing the game in real time. In the online experiments, 3 sets (sessions) of game are played for all the 3 difficulty levels. Each session requires the player to repeat the matrix filling operation 6 times. It implies that for difficulty levels 1, 2 and 3, the maximum points that can be achieved by the subject are 18, 24 and 30 respectively.

V. ANALYSIS IS AND RESULTS

In all the 5 subjects, enhancement of performance in terms of attentions skills and memory power has been observed after playing the game. The impact of the proposed game are evaluated using:

(a) Percentage accuracy of filling the matrix elements,
(b) Number of completely filled matrices,
(c) Time taken to place the smiley back to the highlighted text box position, and
(d) Ability of the player to sustain his attention above threshold for longer periods of time.

The percentage accuracy of filling the matrix elements for all subjects over 3 sessions is plotted in Fig. 4 (a)-(c) for Level-1, level-2 and Level-3 respectively. It is found that for all subjects, this index increases significantly across sessions where the statistical paired t-test provided a p- value of 0.005 comparing the first and last session of all subjects.

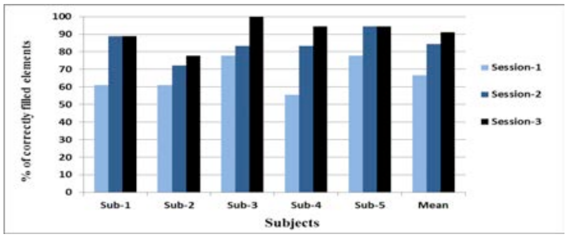

Fig. 4 (a) Accuracy of filling the matrix for difficulty Level-1.

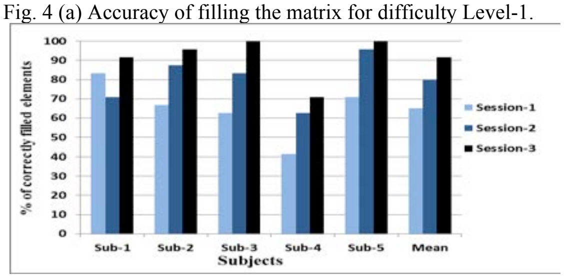

Fig. 4 (b) Accuracy of filling the matrix for difficulty Level-2.

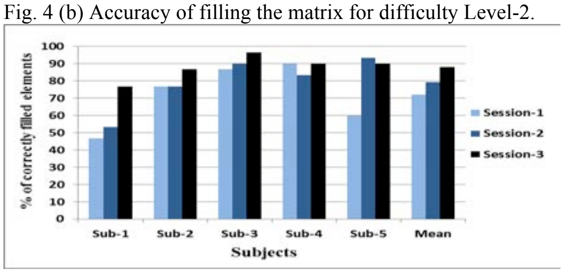

Fig. 4 (c) Accuracy of filling the matrix for difficulty Level-3.

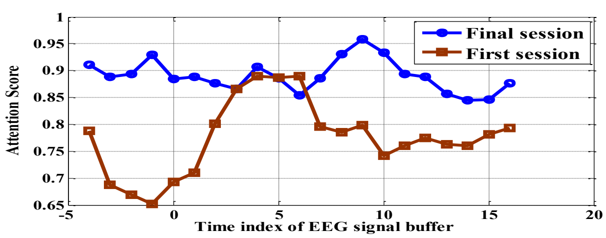

Fig. 5 Variation of attention scores in the1[st] and last session for Subject-1.

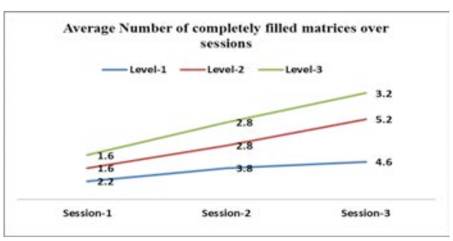

Fig. 6 Change of number of correctly filled matrices across sessions.

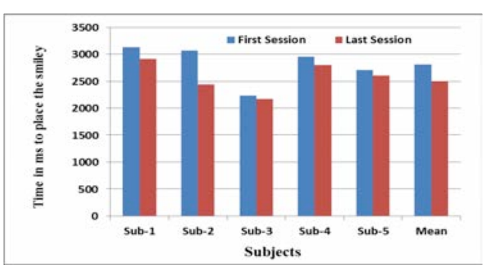

Fig. 7 Change of average time taken to place the smiley to textbox.

The attention score values in the first and last session for Subject-1 are also plotted in Fig. 5 for evaluation. The sustained attention scores of EEG signals show the clear picture of significantly improved sustained attention of the player in the final session compared with the first session of the experiments. Also Fig. 6 shows the average number of correctly filled matrices in difficulty levels 1, 2 and 3 for all subjects. Across the sessions, the graph explicitly shows the increment in the enhanced memory power of the subjects. The game protocol design also requires the player to put the smiley to the highlighted textbox using his attention. The smiley takes less time if the subject concentrates well. The average time taken by the subject in the first and last sessions of game is plotted in Fig. 7. The results show that all the subjects completed the task successfully in a shorter time during the last session compared to the first sessions, which is a clear indication of performance improvement with game practice. The evaluation of the results show that performance of healthy subjects can be improved significantly by playing the proposed attention driven game. Hence, this game could be a potential tool for boosting the cognitive skills of ADHD children.

VI. Conclusion

EEG based neurofeedback therapy is considered as a promising candidate for boosting the cognitive skills of children with ADHD. This paper proposes a new neurofeedback based game which is designed to enhance the working memory and attention skills of players. The experimental analysis of 5 healthy subjects shows significant performance improvement in terms of visual skills for five healthy subjects. More analysis is required in future to explore the impact of this game on children with ADHD.

VII. References

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