A Study on the Impact of Neurofeedback in EEG Based Attention-driven Game

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Abstract**—**Multi-disciplinary study of human computer interaction has provided significant impact in the fields of neural engineering, cognitive neuroscience, rehabilitation and brain-computer interaction. This paper evaluates the impact of neurofeedback in the context of a simple computer game controlled by attention based brain signals. The designed game protocol requires the player to memorize a set of numbers displayed in a matrix format, and to correctly fill the matrix using his attention based brain patterns. Attention level of the player, quantified using sample entropy values of Electroencephalogram (EEG) signals, is the core control parameter of the game. A comparative study using a single neurofeedback group and 2 control groups (each group consists of 8 subjects) has been carried out to examine the impact of neurofeedback on enhancing attention score and cognitive skill in the context of the attention-driven game. Experimental results explicitly demonstrate the significance and usefulness of neurofeedback in EEG based games.

Keywords—Neurofeedback, attention, cognitive skills, entropy and EEG.

I. INTRODUCTION

Neurofeedback training is a biofeedback modality that allows self-regulation of specific brain rhythms of an individual by means of an operant conditioning paradigm [1]. The basic working principle of this technology consists of recording the brain activity, decoding or identifying the brain patterns of interest, and providing user with relevant feedback stimuli based on the current/required working levels of their brain rhythms [2]. On account of the received visual/auditory feedback of an individual's brain patterns, neurofeedback allows the self-regulation of his/her brain activity in real time [3]. Neurofeedback selectively enhances or suppresses frequency, location, amplitude or duration of a specific EEG activity which allows users to maintain their brain state in a specific condition and to improve their brain functions through training [1]. Several studies have revealed the therapeutic effects of neurofeedback training to treat variety of neurological and psychological disorders such as attention deficit hyperactivity disorder (ADHD) epilepsy, anxiety and depression and in the rehabilitation of locked-in patients too [4-8]. Furthermore, this training has also been applied to healthy users for demonstrating its ability to improve certain cognitive aptitudes [4, 9, 10]. Neurofeedback based training systems typically employ Electroencephalogram (EEG) based brain signal measurements as it is relatively cheap, portable, convenient and has a low set-up cost compared to other non-invasive techniques such as functional Magnetic resonance Imaging (fMRI), functional Near Infrared Spectroscopy (fNIRS) and Magneto encephalography (MEG) [11].

As a result of EEG-based neurofeedback training in a group of healthy people, improvements in certain cognitive aptitudes of brain have also been reported in [9, 12]. Majority of neurofeedback studies focus on frequency training method of brain signals that involves enhancement or inhibition of EEG activity present in its specific frequency bands, namely delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz) an gamma (>30 Hz) bands. Improved cognitive and behavioural performance after frequency training of Slow Cortical Potential (SCP) of EEG signals in theta/beta bands of children with ADHD have also been reported in [13]. Traditionally, in neurofeedback systems, the subjects are trained with visual or auditory feedback of their EEG to control their brain activity to a desired state. But, if the feedback signals are presented in the framework of a computerized game, user feels more motivated and rewarded and does not get bored or frustrated easily [4].

A number of EEG based games are available in literature and many of them employ attention related EEG feature as the control parameter, as attention is a key determinant for human cognition [11, 13]. It is reported that player has to decrease his slow wave EEG activity (delta/theta) and/or increase his fast wave activity (alpha/beta) in his brain signals for achieving attention/cognitive enhancement [12]. However, the complexity of frequency-specific correlation between EEG activity and cognition makes it extremely difficult to clarify a priori the cognitive objectives of an inhibition or stimulation protocol of the EEG activity in a specific frequency band. Besides, when a person's attention level is high, his brain's neuronal networks process higher amount of information and the resulting EEG signals are reported to be more complex [14]. Therefore frequency-specific band power features may not fully reveal the whole complexity of the brain activity always [15]. More advanced features such as entropy values might better extract the nonlinear properties of non-stationary EEG signals. The study in [16] reports the superior classification performance of sample entropy features of EEG

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for assessing different levels of attention compared to linear power spectrum parameters and other popular non-linear parameters such as approximate entropy.

Motivated by these facts, sample entropy based features of EEG have been employed for quantifying attention successfully in our neurofeedback game reported in [17]. It proposes a simple matrix based memory game where the player employs his attention based EEG signals to control the game protocol and to win points. Using this game, it has also been investigated in [18] that whether performance enhancement is achievable through a number of training sessions. The experimental results in [18] show that the adopted neurofeedback training paradigm instigates the player to improve his entropy scores, enhance attention level and achieve higher points in the game. The current study presented in this paper specifically evaluates the impact of controlling the same game using traditional keyboard inputs, without providing any neurofeedback to the player and compares the obtained results with performance reported in [18].

The rest of this paper is organized as follows. Section II describes the neurofeedback system employed in this work. The details of the experiments conducted are given in Section III. Section IV analyses experimental results. Section V concludes our paper.

II. Methodology

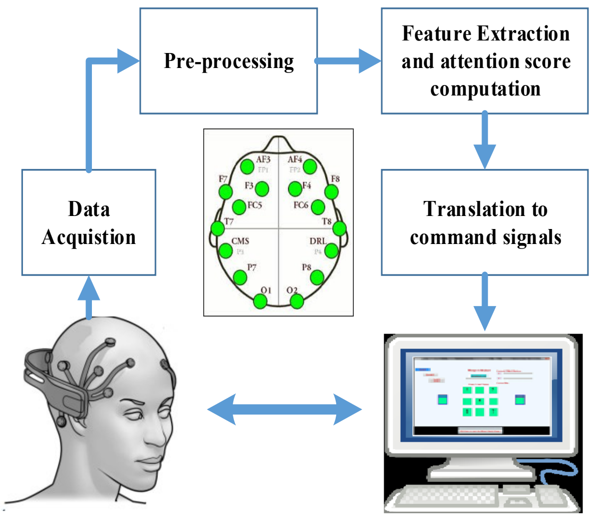

Fig. 1 Schematic of the neurofeedback system.

The schematic of the neurofeedback system for performing the attention driven game is shown in Fig. 1. The various modules are explained in this section.

A. Data Acquisition

Data acquisition module consists of a wireless headset named Emotiv Epoc Neuroheadset [19] for recording EEG signal from scalp, 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 0.2-30 Hz), and analog to digital conversion.

B. Signal Processing Module

The signal processing module consists of 3 stages namely pre-processing, entropy estimation and attention score computation stages.

1) Pre-processing Stage

The pre-processing stage is responsible for fine tuning the raw signal obtained from the headset for further processing. For every EEG channel recorded, baseline correction of the incoming data has been performed at all time-points. This is to nullify the effect of possible time-domain shifts of EEG from zero line over time due to various noise resources, and to ensure that an observed effect is not already present in the signal before the stimuli were actually present. EEG signal recorded from all EEG channels for duration of 2 seconds (256 samples) just prior to the instant of providing the game matrix on the computer screen is considered as baseline in this work. For each recording channel, the mean signal over this interval is computed and subtracted from the signal at all time-points after this instant.

2) Feature Extraction and attention score computation

EEG signal from the pre-processing unit then undergoes the entropy estimation stage. Entropy is the rate of information production [15]. It is the measure of complexity of a signal which increases with the degree of disorder in the system. It has been reported in literature that EEG activity during attention is slightly more complex than that in inattention task because of the increased firing rates and synchrony in neuronal circuits. Hence, entropy measures of EEG signals during attention tasks are reported to be higher than inattention task [20]. Out of the two types of entropy measures: Approximate Entropy (*ApEn*) and Sample Entropy (*SampEn*) available in literature, *SampEn* is more suited for biological time series signal because of its independency on data length and more consistency than that in *ApEn*. As *SampEn* features have also been reported as robust feature for for quantifying the attention level from EEG, our work also employs the *SampEn* to measure attention [15, 16].

After estimating the *SampEn* features of all EEG channels, the attention score is computed as the average of *SampEn* values obtained from all channels. Then, the translation module maps the attention score values to command signals as explained in [17].

C. Output Module

The brain signal controlled Graphical User Interface (GUI) is the essential component of the output module. 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 using his attention based EEG signals. At first, a set of vacant textboxes in the form of a 3 x 3 matrix are presented to the player in the GUI. Based on the player's selection of Level-1, Level-2 or Level-3 buttons provided on the gaming interface, the computer 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) in a single matrix. Each game session requires the player to repeat the matrix filling operation 6 times. It implies that the maximum points that can be achieved by the subject are 18, 24 and 30, for difficulty levels 1, 2 and 3 respectively [17].

Game is designed such that it can be played either in 'neurofeedback' mode or 'general' mode. In 'neurofeedback' mode, subject is able to refill the matrix correctly only if his attention level exceeds 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 element in the game. In 'general' mode, player can do the answer selection only by keyboard inputs. No neurofeedback will be provided. Details of gaming protocol, GUI and control mechanisms are explained in [17].

D. System Controller

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. EXPERIMENTS

All experiments are done in a silent room so that no other distractions are allowed while performing them. Details of EEG data collection, subjects and experiments are as follows.

A. Data Collection

During the experiments, the subject has been sitting in an armchair, facing the computer monitor at about 60 cm apart. Ten electrode locations namely AF3, F7, F3, P7, O1, O2, P8, F4, F8 and AF4 according to 10-20 international system of EEG electrode placement have been used to record EEG and to compute the entropy. This is based on the validity of similar channel selection reported in [14]. EEG signals are measured with Emotiv Epoc neuroheadset. During experiments, subjects are instructed to refrain from voluntary eye movements and muscle movements, to eliminate artifacts.

B. Subjects

Table 1 Details of subjects

Specifications	Groups		
	NFG	CG-1	CG-2
Number of subjects	8 (3 females and 5 males)	8 (2 females and 6 males)	8 (3 females and 5 males)
Age group	29.6±2.4 yrs	27.1±3.2 yrs	19±2.5 yrs
Game play	Yes	No	Yes
EEG recording	Yes	No	Yes
Neurofeedback	Yes	No	No
Cognitive test	Yes	Yes	Yes

24 healthy subjects have volunteered to take part in the experiments. The enrolled subjects have been divided into 3 groups where each group consists of 8 subjects. Distinct groups are created for the purpose of exactly identifying the specific effect of neurofeedback on enhancing attention/cognitive skills of players. The first group, referred to as neurofeedback group (NFG), played the proposed neurofeedback game for a fixed number of days. Cognitive tests have been conducted for NFG on first and last day of the experiment. The second group, referred to as control group-1 (CG-1), performed only cognitive tests on first and last day of the experiment, and was not provided any neurofeedback. The third group, referred to as control group-2 (CG-2) played the proposed game for the same number of days as that in NFG, but game control was solely done by computer's keyboard. No neurofeedback has been provided for CG-2 (attention bar has been removed from the game GUI), but their EEG signals and attention scores during the game have been stored for further analysis. Cognitive tests have also been conducted on first and last days. None of the subjects in CG-1 and CG-2 had previous neurofeedback experience. Control participants were asked not to expose themselves to exceptional stress. Particulars of each group have been described in Table 1.The experiments consist of 2 major sessions: calibration (for NFG) and testing sessions (for NFG, CG-1 and CG-2).

C. Calibration

At first, every subject in NFG has to undergo a short calibration/training session of 10 trials for computing the subject-specific threshold which is used to assess his attention level while playing the game online. Each trial composes of 3 phases such as preparation, concentration and relaxation 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. Offline analysis of the data has been done to estimate the entropy values of the EEG signal from all channels during the active concentration period. A threshold value is computed for each subject using the entropy values estimated during concentration and relaxation phases of the training data as explained in [17]. It is expected that subject is able to attain a score that is higher than this threshold value, whenever he/she concentrates well.

D. Testing

For NFG, the test experiment is designed and conducted for investigating whether the players are able to improve their performance after a few days. In order to examine this, 5 game sessions have been conducted for each subject within the same week from Monday to Friday with one game session each day. Within one session, the subject is required to play one set of Level-3 game. The feasibility of improvements in attention score, subject-specific threshold set in the game and cognitive skills have been reported in [18]. In order to assess the impact of neurofeedback on cognitive skills, cognitive tests have also been performed on the Monday and Friday. We used a cognitive test that is publically available online, designed for checking subject's attention, working memory and cognitive skills [20]. It also requires answer selection using keyboard inputs as similar to the EEG based game.

During the test, subjects are encouraged to place their index fingers of both hands on the left and right arrow keys in preparation for a response while he/she is presented with a word and picture on the computer screen. If the word correctly represents the picture, the player has to respond 'YES' by pressing the right arrow key in the computer keyboard and if they are different, left arrow key has to be pressed to convey 'NO' to the computer. For example, if the word 'CAT' and the image of a dog appears on the screen, the player has to press left arrow key for correct hit because the word ('CAT') does not represent the image ('DOG'). But, if the word 'REVERSE' appears along with word and image pair, the player has to reverse the strategy of responding answers. When 'REVERSE' is displayed, if the word and object are the same, the player has to answer 'NO' with left arrow key. If the word and object are different, answer 'YES' with right arrow key. For completing the test, the player has to respond to set of 20 trials. Fig. 2 shows snapshots of 4 trials given in the cognitive test where the correct answers are YES, NO, NO and YES respectively for options in (a), (b), (c) and (d). For completing the test, player has to respond to 20 trials.

Fig. 2 Examples of trials in the cognitive test employed.

The objective of the test is to get as many correct answers as fast as possible. At the end of this test, the user will be provided with a graph showing the obtained cognitive score, average time taken for answer selection, its standard deviation and percentage of correctly performed trials. The cognitive score achieved is a weighted measure obtained from the correct/incorrect choices with reaction time, representing the attention/cognitive skill of the tested subject. This test has been developed in the Institute for Neural Computation at the University of California at San Diego, and is intended to support standardized cognitive health assessments for all ages and to improve quality of life [20].

IV. EXPERIMENTAL RESULTS AND ANALYSIS

In order to evaluate the relative performances of subjects in 3 groups, the main performance indices utilized in this study, the attention and cognitive scores have been compared here. Effect of neurofeedback on attention scores is discussed by comparing NFG with CG-2 and effect of neurofeedback on cognitive enhancement is discussed by comparing performances of NFG, CG-1 and CG-2.

A. Attention enhancement

All subjects in CG-2 played the matrix game using keyboard inputs for 5 days and it is found that game points for most of the subjects increase slightly over time giving an average accuracy of 93 % on Day-5 whereas it is 91 % on Day-1. But it is noted that the attention scores computed from EEG slightly decreases over time. Fig. 3 shows the average attention score and its standard deviation (SD) over 5 days. However, the statistical comparison of attention scores on Day-1 and Day-5 using Wilcoxon non parametric test provides *p*-value of 0.06, showing that the decrease is not significant.

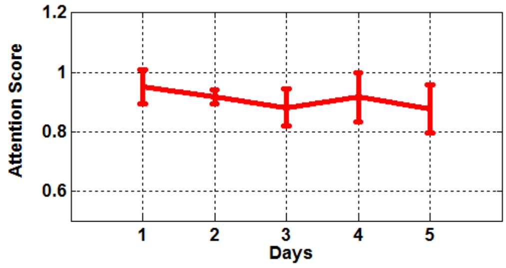

Fig. 3 Average attention score and its SD of 8 subjects over 5 days.

In order to compare CG-2 with NFG, mean and SD of attention scores obtained on Day-1 and Day-5 of CG-2 and NFG are plotted together in Fig. 4. Attention score increases in NFG whereas it decreases in CG-2. In CG-2 and NFG, subjects were playing same game (even though the numerals vary over days) on all the 5 days by which players become more familiar with strategies in memorizing/refilling numerals. This reduction in challenge or interest and simplicity of the game design might have been reflected as a slight decrease in attention scores of subjects in CG-2 on Day-5. However the decrease is not found to be statistically significant. But it has to be noted that subjects getting neurofeedback based control of game are able to improve the attention scores and game performance greatly through training. In NFG, EEG based attention score has a direct control on the success of game which must have helped the players for enhancing their game scores over time.

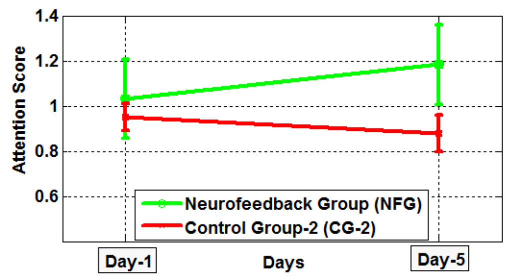

Fig. 4 Average attention score values and SD of NFG and CG-2.

B. Cognitive enhancement

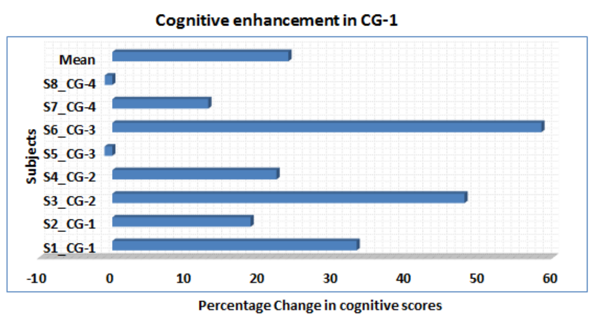

Fig. 5 Percentage change in cognitive scores for 8 subjects in CG-1.

Cognitive tests have been conducted for all subjects in CG-1, CG-2 and NFG on Day-1 and Day-5. The percentage change of cognitive scores on Day-5 compared to that of Day-1 for CG-1 are plotted in Fig. 5. Subjects are denoted as S1_CG-1, S2_CG-1, S3_CG-1, S4_CG-1, S5_CG-1, S6_CG-1, S7_CG-1 and S8_CG-1in the figure. The statistical comparison of obtained cognitive scores using Wilcoxon non parametric test provides *p*-value of 0.08.

For CG-2, the percentage change in cognitive test scores are shown in Fig. 6 where S1_CG-2, S2_CG-2, S3_CG-2, S4_CG-2, S5_CG-2, S6_CG-2 and S8_CG-2 stand for 8 subjects. The cognitive scores slightly improve, but the Wilcoxon parametric test provides a *p*-value of only 0.07.

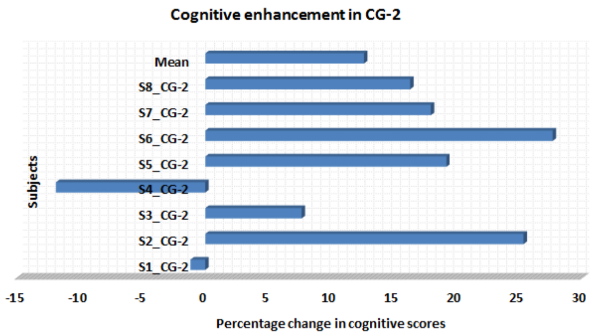

Fig. 6 Percentage change in cognitive scores for 8 subjects in CG-2.

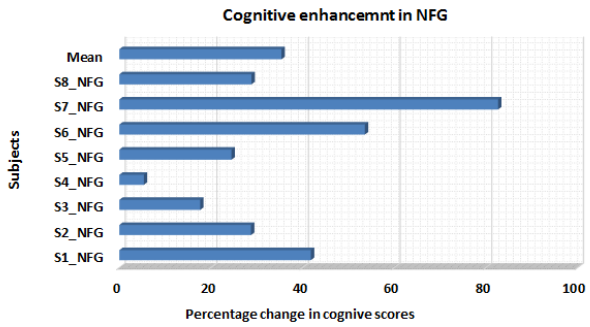

Fig. 7 Percentage change in cognitive scores for 8 subjects in NFG.

Fig. 7 shows the percentage changes in cognitive scores of NFG. All subjects, namely S1_NFG, S2_ NFG, S3_ NFG, S4_ NFG, S5_ NFG, S6_ NFG and S8_ NFG, perform better in the final session than first session. The statistical comparison of obtained cognitive scores on Day-1 and Day-5 using Wilcoxon non parametric test provides a *p*- value of 0.01. The statistical analysis shows that cognitive scores in NFG are significantly better whereas they are not significantly better in both CG-1 and CG-2. This explicitly shows the impact of neurofeedback on game play.

For better comparison, the mean and SD of the cognitive scores for all the 3 groups on Day-1 and Day-5 are plotted in Fig. 8. The slope for NFG is higher compared to that in control groups which indicates the influence of neurofeedback on cognitive skill enhancement. However, the incremental enhancement in NFG compared to those achieved in CG-1 and CG-2 is not statistically significant.

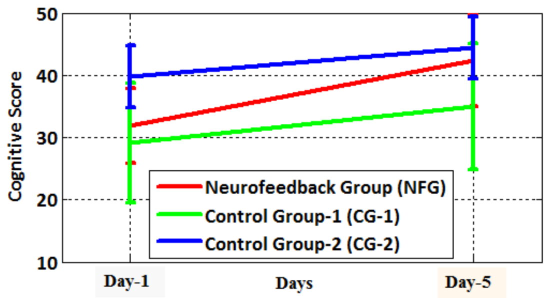

Fig. 8 Average cognitive scores and SD for CG-1, CG-2 and NFG.

As depicted here, results of test experiments show promising feasibility of neurofeedback on enhancing attention level and cognitive scores. However, the exact quantification of enhancements offered exclusively by neurofeedback is difficult in the scope of this work because of a number of limitations in this study for generalizing and identifying underlying complexity and connections in the neural dynamics of attention. The small group size (of 8 subjects in each group) is having a major influence on the results and their interpretation. Results would be more informative if more participants are added to every group and if their long-term game performance is noted. Besides, this work employs a simple technique, the average of sample entropy values computed from all EEG channels to estimate the attention level in a simple matrix based memory game. The employed methodology does not take care of possible channel-specific or frequency dependent variations in EEG in the current or more enhanced gaming environments. It is reported that attention directed towards stimuli activates different parts of the brain, especially the visual cortex, occipital area and parietal in distinct manner [2, 21]. More robust methods such as weighted measure of entropy features extracted from subject-specific frequency bands can be more effective for understanding complex brain dynamics and their association with cognition. Further investigation using higher number of subjects, more robust methods, precise training protocols and more creative gaming environments is essential to precisely quantify the effect of neurofeedback on EEG based games.

V. Conclusion

EEG based neurofeedback is considered as a promising candidate for boosting the cognitive skills of healthy as well as disabled people. This paper evaluates the impact of neurofeedback in the context of an attention-driven EEG based game and investigates its effect on improving attention and cognition of players. During the game, the player has to focus on a set of displayed numbers on a computer screen, memorize and re-fill them correctly using his attention related brain signals. The attention levels of all the players have been assessed using entropy based EEG features. The experimental analysis shows that the designed neurofeedback training paradigm explicitly helps the player to improve his entropy scores, to enhance attention level and to achieve better cognitive scores. In future, we will focus on developing long-term neurofeedback training protocols in better gaming environments; including large population of both healthy and attention-deficit subjects, for quantifying and evaluating the exact and extensive utility of neurofeedback on EEG based games.

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