Cognitive Assessment and Enhancement through Video Gaming using Brain Computer Interface (BCI)

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Abstract

Advancements in biomedical engineering with the use of electrophysiological signals for Electroencephalography (EEG) techniques have led to be more widely used in the diagnosis of brain diseases and in the field of Brain Computer Interface (BCI). BCI is an interfacing system that uses electrical signals from the brain (e.g. EEG) as an input to control applications such as video game. Attention, concentration is the indispensable basis for learning. We found that the attention of the students is reducing day by day. The case of attention decreasing can be found not only within students but also in adults. The aim of this work is to capture and analyze the EEG data from human brain and to enhance their cognitive skills like attention, concentration by giving 20 days mental training on BCI application. Three BCI enabled video games are played before and after the 20 days training session. Humans can control these games using their thoughts.

Emotiv headset is used to play the games and signals are recorded when person was playing games in a computer. BCI games are used for this experiment. These games are the special games developed for BCI experiment especially. Various BCI games are available on Emotiv site. These games can be connected automatically with Emotiv software in a computer. Emotiv TestBench software will be used to capture signals and it will also perform analog to digital conversion of the signals. Converted digital data will be processed through signal processing algorithms in Matlab.

Recorded EEG signals contain noise and artifacts. These artifacts have been removed using filters and desirable features are extracted from cleaned signals. The significance of the results is tested using SPSS (Statistical Product and Service Solutions).

Key words: Electroencephalography (EEG), Brain computer Interface (BCI), Cognitive Enhancement, SPSS

I. Introduction

The past two decades have seen an explosion of scientific interest in a completely different and novel approach of interacting with a computer. Inspired by the social recognition of people who suffer from severe neuromuscular disabilities, an interdisciplinary field of research has been created to offer direct human computer interaction via signals generated by the brain itself. Brain- Computer Interface (BCI) technology, as it is known, is a revolutionary communication channel that enables users to control computer applications

through thoughts alone. The development of the cognitive neuroscience field has been investigated by recent advances in brain imaging technologies such as EEG, Magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI). The growing field of BCI research is however in its infancy. First signs of BCI research can be dated back to the early 1970s. The work of Dr. J. Vidal and his military research group at UCLA is cited as the first successful BCI implementation endeavor.

In our study we are using electrophysiological signals to analyze brain using Electroencephalography (EEG). Electroencephalogram (EEG) is a non-invasive technique recording the electrical potential over the scalp which is produced by the activities of brain cortex and reflects the state of the brain. For achieving signals from human brain an array of electrodes attached to the scalp via conductive gel or paste is used to detect electrical activity produced by neurons firing within the brain. The resulting waveforms popularly referred to as " brain waves" , can be used to diagnose abnormal brain condition.

Three main EEG-related application fields have been researched for several years: a) BCI applications that help disabled people to communicate with machines; b) BCI applications for video games as game controllers; and c) Neurofeedback games. With the development of wireless EEG devices, expanding the EEG applications out of the lab became possible. In order to play EEG-based games, the user needs EEG electrodes and computer/playstation.

II. Motivation

The original motivation that inspired this line of research was to develop an alternative and Replacement communication technology for severely disabled people. For people who are ' locked-in' as a result of a severe neuromuscular disability, this may offer the only means of communication and environment control. Several rehabilitative communication systems have been developed over the years to compensate for this communication impairment, but most of these require some sort of limited movement ability in order to function. In the worst cases of the disabilities when the sufferers loose all voluntary muscle control but remain cognitively intact, harnessing brain activity is the only viable method of communication.

Despite the principal motivation being to offer a means of communication for individuals with neuromuscular impairments, more and more media attention has been attributed to exploring the full potential of this communication medium for the wider audience in areas such as Multimedia applications and video games.

III. Objective

The aim of this research was to gain an insight into the rapidly developing field of BCI research. Focusing on the EEG as the BCI input modality, the goal was to develop a deep understanding of the neurophysiological processes that could be exploited to implement a BCI system. After performing a state-of-the-art review of BCI systems, it was envisaged to design and implement a system. A sound knowledge of the data acquisition process, EEG waveform characteristics, signal processing methodologies for feature extraction and

classification is a prerequisite before attempting to design and implement a BCI system. The projects objectives can be summarized as follows:

1 .To analyze EEG signals recorded from human brain, based on some parameters like energy of signals, power of signals.

2. To compare pre experiment and post-experiment results after giving training to all the subjects.

3. To enhance cognitive functions like attention, concentration, and performance based on these results.

IV. Scope

The general intent of most BCIs is to operate a device or application by detecting small differences in brain signals. Therefore, almost every BCI system includes a set of tasks or capabilities that a user can influence by changing aspects of selected brain signals. Typical tasks intended for subject training include positioning a cursor, tracking a moving object, or selecting a target. Once these skills are acquired, the subject can progress to applications that perform real-world tasks such as communication, controlling the environment, or moving prosthetic limbs.

This technology will enable computers to analyze and predict what users are attempting to communicate. This technology can be helpful for mental state detection like frustration, confusion etc after analyzing brain signals.

Apart from above medical applications which in some cases might even be used for healthy users (e.g. Elderly care), entertainment is not the limit here. BCI can provide remote control in situational disability circumstances such as astronauts and surgeons to improve cognitive functions, such as improving attention etc.

V. Methodology

Experimental Design

Five Personnel out of twelve varying between ages of 20 to 23 yrs were selected for Experiment. Pre and Post Recording were performed. Both recordings comprised of Physiological recording which consisted of a 5 minute Base line recording (rest time).

A. Signal acquisition

In pre-experiment all the subjects played cortex arcade in which they tried to perform some actions using their thought on 3 games. For example in first game, they lifted a helicopter using his thought. Then signal are recorded in the TestBench software of Emotiv. In Training session the brain of each subject was trained by playing cube application. After 20 days in

post processing, the subject performs better than pre processing on BCI video games (Cortex Arcade).

Each subject participated in three sessions:

1. Pre experiment (20 minutes)-three games
   Game 1 lift action using thought-8 min
   Game 2 left and right action using thought-8 min
   Game 3 lift and drop action using thought-8 min
2. Training (around 30 minutes daily)
   Cube application including actions like push, pull, lift, drop, left, right etc using thoughts (5 min each) using thoughts
3. Post experiment (20 minutes)
   Same as pre experiment

B. Preprocessing

After preprocessing of interested channels, we decompose them in different EEG frequency such as Delta, Theta, Alpha, Beta and theta by Discrete Wavelet Transform **(**DWT). Wavelet decomposition was done with two motives in mind, firstly, to reduce the amount of relevant EEG signal being removed during the contamination removal process.DWT has recently been applied in wide range of signal processing applications and provides a flexible method of time-frequency representation of signals using flexible window sizes. In this paper we used forth order Daubechies (db4) up to fifth level to decompose EEG signals into its sub-bands, in DWT the each channel of EEG signal is passed through a half band digital low-pass filter (LP) and a half band high pass filter (HP). The lowest half band corresponds to all frequencies less than half of the highest frequencies in the input signal i.e. approximate (A) component. The highest half band corresponds to all frequencies higher than half of the highest frequency in the input signal i.e. Details (D) component. By Nyquist rule, half of the sampled are eliminated from the approximate and details components because they have half of the highest frequency of the input signal. Here the sampling frequency of recorded EEG signal is 128 Hz so at first level of DWT the approximate Component and details component will be (0-64) Hz and (64-128) Hz respectively.

C. Feature extraction

A crucial part of the extraction is to gather relevant features from EEG data. We selected relative wavelet energy from alpha band (8-16Hz). Wavelet transform decomposes a signal into small waves with energy concentrated in time called wavelets. Wavelets are the scaled and shifted copies of the main pattern, so-called the " mother wavelet" The mother wavelet function is defined by equation,

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad \ldots (1)$$

Where 'b' is a translation parameter and ' a' is a scale parameter to extract alpha band. We use discrete wavelet transform and dB4 mother wavelet. We decompose EEG data up to 4th level of decomposition. DWT analyses the signal by decomposing the signal into approximations and detail information by employing two functions: scaling and wavelet function as shown in equation. For a given signal x (t) the DWT decomposition can be represented by equation:

$$x(t) = \sum_{k=-\infty}^{k=+\infty} C_{N,k} \emptyset(2^{-N} t - k) + \sum_{j=1}^{N} \sum_{k=-\infty}^{k=+\infty} d_{j,k} 2^{-j/2} \psi(2^{-j} t - k) \quad \ldots (2)$$

Where CN, k represents approximation coefficients at level N, while dj, k (j = 1 to N) represents detailed coefficients or wavelet coefficients at level j. ψ(t) is the wavelet function, while φ(t) is a companion function, named as scaling function.

1. **Relative Energy**

RWE gives information about relative energy with associated frequency bands and can detect the degree of similarity between segments of a signal. RWE is defined by the ratio of detail energy at the specific decomposition level to the total energy. Thus the relative energy is given by:

$$RWE = E_j / E_{total} \ldots\ldots (3)$$

RWE resolves the wavelet representation of the signal in one wavelet decomposition level corresponding to the representative signal frequency. Thus this method accurately detects and characterizes the specific phenomenon related to the different frequency bands of the EEG signal. RWE gains an advantage over DWT based feature extraction in terms of speed, computation efficiency.

2. **Power spectral density**

The goal of spectral estimation is to describe the distribution (over frequency) of the power contained in a signal, based on a finite set of data. Estimation of power spectra is useful in a variety of applications, including the detection of signals buried in wide-band noise. The power spectral density is calculated in units of power per radians per sample.

The method is based on the concept of using periodogram spectrum estimates, which are the result of converting a signal from the time domain to the frequency domain. Maximum psd of theta band is extracted.

For calculating power Welch function in Matlab is used for estimating the power of a signal at different frequencies, that is, it is an approach to spectral density estimation.

Numerically Welch method is similar to Bartlett's, but with an additional index, and scaling factor:

$$S(\omega) = \sum x(n)\, w(n)\, e^{-2(\omega/\omega s)\, n} \ldots..(4)$$

$$I_{xx}(\omega) = 1/LU|S(\omega)|^2 \ldots\ldots (5)$$

$$U = 1/L\sum|w(n)|^2 \ldots\ldots.. (6)$$

Where *S (ω)* is the windowed DFT, Ixx is the spectral estimate, and U is the normalizing factor, based on the particular windowing function.

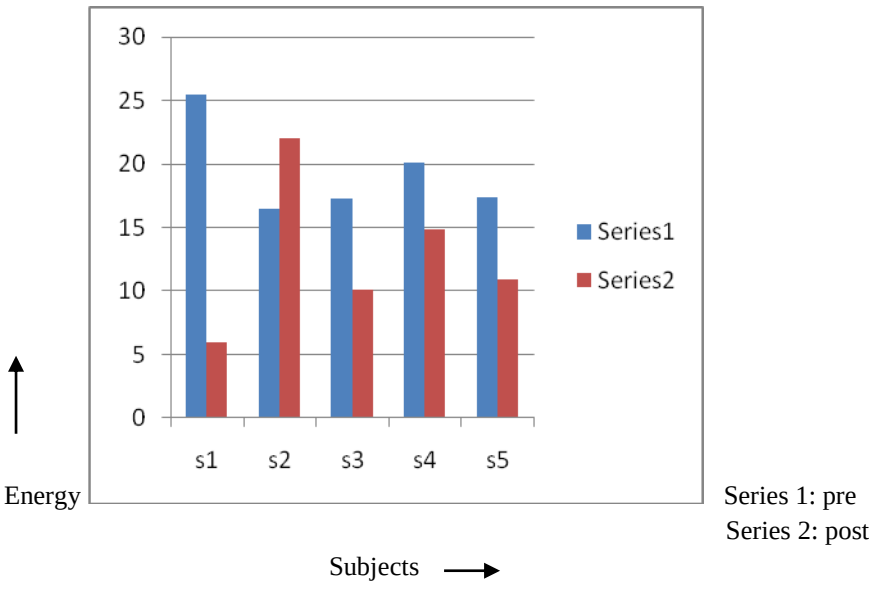
D. Result

In this chapter, we present the analysis of the recorded data and the final results of the study. The major part of the chapter focuses on the results of the experimental condition, when the subject plays the three BCI games using thought control process.

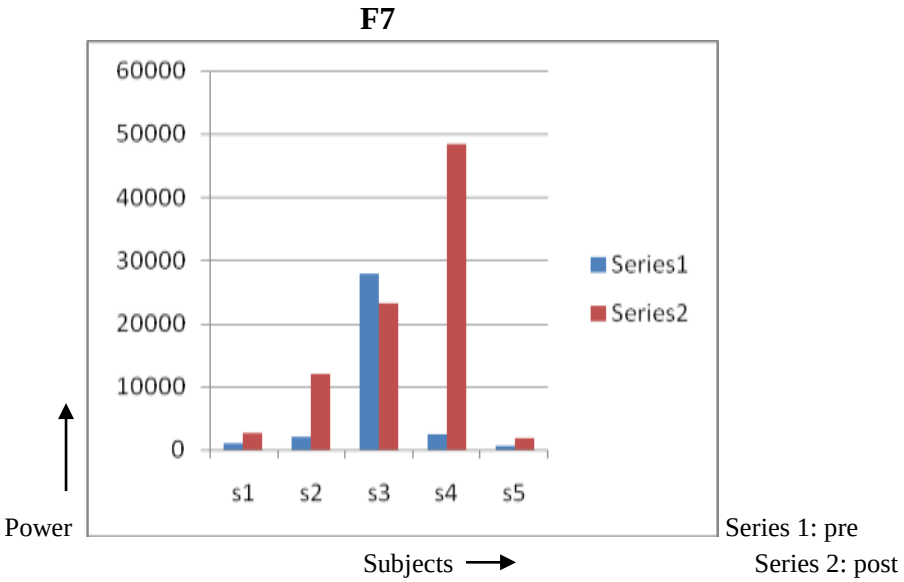
1. Channel Selection

Among the 12 channels three channels F7, F8, and FC5 are selected. In 80% of subjects, theta power was increasing for F7 channel, alpha energy was decreasing for F7 and F8 channels and beta energy was decreasing for F7 and FC5 channels. But after using Spss. we found that the results of FC5 are not significant. So we are focusing only on Channel F7 and F8 for alpha and theta.

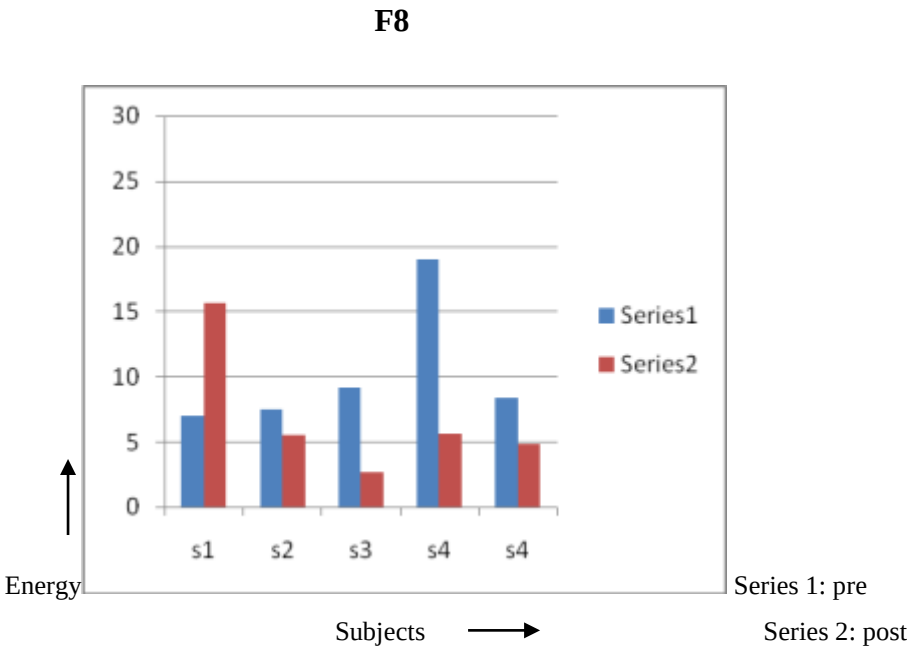
F7



(a) Alpha energy



(b) Theta power



(c) Alpha energy

Figure8.1: illustration of pre and post selected features (a) pre and post alpha energy on F7, (b) pre and post theta power on F7, (c) pre and post alpha energy on F8

2. Significant results using SPSS

The relation among Pre and post results and training results is investigated using correlation and ANOVA in SPSS tool. Lift action of gaming is compared with the lift action of training application. Left and right action of second game is compared with left and right action of training and lift and drop action of third game is compared with the lift and drop action of training. The results are as follows:

Table 2.1: significant results

Channel	**EEG Band Feature**	**Relation**	**P(<.05)**
F8	Alpha energy Jedi mind trainer Post	Training 3-lift	0.006
F8	Alpha energy Cerebral constructor Pre	Training1-left/right	0.001
F8	Alpha energy Cerebral constructor Pre	Training3-left/right	0.007
F8	Alpha energy cerebral constructor Post	Training2-left/right	0.02
F8	Alpha energy emotipong Post	Training 3-lift	0
F7	Theta Power emotipong Pre	Training 2-drop	0.016
F7	Beta energy Jedi mind trainer Pre	Training 1-lift	0.005
F7	Beta energy emotipong Pre	Training 3-drop	0.033
F7	Alpha energy Cerebral constructor Post	Training3-left/right	0.013

F7 and F8 are the Channels of frontal region; we can understand the results of table as for example, in case of F8 channel it is clear that alpha energy of Jedi Mind Trainer in post analysis is significant and correlated with lift action of last day training 3. P is the probability that should be less than .05. It means our hypothesis is 95% correct in the above cases.

Decreased alpha energy on frontal region is related to the increased attention and concentration and increased theta power on frontal region is related to improved motor functions and also we can say that there is a good effect of mental training.

3. Mood Assessment Results

A Mood questionnaire was also filled by the subjects to assess their mood before and after the experiment. The result results show that in 60% of subjects mood is improving. This is clear from the scores, calculated from questionnaire. Standard score graphs of pre experiment mood results and post experiment mood results are as follows:

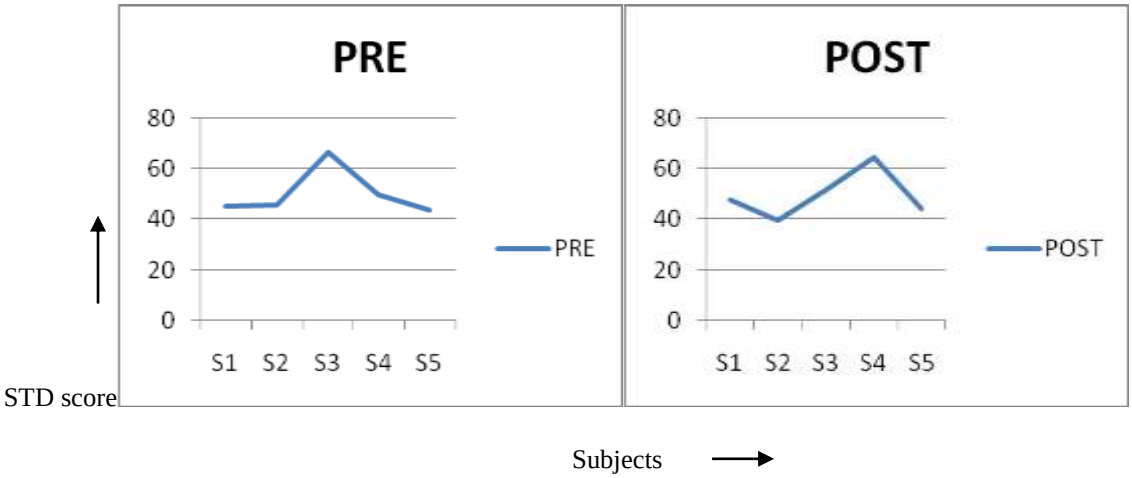


Figure8.2: mood results in pre and post experiment

Graph plotted between the standard score of mood results and subjects. It is clear that the mood is improving in s1, s4 and s5 subjects.

VI. Ethical issues

We should recognize how new video games are ethically affecting people who play them. The ethical issues of video gaming that influences many people include: violence, rating, education, stereotyping against women, community and addiction. Ultimately, each topic is linked to violence involved in video games. The ethical issues surrounding cognitive enhancement via video game can be grouped into 4general categories.

The first is safety. Side effects and unintended consequences are a concern with all procedures, but in comparison to other comparably elective interventions involves intervening in a far more complex system. We are therefore at greater risk of unanticipated problems when we tinker.

The second category of ethical issue is social: how will the lives of all individuals, including those who chose not to enhance, be influenced by living in a society with widespread enhancement? Even in everyday work and school contexts, enhancement is likely to touch all of us. The freedom not to enhance may be difficult to maintain in a society where one's competition is using enhancement to improve attention, memory, or the ability to withstand unsettling experiences. Conversely, barriers such as cost will prevent some people who would like to enhance from doing so.

The third category of ethical issue could be called philosophical, in that it concerns our values and our sense of self. We generally view self-improvement as a laudable goal. At the same time, improving our natural endowments for traits such as attention span runs the risk of modifying those traits. We generally encourage innovations that save time and effort, because they enable us to be more productive and to direct our efforts toward potentially more worthy goals.

Fourth category can be " Game addiction which is a form of psychological addiction related to a compulsive use of computer and video games, most notably MMORPGs - open ended, online video games known for their depth, breadth, and social interaction."

VII. Conclusion

In our project pre-experimental data has been taken from 5 subjects when they were playing BCI game on computer system using Emotiv headset. Next is a training session of 20 days for each subject and after getting training data, pre-experimental data and post-experimental data will be processed and compared using Matlab with the help of various signal processing algorithms.

The results from this experiment shows that paralyzed people can also enhance their cognition using Brain Computer Interface technology. But there are many limitations discussed in previous chapter. Another problem was that the computer games are not generating scores automatically. On the basis of scores of game, we can check the scoring performance of the player in pre and post analysis. On the basis of physiological results or EEG results we can prove that mental training has a significant effect on human cognition. All the problem of this experiment should be overcome in future to make it completely strong research. EEG is a very strong technology in biomedical field.

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