Media Engineering and Technology Faculty
German University in Cairo

Department of Computer Science
Duale Hochschule Baden-Württemberg Stuttgart

Brain Computer Interface (BCI) - Emotional Reactions and Control

Bachelor Thesis

Author: Heba Alaa Ahmed Diaa Abdelrazek
Supervisors: Prof. Dr. Dirk Reichardt
Submission Date: 27 August, 2019

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This is to certify that:

(i) the thesis comprises only my original work toward the Bachelor Degree

(ii) due acknowledgment has been made in the text to all other material used

Heba Alaa Ahmed Diaa Abdelrazek
27 August, 2019

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Abstract

Brain-Computer Interfaces (BCI) are considered a rising field of Computer Science and a notable technological development. They help in the process of understanding the human brain with all its complexities and to interpret it on a computerized level. One of the aims of BCI is understanding the human mind states and overall well-being. Moreover, BCIs could be used to attempt to improve such states after understanding them. This paper uses BCI to record and analyze the brain data, in order to test if it's possible to drive people to mental well-being and a state of relaxation. For this cause, Auditory Beat Stimulation (ABS) is used as the stimuli testing its potential to drive people into a relaxed state. Binaural Beats of Alpha frequency (within the range 8-12 Hz) are chosen for such stimulation. Twelve healthy test subjects of equal female to male ratio have been chosen to perform two sets of experiments after some of whom carry out two preliminary experiments. Results have shown that the binaural beats indeed do have a potential for being used to drive a person to a state of relaxation by increasing the Alpha brain wave production, which is related to being in a relaxed state. Further research is definitely needed with a larger sample size considering how modest this sample size was.

Contents

Chapter 1

Introduction

1.1 Thesis motivation

Along the ages, humans always tried to keep up with life's speed, hence losing themselves in a spiral of stress. Nevertheless, moved by their survival instinct, humans always sought ways to reach a relaxed mental state. But can they manipulate themselves into such a mental state? To answer this question, one needs to understand first what constitutes a mental state. Different conscious states could be measured by self-reports, physical reactions, but most importantly, brain signals. Electroencephalography (EEG) is the technology of actually recording and reading such brain signals using Brain Computer Interfaces (BCI). In consequence, managing to alter such brain signals can somehow enforce a specific conscious state upon a person. This is called Brain Wave Entrainment (BWE).

1.2 Aims and Goals

This thesis aims to use Auditory Beat Stimulation (ABS) as a form of music modulation for the brain wave entrainment, in order to determine the ability of driving a person into a deep state of relaxation. Binaural beats will be the tool used to attempt to reach some relaxation state. This will be carried on by tracking the EEG changes due to exposure to binaural beats. Based on the frequency following response effect of the brain, it will be expected that the brain will increase its production for the brain waves that resonate at the same frequency of the used binaural beats. In the carried out experiments, this level of relaxation one can delve into is tested using binaural beats of Alpha frequency (10.5 Hz) masked with pink noise as the auditory beat stimulus, since Alpha brain waves have been related to being at a meditated unstressed state.

1.3 Thesis Outline

Starting off with Chapter 2: the background, an overview about the human various mind states and their effects. To understand how to alter one's conscious state, if possible, one has to get a grasp on how the brain actually translates that state in the first place. After illustrating the different brain waves and their characteristics, the chapter explores the technology used to connect such brain signals and other devices, the Brain-Computer Interfaces. Brain-Computer Interfaces need an imaging technique to capture and record the brain signals, which leads to introducing Electroencephalography (EEG). Furthermore, the chapter discusses the ability to alter one's brain signals, that is brain wave entrainment. The method for brain wave entrainment used in this research to alter such brain signals is binaural beats. The concept behind binaural beats is discussed in this chapter, followed by literature that inspired this research.

After going over most of the important concepts utilized in this research, Chapter 3 discusses the methodology of our research. The equipment used in the experiments to track the EEG changes are mentioned as well as how the binaural beats are generated to fit the hypothesis aimed to test.

Chapter 4 is concerned with discussing the experiments and results in this research. It starts off by explaining the two preliminary experiments testing the effects of binaural beats in a short duration of time, as well as testing the effectiveness of the Sustained Attention to Response Task which is supposed to grasp the attention of the test subjects and to cause the same level of lack of relaxation for all candidates. Following up, the design of the main experiments is discussed, as well as the analysis used to test the effectiveness of binaural beats set in Alpha frequency (10.5 Hz) aimed to enforce a state of relaxation onto the test subjects.

At last, Chapter 5 discusses the results of the experiments in order to reach the conclusion about the methods utilized in the experiments and how efficient they are. Future work is recommended afterwards and the challenges that occurred in such process are discussed.

Chapter 2

Background

2.1 Human Mind States

Humans have several states whether emotional, mental, psychological, or physical. Each and every state affects the human activity in one way or another. Those states can vary from exhaustion and anger to meditation and relaxation.

Moreover, to perform as functionally as possible in one's daily life, one needs to acquire a relaxed state. According to Jo Anne Herman [22] stress is related to all kinds of sicknesses. Which in terms would mean that relaxation and lack of stress would promote healthiness and well-being. Throughout all ages, humans always looked for different ways and methods to self meditate.

There are a lot of ways to define relaxation. The most general one would be according to Oxford Dictionary [6]; the state of being free from any tension or anxiety. Relaxation is derived from the Latin word "Laxare" which means "To loosen up", the prefix "Re" is added to mean "Again". Relaxation can be looked at as a decrease in the intensity of emotional arousal [22].

Forms of relaxation include being physically at ease, where some muscles cease to contract and others get unclenched. Relaxation also has an effect on skin conductance and other bodily functions such as heart rate, respiratory rate, and blood pressure. Not only does relaxation benefit the physical well-being of humans, but also it can affect their psychological and mental states, evidently changing their emotional state.

According to Hope Titlebaum [36], relaxation has significantly good outcomes on the physical and mental health of people, and furthermore on their level of productivity. Lack of relaxation can cause multiple unpleasant results both physically and mentally or emotionally. Those results might include insomnia, increased blood pressure, anxiety disorder, headaches, as well as chronic migraines induced from stress. In addition to this, its lack can encourage physical deterioration and joint dysfunction. Thus, being relaxed is a goal almost everyone is trying to attain.

Since all human states are controlled via the brain, one needs to understand how it is interpreted in the brain itself in order to have a further understanding of the relaxation state. Consequently, one needs to take a deeper look on the brain waves, and what their significance is.

2.2 Brain Waves

The brain waves are produced from numerous neurons in the brain actively sending some sort of synchronized pulses to each other as their way of communication. According to Jaganathan et al. [25], ions are pumped via the membrane transport ions into the brain which electrically charges the neurons. Neurons are simultaneously exchanging ions with each other to transfer brain data. During this process, ions with similar charges would repel each other, pushing other neighbouring ions. The combination of such electrical activity in the brain is what is called a brain wave pattern, for its wave-like nature.

Brain waves consist of different bandwidths that belong to the same spectrum. Brain waves speed is measured in Hertz (Cycles per second) denoting how frequently they occur. The range of the bandwidths varies among different research papers.

However, this paper's approach will be following EmotivPRO's [4] set bandwidth ranges since this headset was the one utilized in the research and experiments. Emotiv's approach states that Delta brain waves range from 1 to 4 Hz, Theta brain waves range from 4 to 8 Hz, and Alpha brain waves range from 8 to 12 Hz. Moreover, Beta brain waves are divided to two parts; the Low Beta ranging from 12 to 16 and the High Beta ranging from 16 to 25, and finally, Gamma brain waves range from 25 to 45 Hz. These brain waves are further shown in Figure 2.1.

Researches have shown that each wave of the mentioned brain waves can have a corresponding significance to the emotional or mental state of the humans. In other words, one can translate the abundance of a certain brain wave production into a certain level of consciousness or state of the person under test.

Delta brain waves are of the lowest frequencies, and they are considered to be the slowest vibrating brain waves. The production of the Delta brain waves occurs most commonly in the unconscious mind. In addition to them being observed as a source of empathy, Delta brain waves could be generated during a deep dreamless sleep, as well as in states of extremely deep meditation [9]. Most commonly, healing from things people were subjected to occurs during deep dreamless sleep. Thus, Delta brain waves are essential for the healing process of humans [7].

Theta brain waves are more about what goes on in the subconscious mind, they could include activities such as sleeping or dreaming [9]. Another study by Erik Andreas Larsen [28] has related Theta brain waves to daydreaming and inefficiency. Moreover, theta waves are observed more frequently in states of stress, specially if the person is disappointed or frustrated. According to EOC institute [2], the production of theta waves is linked to insight and intuition. It also can induce lucid dreams which are dreams that give a feeling of floating when one is sleeping.

Alpha brain wave production is clearly noticeable when people are in a relaxed disengaged peaceful state, yet aware of themselves. The production peaks when the brain is not very active and overflowing with quiet thoughts [9]. Alpha brain waves are mostly visible in the frontal lobe, as well as in the back of the head, in the occipital region of the brain (O1 and O2) [14]. Alpha waves are the 'Power of now'; they help coordinate the state of the body and the integration of the mind and body, and calmness and the alertness. People experience an abundance of Alpha waves in focused yet a deeply relaxed states [2].

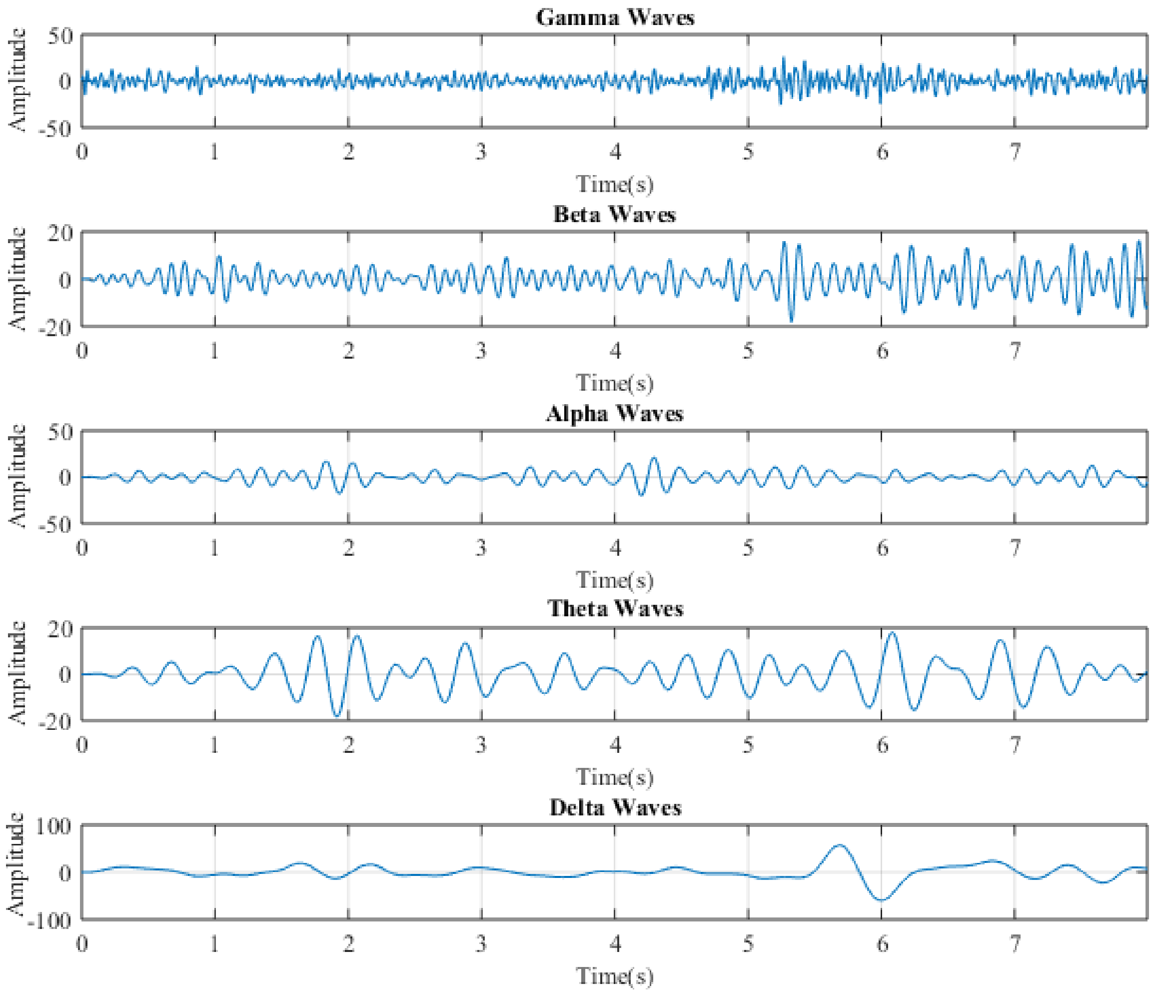


Figure 2.1: Brain Waves Patterns [23]

Beta brain waves work as a monitor for brain activity and arousal. According to Erik Andreas Larsen [28], Beta waves are linked to focused concentration, judgment, as well as decision making. Beta brain waves can also increase when one is suppressing movement or perhaps solving a maths question. This kind of brain waves is mostly visible in the frontal and central parts of the brain. The Beta/Alpha brain wave ratio could be an indicator for the person's level of arousal and excitement. According to B. Shanmugapriy et al. [31], Beta waves are produced when the user is feeling stressed, afraid, or in a state of agitation. Low Beta waves occur mostly in idle states and they are emitted more often in musing states. High Beta waves are related to new experiences or the excitement level of a person. The excessive production of Beta waves might cause insomnia; they are also produced more in states of depression, hunger, and moodiness [2].

Gamma brain waves are the waves with the highest of frequencies observed in the brain. They are mostly produced when the person is at a quiet mind state. Gamma brain waves transfer information rapidly, hence they are related to the information processing section in the brain. Gamma brain waves production is related to states of high level of consciousness, spirituality, and higher virtues.

In order to have access to the brain and to actually retrieve the mentioned brain waves, one needs a connection between the human brain and devices, introducing the role of Brain-Computer Interfaces (BCI).

2.3 Brain-Computer Interfaces

Brain-Computer interface is a real-time path of communication between a user who uses the computer system and between accessing the neural activity of the brain as defined by Erik Andreas Larsen [28]. It's a channel of output for the brain controlled by the user. Brain-Computer Interfaces aim to deliver people's intentions to the outside world just by reading their thoughts.

Brain-Computer Interfaces aim to develop a distinction between various patterns of brain activity, and to reach that distinction with a level of accuracy. But the Brain-Computer Interfaces will not manage to form such a distinction without the user actually performing different mental tasks which in accordance would produce distinct brain signals [10]. Some may argue that the brain's normal neuromuscular channels could affect the input to the brain activity detected by the Brain-Computer Interfaces, however, the brain signals are the ones that get inputted to the Brain-Computer Interfaces not the peripheral nerves and muscles.

The Brain-Computer Interfaces have grown a popularity as they are invested in many fields and have several applications including Human-Machine Interaction and neuroscience research. Most commonly, Brain-Computer Interface applications would be focusing on researching and trying to find solutions for disabled people for improving their quality of life. This can be accomplished by allowing the disabled people to work independently from their bodies' support like in bio engineering applications.

Another focus for the Brain-Computer Interfaces would be detecting diseases and disorders like the human subject monitoring applications. Some researches may even delve into finding ways to bring balance to the body that needs adjustment. For instance, Deepika R. Chavan et al. [14] used Brain-Computer Interfaces to detect stress that disrupts the body and mind, and then they tried to treat it. The detection of the brain waves using the Brain-Computer Interfaces requires a system that could translate the brain wave signals into something readable, hence the use of a system called Elecroencephalography (EEG), which is a common method in developing a Brain-Computer Interface.

2.4 Electroencephalography

According to Soraia M Alarcao and Manuel J Fonseca [9], there is an imaging technique that is able to read brain activity by measuring some voltage fluctuations of brain waves. This technique is called Electroencephalogram (EEG). Commonly, the EEG signal measured is in the range 10-100 micro volts. The EEG data can be analyzed using a lot of programs such as Matlab which offers a lot of toolboxes designed for EEG analysis.

Moreover, some other research [12] described EEG as a collection or an embodiment of some signals that occur from the brain cells, formed from their synchronous actions. The origin of the word itself comes from two Greek words; "Enkephalo" which is the brain and "Graphein" which is the act of writing.

EEG data is measured using electrodes in contact with the scalp. However, there is an another way to use them, which is directly on the cortex. This way is called Electrocorticogram (ECoG). There are two kinds of electroencephalograms, one of which is recorded when there is stimuli occurring. This stimuli could be internal like skipping an expected stimulus, or an external stimulus like a tone or a light flash which is the Event-Related Potential (ERP). The other type of EEG is without any stimulus occurring which is considered the spontaneous type.

Electroencephalography is mainly describing how the electroencephalogram, the EEG, is recorded and translated. EEG-based Algorithms appear to be the most valid and reliable emotion and mental state recognition system algorithms according to Olga Sourina et al. [33]. Brain activity reactions to events can not be altered by the test subjects intentionally, unlike their facial expressions, words, and feedback. So one may call EEG signals the truest measure of emotion for the user. The spacial resolution of EEG is not as adequate but in spite of that, its temporal resolution is great (less than 1 millisecond), and that makes it the most spread non-invasive brain imaging technique [11].

A distinction between the EEG and Brain Computer Interfaces could be that EEG is mainly about the brain waves themselves while the Brain-Computer Interfaces are more of the system which interprets those brain waves in a computerized manner. Mental activities would lead to some changes of the electrophysiological brain signals like EEG. The Brain-Computer Interface system would detect such changes and then it would be able to transform it into some sort of a control signal. This control signal generated could be used in multiple applications such as motion of wheelchair, giving commands using one's thinking process, and even commands to one's own brain [10].

As brain waves and signals are easily acquired and translated with the current level of human knowledge and technology, this triggers the question of whether or not one can manipulate these waves that are related to different mental states. If yes, one might even wonder about the methods to accomplish this.

2.5 Brain Wave Entrainment

The connection between brain waves and the human states can not be simply overlooked. Since they are both interconnected, it follows that a change in either one gets reflected on the other. This raises the question of whether or not there is a tiny possibility to alter one's brain waves transitioning them to a particular mental state. Medications and recreational drugs are an example of the alteration of mental states using chemicals [7]. Other methods could be used to entrain your brain waves into an equilibrium state like Yoga and meditation.

Brain wave entrainment is basically when you try to temporarily delve into a specific mental state with the usage of external stimuli like light, pulsating sounds, or some sort of electromagnetic field. Such external stimuli may trigger the brain's frequency following response which in terms may coincide with the external stimulus frequency [1]. In other words, the frequency following response of the brain is synchronizing it with another frequency enforced on it.

Brain wave entrainment could drive the person temporarily to a desired state which could be focused, sleep inducting, meditated, or a relaxed state. The brain waves are always running simultaneously, however, the most dominant brain waves are the determinant of the current state of the person. A study [24] shows that brain wave entrainment contains a lot of potential that it can be used as an effective therapeutic tool, however, further research is needed.

Since each human is distinctive from the others by a unique fingerprint, brain activity and brain wave production are different from one person to the other as well. This illustrates how brain wave entrainment of the same wave(s) could have a positive effect on one person, a negative, or a neutral effect on the other. Brain wave entrainment is often referred to as a 'hit or miss' [1].

There are various methods and ways in which brain wave entrainment can occur. Those methods were often required to go further than the physical limitations of the human noticeable frequencies 20 to 20000 Hz, since the useful brain waves are from 1 to 45 Hz. EEG active entrainment is a brain wave entrainment method with the utilization of either light or sound or even both of them combined.

The brain waves can be altered as the EEG data is seen in real-time from the EEG sensors [1]. Some people might confuse this with Neurofeedback, which is the ability to control your own state by simply having access to the real-time data instead of pushing it by the entrainment methods.

By nature, the brain waves are electromagnetic. So it makes perfect sense to use electromagnetic waves to actually entrain the brain waves and enforce the brain into a certain state. This method doesn't have to be forced on all the cortex of the brain. It can simply be directed to a specific area and then its frequency would be changed accordingly. Electromagnetic brain wave entrainment is a very fast method as it can occur in terms of milliseconds.

Another kind of brain wave entrainment would be using light, such as flashing in a special pattern to produce a stimuli which in turn can influence the brain waves into the desired state. Light brain wave entrainment could be used with sound brain wave entrainment or as a stand alone, and so can the sound brain wave entrainment.

Sound brain wave entrainment is defined as a for of music modulation [1], since most of it is embedded in some musical tracks. This music modulation form is considered an Auditory Beat Stimulation (ABS). First kind of ABS is the usage of isochronic tones, which are beats of a single tone situated in a narrow bandwidth of the musical track. This means that just one band of the musical track is oscillating, while the rest remains without alterations. These isochronic tones are recognized as the most effective type of auditory beat stimulation used for brain wave entrainment.

The second type of auditory beat stimulation is with the usage of monaural beats. These beats area single pulsating click sound, created by overlapping the two tones coming out of the same speaker, their two frequencies are presented to both ears at the same time. Monaural brain wave entrainment is risky because the monaural beats could easily interfere with the musical track used in the modulation. In monaural beats, one doesn't have to wear headphones unlike the binaural beats method, which is the third kind of brain wave entrainment using music modulation.

2.6 Binaural Beats

Binaural beats, the third type of auditory beat stimulation for brain wave entrainment, is basically a method of neural-occurring phase subtraction to reach the required frequency [34]. As previously stated, one should be exposed to binaural beats with headphones on as their use is contributing to the mechanisms of the binaural beats.

For instance, if a person listened to a tone of sinusoidal origin of 440 Hz in the left channel of the headphones and another one of 446 Hz in the right channel of the headphones, this will produce a resultant tone of 6 Hz, their difference. This is illustrated in Figure 2.2. In other words, according to the frequency following response effect, the brain resonates with the frequency of the binaural beat at hand, and produces synchronized waves to that beat, and hence further altering the test subject's state of consciousness [15].

After the brain hears two different frequencies at each ear using the headphones, a nerve hearing route makes sure that the brain exchanges auditory information between

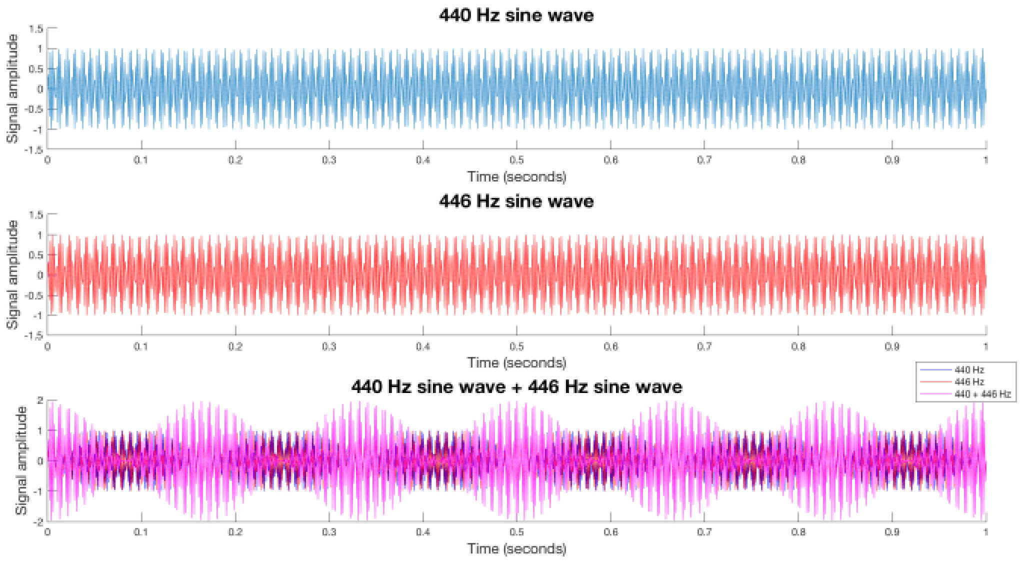


Figure 2.2: How binaural beats waves are formed [17]

the two sides of the brain, before the sound reaches the cortical cortex. This exchange of auditory information happens in at least two places in the olivary body, the auditory route, which processes the sounds and transfers it to the colliculus inferior (small nuclei) that is the next element of this auditory route. This passage of sounds of binaural beats gives information to the reticular system, which decides about concentration and consciousness. If there is no conflict of internal stimuli (e.g. feelings) or external sensory stimuli, the brain manages to sync its brain wave activity to the frequency of the binaural beats [26].

Binaural beats are not as effective as monaural beats for the brain wave entrainment, however, they do have an edge over the monaural beats because binaural beats are not as noticeable to the ear as much as the monaural beats. Consequently, binaural beats will not switch the person's focus to the beats themselves if they weren't as audible as the monaural beats.

Binaural beats theoretically speaking, seem to be an efficient brain wave entrainment tool. But even practically they have proven it does have a significant effect on the brain waves and hence the mental state. A pilot study [8] utilizes binaural beats with different ranges of frequency to test their effect on sleep quality improvement and post-sleep mental state of athletes. The study concludes that it is a valuable method and that it has positive effect on the brain wave entrainment.

2.7 Related Work

A lot of research has been done concerning the usage of binaural beats. There is a lot of potential for its effectiveness. However, more research is needed since there are a lot of contradictory results. Some of the researches that inspired this thesis's hypothesis and research questions are collected. Most of the researches found clearly show that the binaural beats have a positive effect on the brain waves of the people. Consequently one can use it to enforce a mood state successfully.

A study investigated the effects of 18.5 Hz visual and auditory stimulation on EEG amplitudes. Their results supported their hypothesis that they can entrain the EEG rhythms using audio and visual stimulation which can be used in biofeedback therapies [18].

The usage of Alpha based binaural beats with frequency 10.2 Hz to improve cognitive performance was tested by V.D. Cruceanu and Violeta Rotarescu [15]. The cognitive performance is basically how one can acquire information and the learning process in humans, as well as developing concepts and reasoning. This research utilized some stroboscopic light along side the Alpha binaural beats. Their hypothesis was proven to be true and they recommended further research while measuring Alpha activation levels using EEG of functional magnetic resonance imaging (fMRI).

A comparative study was seeking the comparison of effects of Alpha (10 Hz) and Gamma (40 Hz) binaural beats on audio reaction time, visual reaction time and short-term memory. The results obtained showed that there was an evident decrease in both the audio and visual reaction time which in terms enhances attention and cognitive function. However, although it had improved short-term memory results, they were not as significant [32].

Moreover, another study investigated how the binaural auditory beats would affect vigilance and cognition and its effect on mood. This study compared the effects of Beta and Theta/Delta binaural beats masked with pink noise. The candidates were unaware of the binaural beats existence as it was assumed to have a better effect that way. The Beta binaural beats had a better measure of vigilance performance and it was related to a less negative mood than the Delta/Theta binaural beats [27].

Instead of providing the binaural beats in one chunk, Vernon, et al. [37] decided to track responses for ten 1-minute epochs from the temporal regions. They observed the EEG changes when subjected to an Alpha (10 Hz) binaural beat, and a Beta (20 Hz) binaural beat. Unfortunately, no observed effect was concluded. This was due to the absence of the frequency following effect that could have been because of some mediating factors in the experiment. They recommended that future research should look onto a different duration of exposure instead of the interleaved 1-minute epochs as that was not sufficient. They also added that there should be future full scans not just on the temporal area.

Taking into consideration the Relative Power (RP), Phase Locking Value (PLV), and Cross-Mutual Information (CMI), Xiang Gao et al. [19] utilized them in analyzing the EEG activity after being exposed to binaural beats in Delta (1 Hz), Theta (5 Hz), Alpha (10 Hz) and Beta (20 Hz) bands. There was no clear observation of any brain wave entrainment or the effect of frequency following response effect, however, it hypothesized that binaural beats could affect the functional brain connectivity.

Anushka Gupta et al. [21] tested the effect of Alpha binaural beats of 10 Hz with base frequencies 370 Hz and 380 Hz on the levels of attention and meditation. They subjected 10 people to a 3 minute long Alpha binaural beat track generated via Matlab. The brain wave data was captured via Neurosky MindWave Mobile Headset. Their experiment was 5 minutes in total, before the 3 minutes of binaural beats exposure there was 2 minutes baseline where their normal state was recorded. They could walk around which could possibly induce artifacts that were overlooked in this research. Anushka Gupta et al. [21] observed higher levels of meditation and lower levels of attention during the exposure of the Alpha binaural beats. This research highlights the potential of using Alpha binaural beats for enforcing a relaxed state upon test subjects. They recommended for testing this hypothesis the usage of an actual EEG equipment that should give more accurate, spatially larger results.

As per Miguel Garcia-Argibay et al. [20], as the duration of exposure to binaural beats increase, the better the effect. So one would need a track longer than 3 minutes to see more accurate results that could not have been altered by some artifacts. It was clear to conclude how the conditions around manufacturing the binaural beats contribute a lot to its effectiveness. For the sake of our experiments, these conditions were investigated in Binaural Beats Settings 3.2.

Chapter 3

Methodology

3.1 Equipment Used

3.1.1 Emotiv EPOC+ EEG Headset

The sensor used to carry out the experiments and extract EEG data in this research paper is Emotiv EPOC+ headset, Figure 3.1. This device is very convenient for research and experimental purposes for its high resolution and quality. It has a fast setup of around 5-10 minutes. It has a lot of advantages that makes it stand out from other EEG sensors. Some of which include its ability to connect to PC and mobile devices using Bluetooth in a wireless manner. Emotiv's motto is "You think, therefore you can". This motto illustrates what Brain-Computer Interfaces (BCI) are there to pursue; how one's thoughts can be the engine used to control devices using BCI. This headset

Figure 3.1: Emotiv EPOC+ Headset. [3]

consists of 14 electrodes that should get soaked in saline solution before usage. It has two electrode arms each containing 9 locations (7 sensors and 2 references) as per Figure 3.2. Two sensor locations (M1/M2) already have rubber sensors fitted because they are the alternative positions for the default references (P3/P4). The electrodes are labeled using some combinations of letters and numbers. The letters are F, C, T, O, and P which correspond to frontal lobe, central position, temporal lobe, occipital lobe, and parietal

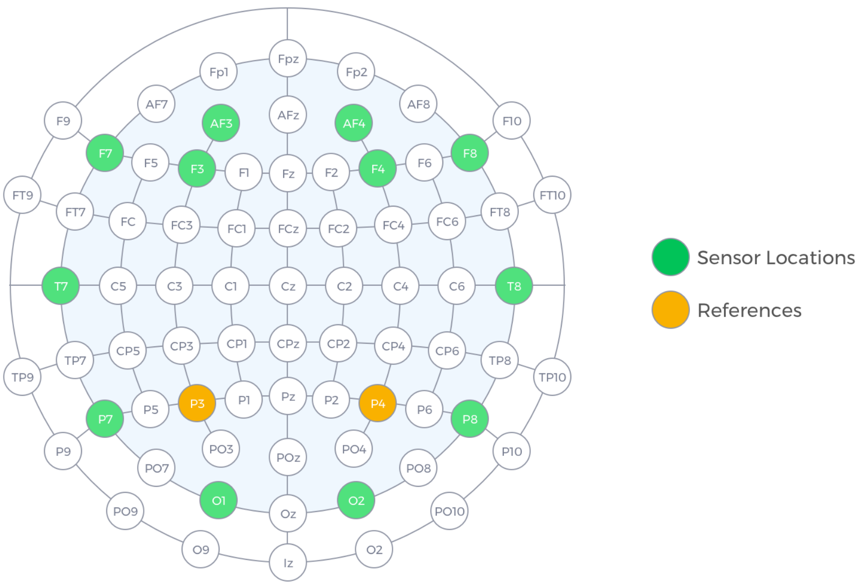


Figure 3.2: Emotiv EPOC+ Headset sensors and reference sensors. [3]

lobe. The numbers indicate which electrodes are on the right (even) and which are on the left (odd) [3].

Alongside the Emotiv EPOC+ headset, Emotiv Inc. provides a software EmotivPRO which observes and records the EEG data sent to it via the headset.

3.1.2 EmotivPRO

EmotivPRO software [4] has a lot of data streams, introduced here are the three main ones: raw EEG, frequency analysis, and the performance metrics, however in this research, the last data stream is ignored because Emotiv Inc. have not announced its algorithm so one can never be certain if it is reliable enough for sensitive data. All of the data streams can be exported as CSV or EDF files. Firstly, the raw EEG data stream shows the voltage fluctuations of all sensors versus time. It is shown in Figure 3.3.

Second data stream in Figure 3.4 is the frequency analysis which views all the frequency data and their bandwidths of a single sensor at a time. It shows the levels of Theta waves (4-8 Hz), Alpha waves (8-12 Hz), Low Beta waves (12-16 Hz), High Beta waves (16-25 Hz), and Gamma waves (25-45 Hz) for each electrode. EmotivPRO performs Fast Fourier Transform on the raw data and shows in the frequency analysis data stream the FFT graph of this electrode's data as dB over Hz. One can adjust some of its variables in EmotivPRO such as the maximum/minimum amplitude or frequency, transform length, and the step size of the FFT analysis. The last data stream in Figure 3.5 is the performance metrics data stream. It uses an Emotiv based algorithm to compute a cognitive state measure. These measures include engagement, stress, interest, relaxation, focus, excitement and long term excitement.

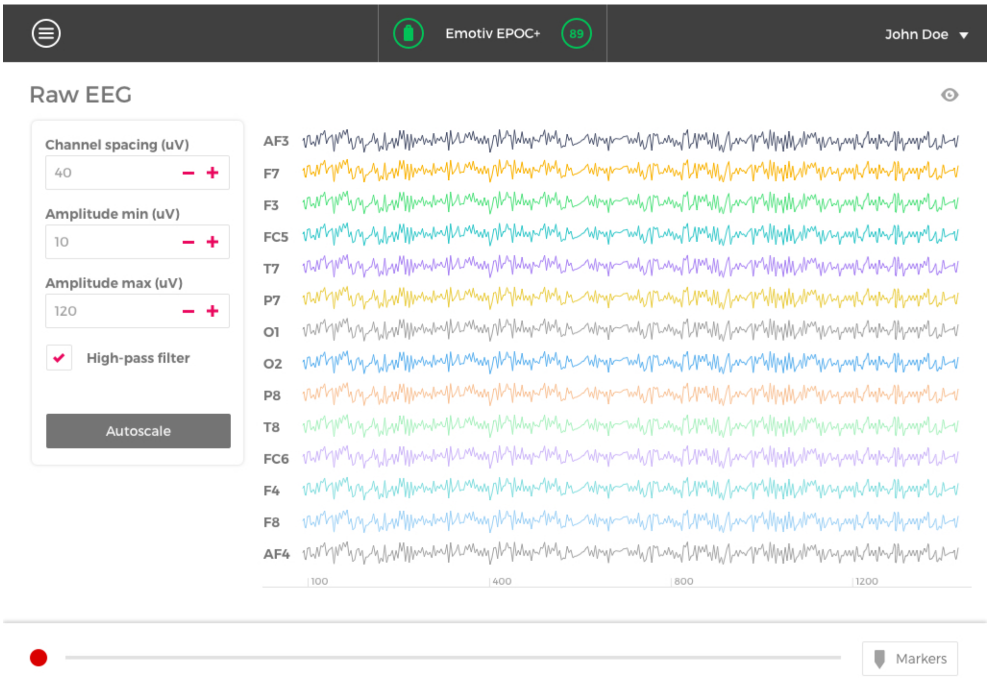


Figure 3.3: Raw EEG - EmotivPRO [4]

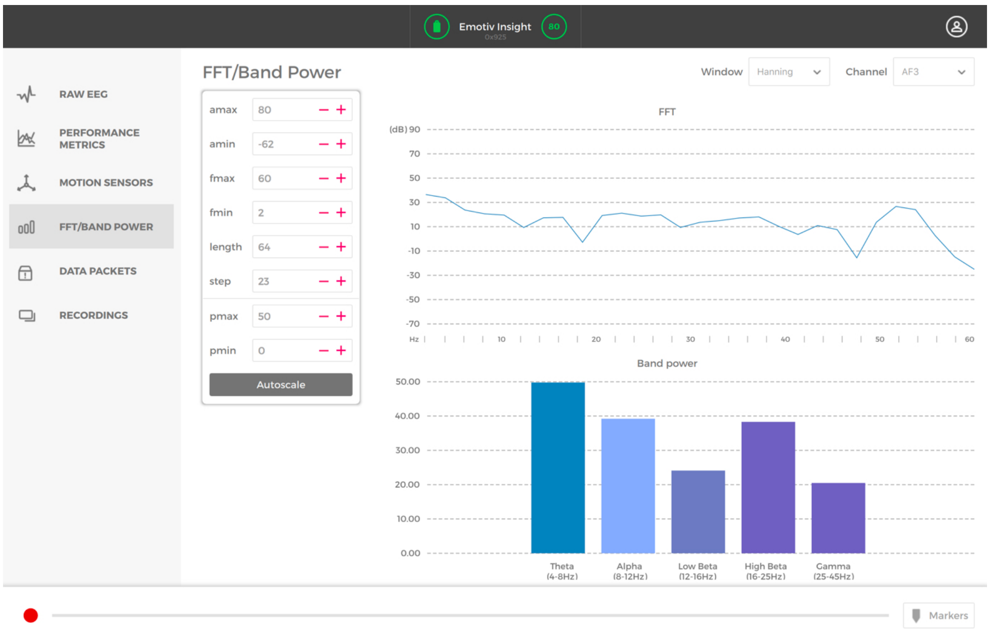


Figure 3.4: Frequency Analysis - EmotivPRO [4]

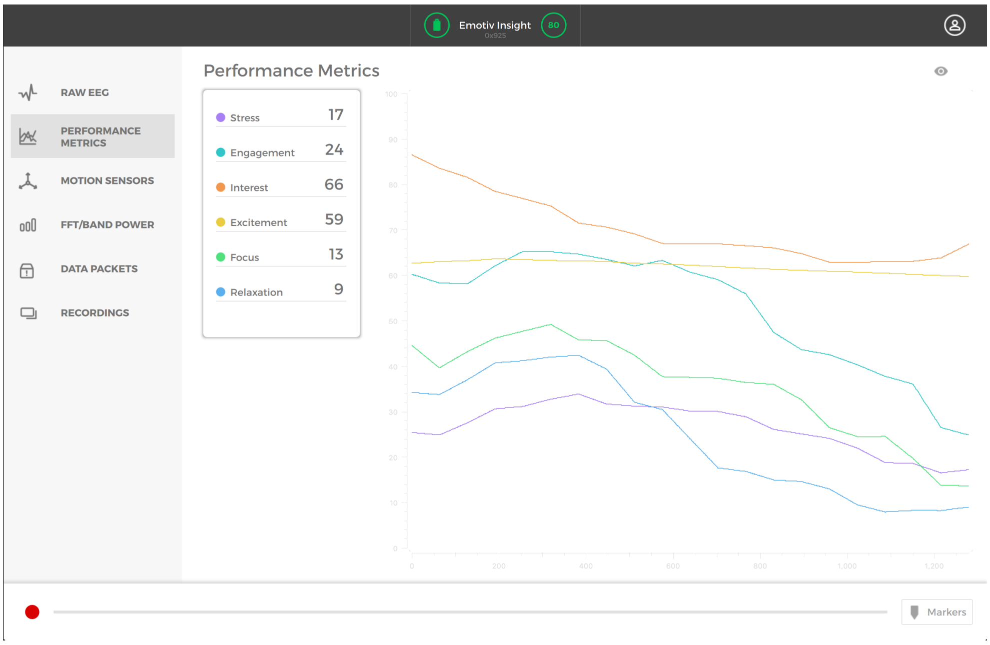


Figure 3.5: Performance metrics - EmotivPRO [4]

3.1.3 Sustained Attention To Response Task - SART

Before measuring the effect of binaural beats on triggering a relaxed state, the subjects need to be driven to an equally neutral state, yet not stressful. To accomplish such a state, the test subjects are required to do a task that captures their sustained attention for a period of time. Sustained Attention to Response Task (SART) is therefore introduced.

SART is a computer-based task where the test subjects are presented with digits appearing on a black screen, randomly selected from 1 to 9 at a rate of one every 1.15 s [30]. Each digit is shown for a period of 250 ms then a mask (a circle with an X in it) is shown for 900 ms. Figure 3.6 shows some frames of how the masks and digits are presented. The test subjects should click on the space bar whenever they see a digit that is not "3". Whenever the digit "3" appears they should refrain from hitting the space bar. The task is a total of 225 trials (25 times for 9 digits). It lasts for about 4 minutes with an introductory screen explaining the instructions of the task that would already be informed to the test subjects, followed by a short trial period. SART is basically a Go/NoGo task where the NoGos are the infrequent ones.

SART is used in researches typically aimed for investigating patients with brain injury that affect the frontal lobe which is the region mostly related to sustained attention in the brain. SART is designed to measure the capability of the people to hold their responses to such unpredictable and infrequent stimuli (the digit "3"), where the response time should be minimized as well as the number of errors [30].

It is argued that SART can put the test subjects in a state of mindlessness while trying to keep them focused in the task itself. These accusations are based on the fact

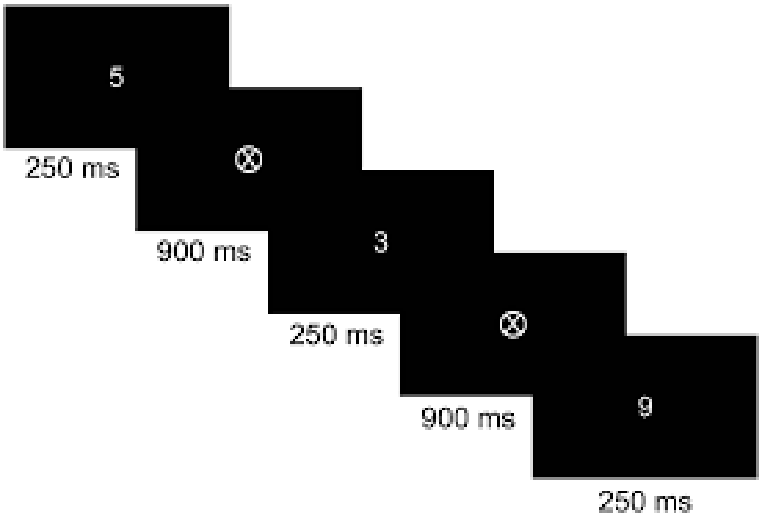


Figure 3.6: Sustained Attention to Response Task - SART [13]

that vigilance and attention sustaining tasks are mostly go-trial oriented tasks, where the test subjects have to respond to the stimuli and not to withhold action from it. However, a study by Michael B. Dillard et al. [16] concludes how SART is not a machine of mindlessness, instead it manages to sustain the attention of the test subjects rather than leave them in a mind wandering state.

SART script is acquired from Milliseconds, Inc [13]. It was written by Katja Borchert, Ph.D. in 2013. The script have been run with Inquisit Lab 5 software on Mac OSX.

3.1.4 Gnaural Java

In the experiments for the auditory beat stimulation, a binaural beat track ought to be generated. For this, the Gnaural software is utilized. Gnaural is an open-source programmable auditory software that can generate binaural, monaural, and isochronic beats. It was designed following the principle described by Gerald Oster concerning auditory beats in the brain [29]. Gnaural have extended their software to be used as synthesizer for music composition.

Gnaural eliminates any platform compatibility issues by building a Java version. This is a result of going over multiple platform phases on its course of action. Gnaural started as a DOS program in middle of the 1990s, then it transformed to WinAural which operates on Windows, then to BrainJav which is simple Java Applet versions, till finally reaching the current cross-platform Gnaural for Java version. A screenshot of how Gnaural operating screen looks like is shown in Figure 3.7.

Gnaural can generate the auditory beats to whatever frequency one seeks. One can make the beat frequency follow any brain wave frequency in a really easy manner. With Gnaural, one can also adjust the volume to whatever is comfortable to the test subjects, and one can set a base frequency for the tone (e.g. sinusoidal wave). Gnaural is able to

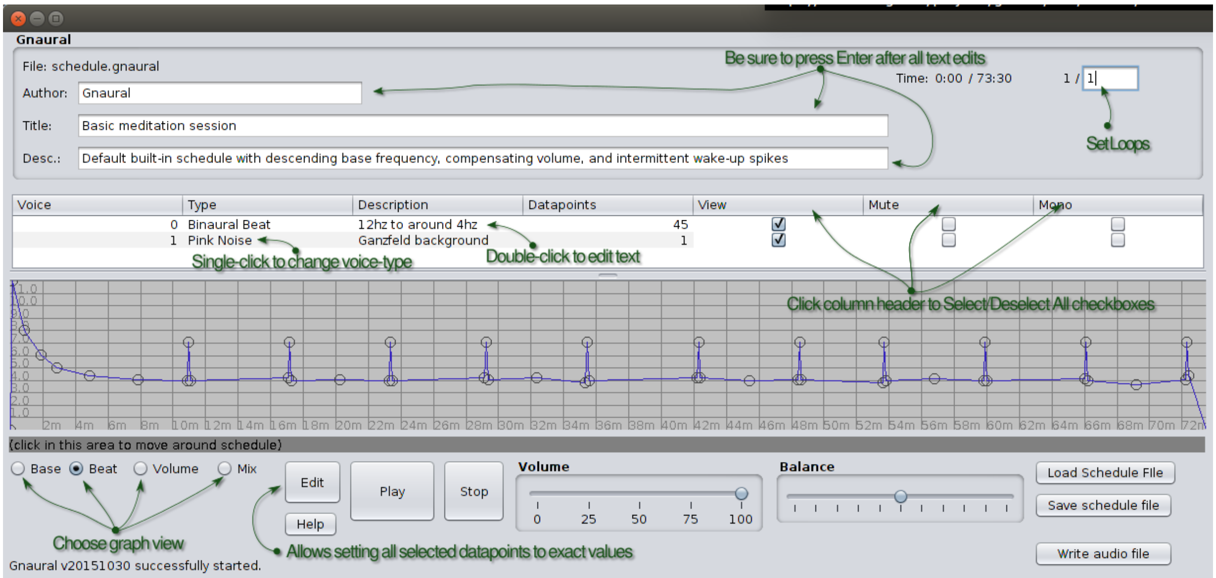


Figure 3.7: Gnaural Auditory Beats Synthesizer [5]

add more than one sound together alongside the auditory beat in hand. Those sounds added could be rain, waves, droplets, pink noise or even another auditory beat.

3.2 Binaural Beats Settings

The binaural beats that are used in the experiments are synthesized using Gnaural software as previously stated. The main aim of this research is to study the effects of binaural beats set on the Alpha brain wave frequency, hence the binaural beat generated have their beat frequency set on 10.5 Hz which is within the Alpha brain wave range (8-12 Hz). The volume is adjusted to the level of comfort of the test subjects.

There are a lot of binaural beats control variables in the experiments that should be investigated because they play a major role in the effectiveness of binaural beats. Such control variables include time under exposure, the masking sound (pink noise, white noise, music, or unmasked), and the moment of exposure to the binaural beats.

A meta-analysis by Miguel Garcia-Argibay et al. [20] collected, categorized, and further analyzed around 22 studies about binaural beats that fit some requirements. Those studies were required to use binaural beats as a treatment or an experimental factor, therefore they had to be experimental studies. The areas where the application of binaural beats were investigated had to contain at least 3 researches from the 22 obtained. The 22 studies selected needed to have sufficient information about their control variables for their further analysis and comparison.

3.2.1 Total time of exposure

Total time of exposure of binaural beats ranges from 4 to 130 minutes in all the 22 studies [20]. This meta-analysis concluded that the time under exposure to binaural beats doesn't promote a habituation to binaural beats as implied by some of the 22 studies hypotheses. A positive relationship between the time under exposure and the effectiveness of the binaural beats was found. As recommended from this meta-analysis, the binaural beats that were synthesized for this research paper's experiments (preliminary and main experiments) are generated to be 5-8 minutes long as it is in line with the suggested duration of exposure.

3.2.2 Moment of exposure

In regard to the moment of exposure, the meta-analysis supports that the moment of exposure to binaural beats should be before the actual comparison phase. So one can compare the baseline before the exposure period, to the following period after the exposure of the binaural beats.

3.2.3 Masking sound

As for the masking of the binaural beats, the meta-analysis finds that in comparing the 22 studies, the unmasked binaural beats show larger effectiveness than the ones that are infused with musical tracks. However, there is no difference observed in comparing the unmasked binaural beats to the ones masked with pink or white noise. Consequently, it is of no harm to use pink noise in one's investigations. For the sake of the comparisons made in the experiments in this research paper, pink noise is the masking sound used for the binaural beats.

Chapter 4

Experiments and Results

4.1 Preliminary Experiments

There are two preliminary experiments, Sustained Attention to Response Task (SART) experiment and binaural beats experiment. Those two experiments are basically tests in order to compare the EEG data before and after the exposure to the method in question, whether it is SART or the Alpha binaural beats.

Before the start of both experiments, the participants are briefed about the experiments nature and settings. The participants are told not to move unless it is required in the experiments as to avoid any possible movement artifacts. The experiments are taking place in dim light in the same room with the consent of all participants.

The Emotiv EPOC+ headset is adjusted to its correct measures of quality and to the test subjects comfort to ensure the best accuracy of the results. Radio frequency emitting devices such as mobile phones are shut off during the time of the experiment to avoid any possible corruption of signals.

4.1.1 SART Experiment

Six testing experiments are carried out for the sake of testing the changes that could occur to EEG data after undertaking the Sustained Attention to Response Task (SART). Those six experiments are done on five participants one of which is tested on two times at different conditions and on different days. The age and gender of the test subjects are of some limitations since only one test subject is female and only one test subject is aged above forty while the rest are in their early twenties.

This experiment has three phases. The first phase is an eyes open 2 minute baseline phase, where the test subjects should remain still and relaxed. The next phase is where they start doing the SART, which is explained in 3.1.3. This phase should take around 6 minutes in total, 4 minutes doing the SART and around 2 minutes preparing the subjects with on screen instructions and a small trial period. This is followed by an eyes open 2 minute rest period as the last phase.

4.1.2 Binaural Beats Experiment

The binaural beats experiment is supposed to compare the resting periods before and after being exposed to the Alpha binaural beats track. This in terms should have determined whether there is a potential in later on using the Alpha binaural beats in attempting to drive a person to a relaxed state. Six experiments are done using four participants. Two of which have two trials to be tested on them on different days. There is a shortage in acquiring female test subjects for this experiment so the four of them are males, with one aging over forty years old while the rest of them are in their early twenties.

Similarly to the first preliminary experiment 4.1.1, this experiment has three phases. The subjects are instructed to remain still and to relax for the whole 9 minutes. The first and third phase are eyes open 2 minute silent resting periods each. The second phase is 5 minutes long, where the test subjects are subjected to the binaural beats track set as per the settings discussed in Binaural Beats settings 3.2. The binaural beats track utilized in this preliminary experiment is of Alpha frequency (10.5 Hz), masked with pink noise, and of base frequency 300 Hz.

4.2 Results of Preliminary Experiments

After acquiring the recordings of all the participants. EmotivPRO is used to extract the raw data and the frequency analysis into two separate CSV files. Those CSV files are then combined and further analyzed using Microsoft Excel. As mentioned in Chapter 3.1.2, EmotivPRO already calculates the Fast Fourier Transform of the band frequency waves so the data in the frequency analysis CSV file is ready for further computations.

The first step in analyzing the data of both preliminary experiments is to use the raw data CSV file to determine the time stamps of the start and the end of each of their 3 phases. Those time stamps will be used to separate the three phases for their individual analysis. The next step would be calculating the average, minimum, maximum of every bandwidth of every channel in each phase. Following this one can easily determine the average, minimum, maximum of the combined phases in all the channels.

4.2.1 SART Results

Figures 4.1, 4.2, 4.3, 4.4, 4.5, and 4.6 show the results of the 6 SART experiments. These results compare the average values of all the frequency bands for all the 3 phases of this experiment. For 100 percent of the experiments carried, Alpha has the lowest average values in the SART phase, so does Low Beta for 83.33 percent (5 out of 6 experiments). This results complies with our expected claim that SART would put the test subjects in a state of unrest even if they are at some level of relaxation in the first phase. Theta brain wave values are highest in the last resting period (RP3) for 4 out of the 6 experiments, which could signify that their brain is still active due to SART. As for High Beta and Gamma average values, they consistently peak in all the 6 experiments in the last resting period (RP3).

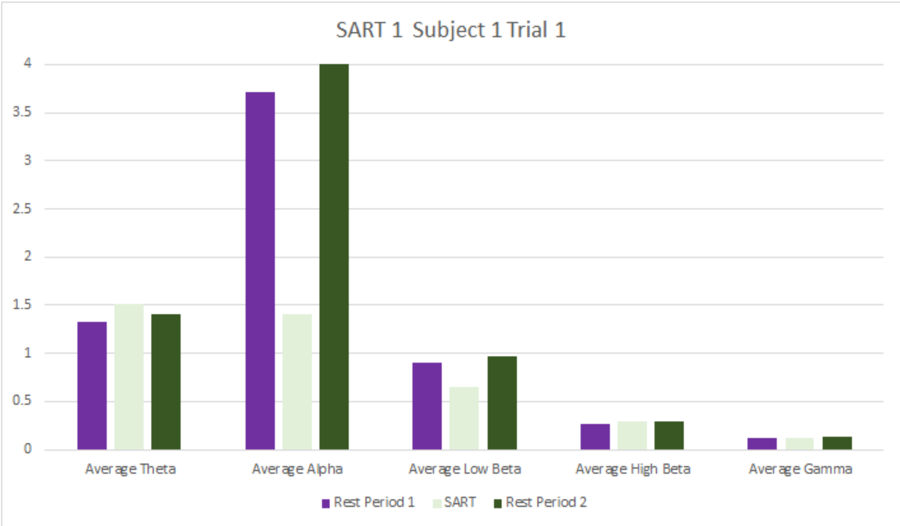


Figure 4.1: SART 1st Experiment - Subject 1 Trial 1

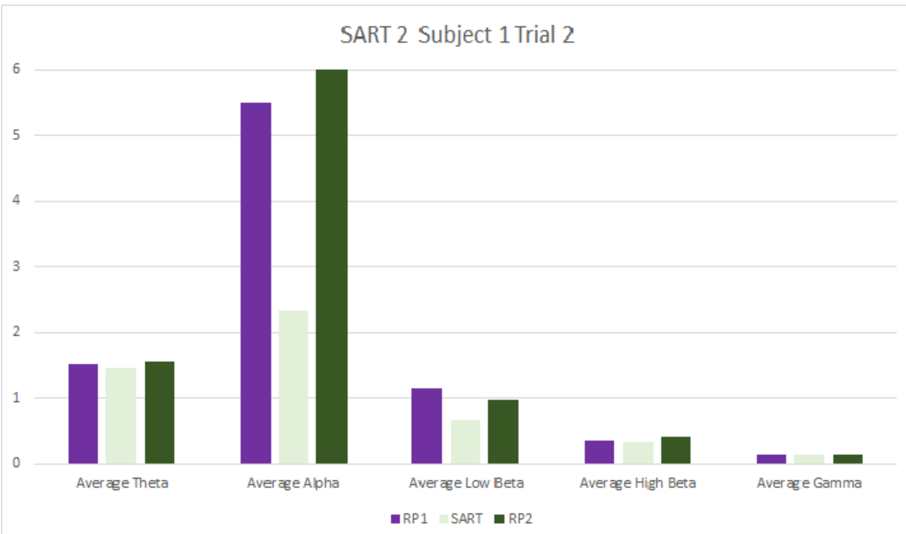


Figure 4.2: SART 2nd Experiment - Subject 1 Trial 2

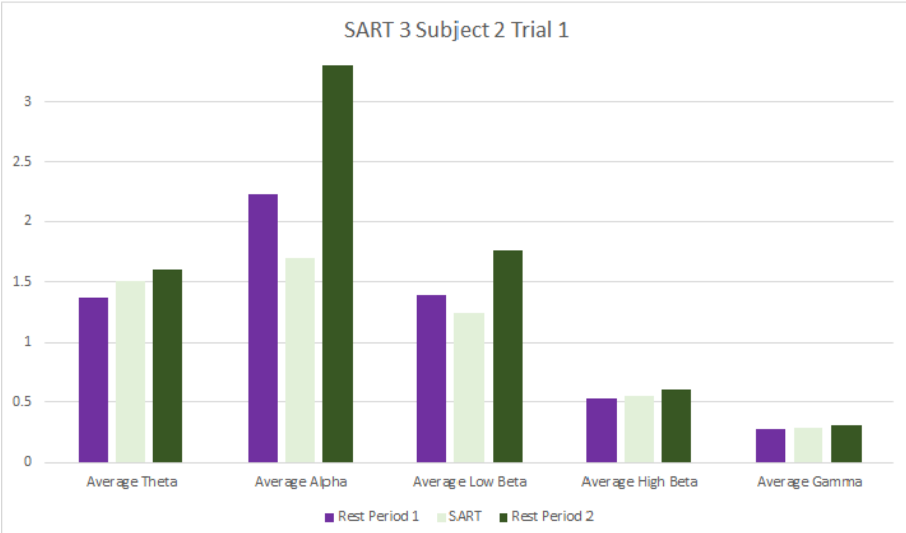


Figure 4.3: SART 3rd Experiment - Subject 2 Trial 1

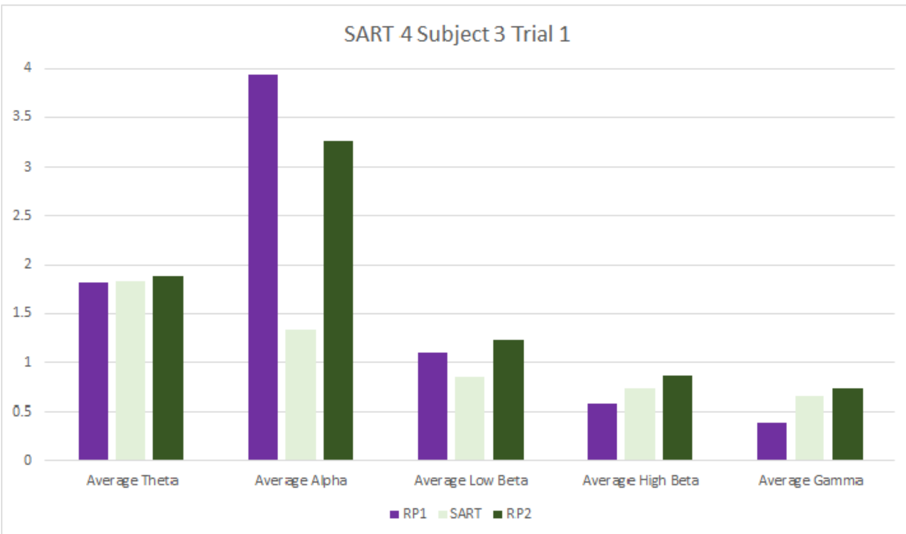


Figure 4.4: SART 4th Experiment - Subject 3 Trial 1

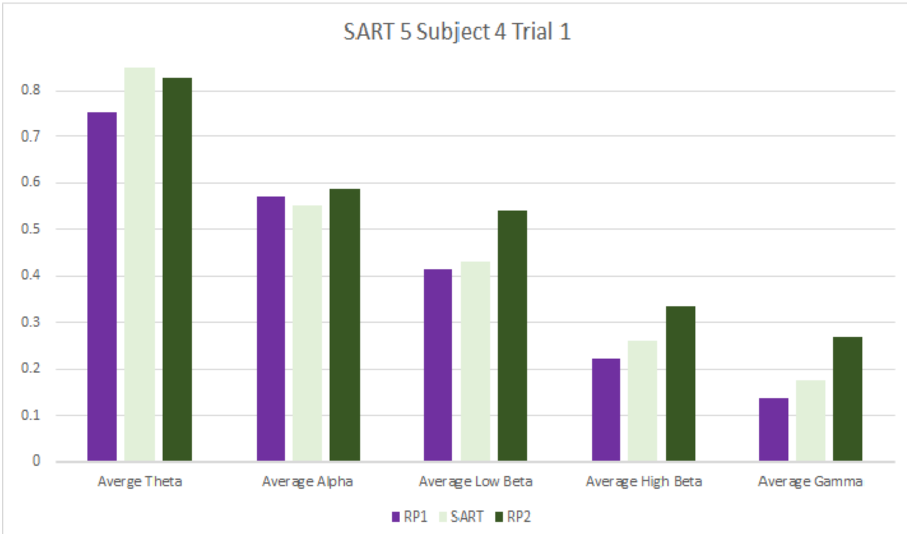


Figure 4.5: SART 5th Experiment - Subject 4 Trial 1

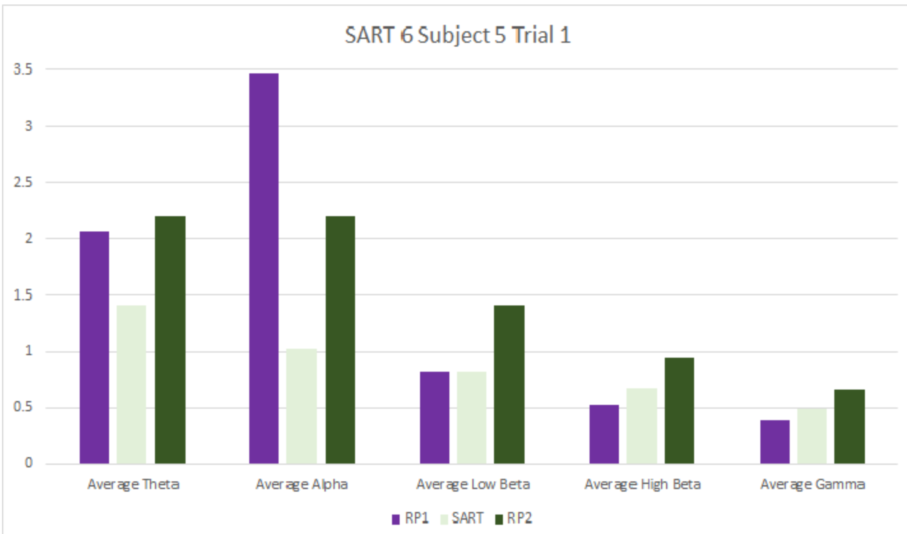


Figure 4.6: SART 6th Experiment - Subject 5 Trial 1

4.2.2 Binaural Beats Results

The results of the binaural beats experiment are illustrated in figures 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12. Each figure consists of both the average and maximum analysis of each band for each phase of each test subject. Focusing on the Alpha band comparison, 4 out of the 6 experiments reach their highest Alpha brain wave values in the post-binaural resting period (RP2), the 5th experiment has reached it in the binaural beats phase. In other words, 83.33 percent of the binaural preliminary experiments have their Alpha average levels higher in the phases of either being exposed to the binaural beats track or in the phase after such exposure. This highlights that the Alpha binaural beats may have primary potential to accomplish a relaxed state after the exposure of it.

In 3 of the experiments, it is observed that the test subjects experienced maximum values of all the bands in the binaural beat track exposure period. This means that for the Alpha band, 3 experiments exhibit the maximum level of Alpha in the binaural beats track. Moreover, 2 more experiments are observed to peak in Alpha in the post binaural beats track, concluding the results of the 6 preliminary binaural beats experiments to 83.33 percent of reaching the maximum Alpha wave values in the phases of either being exposed to the binaural beats track or in the phase after such exposure.

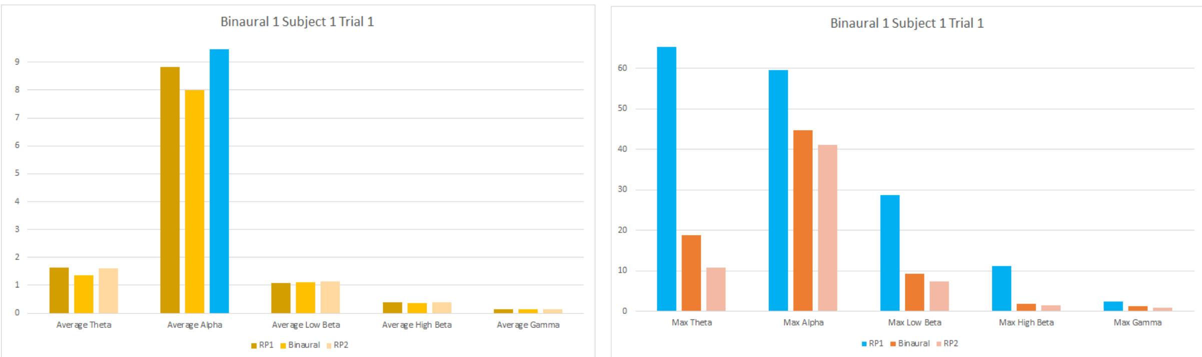


Figure 4.7: Binaural Beats Preliminary 1 - Subject 1 Trial 1

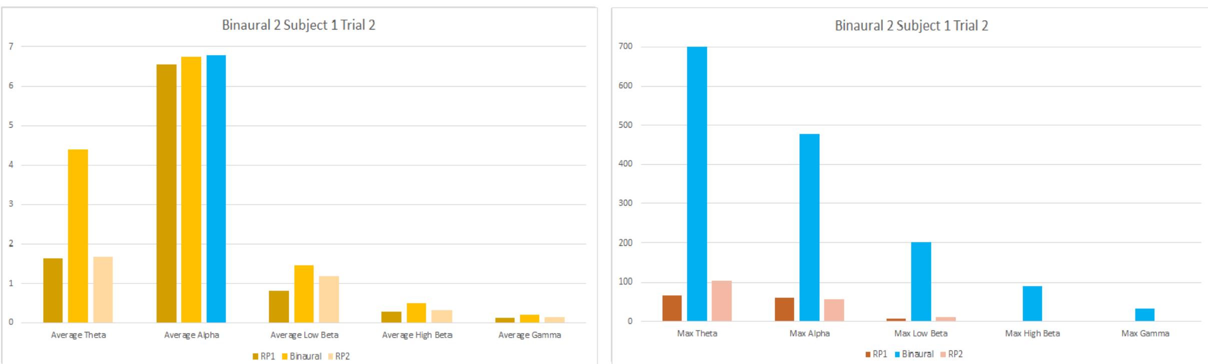


Figure 4.8: Binaural Beats Preliminary 2 - Subject 1 Trial 2

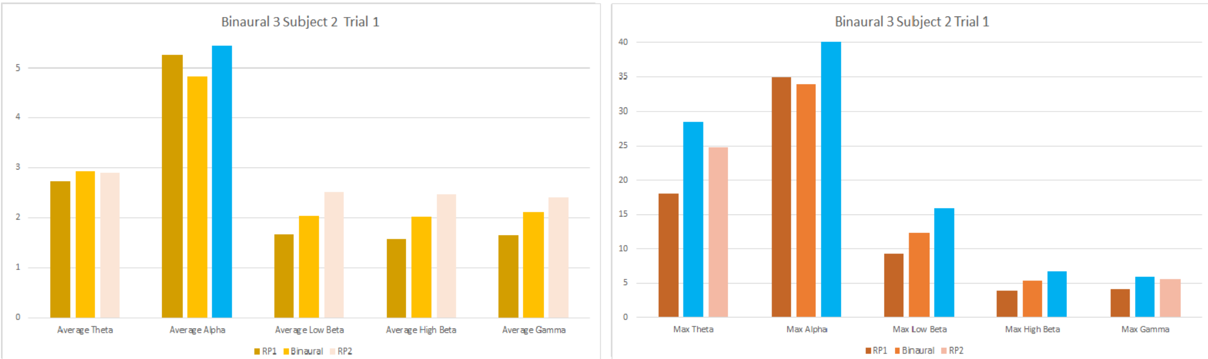


Figure 4.9: Binaural Beats Preliminary 3 - Subject 2 Trial 1

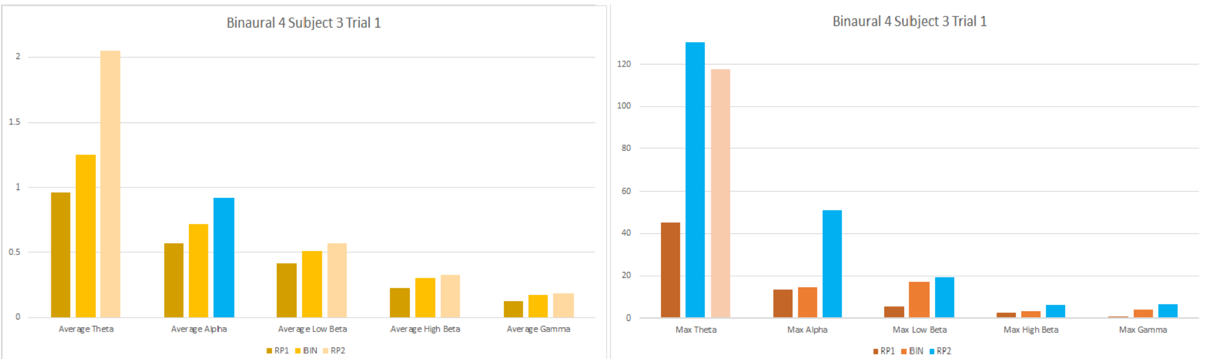


Figure 4.10: Binaural Beats Preliminary 4 - Subject 3 Trial 1

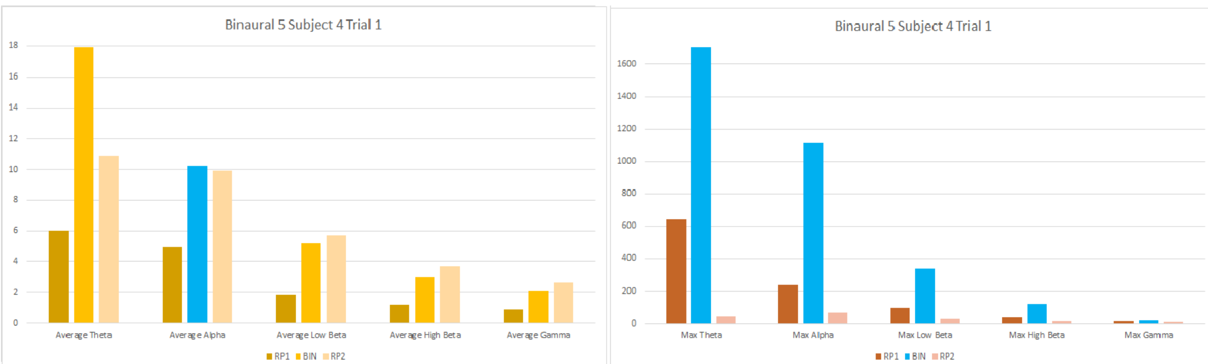


Figure 4.11: Binaural Beats Preliminary 5 - Subject 4 Trial 1

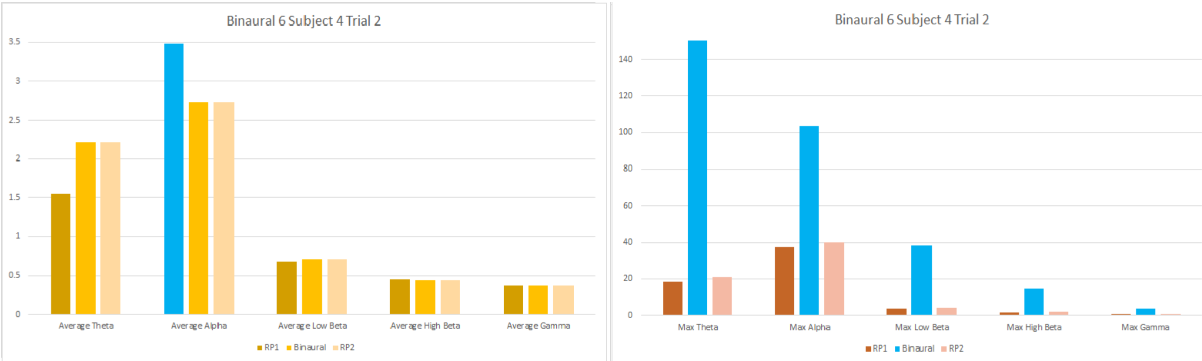


Figure 4.12: Binaural Beats Preliminary 6 - Subject 4 Trial 2

4.3 Experiment Design

The main experiment is divided into two experiments: experiment A and experiment B. Each of the experiments contain five phases, four of which are common between them. Those common phases are phase one which is Resting Period 1 (RP1) for 3 minutes, phase two which is the Sustained Attention to Response Task (SART) which lasts around 6 minutes, phase three which is Resting Period 2 (RP2) for 4 minutes, and phase five which is Resting Period 3 (RP3) lasts for 4 minutes. The difference between both experiments is in phase four.

Phase four is basically the essence of this research. In experiment A, the test subjects were exposed to Alpha binaural beats of frequency 10.5 Hz masked with pink noise for a period of 8 minutes. The binaural beats base frequency is set to be 390 Hz as George Oster [29] recommends the base frequency to be close to 400 Hz for the better results. On the other hand, in experiment B, the test subjects are subjected to pure pink noise for the same amount of time which is 8 minutes. This difference is aimed for the testing of effectiveness of the used binaural beats masked with pink noise in comparison to the exposure to only pink noise for the same amount of time.

Twelve participants are chosen for the main experiments, all in their early twenties. Each one of them is experimented on twice, once in experiment A and once in experiment B. Their order is arranged taking in consideration a learning effect, the first six who are tested in experiment A are the last six who are tested in experiment B, and vice verse. The test subjects are briefed about the nature and settings of the experiments before starting. Movement is not allowed unless the experiment requires so. Moreover, the test subjects are asked to turn off their phones and any other gadgets so that their radio frequency waves does not interfere with the experiments.

Emotiv EPOC+ Headset is adjusted to its 100 percent quality settings where all its sensors are in contact with their respective positions on the scalp. The markers for each phase is set on the EmotivPRO software which starts the recording and allows the viewing of raw data and the frequency analysis while it is recording as per the description in 3.1.2. The setting up of Emotiv Headset got more challenging by time. The amount of time taken to to set up the device on the test subjects have ranged from 6 to 30 minutes depending on their hair thickness and the device conditions.

The experiments take place in the same conditions of the preliminary experiments, in the same room with dim light and quietness. Room temperature is neither cold nor warm, and the test subjects are sitting in their comfortable position. The same set of earphones is used in all of the experiments and the test subjects have to put them on from the beginning of the experiments.

4.4 Results and Analysis

Same as for the preliminary experiments data analysis, each experiment's data is analyzed individually at first. EmotivPRO enabled extracting the raw data and the frequency analysis data in separate CSV files. Those CSV files are then combined and further analyzed using Microsoft Excel.

Using the raw data CSV file, the time stamps of the markers which determine the start and end of each phase of the experiment are collected. As follows, the frequency bands data CSV file is divided to the five phases utilizing the acquired time stamps.

As expected there have been some spikes in the data throughout the experiments which are due to uncontrollable artifacts like involuntary movements since it is bound to happen as the experiment is 25 minutes of sitting still while having to stay awake. Those spikes are removed from the data by carefully observing when exactly they take place and respectively removing them during that time of occurrence for all of the phases in all the experiments before analyzing them any further.

The average, minimum, and maximum values of each channel's band waves are calculated for each phase. A snippet of such per phase analysis is shown in Figure 4.13.

Moreover, after each phase of the experiment is analyzed on its own, graphs are computed to compare the average values of all the phases. Those average values are calculated for all the channels and all their bands. Figure 4.14 shows a snippet of these graphs. The total Theta, Alpha, Low Beta, High Beta, and Gamma values for each experiment are analyzed as well. This includes the average and maximum data analysis viewed in Figure 4.15. The maximum value comparison for all the phases in the experiments are analyzed as well.

Each one of the 24 experiments carried out are analyzed on their own as stated above. Following this, a comparison between each test subject's experiment A and experiment B takes place. As stated before, the only difference between both experiments is in phase 4; the audio phase. In experiment A, the test subjects are exposed to the Alpha binaural beats track designed for this experiment, while in experiment B, the test subjects are exposed to only pink noise for the same amount of time that is 8 minutes.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	TimeStamp	AF3_THET/	AF3_ALPH/	AF3_LOW_	AF3_HIGH_	AF3_GAMI	F7_THETA	F7_ALPHA	F7_LOW_E	F7_HIGH_E	F7_GAMM	F3_THETA	F3_ALPHA
1444	1.562E+09	3.98802	1.5554	1.28032	0.84132	0.36119	9.11768	4.21407	0.61424	1.03686	0.29954	2.1988	1.15816
1445	1.562E+09	4.66629	1.77358	1.1974	0.82631	0.35898	9.51795	3.70549	0.57229	1.00705	0.33047	2.12428	1.46584
1446	1.562E+09	4.99331	1.99856	1.17725	0.78638	0.34741	10.251	3.00151	0.57908	0.92479	0.34834	1.93774	1.8198
1447	1.562E+09	4.83957	2.17143	1.22355	0.7425	0.32801	10.291	2.28191	0.64563	0.82419	0.34658	1.7203	2.11606
1448	1.562E+09	4.33445	2.24519	1.29271	0.7084	0.30614	9.51032	1.7178	0.76234	0.73605	0.32772	1.46697	2.26375
1449	1.562E+09	3.61493	2.2079	1.32331	0.68545	0.28915	8.00934	1.41057	0.90373	0.67609	0.30193	1.24163	2.23058
1450	1.562E+09	2.8787	2.08899	1.26308	0.66341	0.28522	6.55205	1.36155	1.02136	0.64386	0.28224	1.01228	2.04511
1451	1.562E+09	2.2226	1.93571	1.10173	0.63682	0.29917	5.60953	1.48314	1.07745	0.63185	0.27761	0.86949	1.77079
1452	1.562E+09	1.6856	1.80252	0.86974	0.61344	0.33035	5.08114	1.66926	1.05164	0.63046	0.28953	0.73788	1.48719
1453	1.562E+09	1.30515	1.72312	0.63535	0.60717	0.37078	4.66705	1.88802	0.9586	0.63093	0.31249	0.7119	1.27464
1454	1.562E+09	1.09979	1.70155	0.47087	0.62833	0.40874	4.49969	2.155	0.84119	0.63094	0.33552	0.74267	1.18037
1455	1.562E+09	1.15113	1.71408	0.42149	0.67295	0.43415	4.53944	2.4719	0.75903	0.62631	0.34666	0.82236	1.20076
1456	1.562E+09	1.39929	1.72311	0.49533	0.72852	0.44181	4.77069	2.815	0.75613	0.61552	0.33946	0.90383	1.29739
1457	1.562E+09	1.76892	1.71022	0.65121	0.77803	0.4321	5.22238	3.09419	0.83048	0.59819	0.31545	0.9799	1.43398
1458													
1459	Average	15.0933	4.04497	1.79485	0.77238	0.36283	6.98939	2.48119	1.0941	0.58691	0.29563	2.32167	1.5214
1460	Min	0.44201	0.24257	0.13278	0.16076	0.11864	1.92821	0.35965	0.21784	0.16037	0.12943	0.26438	0.25617
1461	Max	2280.94	414.721	128.257	28.1951	13.0871	41.7288	16.5761	4.8985	3.16126	0.98142	19.6172	12.6742
1462													
1463		Theta	Alpha	Low Beta	High Beta	Gamma							
1464	Average	5.068	3.05534	2.10909	1.40453	1.13224							
1465	Min	0.093	0.14544	0.11108	0.07272	0.05769							
1466	Max	2280.94	767.087	763.708	783.925	790.325							
1467													

Figure 4.13: Analyzing the channels and their bandwidths of one phase in an experiment.

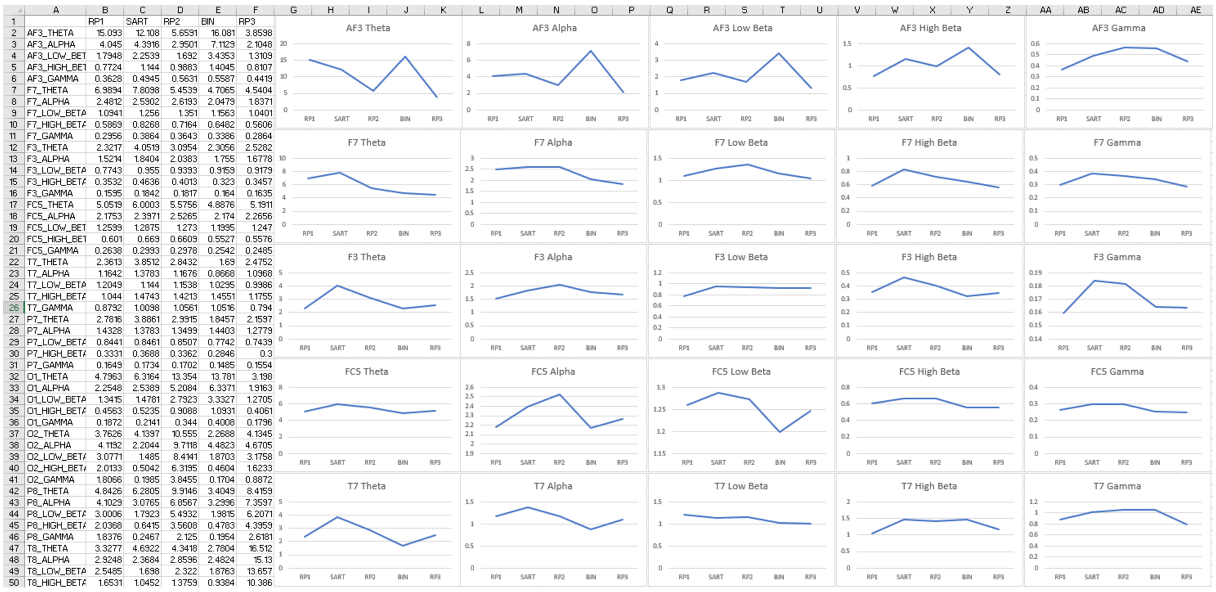


Figure 4.14: Snippet of Average Waves comparison of the five phases for each electrode of Experiment A on one of the test subjects.

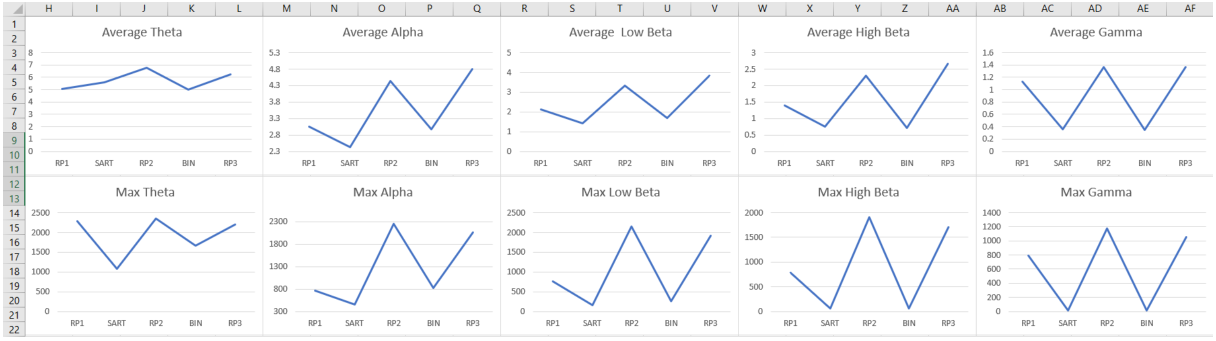


Figure 4.15: Snippet of Average and Maximum combined analysis for each brain wave for an experiment.

This comparison between the data of the same test subject during experiment A and experiment B is due to the fact that each person's brain activity is as unique as their finger prints. For instance, one can't simply formulate an observation from comparing one's Beta brain waves activity to another and comparing their levels of concentration, it has to be comparing one's Beta brain wave activity and that same person's data under different conditions or at another time.

As per the learning effect taken in consideration, half of the test subjects undergo experiment A first (test subjects 1-6) and the other half undergo experiment B first (test subjects 7-12). Each half consists of 3 females and 3 males, which amounts to having a 50:50 ratio of females and males as a total for the experiments. This aims to eliminate any gender bias in this research.

4.4.1 Average Cumulative Alpha Band Analysis

In Figures 4.16, 4.17, 4.18, 4.19, 4.20, and 4.21 each of the graphs shown compares each subjects average Alpha values of all the phases of experiment A to that of experiment B. "RP" is the Resting Period phase, "SART" is the Sustained Attention to Response Task phase, "BIN" is the binaural beats phase in experiment A, and lastly, "PINK" is the pink noise phase in experiment B.

The average Alpha comparison results of the phases of both experiments A and B for all test subjects has a lot of significance. Firstly, as expected from the results of the preliminary SART experiment in 4.2.1, for 95.8 percent of the 24 experiments Alpha average values in SART phase are less than the first resting period (RP1) before SART and the second one after it (RP2). In other words, this includes all the experiments except one; that is test subject 7 experiment A. This observation shows the ability to attain a state of neutral relaxation in the second resting period since it spikes from a concentrated unrest period of doing SART.

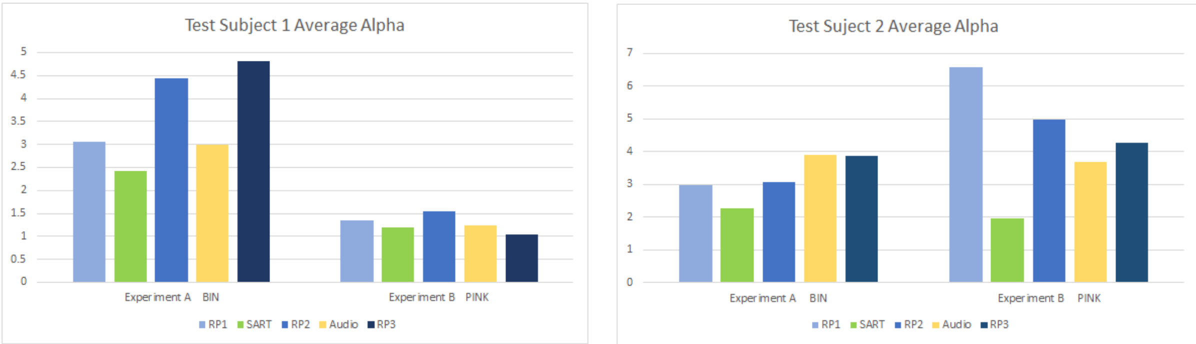


Figure 4.16: Average Alpha Waves Test Subjects 1 and 2

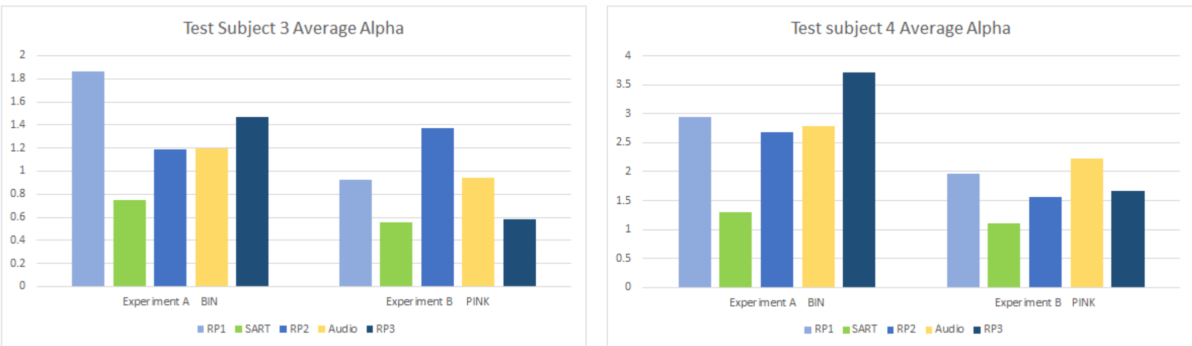


Figure 4.17: Average Alpha Waves Test Subjects 3 and 4

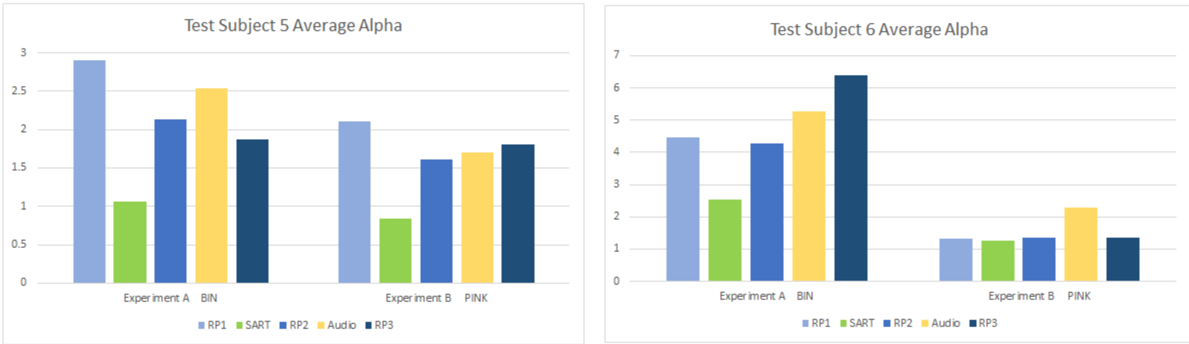


Figure 4.18: Average Alpha Waves Test Subjects 5 and 6

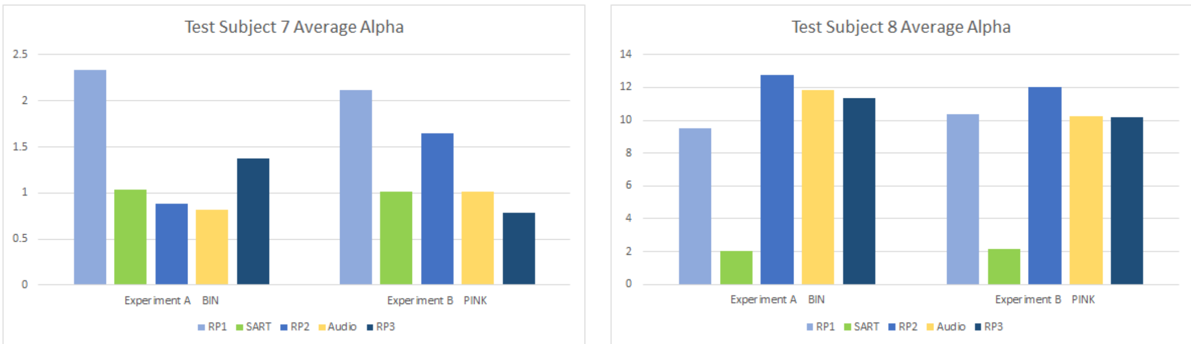


Figure 4.19: Average Alpha Waves Test Subjects 7 and 8

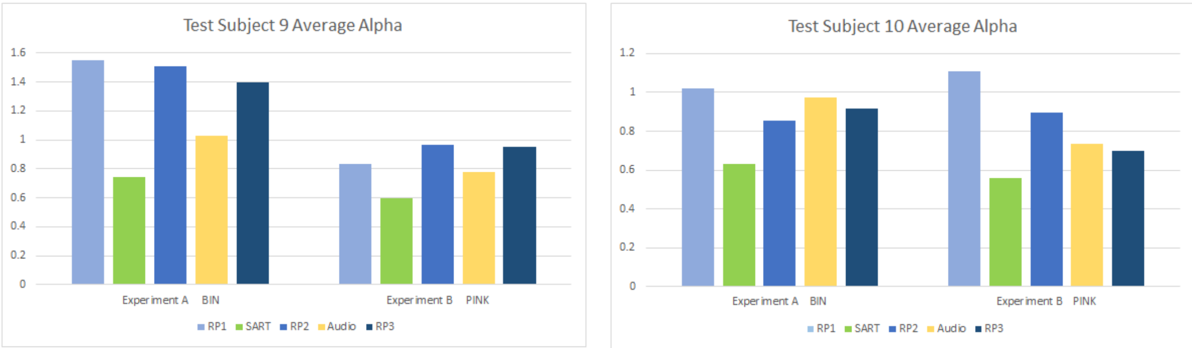


Figure 4.20: Average Alpha Waves Test Subjects 9 and 10

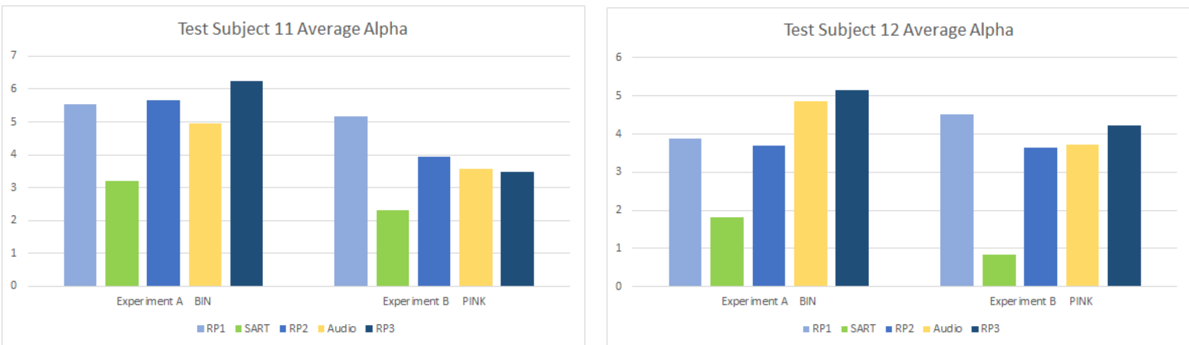


Figure 4.21: Average Alpha Waves Test Subjects 11 and 12

Secondly, for 75 percent of the 12 test subjects in experiment A, the Alpha binaural beats track manages to increase the average values of their Alpha brain waves after the exposure of it. This percentile is based on the fact that 9 test subjects out of the 12 are responsive to the binaural beats in a positive way. The ones who are not as responsive are test subjects 5, 8, and 9. This observation is considered a success to push those 9 test subjects into a state of relaxation.

However, one might wonder if the alleged state of relaxation reached is due to the elongation of time of rest after SART, which is 16 minutes. For this needed distinction, experiment B is formed. Its aim is to provide the same circumstances and settings of experiment A, including the same pink noise used in the auditory track in experiment A to mask the binaural beats. The only difference is that the track does not contain the binaural beats themselves. The track of experiment B only consists of pink noise to test whether the elongation in time for the resting period itself is the main driving force of reaching a better relaxed state instead of the auditory stimulus enforced in that state.

For 75 percent of the 12 test subjects in experiment B, as per the average Alpha brain waves value analysis, it is clear to see that there is a decrease of Alpha brain wave production as time passed. In other words, the last resting phase (RP3) post-pink noise exposure average overall Alpha values are less than those of the second resting phase (RP2) pre-pink noise exposure which is basically the main focus of our comparisons.

Only 3 of the test subjects experience an increase in Alpha as time passed after the exposure of pink noise, those are test subjects 4, 5, and 12. For 77.78 percent of the 9 test subjects who exhibit a decrease in Alpha due to the pink noise and time passing, the Alpha binaural beats audio used in experiment A manage to increase the average overall Alpha wave production in the last resting phase, unlike the pink noise only audio used in the respective experiment B of the test subject that manages to drive someone to an unease state. Test subject 8 and 9 fail to join this percentile.

4.4.2 Average Separate Channels Alpha Band Analysis

To take a deeper look on the effect of both auditory stimulus on the Alpha average values of the test subjects, one delves into comparing the values of the 14 channels observed in the experiments by the Emotiv EPOC+ Headset and to distinguish which of those channels are affected positively by the Alpha binaural beats exposure.

This analysis is based on comparing the average Alpha values of all the channels between all the test subjects, in both experiments A and B. Respective successes in both experiments in all test subjects are then combined to evaluate which of the 14 channels exhibit the expected results most in both experiments A and B.

Starting with experiment A whose table of analysis is shown in Figure 4.22, the average Alpha values of all channels for the 12 test subjects are recorded in a descending order of the last three phases; RP2, BIN, and RP3. The green cells of the table mark the success in experiment A where the average Alpha values of the post-binaural resting period (RP3) are higher than those of the pre-binaural resting period (RP2). Moreover, this signifies the effectiveness of the binaural beats in driving the test subjects to a more relaxed state since there is a clear increase in Alpha values. The yellow cells are considered to be a semi-success. This case happens when the average Alpha brain wave values are the highest in the binaural beats exposure phase (BIN), however, those average Alpha brain wave values of RP2 are greater than those of RP3, or else this would be considered as a total success case.

For experiment B, the analysis table is shown in Figure 4.23, the green cells are marked for total success and the yellow ones for semi-success exactly as in experiment A. Moreover, for experiment B, the total success cases happen when the average Alpha brain wave values of the pre-pink noise resting period (RP2) is higher than those average Alpha brain wave values of both the post-pink noise resting period (RP3) and the pink noise exposure period (PINK).

Experiment B aims to observe if the test subjects will be able to drive themselves into a state of relaxation with the elongation of the duration of the resting period without any external stimuli that could be a catalyst. The test subjects are only subjected to a track of pure pink noise (the PINK phase) which contains no auditory stimuli unlike experiment A. The yellow cells (semi-success) signifies that PINK phase has the highest average Alpha brain wave values in this experiment, however, those values of pre-pink noise resting period (RP2) are also higher than those average Alpha brain wave values of the post-pink noise resting period (RP3).

In both tables of experiment A and B analysis, the red cells signify that this specific channel for this specific test subject in the respective experiment has an invalid input. This channel is corrupted during the experiment by either the failing of the sensor or artifacts pushing the channel to exhibit abnormal fluctuations so it has to be eliminated otherwise it would present false data which could negatively influence the accuracy of this analysis.

Figure 4.24 shows the resulting table of this average separate channels Alpha band analysis. The green cells signify the combination of either the total successes of the corresponding cell in both experiments A and B, the total success of one and semi-success of the other, or the semi-success of both of them. The last column concludes this analysis by counting the number of positive result combinations for the 12 test subjects for each channel based on the analysis as explained previously.

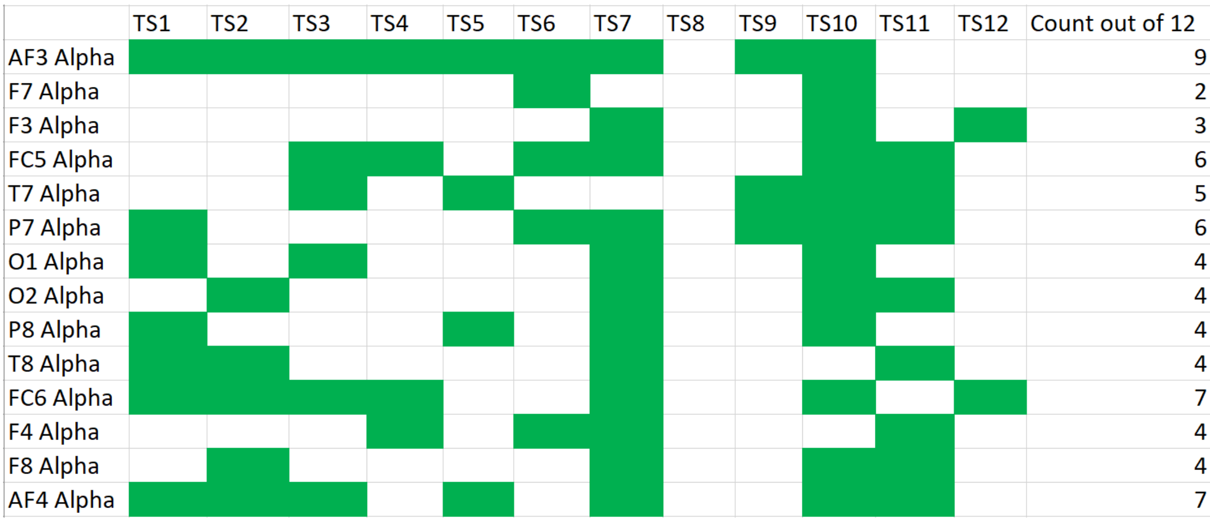
The average separate Alpha band analysis is further concluded in Figure 4.25, where the percentages of positive results are calculated. This analysis shows that the frontal lobe located sensors are the most affected by the Alpha binaural beats track since those channels show the best of the results of combining the positive results of the two experiments together.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12
2	AF3 Alpha	BIN>RP2>RP3	RP3>BIN>RP2	BIN>RP2>RP3	RP3>BIN>RP2	BIN>RP2>RP3	RP3>RP2>BIN	RP3>RP2>BIN	RP2>BIN>RP3	RP3>RP2>BIN	BIN>RP3>RP2	RP2>BIN>RP3	BIN>RP2>RP3
3	F7 Alpha	RP2>BIN>RP3	BIN>RP3>RP2	RP3>BIN>RP2	RP3>RP2>BIN	BIN>RP2>RP3	RP3>RP2>BIN	RP3>RP2>BIN	RP2>BIN>RP3	RP2>RP3>BIN	RP3>BIN>RP2	RP2>RP3>BIN	RP2>BIN>RP3
4	F3 Alpha	RP2>BIN>RP3	BIN>RP3>RP2	RP2>RP3>BIN	RP3>BIN>RP2	BIN>RP2>RP3	RP2>RP3>BIN	RP3>BIN>RP2	RP2>RP3>BIN	RP2>RP3>BIN	RP3>RP2>BIN	RP3>RP2>BIN	BIN>RP3>RP2
5	FC5 Alpha	RP2>RP3>BIN	BIN>RP3>RP2	RP3>BIN>RP2	RP3>BIN>RP2	BIN>RP2>RP3	RP3>RP2>BIN	RP3>RP2>BIN	RP2>BIN>RP3	RP2>RP3>BIN	BIN>RP3>RP2	RP3>RP2>BIN	
6	T7 Alpha	RP2>RP3>BIN	BIN>RP2>RP3	RP3>RP2>BIN	BIN>RP2>RP3	BIN>RP2>RP3	RP3>BIN>RP2	RP2>RP3>BIN	RP2>BIN>RP3	RP3>RP2>BIN	BIN>RP3>RP2	RP3>RP2>BIN	BIN>RP3>RP2
7	P7 Alpha	BIN>RP2>RP3	BIN>RP3>RP2	RP3>BIN>RP2	BIN>RP3>RP2	BIN>RP2>RP3	RP3>BIN>RP2	RP3>RP2>BIN	RP2>RP3>BIN	RP3>RP2>BIN	BIN>RP3>RP2	RP3>RP2>BIN	BIN>RP3>RP2
8	O1 Alpha	BIN>RP2>RP3	BIN>RP3>RP2	RP3>BIN>RP2	RP3>RP2>BIN	BIN>RP2>RP3	RP3>RP2>BIN	RP3>RP2>BIN	RP2>RP3>BIN	RP3>RP2>BIN	RP3>RP2>BIN		BIN>RP3>RP2
9	O2 Alpha	RP2>RP3>BIN	BIN>RP3>RP2	RP2>RP3>BIN	RP3>RP2>BIN	BIN>RP3>RP2	RP3>BIN>RP2	RP3>RP2>BIN	RP2>BIN>RP3	RP2>RP3>BIN	RP3>RP2>BIN	RP3>RP2>BIN	RP3>BIN>RP2
10	P8 Alpha	RP3>RP2>BIN	RP3>BIN>RP2	RP2>BIN>RP3	RP3>BIN>RP2	BIN>RP3>RP2	RP3>BIN>RP2	RP3>RP2>BIN	RP2>BIN>RP3	RP2>RP3>BIN	RP3>RP2>BIN		BIN>RP3>RP2
11	T8 Alpha	RP3>RP2>BIN	BIN>RP3>RP2	RP2>RP3>BIN	RP3>BIN>RP2	BIN>RP2>RP3	RP3>BIN>RP2	RP3>BIN>RP2	RP2>BIN>RP3	RP2>RP3>BIN	RP2>RP3>BIN	RP3>RP2>BIN	RP2>BIN>RP3
12	FC6 Alpha	RP3>RP2>BIN	RP3>BIN>RP2	RP3>RP2>BIN	RP3>BIN>RP2	BIN>RP2>RP3	RP3>BIN>RP2	RP3>BIN>RP2	RP2>BIN>RP3	RP3>RP2>BIN	RP3>RP2>BIN	RP2>RP3>BIN	BIN>RP3>RP2
13	F4 Alpha	RP2>RP3>BIN	RP2>BIN>RP3	RP2>RP3>BIN	RP3>BIN>RP2	BIN>RP2>RP3	RP3>BIN>RP2	RP3>RP2>BIN	RP2>BIN>RP3	RP3>RP2>BIN	RP2>RP3>BIN	RP3>RP2>BIN	RP3>BIN>RP2
14	F8 Alpha	RP2>RP3>BIN	BIN>RP3>RP2	RP3>BIN>RP2	RP3>BIN>RP2	BIN>RP2>RP3	RP3>BIN>RP2	RP3>BIN>RP2	RP2>BIN>RP3	RP2>RP3>BIN	BIN>RP3>RP2	RP3>RP2>BIN	BIN>RP3>RP2
15	AF4 Alpha	RP3>RP2>BIN	RP3>BIN>RP2	RP3>BIN>RP2	RP3>BIN>RP2	BIN>RP2>RP3	RP3>RP2>BIN	RP3>BIN>RP2	RP2>BIN>RP3	RP2>BIN>RP3	BIN>RP3>RP2	RP3>RP2>BIN	RP3>BIN>RP2

Figure 4.22: Experiment A Average Alpha Waves Order for all channels

	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12
AF3 Alpha	RP2>PINK>RP3	RP2>RP3>PINK	RP2>PINK>RP3	PINK>RP2>RP3	RP2>RP3>PINK	PINK>RP2>RP3	RP2>RP3>PINK	RP2>PINK>RP3	RP2>PINK>RP3	RP2>PINK>RP3	RP2>PINK>RP3	PINK>RP3>RP2
F7 Alpha	RP2>PINK>RP3	RP3>RP2>PINK	PINK>RP3>RP2	PINK>RP3>RP2	RP3>RP2>PINK	PINK>RP2>RP3	RP2>PINK>RP3	RP2>RP3>PINK	RP2>RP3>PINK	RP2>PINK>RP3	RP2>PINK>RP3	RP3>RP2>PINK
F3 Alpha	RP2>PINK>RP3	RP3>RP2>PINK	PINK>RP2>RP3	PINK>RP3>RP2	RP3>PINK>RP2	PINK>RP2>RP3	RP2>PINK>RP3	RP3>RP2>PINK	RP2>PINK>RP3	RP2>RP3>PINK	RP2>RP3>PINK	PINK>RP2>RP3
FC5 Alpha	PINK>RP2>RP3	RP3>RP2>PINK	PINK>RP2>RP3	PINK>RP2>RP3	RP3>RP2>PINK	PINK>RP2>RP3	PINK>RP2>RP3	RP2>RP3>PINK	RP2>PINK>RP3	RP2>PINK>RP3	RP2>PINK>RP3	RP3>RP2>PINK
T7 Alpha	RP2>PINK>RP3	RP3>RP2>PINK	PINK>RP2>RP3	PINK>RP3>RP2	RP2>RP3>PINK	PINK>RP3>RP2	RP2>PINK>RP3	RP2>PINK>RP3	RP2>RP3>PINK	RP2>PINK>RP3	RP2>RP3>PINK	RP3>PINK>RP2
P7 Alpha	RP2>RP3>PINK	RP3>PINK>RP2	RP3>PINK>RP2	PINK>RP3>RP2	RP3>PINK>RP2	PINK>RP2>RP3	RP2>PINK>RP3	PINK>RP3>RP2	RP2>RP3>PINK	RP2>RP3>PINK	PINK>RP2>RP3	RP3>RP2>PINK
O1 Alpha	RP2>PINK>RP3	RP3>RP2>PINK	PINK>RP2>RP3	PINK>RP3>RP2	RP3>PINK>RP2		RP2>PINK>RP3	RP2>PINK>RP3	RP3>RP2>PINK	RP2>PINK>RP3	RP2>PINK>RP3	RP3>RP2>PINK
O2 Alpha	RP2>PINK>RP3	RP3>RP2>PINK	PINK>RP2>RP3	PINK>RP3>RP2	RP3>PINK>RP2	PINK>RP3>RP2	RP2>PINK>RP3	PINK>RP3>RP2	RP3>RP2>PINK	PINK>RP2>RP3	RP2>PINK>RP3	RP3>RP2>PINK
P8 Alpha	RP2>PINK>RP3	RP3>PINK>RP2	RP2>PINK>RP3	PINK>RP3>RP2	RP2>PINK>RP3	PINK>RP3>RP2	RP2>PINK>RP3	PINK>RP3>RP2	RP3>RP2>PINK	RP2>RP3>PINK	RP2>RP3>PINK	RP3>RP2>PINK
T8 Alpha	RP2>PINK>RP3	RP2>RP3>PINK	PINK>RP2>RP3	PINK>RP3>RP2	RP3>PINK>RP2	PINK>RP3>RP2	RP2>RP3>PINK	RP2>PINK>RP3	RP3>RP2>PINK	RP2>RP3>PINK	RP2>PINK>RP3	RP3>RP2>PINK
FC6 Alpha	RP2>PINK>RP3	RP2>RP3>PINK	PINK>RP2>RP3	RP2>PINK>RP3	RP3>PINK>RP2	PINK>RP3>RP2	RP2>RP3>PINK	RP2>PINK>RP3	RP3>RP2>PINK	RP2>PINK>RP3	RP3>PINK>RP2	PINK>RP2>RP3
F4 Alpha	RP2>PINK>RP3	RP2>RP3>PINK	PINK>RP2>RP3	PINK>RP2>RP3	RP3>PINK>RP2	PINK>RP2>RP3	RP2>PINK>RP3	RP2>RP3>PINK	RP3>RP2>PINK	RP2>RP3>PINK	RP2>PINK>RP3	RP3>RP2>PINK
F8 Alpha	RP2>PINK>RP3	RP2>RP3>PINK	PINK>RP3>RP2	PINK>RP3>RP2	RP3>PINK>RP2	PINK>RP3>RP2	RP2>PINK>RP3	RP2>PINK>RP3	RP3>RP2>PINK	RP2>PINK>RP3	RP2>PINK>RP3	RP3>RP2>PINK
AF4 Alpha	RP2>PINK>RP3	RP2>RP3>PINK	RP2>PINK>RP3	PINK>RP3>RP2	RP2>RP3>PINK	PINK>RP3>RP2	RP2>PINK>RP3	RP2>RP3>PINK	RP3>RP2>PINK	RP2>RP3>PINK	RP2>PINK>RP3	RP3>RP2>PINK

Figure 4.23: Experiment B Average Alpha Waves Order for all channels



	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	Count out of 12
AF3 Alpha													9
F7 Alpha													2
F3 Alpha													3
FC5 Alpha													6
T7 Alpha													5
P7 Alpha													6
O1 Alpha													4
O2 Alpha													4
P8 Alpha													4
T8 Alpha													4
FC6 Alpha													7
F4 Alpha													4
F8 Alpha													4
AF4 Alpha													7

Figure 4.24: Result of Average Separate Alpha Band Analysis

Channels	Count out of 12	Percentage of positive results
AF3 Alpha	9	75%
F7 Alpha	2	16.67%
F3 Alpha	3	25%
FC5 Alpha	6	50%
T7 Alpha	5	41.67%
P7 Alpha	6	50%
O1 Alpha	4	33.33%
O2 Alpha	4	33.33%
P8 Alpha	4	33.33%
T8 Alpha	4	33.33%
FC6 Alpha	7	58.33%
F4 Alpha	4	33.33%
F8 Alpha	4	33.33%
AF4 Alpha	7	58.33%

Figure 4.25: Result of Average Separate Alpha Band Analysis

4.4.3 Maximum Alpha Band Analysis

Another element is inspected in both experiments, that is the depth of relaxation reached, if any. The maximum value analysis is used to determine the maximum values of Alpha reached in all phases of each of the experiments. For each of the test subjects, the maximum values of Alpha brain waves reached in all the phases in experiment A are compared with those of experiment B. This comparison is shown in Figures 4.26, 4.27, 4.28, 4.29, 4.30, and 4.31.

The red bars in the graphs highlights the phase with the highest maximum Alpha in both experiments of all the test subjects. The horizontally stripped bars highlights the second highest in cases where it's very close to the maximum. Moreover, the dotted bars are some invalid rise in data that occurred in the SART phase due to some artifacts not related to relaxation levels.

Figure 4.26: Max Alpha Values Test Subjects 1 and 2

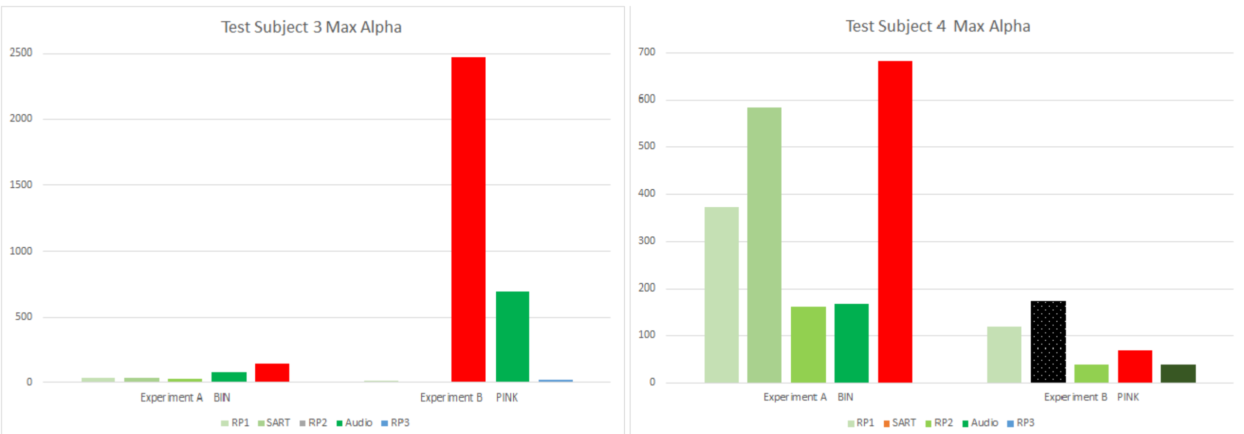


Figure 4.27: Max Alpha Values Test Subjects 3 and 4

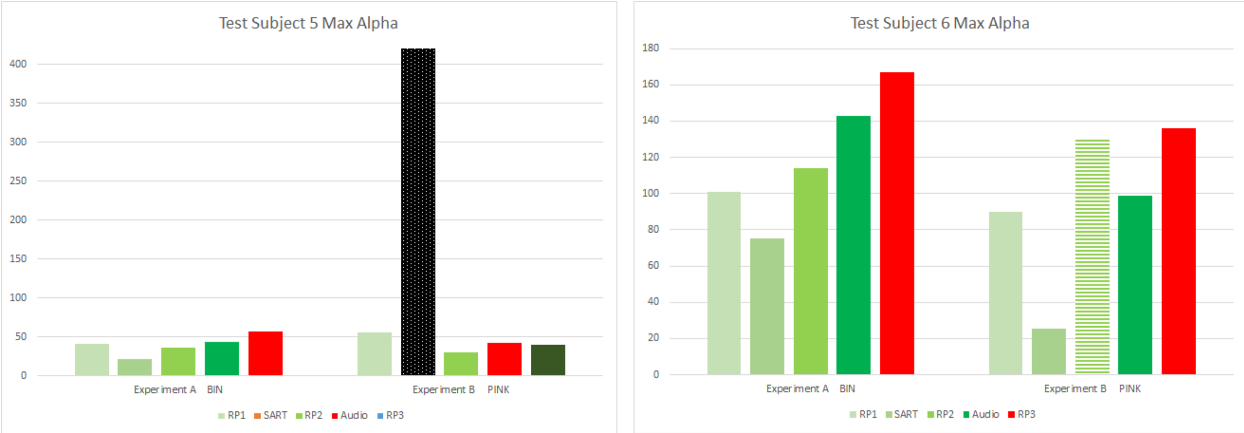


Figure 4.28: Max Alpha Values Test Subjects 5 and 6

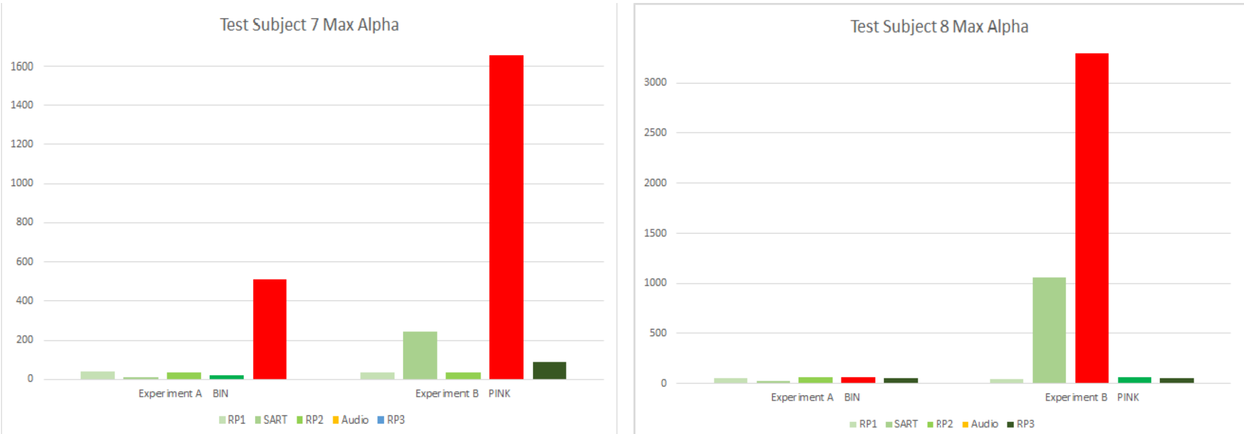


Figure 4.29: Max Alpha Values Test Subjects 7 and 8

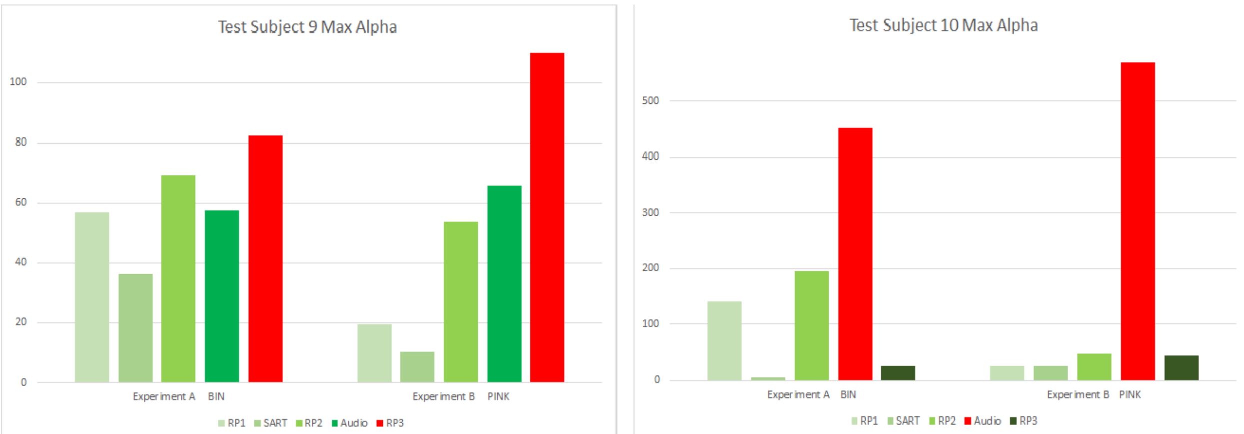


Figure 4.30: Max Alpha Values Test Subjects 9 and 10

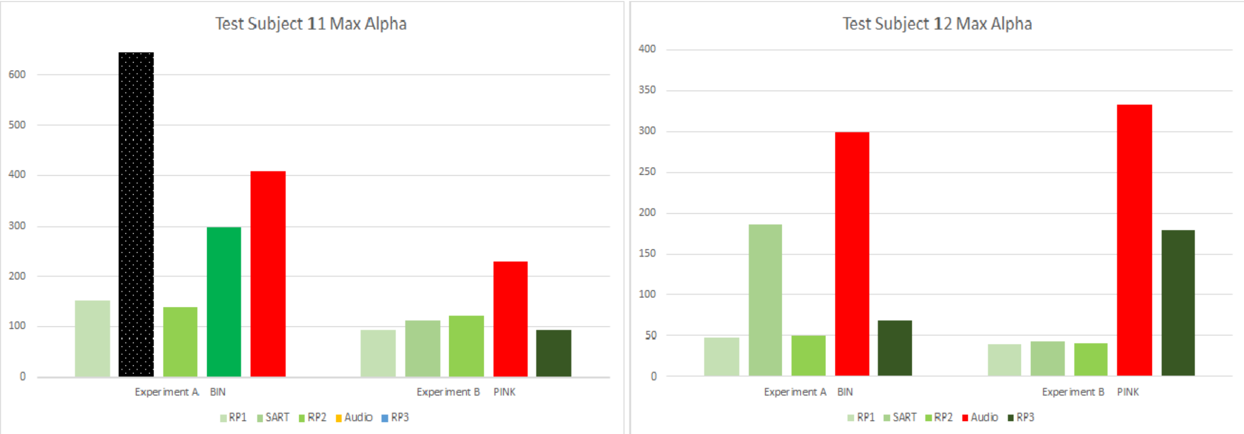


Figure 4.31: Max Alpha Values Test Subjects 11 and 12

From the graphs formed, 37.5 percent of the 24 experiments have the maximum Alpha value in the audio phase. For the binaural beats experiments, 25 percent of the 12 test subjects have reached their maximum Alpha value in the binaural beats exposure period, while 66.67 percent of the 12 test subjects reach the maximum Alpha value in the post-binaural resting period (RP3). For experiment B, 33.33 percent of them have reached their maximum Alpha value in the pre-pink noise resting period (RP2), while 50 percent of them reach such maximum in the pink noise exposure phase. In conclusion, only 2 of the test subjects reach the maximum in the post-binaural resting period in experiment A and the pre-pink noise in experiment B. This analysis doesn't lead us to very positive observations regarding whether or not the Alpha binaural beats manage to drive the test subjects to a deep state of relaxation or just an elongated state of it.

4.4.4 Average Cumulative Bands Analysis

This analysis is basically comparing all the bands, except for Alpha, cumulative average values of all the phases in experiments A and B of each test subject. The graphs of this analysis are found in Appendix A in Figures A.1, A.2, A.3, A.4, A.5, A.6, A.7, A.8, A.9, A.10, A.11, and A.12.

The aim of this analysis is to compare the average values of Theta, Low Beta, High Beta, and Gamma brain waves of all the phases of both experiments for each test subject. Each figure of the mentioned above shows the graphs of both experiments A and B to visualize that comparison. Alpha band is excluded from this analysis since it is already analyzed in the Average Cumulative Alpha Band Analysis found in 4.4.1.

Results of this comparison and analysis is shown in Figure 4.32 and Figure 4.33. In Figure 4.32 the count in the cells is based on the number of claimed successes reached for all the test subjects for each band. "Success in A" means that in experiment A, the Alpha binaural beats manage to increase the respective band value after the exposure of it to be more than its value before the exposure (RP3 is greater than RP2). "Success in

B" means that the pink noise and the elongation of the resting period after the SART do not have a positive impact on increasing the respective bands (RP2 is greater than RP3). "Success in A and B" is the intersection of Successes of A and B, as literal as it may sound, where for each of the test subjects in experiment A their values of the post-binaural (RP3) are higher than that of the pre-binaural (RP2) and in experiment B their values of the pre-pink noise (RP2) are higher than that of the post-pink noise (RP3).

	Theta	Low Beta	High Beta	Gamma
Success in A	7	10	9	9
Success in B	9	8	11	10
Success in A and B	4	6	9	9

Figure 4.32: Count of the successes of the test subjects for each band

The table in Figure 4.33 shows the corresponding percentages of named successes of the experiments for Theta, Low Beta, High Beta, and Gamma brain wave average values as explained previously.

	Theta	Low Beta	High Beta	Gamma
Success in A	58.33%	83.33%	75%	75%
Success in B	75%	66.67%	91.67%	83.33%
Success in A and B	33.33%	50%	75%	75%

Figure 4.33: Percentages of the successes of the test subjects for each band

Chapter 5

Conclusion and Future Work

5.1 Discussion

The preliminary experiments have reached the expected results for both the Sustained Attention to Response Task (SART) experiment and the Alpha binaural beats experiment. For the SART preliminary experiment, Alpha average band values are the lowest in the SART phase for all the 6 performed experiments, this shows that the SART did manage to put all the test subjects in a neutral resting state. In other words, SART managed to put them in an equally unrelaxed state without having their personal stress affect their average Alpha values while maintaining attention for an elongated period of time.

As for the preliminary Alpha binaural beats experiment, its results show a glimpse of potential with its extremely small set of test subjects. 83.33 percent of those experiments have their average Alpha values increased and their maximum Alpha values reached either during the period of exposure of the Alpha binaural beats or during the period after such exposure.

As for the main experiments (experiments A and experiments B) both are simultaneously analyzed individually at first, analyzing each phase on its own, then using such reached analysis data for further integration of four grouping analysis methods. The first three methods focus on analyzing the Alpha band since it is the main focus of this research.

The first method is the average cumulative Alpha band analysis in 4.4.1. This analysis shows multiple observations, one of which is that the SART indeed manages to attain a state of neutral relaxation and focus for 95.8 percent of the 24 experiments. This means that for 95.8 percent of the experiments, the average Alpha values of the test subjects in the SART phases are less than that of the first resting period (RP1). This analysis also shows that for experiment A, 75 percent of the test subjects are driven to a more relaxed state after being exposed to the binaural beats of Alpha frequency (10.5 Hz). As for experiment B, 3 of the test subjects (25 percent) only experience a more relaxed state after the exposure of pink noise track. Out of the 9 test subjects who don't experience such effects, 77.78 percent of them experience an increase in Alpha average values in experiment A in the post-binaural stage (RP3). This analysis shows the positive effectiveness of using the Alpha binaural beats in attempting to increase the Alpha production of individuals after the exposure of such beats for such a modest sample size.

The second method of the grouping analysis for the 24 experiments is the average separate channels Alpha band analysis. This analysis analyzes the Alpha average values of each of the 14 channels provided by the Emotiv EPOC+ EEG headset. Two tables for each experiment are constructed highlighting the total success cases in each experiment as green, and each semi-success case as yellow as explained in 4.4.2. The two tables are combined to form a resulting one intersecting both the success cases of the two experiments. Percentages of the positive results are calculated and it has been observed that most of the frontal lobe referencing electrodes have the highest of scores. This concludes how the frontal area of the brain is the most affected in a positive way by the Alpha binaural beats.

Moreover, the third method of analysis is the maximum Alpha band analysis seen in 4.4.3. This analysis is aimed to test if one can find out if the depth of any reached state of relaxation can be measured. It observes which phase all the test subjects reach the highest Alpha value in both experiments A and B. For experiment A, 25 percent of the test subjects reach their maximum in the binaural beats auditory phase, while 66.67 percent reach their maximum Alpha values in the post-binaural resting phase. In experiment B, only 33.33 percent reach their maximum Alpha values in the pre-pink noise resting period. In conclusion, only 2 out of the 12 test subjects have reached both their maximum Alpha values in experiment A in the post-binaural phase and in experiment B in the pre-pink noise phase. These results show that this maximum Alpha band analysis performed does not manage to measure the depth of relaxation in a positive way as expected.

Last but not the least, one has to look at what changes occur from observing the effect of the Alpha binaural beats on the other bands as well. The last analysis type is the average cumulative bands analysis that looks into the changes in the Theta, Low Beta, High Beta and Gamma frequency bands in 4.4.4. The analysis observes that High Beta and Gamma brain waves are the most affected waves by the Alpha binaural beats in a positive way. They both attain 75 percent of success as to both success in experiments A and B. Such success is experienced in experiment A when the average waves values of the post-binaural are higher than that of the pre-binaural, and in experiment B when such values of the pre-pink noise resting period are higher than that of the post-pink noise resting period. As for Low Beta, it is affected by 50 percent in total of successes of experiment A and experiment B, even though it has individual success in experiment B as 83.33 percent.

5.2 Conclusion

This research aims to study the effectiveness of using Alpha frequency (10.5 Hz) adjusted binaural beats masked with pink noise on driving a neutrally relaxed person into a state of relaxation, while attempting to measure the depth of such relaxation reached, if any. From the results analyzed, it is clear that the Alpha binaural beats have a strong potential to create such a relaxed state. These results should be retested in enhanced settings and a bigger sample size, however, with the little facilities in hand, these results seem to be headed in a positive direction.

5.3 Challenges encountered

There has been a few challenges anticipated to occur in the experiments before starting their process. One of which is the gender bias of the test subjects where George F. Oster [29] shows how the males and females can have different reactions to the binaural beats. This challenge is faced in the preliminary experiments due to lack of test subjects. However, there is an equal ratio of females and males in the main experiments (experiments A and B). A 50:50 ratio of gender is obtained for the 12 test subjects selected for this research.

Another challenge which definitely is observed is the modest sample size. Due to lack of the test subjects and the relatively short duration allowed for this research, the test subjects sample size is only 12 but each are tested on twice concluding 24 experiments which is technically still a very modest sample size, and that may interfere with the accuracy of the results.

Humans have various different characteristics. Those different characteristics could influence their brain activity. Consequently, the effect of external stimuli on different people may be affected by those different characteristics. As Robert M. Stelmack and Kenneth B. Campbell [35] has observed, characteristics like being an introvert or an extrovert could interfere with the effect of binaural beats on the person. This is considered a challenge since this research does not focus on any differences between the test subjects except for their gender as previously mentioned.

The results reached are only attained by analyzing the brain data, however, more confirmation for the mind state induced due to the binaural beats of Alpha frequency is needed alongside the brain activity data recorded. This should increase the data accuracy, however, this could not be reached in this research due to the usage of the Emotiv EPOC+ headset which records and analyzes the brain signals only.

5.4 Future Work

There has been a positive potential of the binaural beats seen from the results reached and the hope of using the binaural beats of Alpha frequency to drive the people to a relatively relaxed state. There is a huge potential for the binaural beats specially the Alpha frequency adjusted ones to be used as a therapeutic tool for relaxing the stressed individuals, however, due to the highlighted small sample size, this needs further research with a bigger sample size to improve the accuracy of the results.

Nevertheless, in this research the only used sensors are EEG based sensors. To improve the results and to further test the realized effects of the Alpha binaural beats, other sensors could be used. Those suggested sensors may include analyzing other factors other than the brain activity such as heart rate, skin conductance, respiratory rate and other bodily functions that are activated due to emotional reactions.

One of the challenges that is met in this research is the inability to detect the distinct the different factors between the test subjects except handling the gender differences. More research should be performed to study the effect of binaural beats on the brain activity keeping in mind such effect could be influenced by the different characteristics on the test subjects. A categorization of results ought to take place based on the aforementioned characteristics to help increase the wellness and accuracy of studying the effect of the binaural beats on the people's brain activity.

Appendix

Appendix A

A.1 Average Cumulative Bands Analysis Graphs

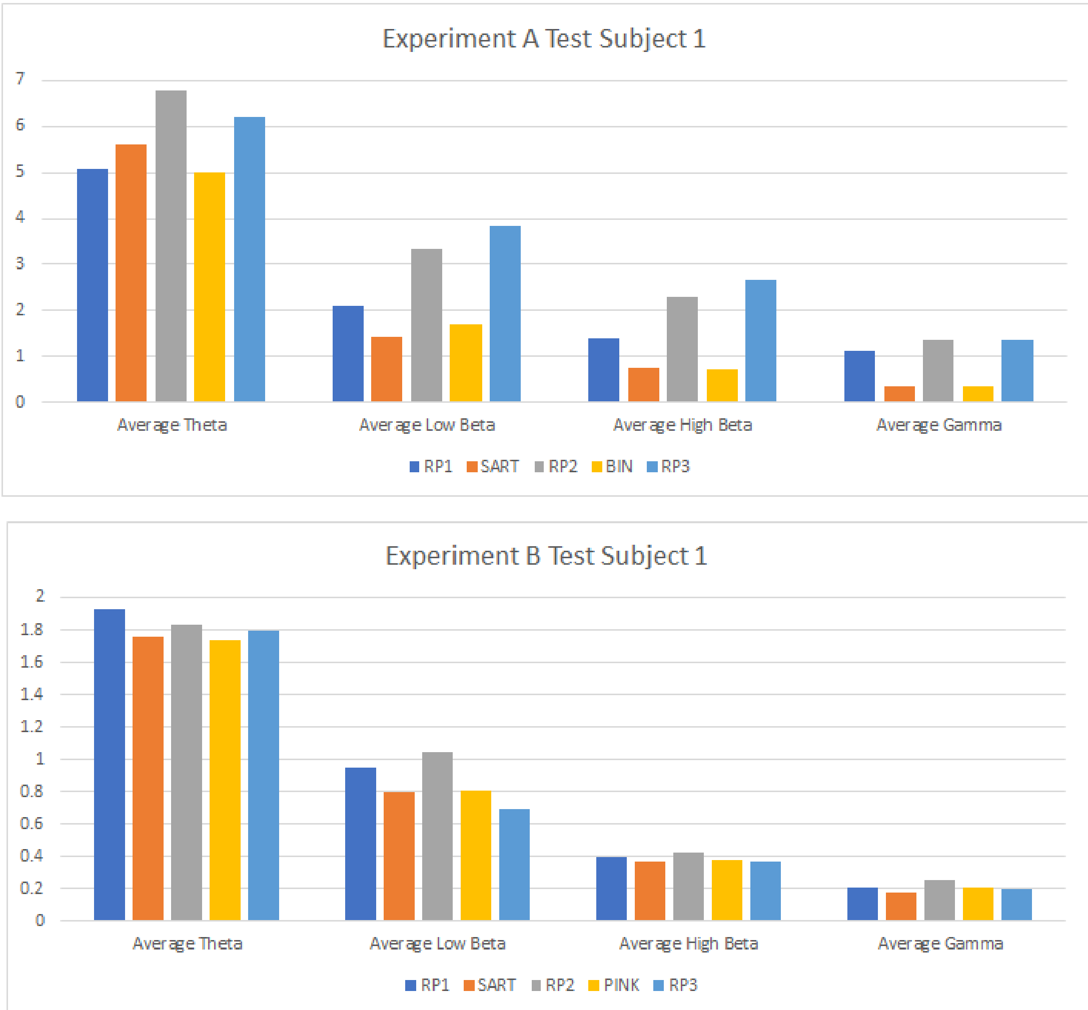
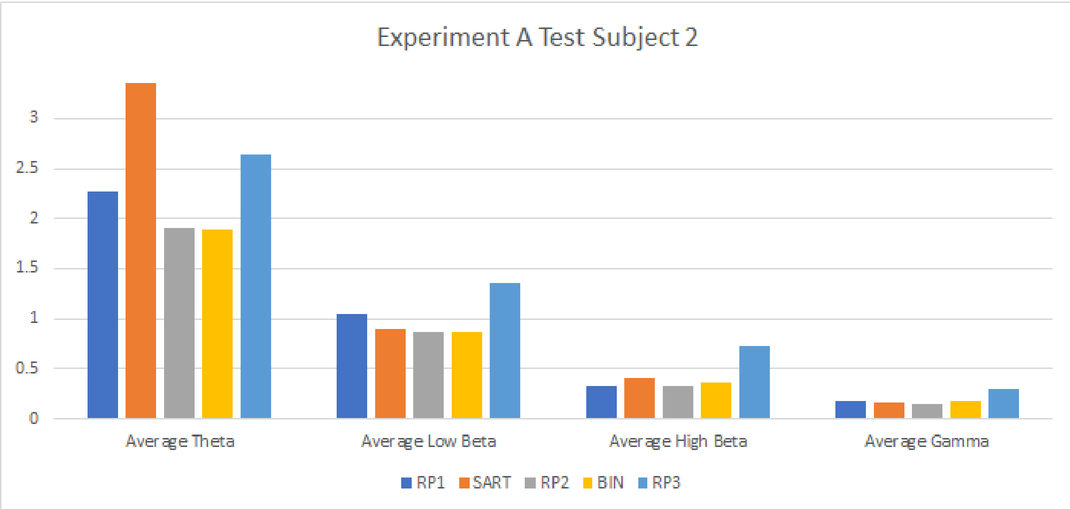


Figure A.1: Test Subject 1 Experiments A and B Bands Analysis



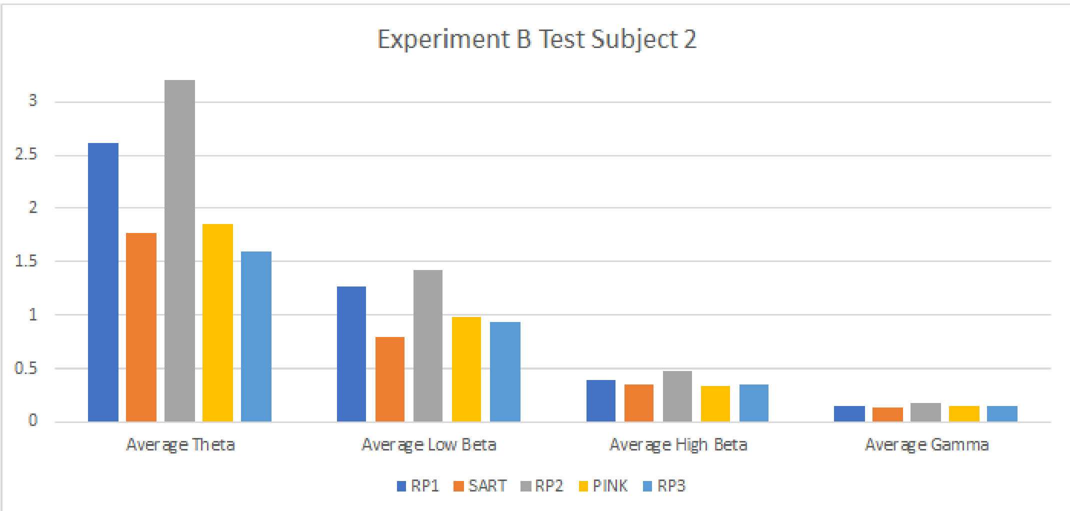
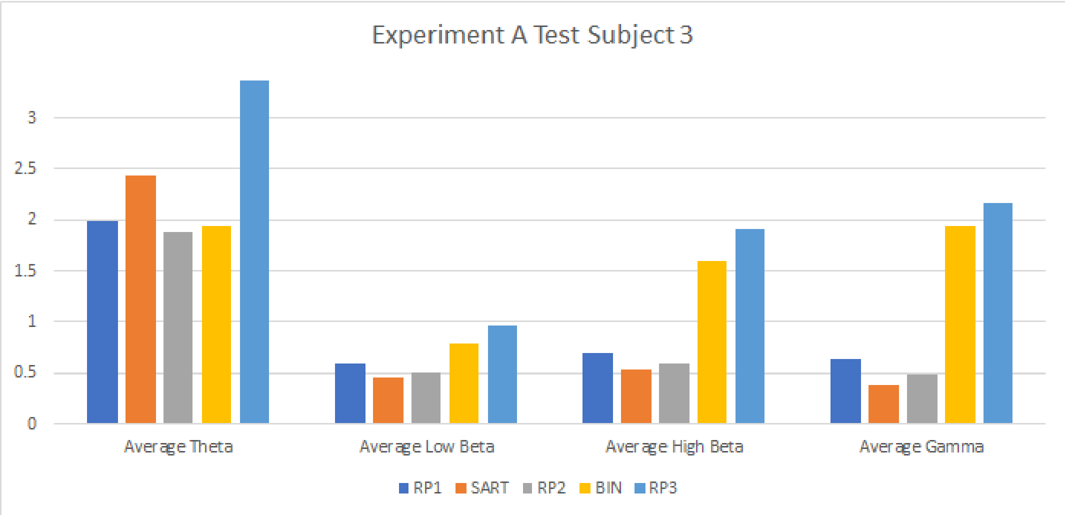


Figure A.2: Test Subject 2 Experiments A and B Bands Analysis



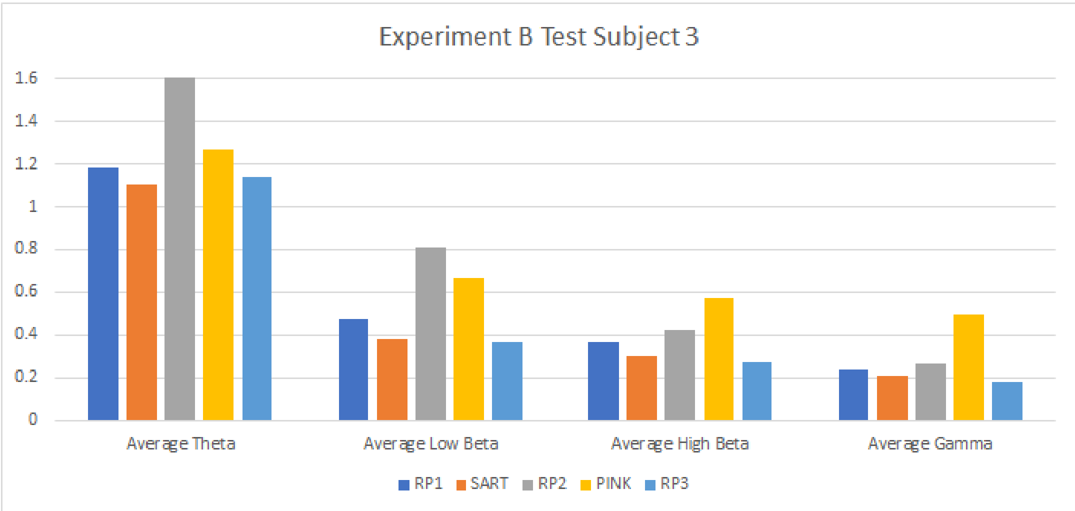
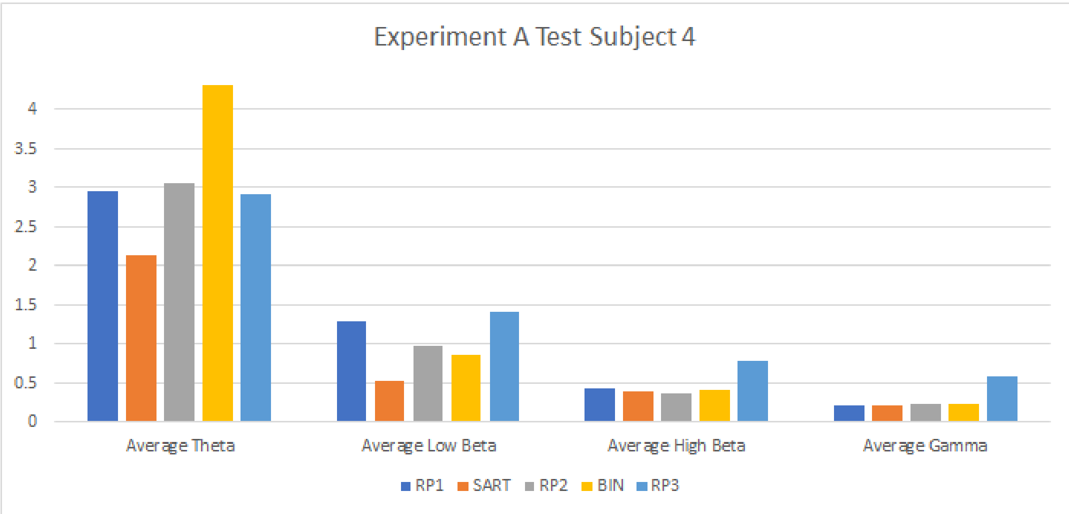


Figure A.3: Test Subject 3 Experiments A and B Bands Analysis



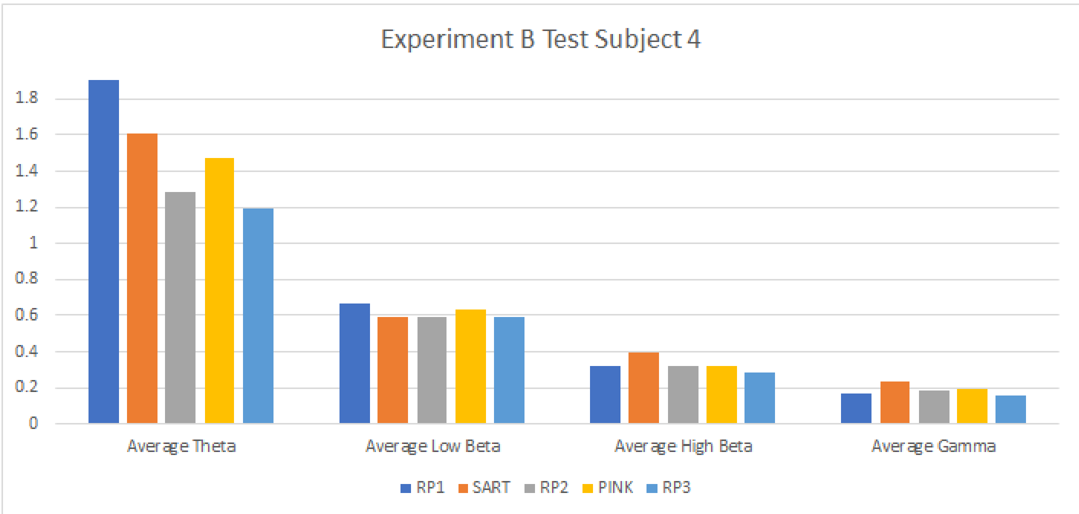
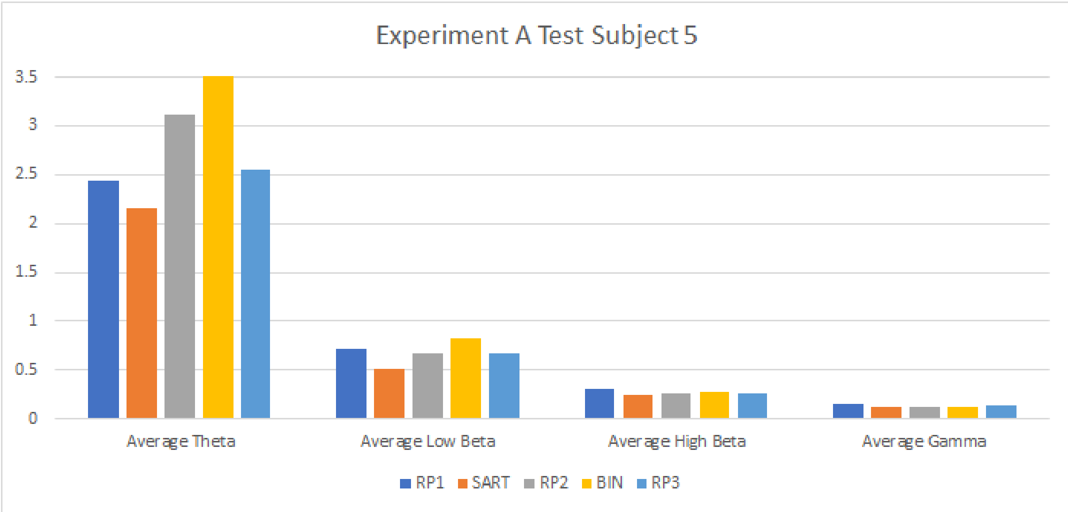


Figure A.4: Test Subject 4 Experiments A and B Bands Analysis



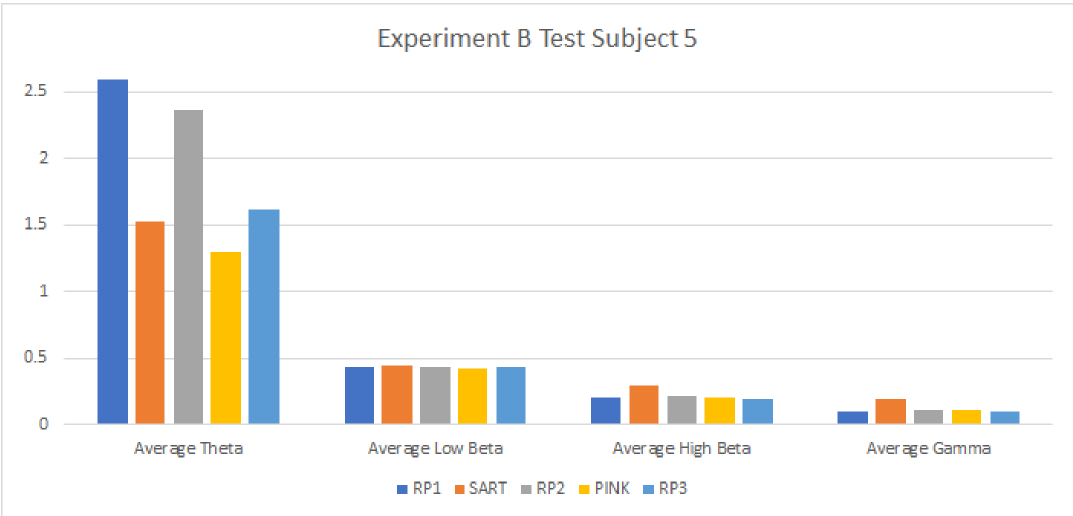


Figure A.5: Test Subject 5 Experiments A and B Bands Analysis

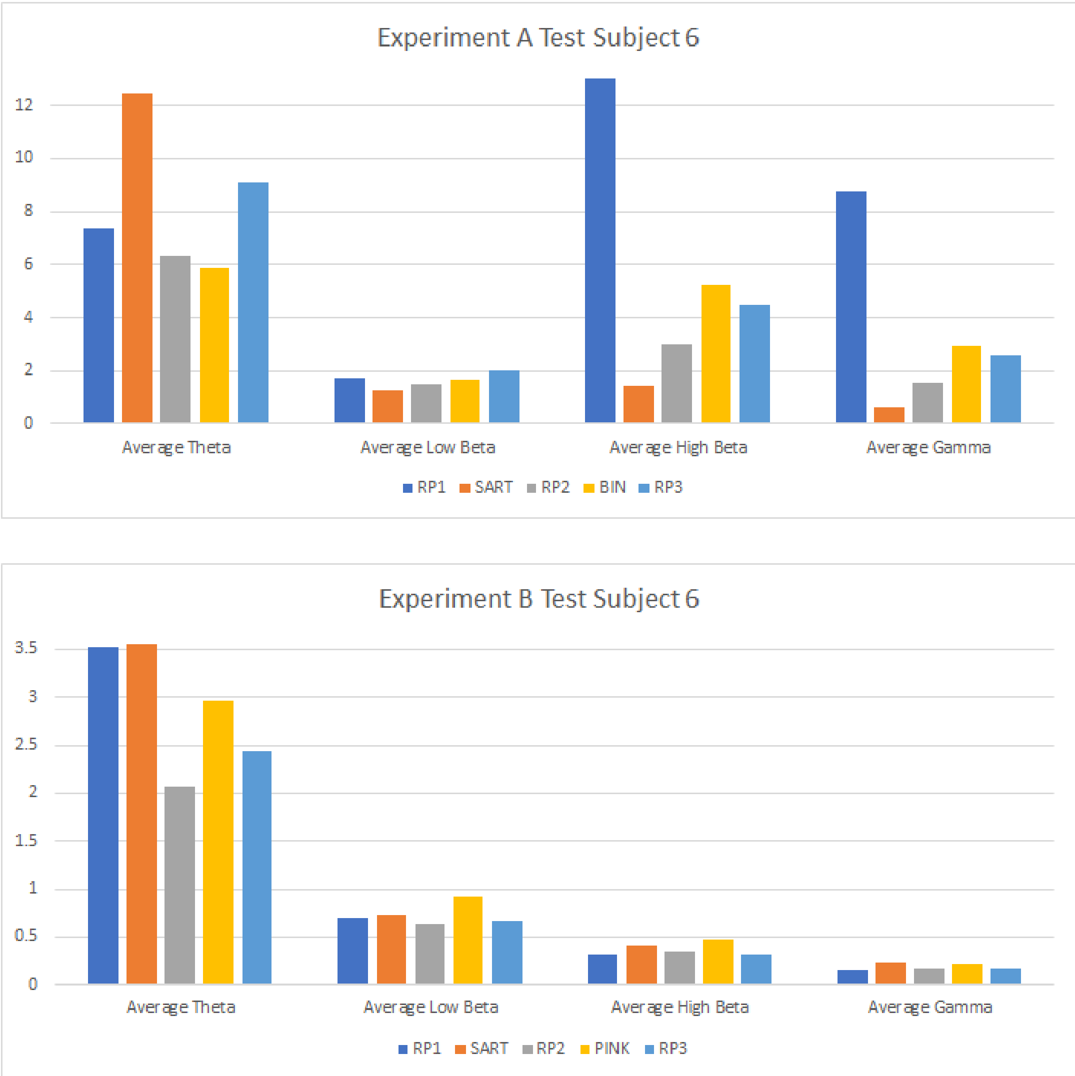
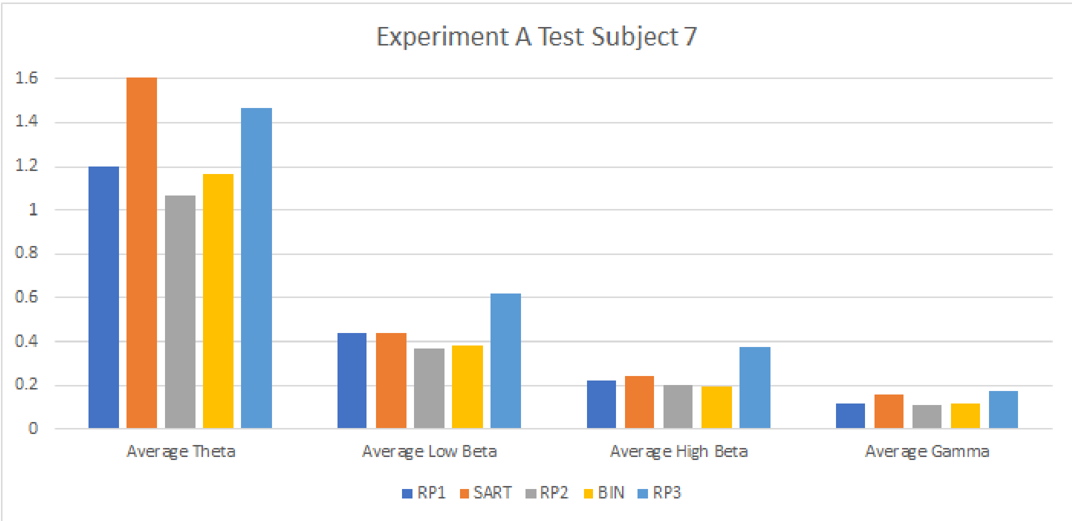


Figure A.6: Test Subject 6 Experiments A and B Bands Analysis



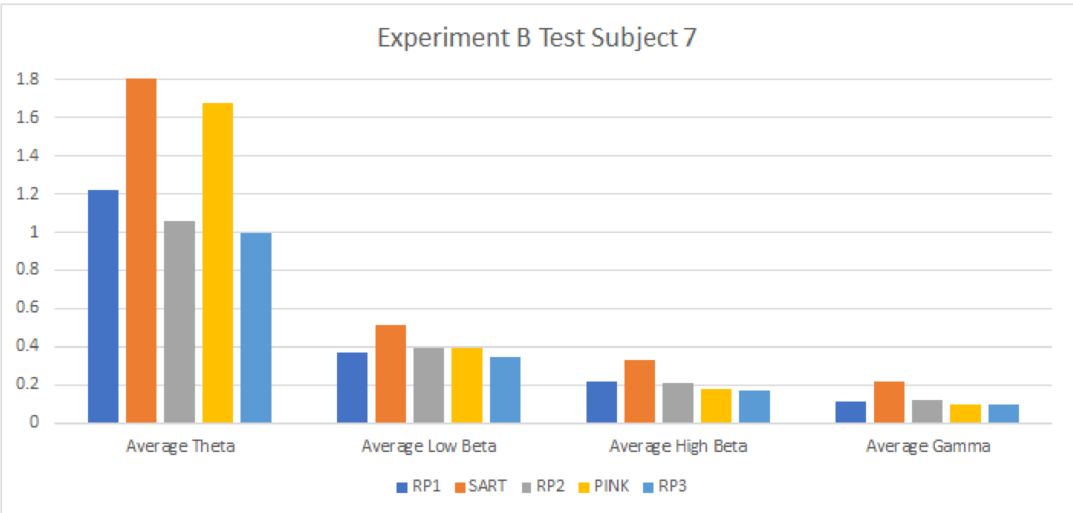
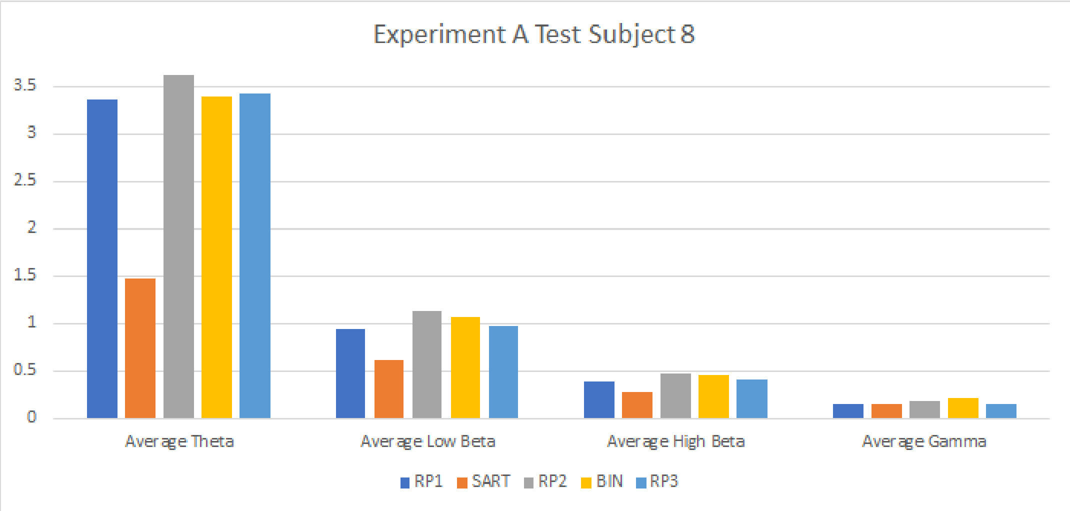


Figure A.7: Test Subject 7 Experiments A and B Bands Analysis



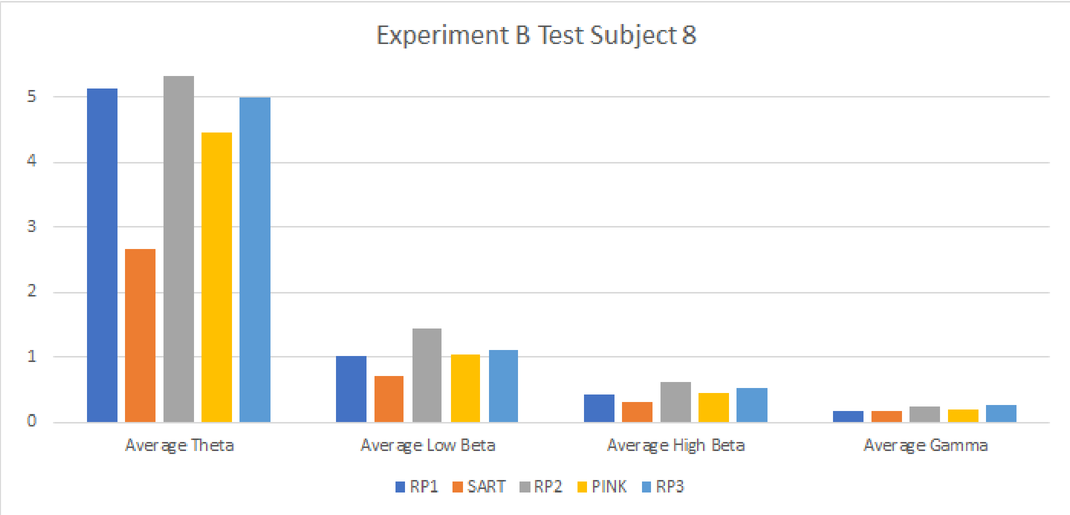
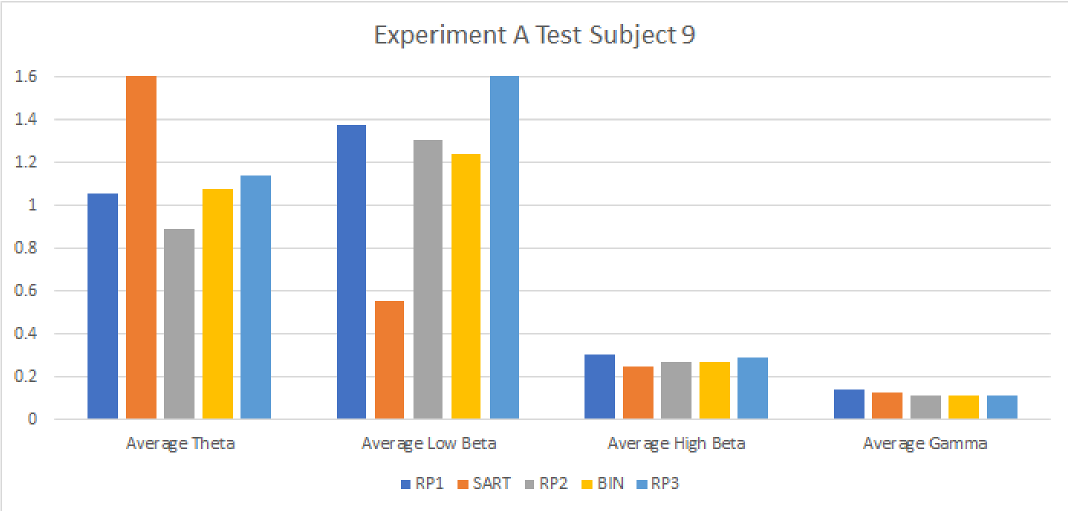


Figure A.8: Test Subject 8 Experiments A and B Bands Analysis



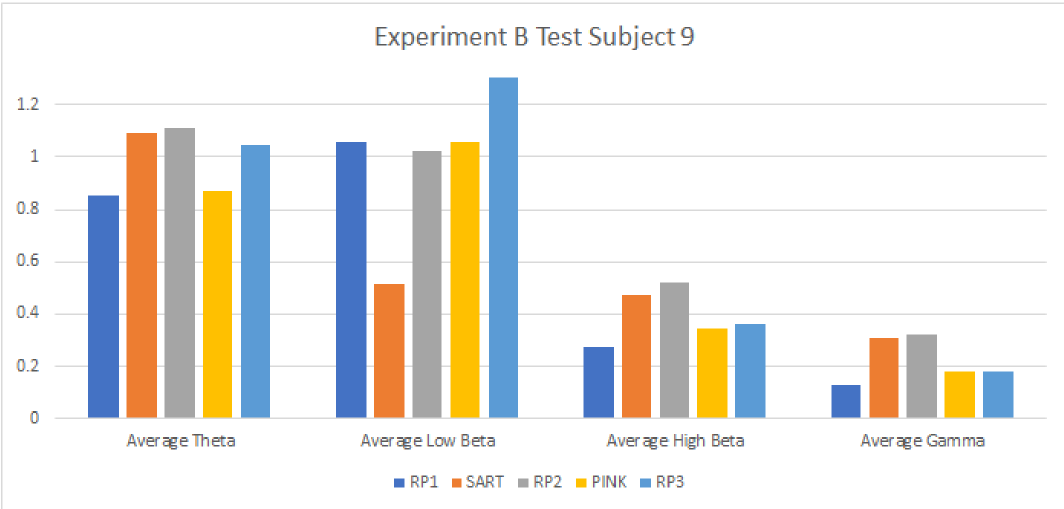


Figure A.9: Test Subject 9 Experiments A and B Bands Analysis

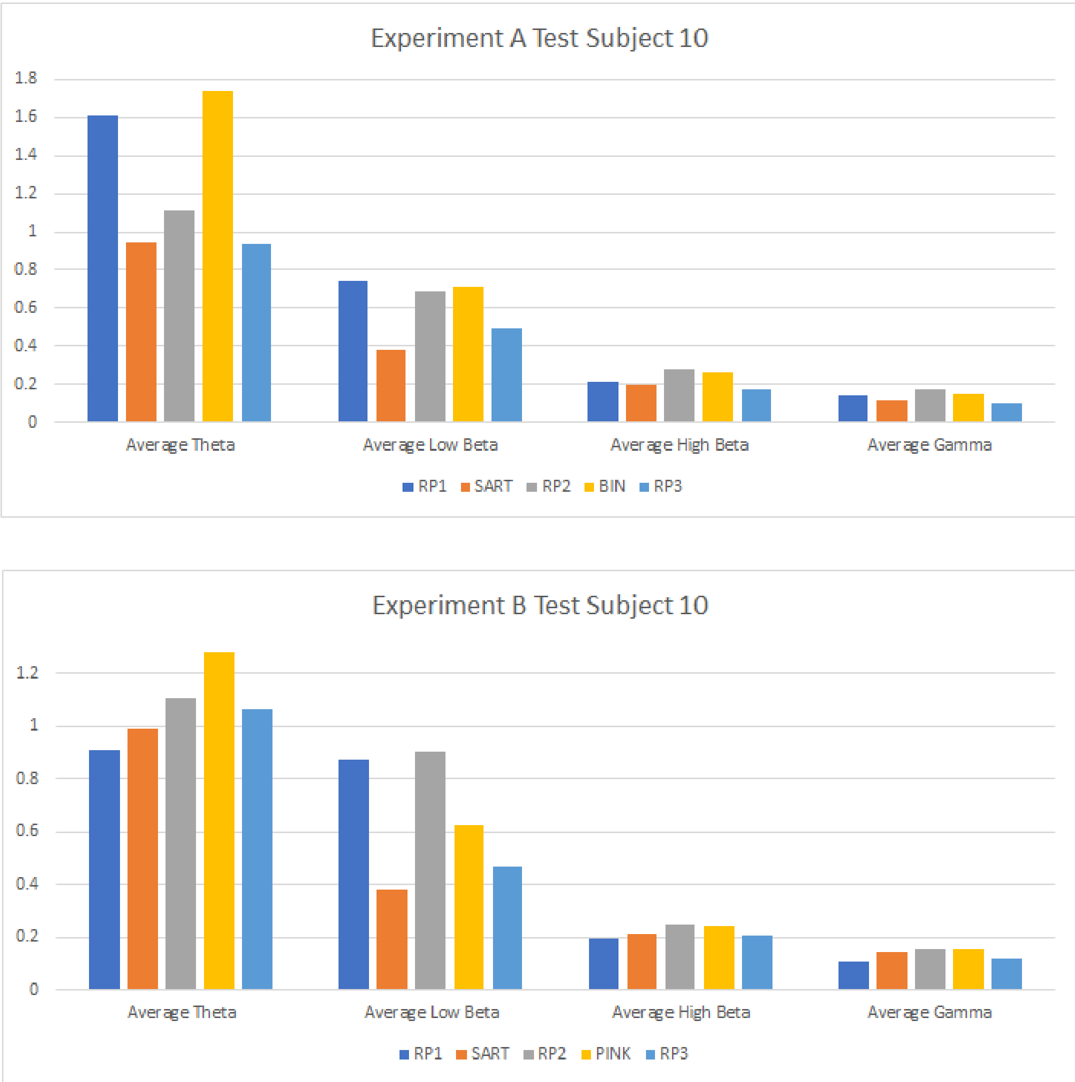


Figure A.10: Test Subject 10 Experiments A and B Bands Analysis

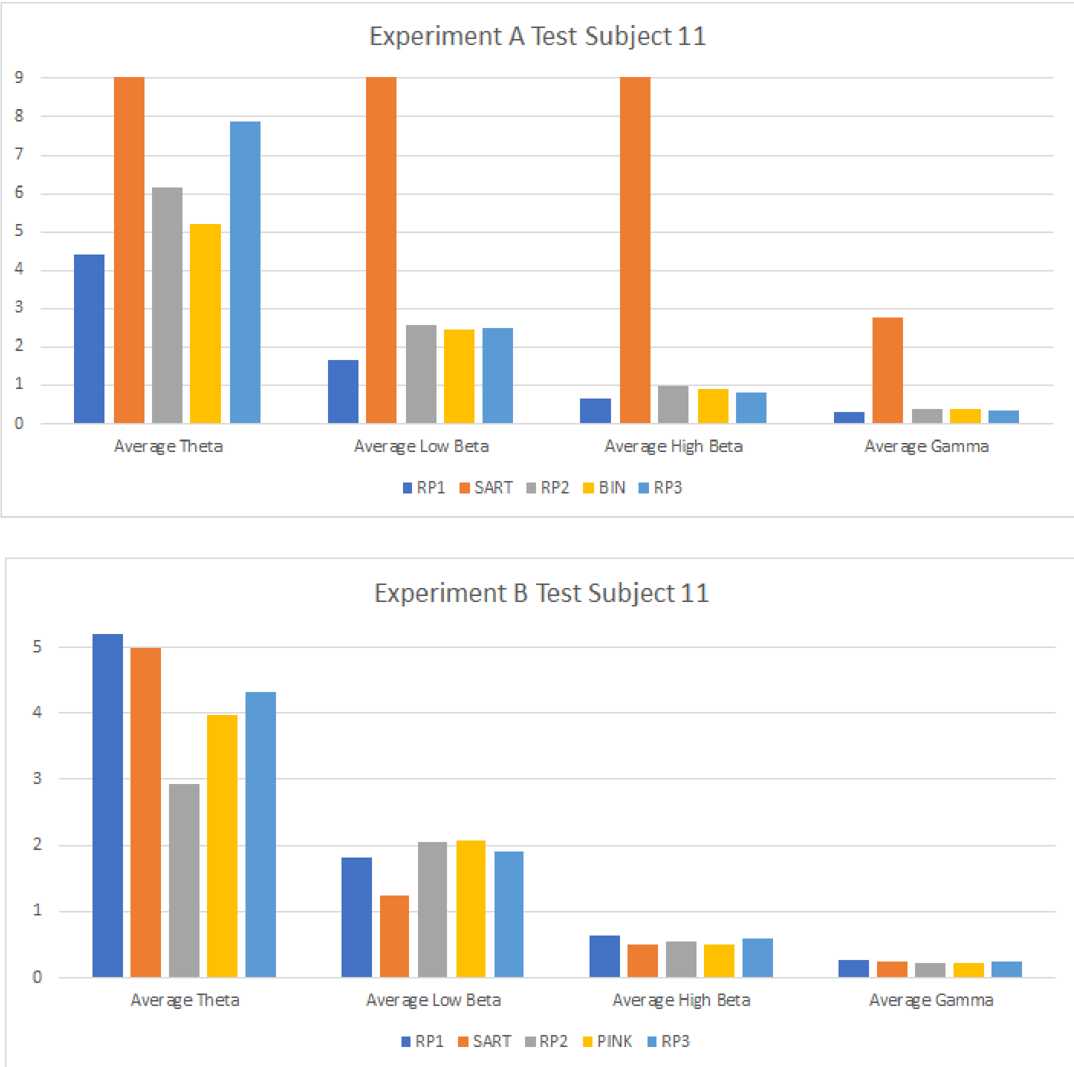
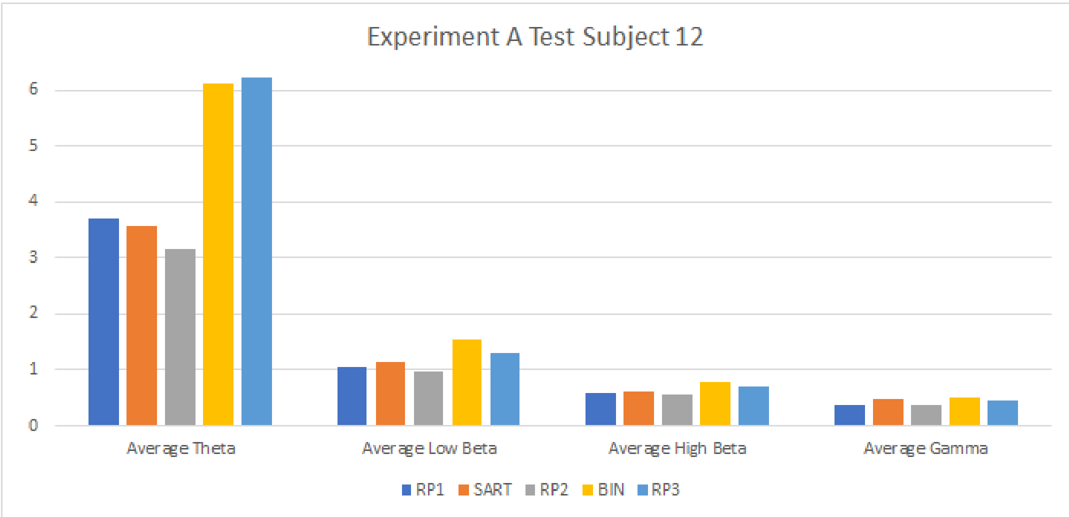


Figure A.11: Test Subject 11 Experiments A and B Bands Analysis



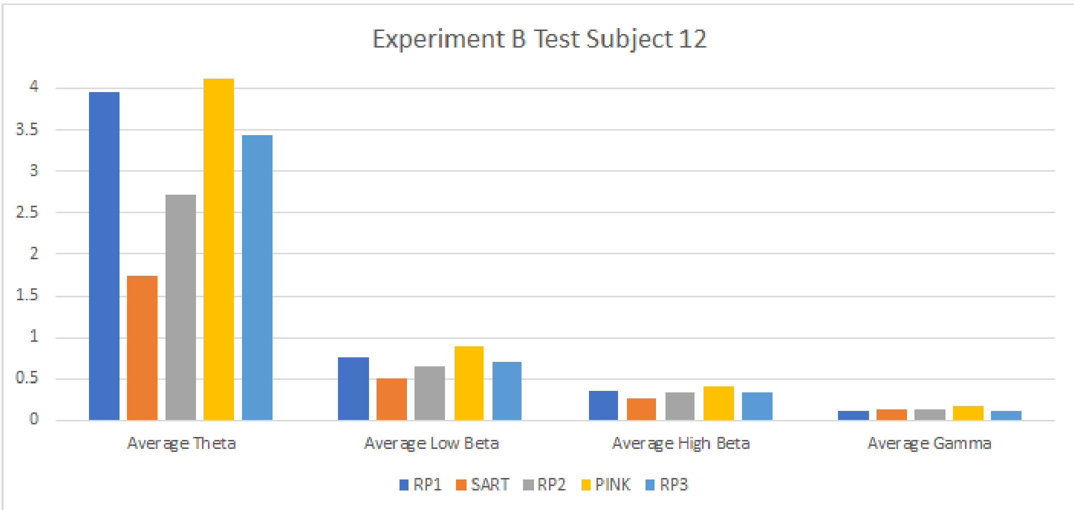


Figure A.12: Test Subject 12 Experiments A and B Bands Analysis

Abbreviations

BCI Brain-Computer Interfaces. 6

BWE Brain Wave Entrainment. 1

EEG Elecroencephalography. 7

SART Sustained Attention to Response Task. 16

List of Figures

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