



IMPROVING PLAYERS' CONTROL OVER THE NEUROSKY BRAIN-COMPUTER INTERFACE

Research Report
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Abstract

In mid-2009, NeuroSky released the first consumer brain-computer interface (BCI). MindGames, since that time, has been developing games which players control with their powers of concentration and relaxation via consumer brain-computer interfaces. At present, all users of these novel interfaces are inexperienced, and have trouble controlling them. Therefore MindGames would like to develop a method for helping as people to learn as quickly as possible to activate the "relaxation" and "concentration" controls of the BCI.

A pilot study with $n=4$ subjects was conducted in order to assess the feasibility of developing a real-time hint system which would: 1) detect what the user needs to do in order to increase the output of the Meditation function of the NeuroSky MindSet; 2) then offer behavioral suggestions which would, if carried out correctly, increase the output of Meditation accordingly. Research was structured into three tracks of inquiry: first, are there behavioral suggestions ("hints") which increase the output value of Meditation; secondly, are there hints which increase the output value of particular brainwave types (alpha, gamma, theta waves) which are known in the literature to be associated with meditative states, and therefore are likely to be part of the Meditation function; and thirdly, is there a typical shape for the power spectrum of the headset output (consisting of alpha, gamma, theta waves) for high values of Meditation.

With a 95% confidence level, several hints which are associated with attaining meditative states were found to significantly increase Meditation. More statistical analysis will have to be performed in order to determine whether some of these hints affect alpha, beta or gamma waves at a high confidence level; however, some patterns were observed in the data which support this idea. However, there is most likely no typical shape for the power spectrum at high values of Meditation. Therefore, a system which gives directed hints (the user must increase his alpha output, therefore an alpha-increasing hint is given) is most likely not feasible. However, there is now support for the effectiveness of certain hints in raising users' Meditation output.

Samantekt

Um mitt ár 2009, gaf NeuroSky fyrsta heila-tölvu viðmótið út á almennan markað. Síðan þá hefur MindGames þróað tölvuleiki sem notendur stýra með athyglis- og afslöppunarkröftum sínum í gegnum heila-tölvu viðmótið. Á þessum tímapunkti eru allir notendur þessarar tækni óreyndir og eiga því erfitt með stjórn viðmótsins. MindGames vill því þróa aðferð til að hjálpa fólki að læra eins fljótt og hægt er að virkja "afslöppunar" og "athyglis" stjórn tæki viðmótsins.

Rannsókn var gerð á $n = 4$ þátttakendum til að komast að því hvort hægt væri að útbúa rauntímavísbendingakerfi sem myndi: 1) finna hvað notandinn þarf að gera til að auka Meditation gildi NeuroSky MindSet; 2) bjóða svo hegðunartengdar ábendingar sem myndu, ef framkvæmdar á réttan hátt, auka gildi Meditation. Rannsóknin var byggð upp í þrjár leiðir; Í fyrsta lagi, eru til hegðunar ábendingar sem auka gildi Meditation; Í öðru lagi, eru til vísbendingar sem auka gildi ákveðinni heilabylgja (theta, alpha, gamma bylgja) sem eru þekktar fyrir að tengjast hugleiðingarástandi; Og í þriðja lagi, er til einkennandi form krafrófs MindSetsins fyrir há gildi af Meditation.

Nokkrar vísbendingar reyndust auka Meditation, með 95% öryggisbili. Frekari tölfraðigreining þarf að eiga sér stað til að ákvarða hvort þessar vísbendingar hafa áhrif á alpha, theta eða gamma bylgjur á háu öryggisstigi. Það er þó líklegast ekki til neitt einkennandi form fyrir krafrófið við há gildi af Meditation. Þess vegna er kerfi sem gefur ákveðnar vísbendingar („notandi þarf að auka alpha-gildin) líklega ekki mögulegt. Þó hefur stoðum verið rennt undir þá kenningu að ákveðnar vísbendingar hækki gildi á Meditation.

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1. Introduction

MindGames is among the first companies in the world to use brain-computer interfaces in commercial gaming. Therefore, players of their games generally do not have good control over the novel interface, which can deter them from continuing to try to play.

Because of this MindGames wanted a method they could use to promote players' learning of control over the interface (in this case, the NeuroSky MindSet, which has Meditation and Attention levels as controls).

One possibility for such a method is to give the player suggestions or hints during gameplay. Those suggestions would be geared toward changing the brainwaves of the player, specifically to increase the value of certain waves, while decreasing others, in order to increase the Meditation output.

Accordingly, we defined the research question as: Can we develop a real-time hint system to give users of the NeuroSky MindSet improved control over its Meditation function?

This research details the background, methodology, results, and conclusions of a pilot study which was devised to address the research question.

2. Background

2.1 Theoretical Background

According to Yasui, measuring brain activity is an essential tool to understanding the different psychophysiological states of humans (1). Such a state is the combination of a physiological state, or the state of the body, and a psychological state, or the state of the mind. Being awake and being asleep are examples of two different psychophysiological states. In order to study brain activity in detail, one must be able to record it. One of the ways to do this is to record and interpret electrical activity along the scalp, usually referred to as brainwaves.

2.1.1 Brainwaves and EEG

Brainwaves are caused by neurons firing within the brain. Each neuron is electrically charged and so has ions flowing across its membranes. Polarized neurons signal their neighbours, who then become polarized themselves and signal their own neighbours and so on. This movement of polarization causes a wave of ions to move through the brain. Electroencephalography (EEG) is the science of recording these brainwaves by attaching electrodes to the head. When the ion-wave reaches the scalp it interacts with the metal in the electrodes. The equipment attached to the electrodes then records the waves (Epstein 31-35).

Brainwaves are divided into different types, depending on their frequencies: delta, theta, alpha, beta, and gamma. Alpha, beta, and gamma waves are quite often divided into two or more narrower bands, for example, low alpha and high

alpha. The different frequency ranges of these brainwaves are described in Table 1 (“Brainwave signal” 2).

Brainwave type	Frequency range
Delta δ	1–3 Hz
Theta θ	4–7 Hz
Alpha α	8–9 Hz (low) 10–12 Hz (high)
Beta β	13–17 Hz (low) 18–30 Hz (high)
Gamma γ	31–40 Hz (low) 41 – 50 Hz (mid)

Table 1 - Different Characteristics of Brainwave Types

Different brainwave types have different characteristics and different source generators. Research done by Klimesch et al. suggests that they also seem to reflect different cognitive processes (439). Delta waves, with the lowest frequencies of all the brainwaves, are most apparent in deep sleep states, where conscious brain activity is minimal. Theta waves, with frequencies ranging from 4 – 7 Hz appear in a relaxed state and during light sleep and meditation. They can be increased by listening to non-harmonious music or by breathing deeply (Scheufele 215). Alpha waves are typically associated with meditation and relaxation, more so than any other waves. Deep breathing and lying back with the eyes closed amplifies them. Beta waves, on the other hand, are connected to alertness and focus (Kraft 2).

The highest frequency waves, gamma waves, can be stimulated by meditating while focusing on a specific object, such as a dark mark of some kind on a light surface and repeating a mantra. This is a common meditative technique in Eastern religions such as Hinduism and Buddhism (Davidson & Lutz 176).

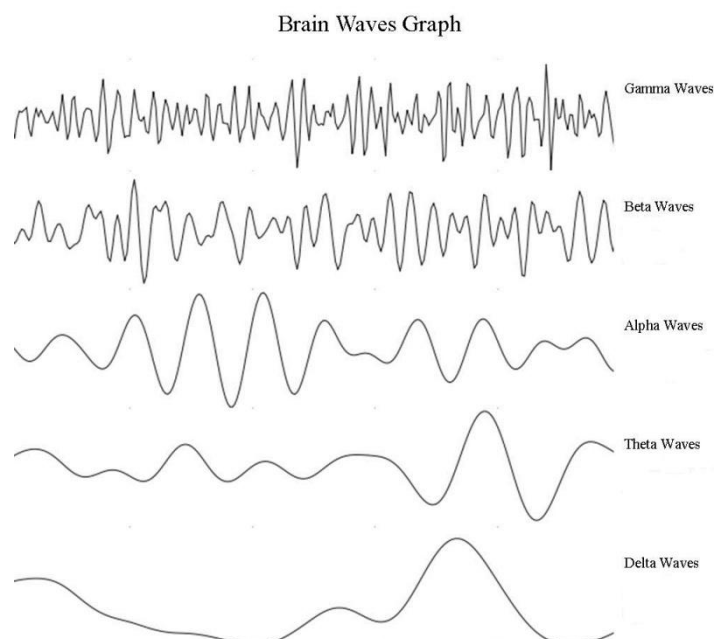


Figure 1 Different Brainwaves

Since this project focuses on meditation rather than attention, the waves relevant are theta, alpha, and gamma waves. With the well researched connection of delta to deep sleep and beta to normal alertness, these two waves will be disregarded from the current research.

2.1.2 Neurofeedback Training

There has been some discussion on whether people can consciously access different brainwave states. Ever since the first recording of human brain activity in 1924 scientists and laypeople have examined the possibility of training the brain to become more efficient. Today, many people believe that accessing the different brainwaves consciously, through meditation and other means, is beneficial and capable of improving creativity and mental well-being (Kraft 1). Vernon mentions claims about performance enhancement training. Such training is meant to make an individual capable of completing a specific task with greater efficiency and fewer errors (347).

Traditional biofeedback training consists of allowing a patient to see or hear physiological measurements that are known to indicate stress, for example, increased blood pressure or heart rate. By listening to a racing pulse the patient understands that she is under stress and can then work to bring her heart rate down voluntarily. Kraft argues that making biofeedback visible on a monitoring device makes the above body functions accessible for the patient's conscious regulation. (1).

EEG biofeedback training, or neurofeedback, is a sophisticated form of biofeedback training. The goal of such training is to allow the individual to learn what specific states of consciousness (as visualized by the electric field activity or brainwaves) feel like and how to access such states consciously. For instance, during the training the EEG could be recorded and the components under review could be isolated and fed back to the individual in the form of audio and/or visual information. Vernon suggests that a combination of auditory and visual feedback is a more efficacious way of transmitting the participant's psychophysiological state to her, compared to feedback based on a single modality (353). The audio and/or visual feedback should be able to represent each of the electrophysiological components separately (Vernon 348). Each could, for example, be represented by a bar, where the amplitude of a frequency corresponds to the size of the bar. The individual's task could then consist of raising the bar of the training-frequency as much and as often as she can. Vernon maintains that the known associations between different aspects of consciousness and specific EEG frequency components provide a reasonable rationale for the use of neurofeedback to enhance specific cognitive processes. He says that, if a specific EEG frequency is associated with a particular cognitive task, then the aim of the training would be to enhance that frequency component in individuals and thus make them more efficient at the task (354-355).

2.1.3 Alpha α

The brainwave most often associated with neurofeedback training is the alpha wave. It is generally associated with both meditation and relaxation and so is of interest to psychologists, specifically in attempts to help people suffering from phobias and attention deficit disorders (Kraft).

Vernon reports that the lower alpha frequencies are related to attentional demands, but that the higher alpha frequencies are associated with memory processes (356). Klimesch et al. report that their research has established quite clearly that alpha power decreases with increasing attentional demands (437). They go on to describe alpha as a rhythmic activity in the EEG and that cortical inactivity, which occurs during rest and the transition between wakefulness and sleep, is often indicated by a strong alpha rhythm (438). This supports the idea that a powerful alpha wave indicates a state of relaxation or calmness. Klimesch et al. also confirms Vernon's ideas on low alpha vs. high alpha, stating that low alpha reflects processes such as attention, and that high alpha is related to cognitive processes, such as memory (439).

2.1.4 Theta θ

Much of the research into theta waves has been done in connection with alpha waves. While alpha is described as a rhythmic activity in EEG theta is more often described as arrhythmic, since its amplitude is less consistent.

A study by Klimesch et al. compared theta waves with alpha waves in memory retention and found some interesting differences. While alpha was shown to decrease with added attention, theta showed a tendency to increase with added concentration demands (438). However, Vernon found that a group trained to augment their theta band performed significantly worse at a concentration intensive task after undergoing neurofeedback training. In comparison, a theta-suppression group performed significantly better. This was only true for subjects who received neurofeedback during a concentration intensive test. When neither group received any feedback, there was no difference in their performance (355). This suggests that the training was successful, that is, the subjects learned to augment their theta waves, which correlates with bad performance on the concentration task.

2.1.5 Gamma γ

There is little information to be found on the effect on gamma waves on relaxation. However, studies have found that long-term Buddhist practitioners of open monitoring (OM) meditation, obtain a much higher amplitude of gamma waves than novice practitioners do (Davidson & Lutz 173). This suggests that an increase in gamma amplitude might be connected with a higher Meditation value.

2.2 The Technology

The usual process to obtain brainwave measurements is a medical procedure supervised and performed by trained personnel, involving several electrodes positioned around the head and attached with conductive gel. This may cause discomfort for the subject of the test, which in turn may lead to erroneous results. This traditional method is also very time-consuming, since the preparation time for each test is so long.

EEGs are quite easily affected by electrical potentials generated by muscle contractions. These potentials are called artifacts, and are often divided into two categories, ocular artifacts (OA), dealing with all movement directly connected to

the eye; and muscular artifacts (MA), dealing with muscle movement of the face, scalp, jaw, and head.

The known correlations between brainwave activity and states of consciousness and intention mean that brainwave activity can be generated and used to control hardware or software devices via a brainwave recorder. Such brainwave recorders are called brain-computer interfaces (BCI). These brain-computer interfaces must, like medical-grade EEG recorders, allow for real or quasi real-time performance in order to translate user input into interactive responses (Rebolledo-Mendez et al. 2).

The NeuroSky MindSet is one such BCI, which is a simplified version of the traditional EEG technology. The MindSet monitors electrical potential between the sensing electrode, positioned on the forehead, and the reference electrodes, positioned on the left earlobe.

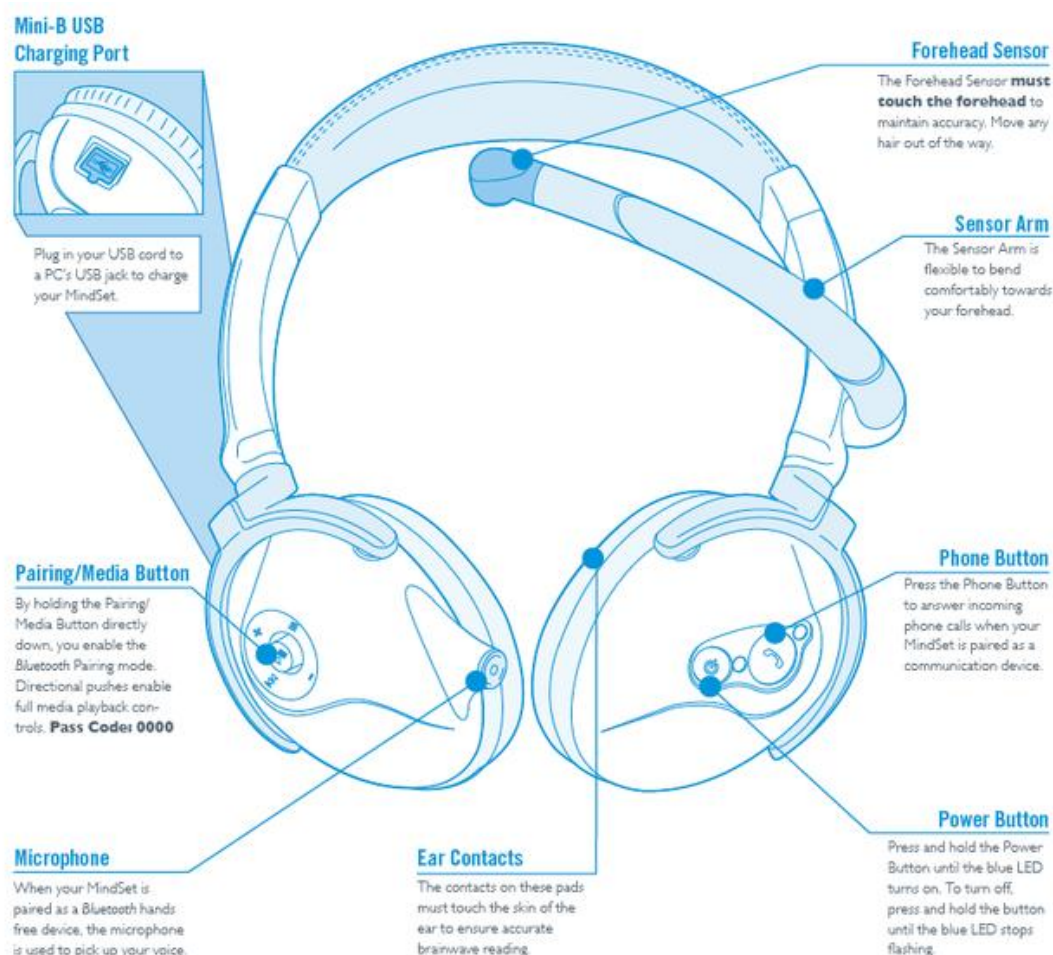


Figure 2 - The NeuroSky MindSet

By using an EEG recording device, such as the MindSet, with a single dry electrode at the forehead, the measuring and analysis of brain states becomes less complex and more comfortable for the subject (Yasui 1). The user can use the device without the help of trained personnel and wherever she wants. The single point electrode means that changes in brainwave activity in different parts

of the brain cannot be monitored. However, volume conduction makes it possible to measure electrical potentials at some distance from their source generators. Therefore, the single point electrode is able to monitor a substantial part of the entire brain's activity. The sensing electrode is positioned on the forehead. There is no hair between the electrode and the scalp, which makes for a stronger, steadier signal. Also, the cognitive signals linked to higher states of consciousness originate from the frontal cortex, which lies directly below the forehead ("eSense Meters and Mental State" 1).

The main drawback to using a single electrode system is its susceptibility to artifacts. Since there is only one sensor in place, separating brainwaves from artifacts becomes a challenge. The OA and MA artifacts occur frequently which causes problems in two ways; they are much bigger than brainwave signals, thus wiping them out, and they can have components that are small enough to be confused with brainwaves. Elimination of these problematic small components would be easier with more than one recording sensor. With more than one sensor, smaller EEG signals can be detected by comparison across recording sensors.

Because the headset is not fastened to the head, pronounced muscle movements, such as yawning, can shift the headset a little. In addition to the MA the movements cause, the movement of the headset may result in a momentary decrease in signal quality.

Inside every NeuroSky product, including the MindSet, is the ThinkGear chip. This chip enables the device to interface with the wearer's brainwaves by amplifying the raw brainwave signal and removing the ambient noise and the artifacts mentioned above. The noise is filtered out of the raw EEG before the calculation of the eSense values, described below. This noise elimination is performed by a proprietary algorithm and no information pertaining to this internal process has been released. When the ThinkGear chip detects too much noise to be filtered out in a satisfactory way, the same eSense meter values are repeated ("eSense Meters and Mental State" 2). Therefore, all meter values that are consecutive and equal need to be marked as noise and removed before data analysis begins.

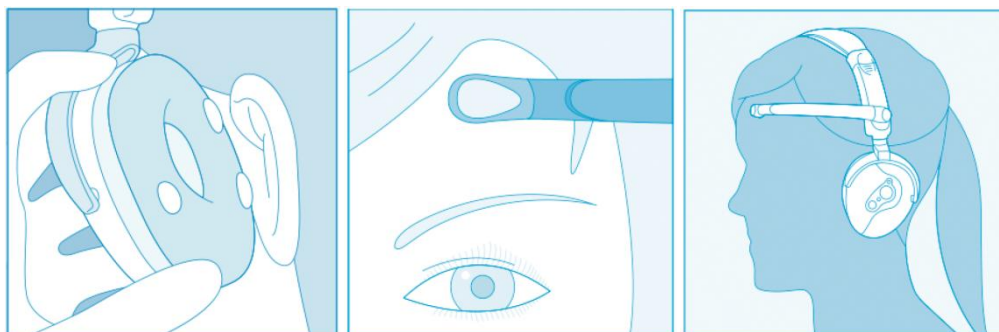


Figure 3 MindSet Positioned Properly

By using NeuroSky's proprietary eSense algorithm, the two eSense meters are calculated. They each describe a mental state and draw their names from them: Attention, which indicates the user's level of mental focus, and Meditation,

indicative of the level of a user's mental calmness. Their values range from 1 – 100 and are updated once per second for each state. The calculated values, as well as the raw brainwaves, are output by the ThinkGear chip to a computer through the headset's Bluetooth connection ("eSense Meters and Mental State" 2). The value-scale for the eSense meters is partitioned as follows:

A value between	Indicates
1 – 20	Strongly lowered eSense levels
20 – 40	Reduced eSense levels
40 – 60	Neutral eSense levels
60 – 80	Slightly elevated eSense levels
80 – 100	Elevated eSense levels

Table 2 - eSense Value-Scale

Crowley et al. showed that the NeuroSky MindSet is suitable as a minimally invasive means of measuring the attention and meditation levels of a user. Their results show that the attention and meditation values output by the dataset clearly indicate when a user experiences a change in concentration or calmness (278).

The Meditation eSense meter was chosen as the focus of this project. It is a measure of mental levels but not physical levels. Therefore, simply relaxing muscles may not have an immediate effect on the meter. However, the act of relaxing muscles may increase mental relaxation in some cases. Distractions, wandering thoughts, anxiety, agitation, and sensory stimuli may lower the meditation meter levels ("eSense Meters and Mental State").

2.3 Research Plan

Three tracks of investigation, as shown in Figure 4, were planned in order to investigate the research question: Can we develop a real-time hint system to give users of the NeuroSky MindSet improved control over its Meditation function?

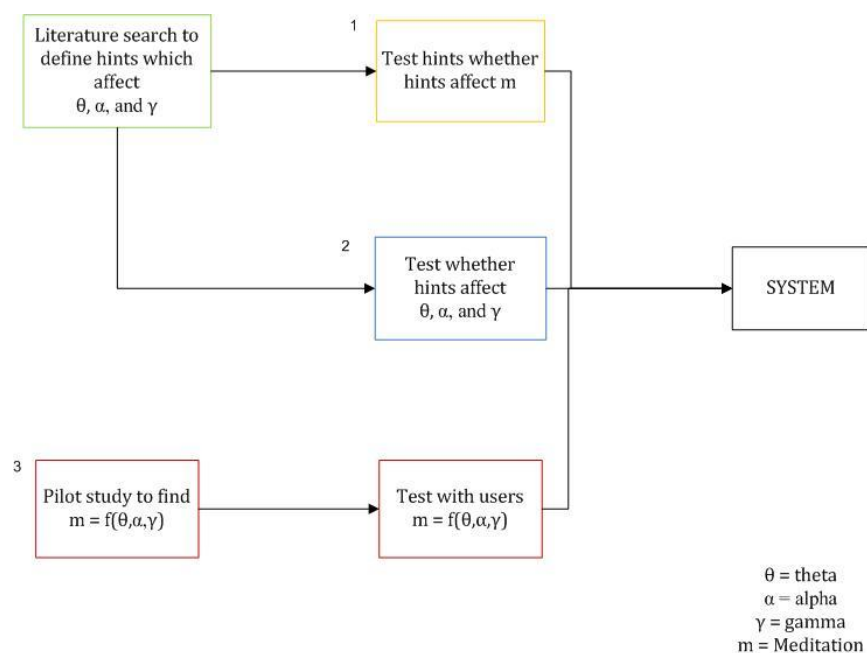


Figure 4 - Three Tracks for Hypotheses Testing

Track 1 investigates what hints affect the Meditation function of the MindSet, while Track 2 investigates what hints affect theta, alpha, and gamma. Both tracks were dependent on a literature review to find those hints; the results are described in chapter 2.1.1. Track 3 investigates the relative contributions of theta, alpha, and gamma to the Meditation function.

The results from these three tracks enable us to determine whether making a control improving hint system is feasible. Table 3 details the possible outcomes.

Significant results from:	System features	Feasible system?
Tracks 2 and 3	Power spectra shapes for high values of Meditation are known. Giving the user directed hints to raise specific parts of the power spectrum is possible, thus increasing Meditation values.	Yes
Tracks 1, 2, and 3	Hints that raise Meditation values are known. Power spectra shapes for high values of Meditation are known. Giving the user directed hints to raise specific parts of the power spectrum is possible.	Yes
Tracks 1 and 2	Information for giving directed hints is in place, but assessing which hints the user needs is not possible.	No
Tracks 1 and 3	Hints that raise Meditation values are known. Power spectra shapes for high values of Meditation are known, but no way to give directed hints to raise specific parts of the power spectrum is available.	No

Table 3 - Outcomes from Different Tracks

2.3.1 Hypotheses

The hints used to investigate Tracks 1 and 2 were determined by literature review and from expert advice. These led to the following hypotheses for Tracks 1, 2, and 3.

Hypotheses for Track 1:

1. Closed eyes increase Meditation
2. Ujaya, a structured form of deep breathing, increases Meditation
3. A combination of closed eyes and deep breathing increases Meditation
4. Non-harmonious calm music increases Meditation
5. Focusing on a single object and continuously repeating a single word or mantra mentally increases Meditation

Hypotheses for Track 2:

1. Closed eyes increase alpha waves
2. Ujaya, a structured form of deep breathing, increases alpha waves
3. A combination of closed eyes and deep breathing increases alpha waves
4. Ujaya, a structured form of deep breathing, increases theta waves
5. Non-harmonious calm music increases theta waves
6. Focusing on a single object and continuously repeating a single word or mantra mentally increases gamma waves

Hypothesis for Track 3:

As values of Meditation increase the associated power spectra converge toward a typical shape.

3. Research Methodology

3.1 Preliminary Data Collection

The Puzzlebox Synapse program¹ was used to record some preliminary data. Once per second it returns Attention value, Meditation value, and amplitudes for the different brainwave types. The Puzzlebox output can be considered a six dimensional vector, with the wave types and Meditation each being a separate dimension, Attention not being within the scope of this project. Data was collected from a single inexperienced subject, (the researcher), using only two conditions, open and closed eyes. This data was gathered during several sessions, each session containing tests ranging from one minute to ten minutes.

Microsoft Excel was used to make 2D graphs of the data, displaying the amplitude changes in each different wave band over time. These graphs were then examined for any correlation between different wavebands and Meditation values. For example, no correlation was obvious by visual examination of the graphs of low-alpha and Meditation below.

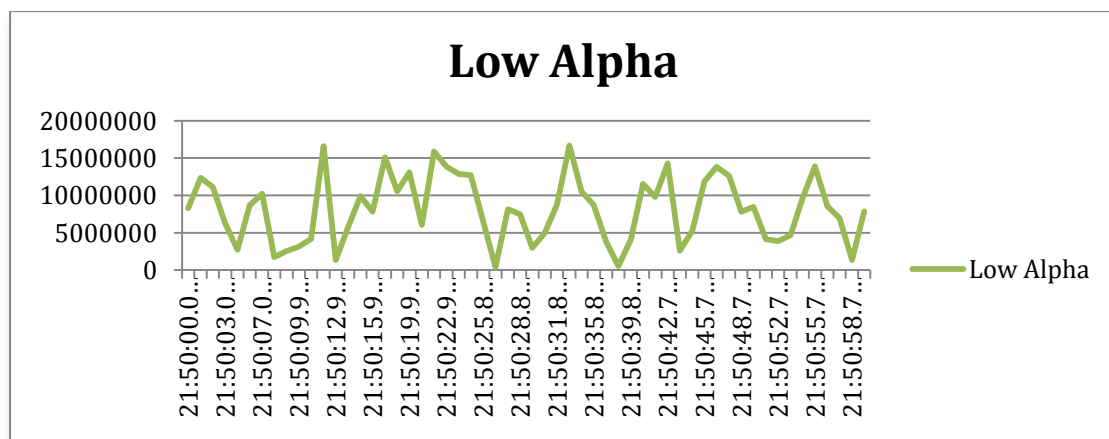
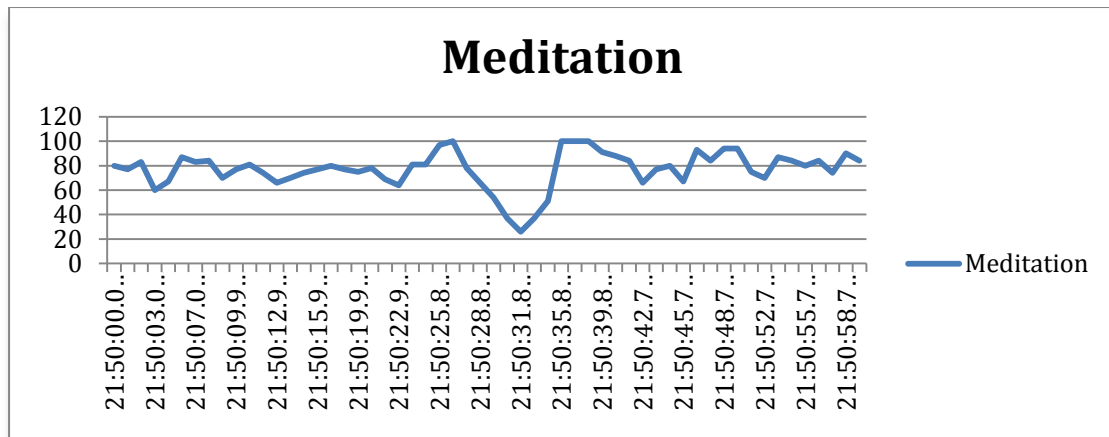


Figure 5 - Low Alpha Over One Minute

¹ <http://brainstorms.puzzlebox.info/>



Matlab was used to make 3D scatter plots in order to look for clustering within the data. Plots were made of each wave type against each of the other wave types, with Meditation as the z-axis. For example, Figure 7 shows a plot of mid-gamma on the y-axis, theta on the x-axis, and Meditation on the z-axis. In all such graphs, no strong signs of clustering are visible.

Since 2D and 3D plotting of the preliminary data proved inconclusive, a new approach to the investigation was needed. This led to the definition of the three tracks of research discussed above in chapter 2.3.

3.2 Programs and Tools

3.2.1 Brainwave Visualizer

Brainwave Visualizer² is a program that comes bundled with the MindSet. It gives the user a colorful graphical representation of her brain activity. Attention

² <http://store.neurosky.com/collections/applications/products/visualizer-2-0>

and Meditation meters are represented by dials and the composite brain signal and its power spectrum are shown.



Figure 8 – Main Screen of Brainwave Visualizer

It also allows the user to play games, one for Meditation control and the other for Attention. The Meditation game shows a ball that rises into the air when the user's Meditation values rise and sinks when they become lower.

The Visualizer was used at the beginning of user testing sessions. Subjects were also asked to play the Meditation game. This allowed the subjects to better understand the MindSet and to see what effect breathing control has on Meditation values.

3.2.2 NeuroView

NeuroView³ is part of the NeuroSky Research Tools package. It is designed to allow EEG researchers to view and record EEG data in real-time. It allows the user to record sessions and outputs the Meditation values, the filtered wave, and the power spectrum in separate files.

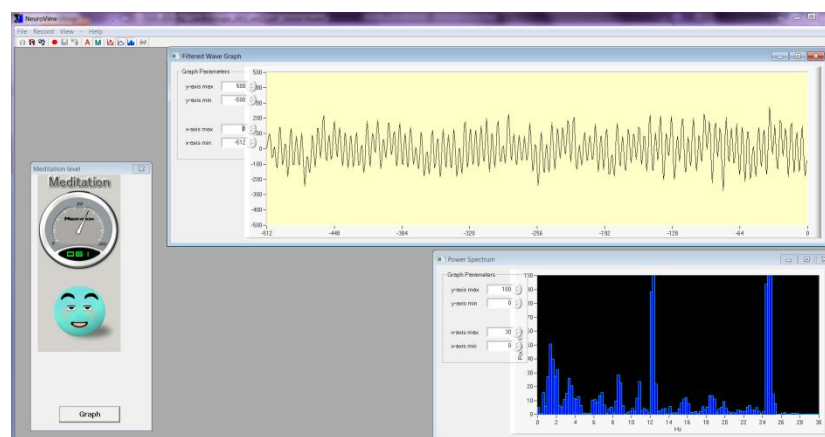


Figure 9 - Screenshot of NeuroView

³ <http://store.neurosky.com/collections/applications/products/mindset-research-tools>

NeuroView shows graphical representations of the Meditation meter as a dial, the filtered EEG wave on a yellow background, and the power spectra as a bar graph like Figure 9 shows. The units on the Meditation dial are the range 1 – 100. The x-axis on the filtered wave graph shows one second at a time. Each second gives 512 data points. The y-axis shows values that are simply called NeuroView Units and are not defined in a more specific way. The power spectrum graph shows frequencies on the x-axis and amplitude values on the y-axis.

NeuroView was used to record all user testing sessions. Since it shows the filtered wave in quasi real-time it is a good tool for observing the effects which artifact-generated behaviours have on the recording. Figures 10 through 12 show the effect blinking, swallowing, and frowning have on the filtered wave.

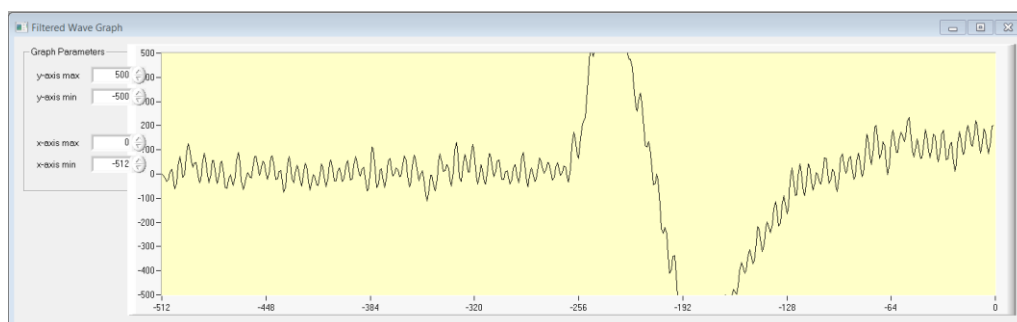


Figure 10 - Effect of Blinking on Wave

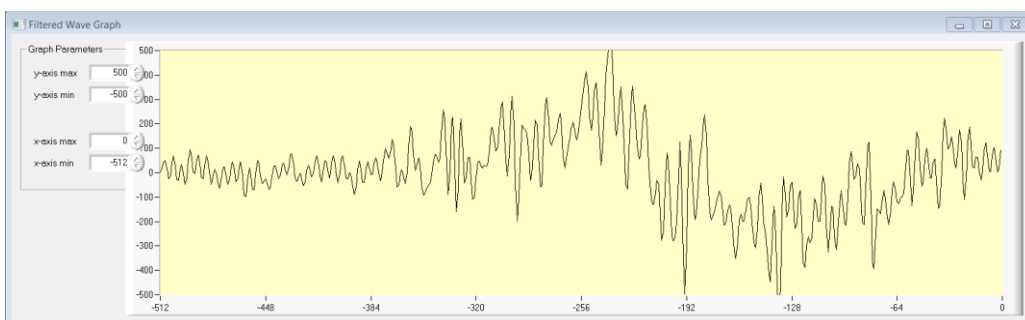


Figure 11 - Effect of Swallowing on Wave

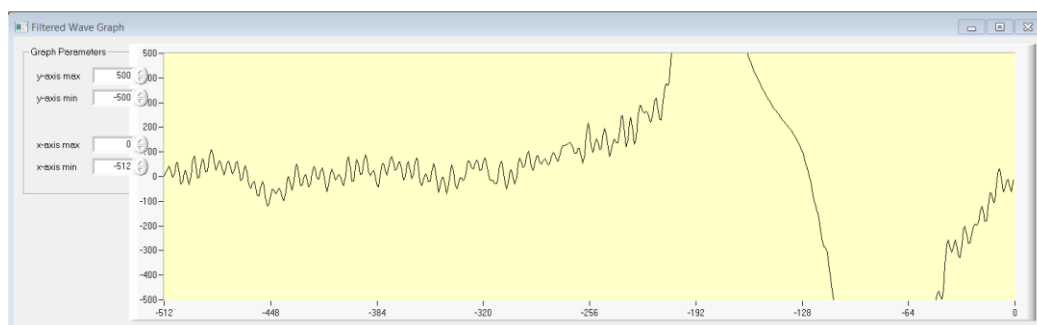


Figure 12 - Effect of Frowning on Wave

3.2.3 Data Analysis Tools

SPSS is a program used for statistical analysis among other things. It allows for easy use of bivariate statistical analysis tools, such as t-tests and ANOVA tests. It is one of the most commonly used programs for this type of analysis in the social sciences, and was relevant to the data analysis portion of this project.

The WEKA program contains a collection of machine learning algorithms for data mining tasks. It provides tools for data classification, clustering, and visualization.

3.3 User Tests

Five structured user tests were performed to gather data for hypothesis testing. Four different test subjects were chosen and then tested one at a time and in separate sessions.

The tests were performed in a quiet room with the subject sitting in a comfortable chair. The researcher sat in the room and controlled the test. At the beginning of the test, after putting on the MindSet, the subject was introduced to the Brainwave Visualizer, as is described above. They were then informed of duration and number of text blocks. However, they were not informed about the nature of the hypotheses. More detailed instructions were given before each test block. The researcher kept notes, in a research log, on the specific conditions of each session, such as the time of day and reported mental status of the subject.

Each test session focused on conditions related to a specific hypothesis or hypotheses. Each condition was tested for one minute at a time for ten minutes. These ten minutes are referred to as a test block from here on.

At the beginning of a session a baseline test block was recorded for comparison purposes. In Sessions 3, 4, and 5 a second baseline test block was added at the end of the session. During the baseline recordings, the subjects were instructed to maintain a 'neutral' mental state as defined by them. They were further instructed to keep their eyes open, but to blink and breathe normally. Table 4 describes the conditions tested in each testing session.

Session	Subject	Conditions	Mental Status of Subject
1	A	Block 1: Baseline Block 2: Eyes closed	Relaxed but not tired
2	B	Block 1: Baseline Block 2: Eyes closed	Stressed and tired
3	B	Block 1: Baseline1 Block 2: Deep breathing Block 3: Ujaya breathing Block 4: Baseline2	Less stressed and tired than in Session 2. Felt a little distracted at the beginning of the session
4	C	Block 1: Baseline1 Block 2: Ujaya breathing Block 3: Focus and Mantra Block 4: Music Block 5: Closed eyes + deep breathing Block 6: Baseline2	Relaxed, calm, not tired
5	D	Block 1: Baseline1 Block 2: Ujaya breathing Block 3: Focus and Mantra Block 4: Music Block 5: Closed eyes + deep breathing Block 6: Baseline2	Relaxed, focused, not tired

Table 4 – Conditions Tested in User Testing Sessions

Subjects were asked to regulate their breathing in two ways. When instructed to breathe deeply they were given no further instructions; their own definition of what constitutes deep breathing determined their behavior. In contrast to regular deep breathing, Ujaya is a structured breathing method commonly used in meditation and yoga. It requires one to breathe deeply in and out of the nose, while constricting the throat slightly. This lengthens each breath and requires a substantial amount of focus on the subject's part. Subjects were instructed in how to properly use Ujaya before the relevant test block was recorded.

When the closed eyes with deep breathing test block was performed, the subjects were asked to keep their eyes closed and to visualize their breath while breathing deeply.

During the focus and mantra recordings the subjects were asked to focus on a red dot fastened to a white wall. They were also instructed to mentally repeat the word 'gamma' constantly during the recording.

During informal tests, one subject, the researcher, attained higher levels of Meditation when listening to a familiar calm song than when listening to an unfamiliar one. Highest values attained during testing with both a familiar and an unfamiliar song are shown in Figure 13.

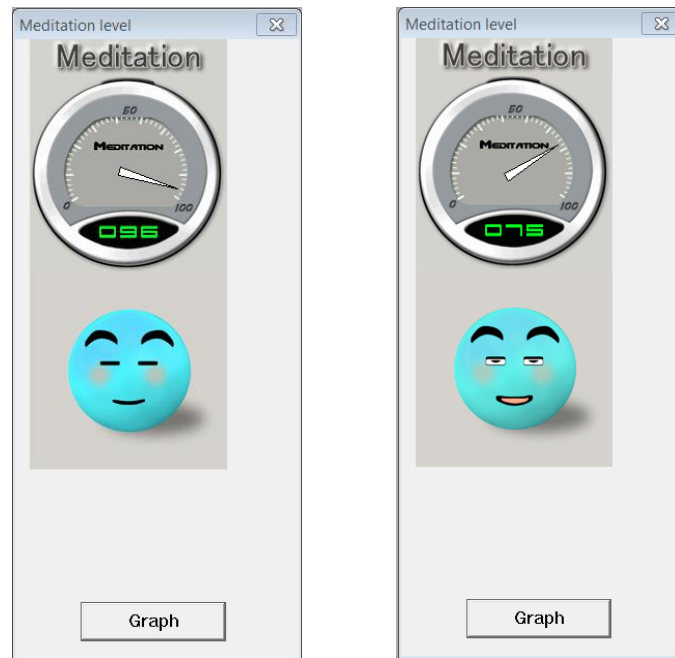


Figure 13 - Familiar Song on the Left, Unfamiliar Song on the Right

Subjects were asked to choose calm music that they were familiar with for the music test block. They were then asked to focus on the music during the recording.

3.4 Data Cleaning

The effect that artifacts have on EEG recordings was introduced in chapter 2.2.

As the NeuroView screenshots in chapter 3.2.2 show, artifacts are quite obvious in real-time. However, these same artifacts are no longer obvious when looking at the saved output of the program. This is due to the greater strength of the artifacts compared to signal. In order to clean the data all values above or below an artifact-free threshold had to be thrown out. Figure 14 shows an artifact-free wave with the threshold at -100 and 100 NeuroView Units, marked with red lines.

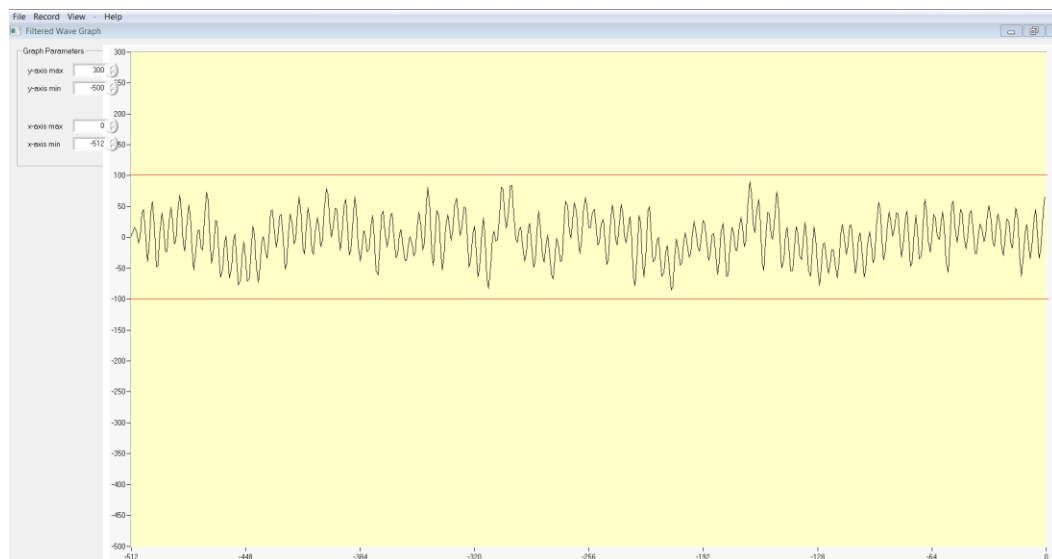


Figure 14 - Artifact-free Threshold

The threshold was determined at -125 and 125, in order to make sure no good values are thrown out.

The cleaning was performed visually at first, to make sure that this method was valid. All data points outside of the threshold were marked and the wave was then graphed, see Figure 15. If a second contained a single marked data point the corresponding Meditation value was thrown out.

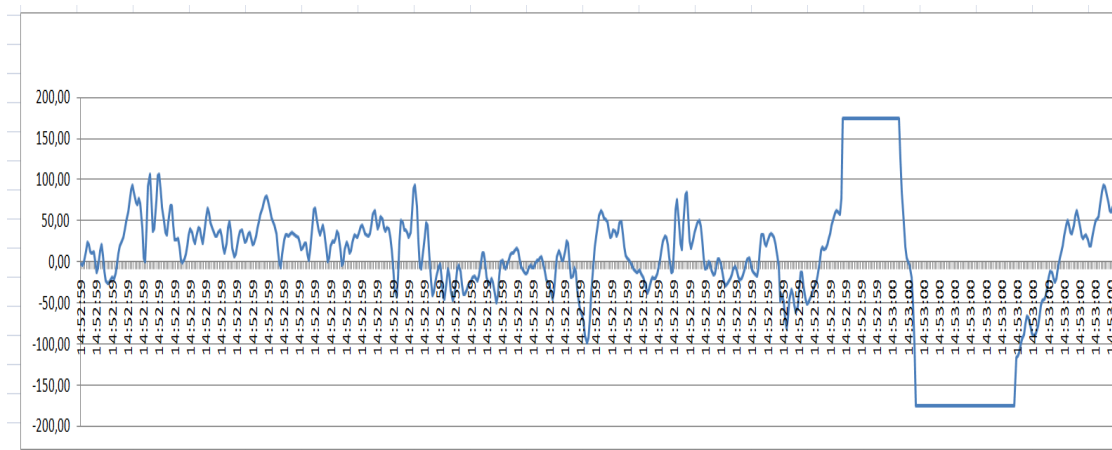


Figure 15 - Cleaning Graph with Data Points Marked as Artifacts

After confirming the method as valid a small program was created to clean the data for further analysis.

3.5 Research Tracks

3.5.1 Track 1 – Hints and Meditation Values

Means and standard deviation were calculated for Meditation values for each one minute test within a ten minute test block. A frequency histogram was also created. Both means and frequency histograms were examined for trends. No trends were found in the data⁴, and so all one minute tests within a block were combined into one large set of Meditation values. The mean and standard deviation for this set was calculated and a new frequency histogram made.

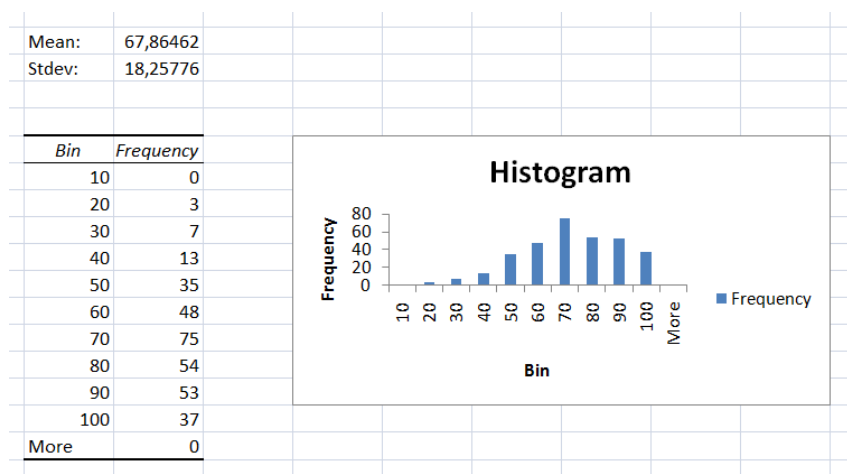


Figure 16 - Statistical Analysis of Clean Meditation Values

⁴ See Appendix B for a collection of histograms displaying no trend

This combined data set was then tested with t-tests and Analysis of Variance, or ANOVA⁵. T-tests were used for sets where only one condition was compared to baseline. ANOVA was used where multiple conditions and baselines were compared.

Our data does not satisfy the condition for homogeneity of variance. Therefore, we used Welch's ANOVA because it does not assume that the above condition is satisfied as regular ANOVA does.

Both T-tests and ANOVA compare means of different samples to determine whether a significant difference is to be found between the means. We used the Tukey post-hoc method along with the ANOVA to find out where that difference lay, if there was any to be found.

All these steps were taken in order to find if and how hints affect Meditation values. That is, whether the mean of Meditation values for a particular hint is higher or lower than the relevant baselines.

3.5.2 Track 2 – Hints and Theta, Alpha, and Gamma Values

For each 10 minute test block the power spectrum is output 600 times, or one time per second. These outputs contain eight amplitude readings per second, and each of the amplitude readings contains a value for each part of the wave band, from 0 Hz to 63 Hz. We are only interested in frequencies pertaining to: theta, low-alpha, high-alpha, low-gamma, and mid-gamma, see Table 1. We chose to examine two seconds for high values and two seconds of low values of clean Meditation for each condition.

Track 2 used the same data as Track 1. It was examined for significant differences between power spectra for equal values of Meditation in baseline versus hint conditions. This was done in order to see whether hints produce changes in theta, alpha, or gamma activity according to the hypotheses.

A small program was created for removing the unnecessary frequencies from the data, that is, the frequencies connected to delta and beta waves. The chosen power spectra were graphed using Microsoft Excel. Low-gamma and mid-gamma were graphed separately for their power values are much lower than those of the other wavebands. Power spectra shapes of the same Meditation value were compared between baseline and conditions, See Figure 17 for an example.

⁵ See Appendix B for samples of t-test and ANOVA results

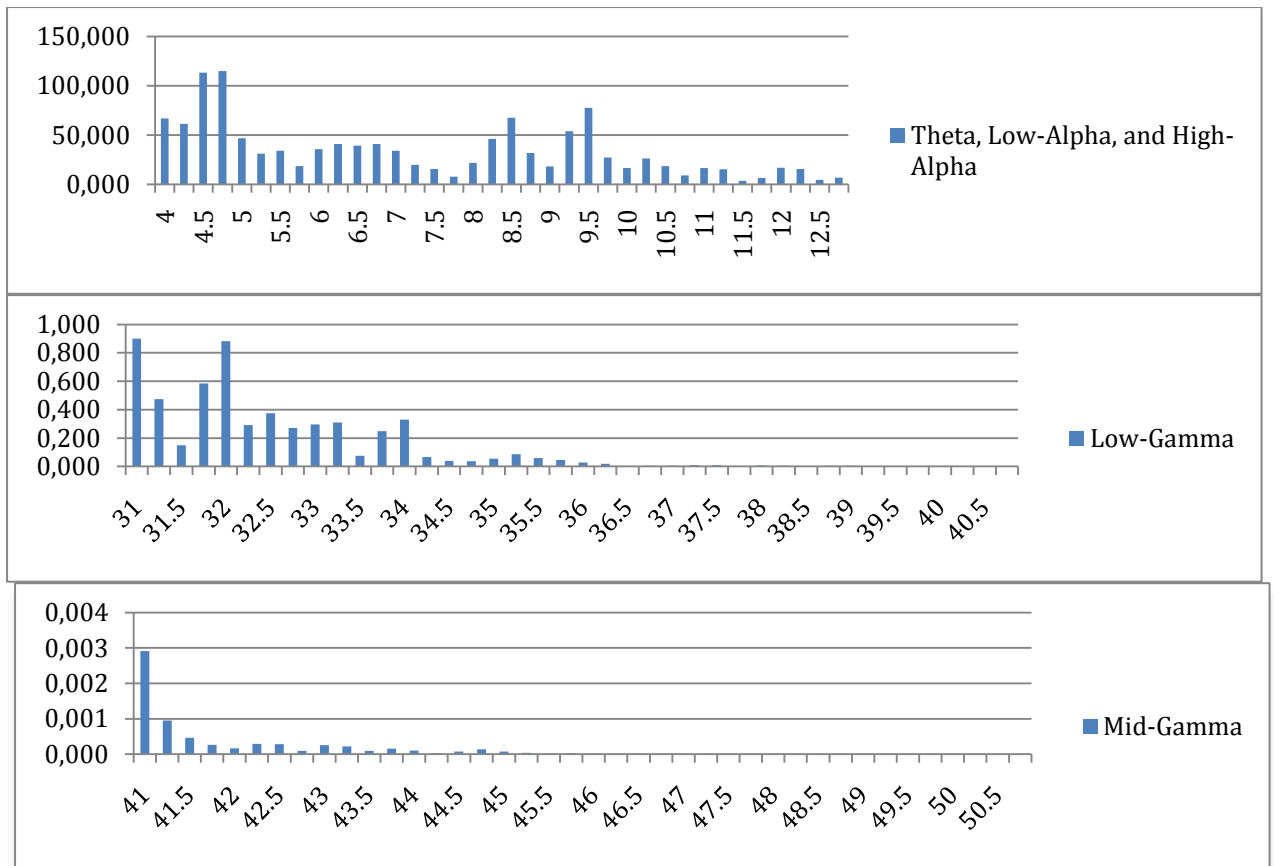


Figure 17 - Power Spectra for One High Meditation Second

3.5.3 Track 3 – Meditation Values Versus Theta, Alpha, and Gamma Values

After cleaning out unnecessary frequencies, all power values from each wave were summed together, which gave us eight values. The mean of these eight values was then calculated, as can be seen in Figure 18.

	Theta sum:	l-alpha sum:	h-alpha sum:	l-gamma sum:	m-gamma sum:
	71,453	21,020	17,954	0,646	0,001
	65,256	18,930	17,668	0,767	0,001
	58,226	22,314	21,183	0,739	0,001
	63,608	23,389	24,974	0,642	0,001
	72,602	31,816	24,390	0,570	0,001
	73,882	35,484	21,856	0,559	0,001
	72,245	30,714	20,733	0,539	0,001
	68,220	23,597	19,531	0,498	0,000
Mean:	68,182	26,238	21,251	0,637	0,001

Figure 18 - Amplitude Values from a Second with Meditation = 100

These means, for all five sessions, were gathered together into one file, resulting in 77 unique samples. The samples were labeled as high (if > 50) or low (if ≤ 50) depending on their Meditation value. The samples were also marked with the condition and session they belonged to.

This data was fed into WEKA for classification, in order to see whether a typical power spectra shape could be found for low and high values of Meditation.

An attempt at classifying it with a J48 decision tree first and a multilayer perceptron neural network second was then made. Those methods were both used with 4-fold cross-validation to prevent overfitting the data.

4. Results

4.1 Results for Track 1 – Effects of Hints on Meditation

We made the following hypotheses, for Track 1, described earlier in section 2.3:

1. Closed eyes increase Meditation
2. Ujaya, a structured form of deep breathing, increases Meditation
3. A combination of closed eyes and deep breathing increases Meditation
4. Non-harmonious calm music increases Meditation
5. Focusing on a single object and continuously repeating a single word or mantra mentally increases Meditation

We tested for a statistically significant difference between the means of the distributions of Meditation values under hint conditions versus under the baseline condition.

In sessions where only one condition and one baseline were recorded, we did a t-test at a 95% confidence level. In sessions where multiple conditions and baselines were recorded, we did an ANOVA test at a 95% confidence level⁶.

There was a statistically significant difference between the baselines for two of the three sessions where multiple baselines were recorded. This difference between the first and second baselines is an indication that the baseline, or “neutral” profile, of a subject likely changes over the course of a session.

Hypothesis 1:

No statistically significant difference was found when comparing baseline with closed eyes. Thus the null-hypothesis was defended at a 95% confidence level.

Hypothesis 2:

Statistically significant differences were found in all three sessions recording deep breathing, both when comparing it to the first baseline and the second baseline. Thus, the null-hypothesis was rejected at a 95%.

Hypothesis 3:

Statistically significant differences were found for the combination of closed eyes and deep breathing. Both sessions recording this condition gave this result. This was true, both when comparing it to the first baseline and the second one. Thus, the null-hypothesis was rejected at a 95% confidence level. In both sessions the difference lay in higher Meditation values for the condition.

Hypothesis 4:

⁶ See Appendix B – Examples of ANOVA and T-test Results

Statistically significant differences were found when comparing baseline with the music hint in one of the two sessions recording it. However, the other of the two sessions contained no significant differences. The test was repeated for a 90% confidence level with the same results. Therefore, the null-hypothesis can neither be defended nor rejected at a 95% confidence level.

Hypothesis 5:

Statistically significant differences were found in both sessions recording the focusing and mantra repeating condition. This means the null-hypothesis was rejected at a 95% confidence level.

4.2 Results for Track 2 – Effects of Hints on Wavebands

We made the following hypotheses, described in section 2.3:

1. Closed eyes increase alpha waves
2. Ujaya, a structured form of deep breathing, increases alpha waves
3. A combination of closed eyes and deep breathing increases alpha waves
4. Ujaya, a structured form of deep breathing, increases theta waves
5. Non-harmonious calm music increases theta waves
6. Focusing on a single object and continuously repeating a single word or mantra mentally increases gamma waves

We examined the power spectra visually for two high values and two low values of Meditation. We did not see any indication that the hints affect specific frequencies in a consistent way. Figures 19 and 20 show power spectra for low-gamma under the baseline and the Ujaya condition. No obvious consistent differences can be seen between the two power spectra in these graphs.

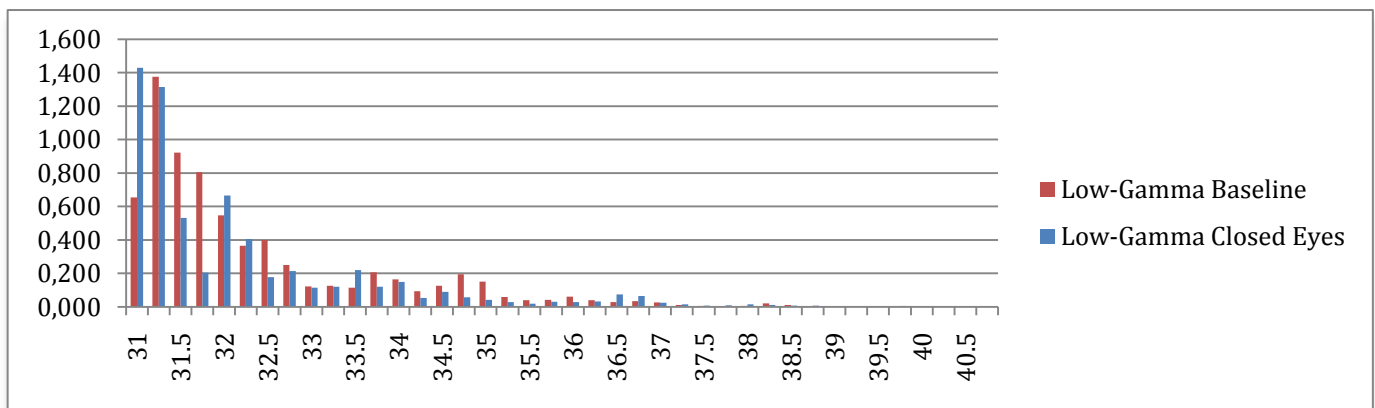


Figure 19 - Power Spectra for Baseline and Closed Eyes in a Low Meditation Second

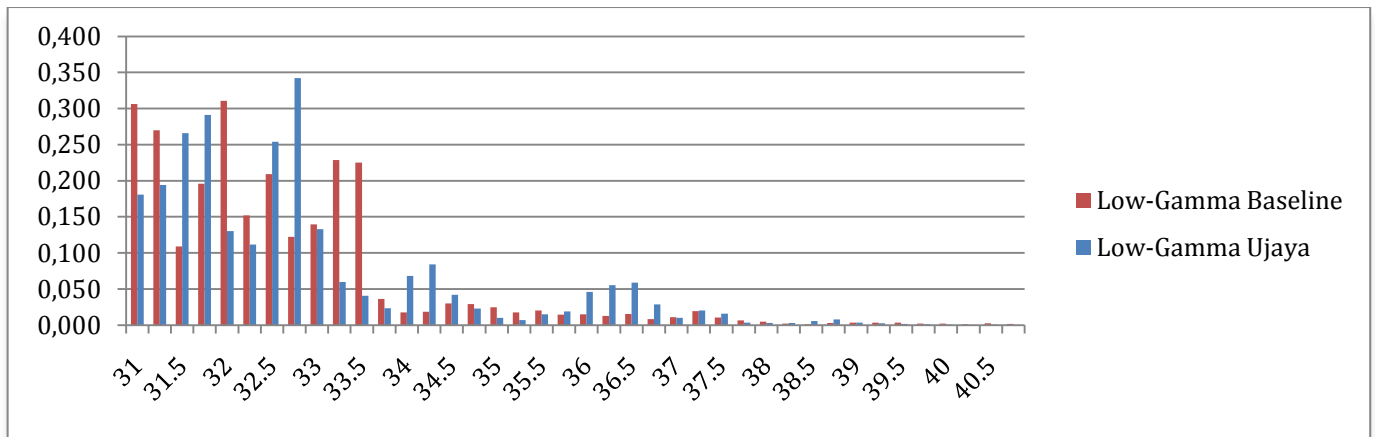


Figure 20 - Power Spectra for Baseline and Ujaya in a High Meditation Second

However, in some cases we did see differences between a hint and baseline for a particular value of Meditation, which were consistent with our hypotheses. These were visible in the total power within theta, low-alpha, high-alpha, low-gamma, or mid-gamma wavebands.

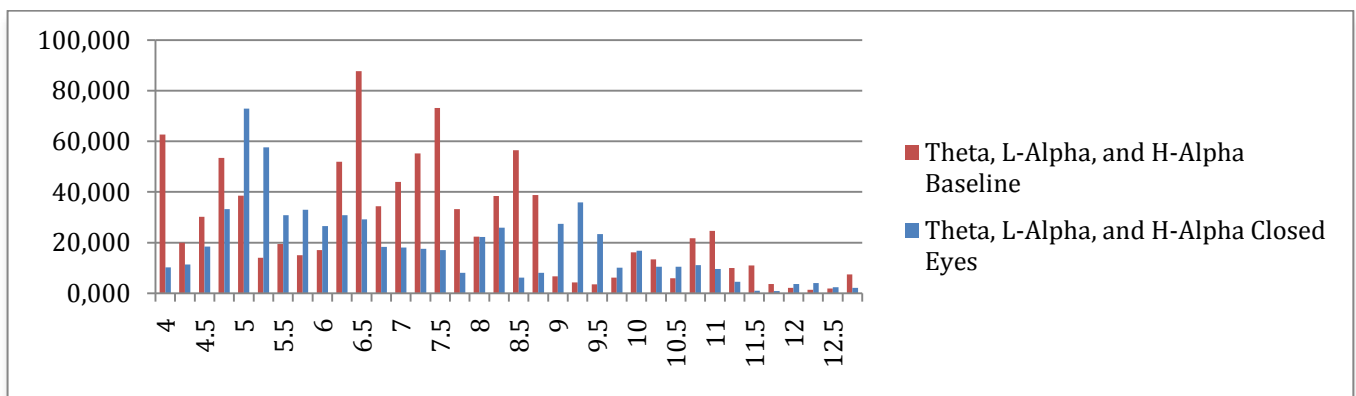


Figure 21 - Power Spectra for a Baseline and Closed Eyes in a Low Meditation Second

Figure 21 shows the power spectra for a single high Meditation value second in both a baseline and 'closed eyes' condition. These show that low-alpha, 8-9 Hz, is higher in the condition than in the baseline.

Given the structure of the data collection sessions we would need to perform a multivariate analysis of variance test (MANOVA), in order to statistically verify these observations. For a particular value of Meditation, the independent variables would be hints and the dependent variables would be the means of total power in the different wavebands.

According to common usage of confidence tests, which must be consistent with the requirements of the Central Limit Theorem, this analysis would require at least $n = 30$ observations of total power for each value of Meditation tested. We may have this number of observations in the data collected up to present. However, due to time constraints this analysis will have to be relegated to the future.

4.3 Results of Track 3 – A Typical Power Spectrum Shape for High Meditation

4.3.1 J48 Decision Tree

We began by attempting to classify the data (as described in chapter 3.5.3) with a J48 decision tree. It managed to correctly classify ~47% of the data. As can be seen in Figure 22, the overlap of the data is so pronounced that the decision tree had no basis for splitting the data set into subsets.

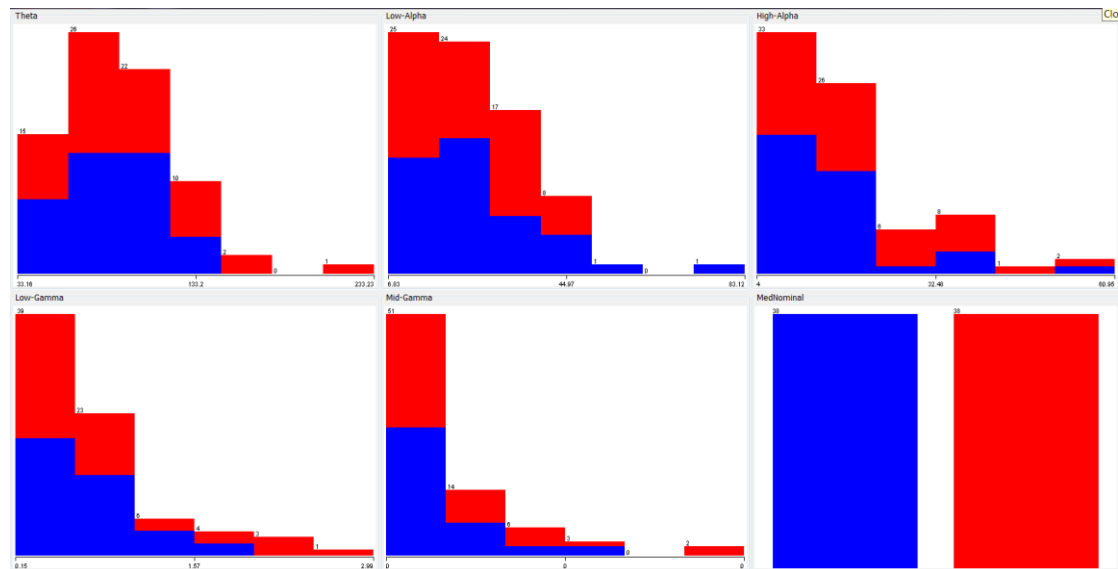


Figure 22 - Results of J48 Decision Tree Classification

Decision trees have the potential to give very descriptive results for the relationship between the different attributes of a dataset. In our case the output of the J48 was non-significant.

4.3.2 Multilayer Perceptron

When the decision tree gave no significant results we created a multilayer perceptron neural network to classify the data. Table 5 shows the result of four different epoch settings for the neural network.

No. Epochs	Correct Classifications
500	44,74%
5000	47,60%
100.000	55,40%
1.000.000	56,58%

Table 5 - Multilayer Perceptron Classification Results

Even though the percent of correct classification was slowly increasing the number of correctly classified instances was still too low.

5. Discussion

5.1 Track 1 – Effects of Hints on Meditation

Examining the effect hints have on Meditation gave the following results:

Hypotheses:

1. 'Closed eyes increase Meditation' was rejected with 95% confidence.
This result is surprising because both the literature review and expert advice describe the connection between closed eyes and meditation practices.

2. 'Deep breathing increases Meditation' was defended with 95% confidence.

This result is plausible because several different types of deep breathing, such as the Ujaya technique used in testing, are associated with the practice of meditation. However, in two of the three tests, this difference was a decrease in the Meditation mean. Therefore, even though the null-hypothesis was rejected, the hypothesis needs further study.

Differences in means of Meditation values between sessions can be explained by a) the test subject's familiarity with Ujaya and b) the subject's ability to focus on her breathing exclusively. Subjects B and D recorded a much lower Meditation mean from Ujaya than subject C. This supports a) because subject D was completely unfamiliar with the breathing technique and had to be reminded to breathe properly. It supports b) as well, since subject B described herself as distracted at the beginning of the session, this could have affected the Ujaya test block, recorded directly after the first baseline.

3. 'A combination of closed eyes and deep breathing increases Meditation' was defended with 95% confidence.

This result is plausible because many meditation techniques incorporate some combination of the two. MindGames staff has also observed informally that this is a reliable hint to raise Meditation.

4. 'Non-harmonious calm music increases Meditation' could not be defended or rejected for 95% or 90% confidence levels.

This result cannot be readily explained. As is mentioned in chapter 3.3, informal testing showed that listening to familiar music gave higher Meditation values than unfamiliar music. Subject C was very familiar with her music while subject D was somewhat familiar with hers. Surprisingly, it was subject C's data that showed no significant difference between the music hint and the baselines, while subject D's data showed a significant difference.

5. 'Focusing on a single object and continuously repeating a single word or mantra mentally increases Meditation'. This was defended with 95% confidence.

This result is plausible because of the connection of this hint combination to traditional Eastern meditation practices. However, the difference was caused by a lowering of Meditation values in one of the sessions, but an increase in the other one.

5.2 Track 2 – Effects of Hints on Wavebands

Examination of the effect of hints on the different wavebands by visually looking at the power spectra graphs gave the following results:

Hypotheses:

1. Closed eyes increase alpha waves – Two subjects displayed higher power in low-alpha within the 'closed eyes' hint than in the baseline. However, two other subjects displayed a decrease in power within this same hint when compared to baseline. All other graphed power spectra displayed no obvious difference between baseline and condition. Therefore, this hypothesis has neither been defended nor rejected with this data.
2. Ujaya, a structured form of deep breathing, increases alpha waves – No differences were noticeable when comparing the ujaya hint with the baseline.
3. A combination of closed eyes and deep breathing increases alpha waves - No differences were noticeable when comparing the combination of closed eyes and deep breathing hint with the baseline.
4. Ujaya, a structured form of deep breathing, increases theta waves - No differences were noticeable when comparing the ujaya hint with the baseline.
5. Non-harmonious calm music increases theta waves - No differences were noticeable when comparing the music hint with the baseline.
6. Focusing on a single object and continuously repeating a single word or mantra mentally increases gamma waves - No differences were noticeable when comparing the focus and mantra hint with the baseline.

5.3 Track 3 – A Typical Power Spectrum Shape for High Meditation

Examination of the typical power spectrum shape for high values of Meditation gave no result. However, this lack of result was expected, given that we observed that the power spectra for equal values of Meditation can differ greatly under different conditions and baseline measurements. Figure 23 shows exhibits this for a second when Meditation = 100.

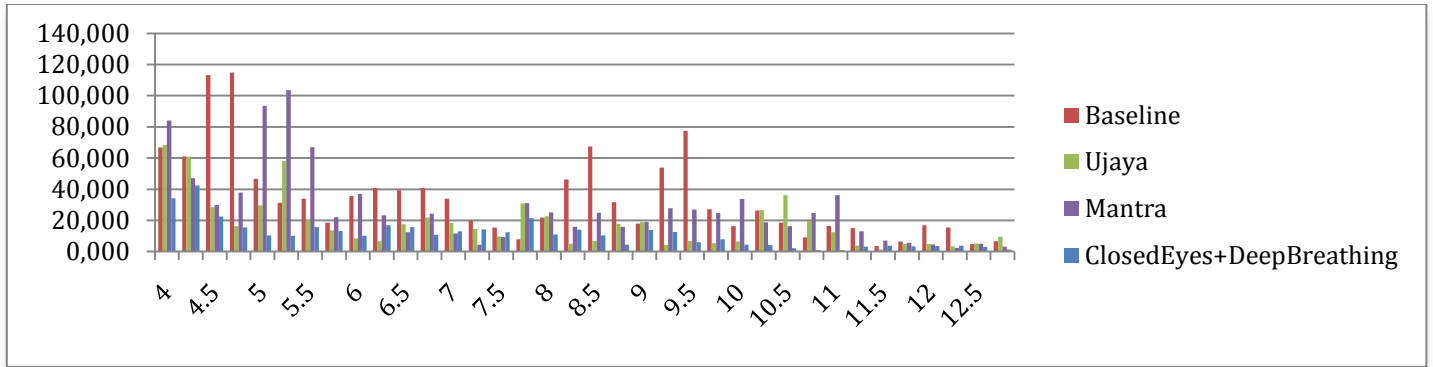


Figure 23 - Theta, Low-alpha, and High-alpha for Meditation = 100

6. Conclusions and Future Work

6.1 Feasibility of Hint System

What do the above results mean for the feasibility of the proposed hint system?

Track	Results
1	We have hints that affect Meditation
2	May give us hints that affect specific wavebands, pending further investigation
3	Did not give us a typical power spectra shape for high values of Meditation

Table 6 - Research Track Results

Given these results, it is not possible at this time to build a system to give directed hints to increase activity in certain wavebands in order to increase Meditation. As was discussed in chapter 2.3, promising results from Tracks 2 and 3 together or from Tracks 1, 2, and 3 would make the proposed system feasible. However, we only have promising results from Track 1, and while that gives us hints that affect Meditation, we have no information on which hint is needed on a case to case basis.

6.2 What is Next?

This project has built a base for further research into how players' control over the NeuroSky MindSet can be improved.

The next step is to determine whether enough data has been collected to do a statistical analysis of Track 2 relevant data. Post-hoc analyses should also be performed in the cases where unlooked-for significant differences are found between condition and baseline in Tracks 1 and 2.

If further examination of Track 2 data gives statistically significant results, this pilot study will have developed a method, which can, and should, be replicated in an expanded study for testing whether hints affect Meditation and particular wavebands.

Should the expanded study confirm these preliminary findings, it will also lend the most detailed support yet to NeuroSky's assertion that the Meditation function is associated with meditative states. Currently the only publicly available literature supporting their claim is a whitepaper published by NeuroSky. It shows significant differences in 9 of 14 subjects between Meditation values generated in one hint condition versus baseline. This is a small version of our Track 1. However, they do not test the effect of hints on specific wavebands which are correlated with meditative states in the scientific literature. This is tested in our Track 2.

7. Acknowledgements

First and foremost I would like to thank my supervisors, Deepa Iyengar and Yngvi Björnsson for their invaluable help and for being available to provide that help whenever and wherever it was needed.

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And last but not least I would like to thank my sister, Björg Guðmundsdóttir, for plying me with food and drink, for being my sounding board in all things, and most of all for being the best at being my sister.

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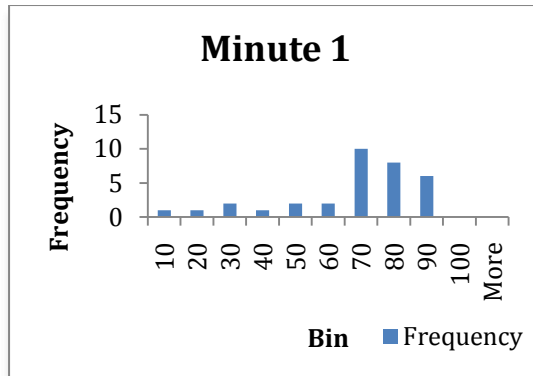
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9. Appendices

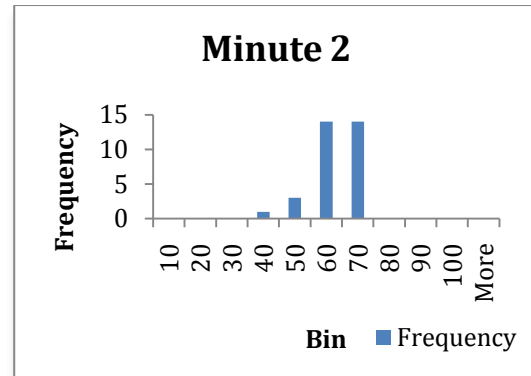
Appendix A – Histograms Showing Lack of Trend

The following histograms show the lack of a trend in clean Meditation data for subject B's second baseline block from session 3.

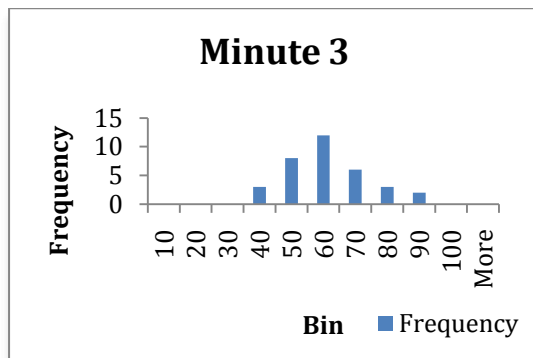
Standard deviation abbreviated to stdev.



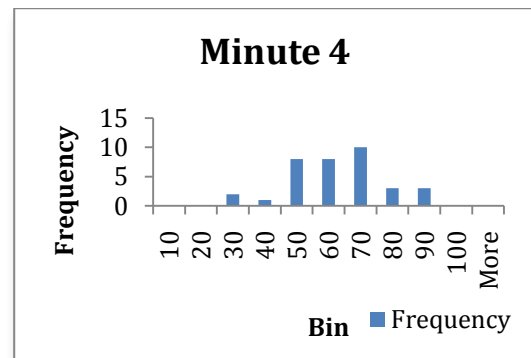
Minute 1:
Mean: 63,36
Stdev: 21,72



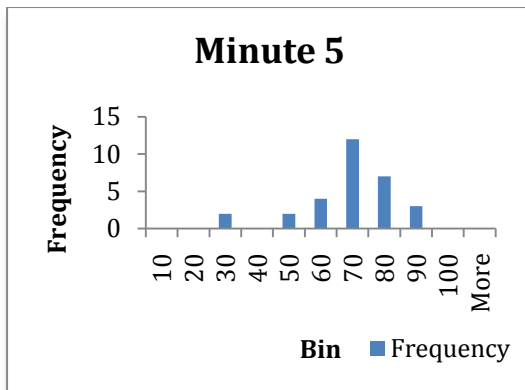
Minute 2:
Mean: 58,53
Stdev: 7,84



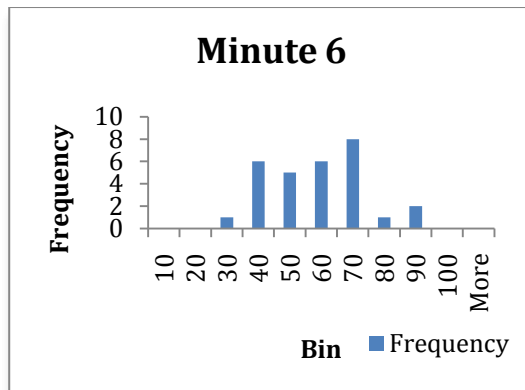
Minute 3:
Mean: 56,65
Stdev: 11,84



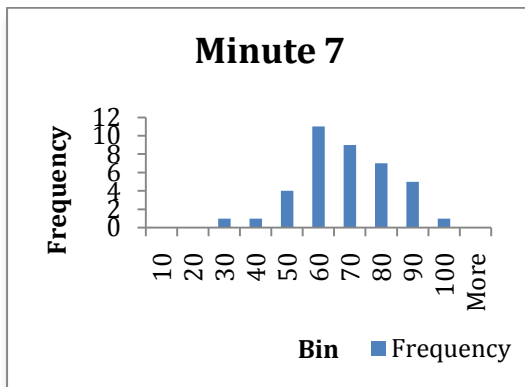
Minute 4:
Mean: 58,89
Stdev: 15,59



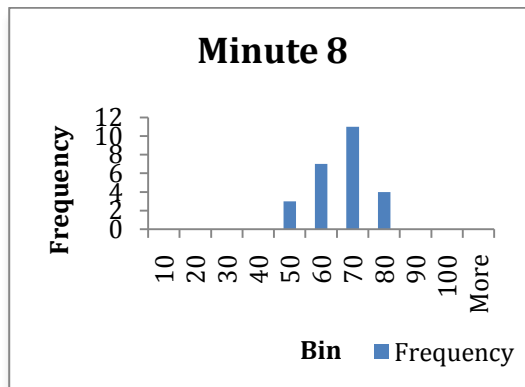
Minute 5:
 Mean: 65,77
 Stdev: 14,07



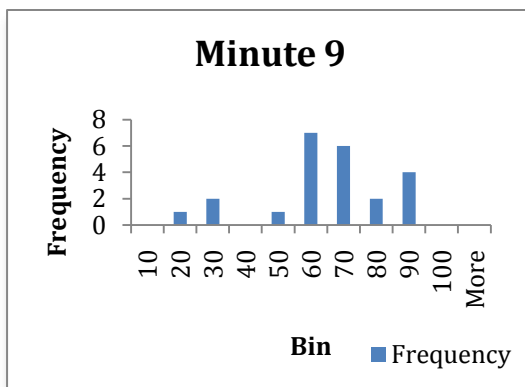
Minute 6:
 Mean: 54,38
 Stdev: 15,67



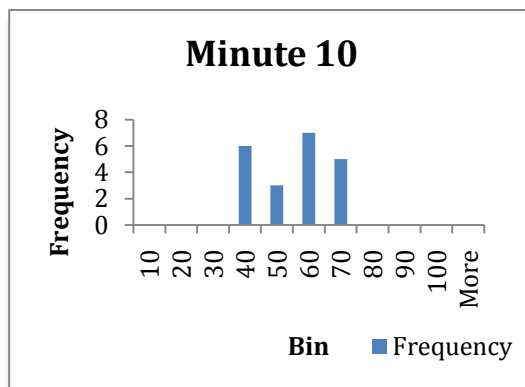
Minute 7:
 Mean: 63,74
 Stdev: 14,82



Minute 8:
 Mean: 62,76
 Stdev: 9,50



Minute 9:
 Mean: 59,57
 Stdev: 18,65



Minute 10:
 Mean: 51,38
 Stdev: 11,05

Appendix B – Examples of ANOVA and T-test Results

B.1 – Single Condition Session – T-test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	A Baseline	53,8374	609	20,43551	,82809
	A Closed Eyes	53,6240	609	14,67044	,59448

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	A Baseline & A Closed Eyes	609	-,075	,066

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)	
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower				Upper
Pair 1	A Baseline - A Closed Eyes	,21346	26,02979	1,05478	-1,85799	2,28492	,202	608	,840	

Significance value is > 0.05 so there is no statistically significant difference

B.2 Multiple Condition and Baseline Session - ANOVA

Descriptives

Meditation

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
C Baseline1	633	50,4645	17,93163	,71272	49,0649	51,8640	1,00	100,00
C Ujaya	618	66,1667	18,66448	,75080	64,6922	67,6411	8,00	100,00
C Mantra	310	63,6226	18,00978	1,02289	61,6099	65,6353	8,00	100,00
C Music	651	51,1843	17,83583	,69904	49,8117	52,5570	7,00	100,00
C Closed Eyes + Deep Breathing	689	72,3396	18,72004	,71318	70,9394	73,7399	14,00	100,00
C Baseline2	624	53,5705	16,06852	,64326	52,3073	54,8337	13,00	96,00
Total	3525	59,3330	19,87456	,33475	58,6767	59,9894	1,00	100,00

Test of Homogeneity of Variances

Meditation

Levene Statistic	df1	df2	Sig.
3,070	5	3519	,009

Sig. < 0.05 so data does not satisfy the assumption of homogeneity of variance (*)

ANOVA
Meditation

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	264857,568	5	52971,514	165,384	,000
Within Groups	1127115,431	3519	320,294	-	-
Total	1391973,000	3524	-	-	-

Because of (*) we do not need to consider this table

Robust Tests of Equality of Means

Meditation

	Statistic ^a	df1	df2	Sig.
Welch	159,807	5	1474,027	,000

Because of (*) we use Welch's ANOVA.

Since Sig < 0.05 there is a statistically significant difference between the means.

Post Hoc Tests

Multiple Comparisons

Meditation
Tukey HSD

(I) Grouping	(J) Grouping	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C Baseline1	C Ujaya	-15,70221*	1,01206	,000	-18,5879	-12,8165
	C Mantra	-13,15813*	1,24065	,000	-16,6956	-9,6207
	C Music	-,71988	,99900	,979	-3,5683	2,1285
	C Closed Eyes + Deep Breathing	-21,87517*	,98532	,000	-24,6846	-19,0657
	C Baseline2	-3,10606*	1,00960	,026	-5,9847	-,2274
C Ujaya	C Baseline1	15,70221*	1,01206	,000	12,8165	18,5879
	C Mantra	2,54409	1,24559	,318	-1,0074	6,0956
	C Music	14,98233*	1,00513	,000	12,1164	17,8482
	C Closed Eyes + Deep Breathing	-6,17296*	,99154	,000	-9,0001	-3,3458
	C Baseline2	12,59615*	1,01566	,000	9,7002	15,4921
C Mantra	C Baseline1	13,15813*	1,24065	,000	9,6207	16,6956
	C Ujaya	-2,54409	1,24559	,318	-6,0956	1,0074
	C Music	12,43825*	1,23499	,000	8,9169	15,9596
	C Closed Eyes + Deep Breathing	-8,71704*	1,22396	,000	-12,2069	-5,2272
	C Baseline2	10,05207*	1,24358	,000	6,5063	13,5979
C Music	C Baseline1	-,71988	,99900	,979	-2,1285	3,5683
	C Ujaya	-14,98233*	1,00513	,000	-17,8482	-12,1164
	C Mantra	-12,43825*	1,23499	,000	-15,9596	-8,9169
	C Closed Eyes + Deep Breathing	-21,15529*	,97820	,000	-23,9444	-18,3662
	C Baseline2	-2,38618	1,00264	,164	-5,2450	,4726
C Closed	C Baseline1	21,87517*	,98532	,000	19,0657	24,6846

Eyes + Deep Breathing	C Ujaya	6,17296*	,99154	,000	3,3458	9,0001
	C Mantra	8,71704*	1,22396	,000	5,2272	12,2069
	C Music	21,15529*	,97820	,000	18,3662	23,9444
	C Baseline2	18,76911*	,98902	,000	15,9491	21,5891
C Baseline2	C Baseline1	3,10606*	1,00960	,026	,2274	5,9847
	C Ujaya	-12,59615*	1,01566	,000	-15,4921	-9,7002
	C Mantra	-10,05207*	1,24358	,000	-13,5979	-6,5063
	C Music	2,38618	1,00264	,164	-,4726	5,2450
	C Closed Eyes + Deep Breathing	-18,76911*	,98902	,000	-21,5891	-15,9491

Differences are statistically significant at Sig. < 0.05

Welch's ANOVA tells us whether there is a difference, but the post-hoc tests tell us where the differences lie. We used the Tukey post-hoc test for analysing our data.

Means Plots

