CE 271 - Sensors and Signal Interpretation

Raw Data Algorithm Comparison
Final Report
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CONTENTS

TABLES

FIGURES

1 INTRODUCTION

The following outlines document progress made toward the brainwave sensor project. It includes our initial design calculations, which is a summary of research, exploratory testing, and analysis performed.

1.1 BRAIN WAVE TYPES

Brainwaves are the signals sent when neurons communicate with each other. These waves are typically measured with an EEG (or an "electroencephalograph") by placing sensors on the scalp. The five types of brainwaves are delta, theta, alpha, beta, and gamma. Each wave has a unique frequency range and affects how people handle stress, focus, and sleep. [1] All five brainwaves are produced simultaneously; however, the ratio of these waves vary depending on the tasks people perform. The figure below shows the type of brainwave with examples at various activity levels.

Table 1-1. Brainwave Types

Brainwave Type	Frequency range	Mental states and conditions
Delta	0.1Hz to 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz to 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz to 12Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12Hz to 15Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz to 20Hz	Thinking, aware of self & surroundings
High Beta	21Hz to 30Hz	Alertness, agitation
Gamma	30Hz to 100Hz	Motor Functions, higher mental activity

1.2 BRAINWAVE PHENOMENA

1.2.1 P-300 Wave (P3)

The P-300 wave is a unique response in the brainwaves to a visual stimuli which is unexpected to the observer. It is called the P-300 wave because it occurs approximately 300 ms after the unlikely or anticipated event occurs. It is associated the oddball paradigm, where low-probability items are mixed with high-probability items. An example of a P-300 wave occurs is when a person is waiting at a red traffic light and suddenly it turns green. An example of the P-300 response is shown in the figure below:

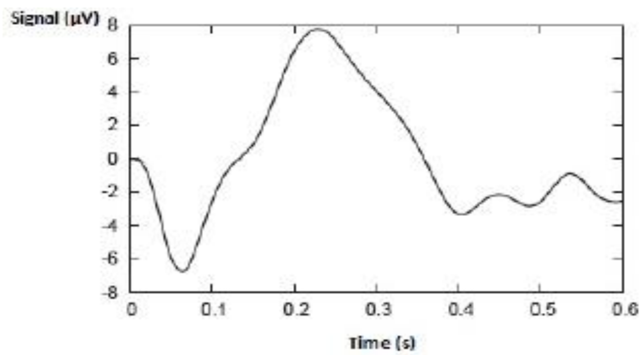

Figure 1-2: Illustration of P300 Response

1.2.2 Steady-State Visually Evoked Potential (SSVEP)

The Steady State Visually Evoked Potential (SSVEP) is a phenomenon that occurs when the retina is excited by a visual stimulus and the brain generates electrical activity at the same frequency of the visual stimulus. SSVEP tests are run using a Brain Computer Interface (BCI) to flash an image at a designated frequency. By focusing on different images and words, users can make selections. SSVEP and BCI are commonly used to allow paralyzed patients to communicate.

2 MATERIALS & PROCEDURE

2.1 EQUIPMENT

2.1.1 Neurosky Mindwave Headset

ThinkGear is the proprietary technology Neurosky uses to connect the headset, USB adapter, and computer. This tool senses raw signals from one electrode on the forehead and converts them into the five main brainwaves. The raw signal includes noise from ambient conditions and movement (blinking, muscle twitches, etc.), and conversion occurs through the eSense algorithm. The algorithm outputs a POOR_SIGNAL quality value which measures the level of noise every second. This one-byte measurement ranges from 0-255 with higher values corresponding to an increase in noise. The two output measurements are attention and meditation on an eSense scale (1-100). The attention measures the level of "focus" while the meditation value measure "relaxation."

2.1.2 Matlab (Signal Acquisition)

Matlab was used to acquire a raw data stream from the Mindwave device. To accomplish this, the Thinkgear.dll and Thinkgear.h files from the Neurosky SDK (software development kit) were used to allow Matlab to act as a data acquisition unit and converter. A C++ compiler and a Matlab 32-bit version are required to be installed in order to use the Thinkgear files.

2.2 METHODOLOGY

2.2.1 Experiment No. 1

To set up a controlled method for collecting data, we set up an experiment involving a complete deck of shuffled playing cards and recorded the brainwaves during this one-minute interval while watching the cards flip. While dealing the cards, we designated an Ace of spades to be a trigger card—a card identified as the most important.

There are several purpose for this experiment and collecting data:

- Investigate P300 wave: to determine if we can see the P300 response upon seeing the trigger card
- Investigate natural brainwave activity over time: to determine if we naturally transition from a state of high attention to a state of high meditation due to anticipation of seeing the trigger card;
- Investigate ability to control brainwaves: to determine if we can forcefully control attention and meditation states; and

- Investigate how to process raw data: to determine how each brainwave type can be extracted from raw data and how the Thinkgear algorithm calculates attention and meditation parameters

When the trigger card was dealt, the time was noted to determine if the brainwaves had a marked P300 wave response. In addition to having a P-300 wave, we hypothesized the card viewer would naturally have a high attention level (Alpha- and Beta-Waves) until the point of the trigger card being dealt, and afterward become more relaxed and rise into higher meditative level. (Delta-Waves). In the first half of trials, we tried to evaluate the natural brain response, while in the second half of trials, we attempted to forcefully control brainwaves by purposely exerting focus on the cards until the trigger card, and then attempting to go into a meditative state.

A total of thirty of these test trials were performed through three different testing phases:

- Phase 1: Testing at home, natural response, not attempting to increase attention or meditation (10-trails)
- Phase 2 - Testing in a room full of people on campus, natural response, not attempting to increase attention or meditation (10-trails)
- Phase 3 - Testing at home, controlled response, attempting to increase attention before trigger card and meditate after trigger card (10-trails).

2.2.2 Experiment No. 2

A Brain Computer Interface (BCI) was tested using Matlab's Psychtoolbox to flash an image of "yes" at various frequencies similar to Figure 1-2. The end goal was to allow a user to select an image based on focusing on that image. The frequency of the image should begin to match the frequency of electrical activity in the brain.

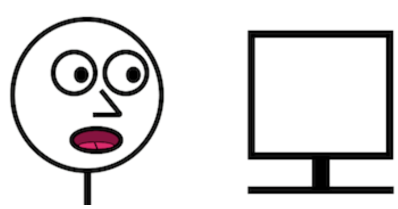

Figure 1-2. Brain Computer Interface Setup

2.2.3 Signal Processing

Finally, we used the data to investigate how the signals were processed for the Thinkgear outputs (attention, meditation, alpha, beta, gamma, theta, and delta waves).

3 RESULTS

The following preliminary results were found by examining the raw signals and mindwave proprietary signals produced during the exploratory testing:

3.1 P300 WAVE

We did not observe the P300 response in the mindwave processed signals. These processed results are only output at 1Hz, while the raw signal is available at 512 Hz. In addition, the magnitude of this wave is not significant enough to noticeably stand out. We looked at plots of raw data during a two-second interval around the approximate time the trigger card was dealt but were not able to observe this response due to the small scale of the response. A couple typical result plots are shown below. The amplitude of the brainwaves was much higher at some times during the testing for an unknown reason.

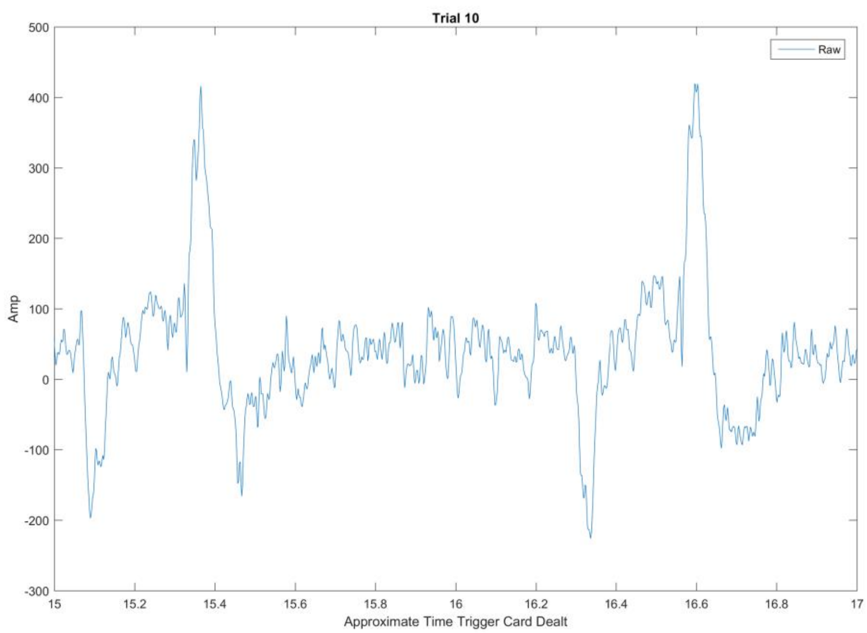

Figure 3-1: Raw Data of P300 Response Investigation-I

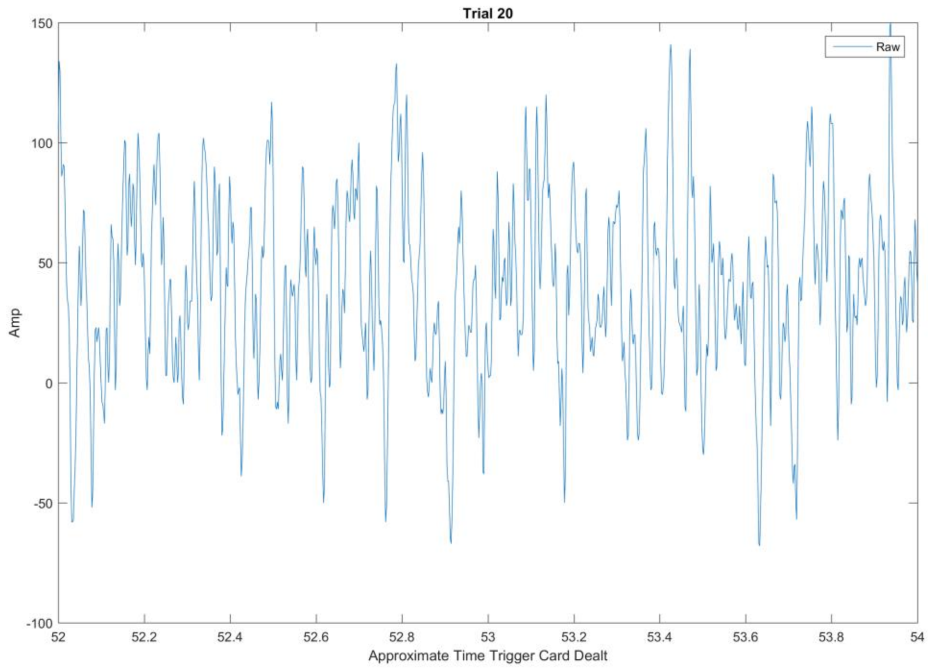

Figure 3-2: Raw Data of P300 Response Investigation – II

3.2 Natural brainwave activity over time

Brainwaves were naturally more sporadic than hypothesized. We could not observe higher levels of attention before the trigger card and higher levels of meditation after the trigger card. A couple typical result plots are shown below.

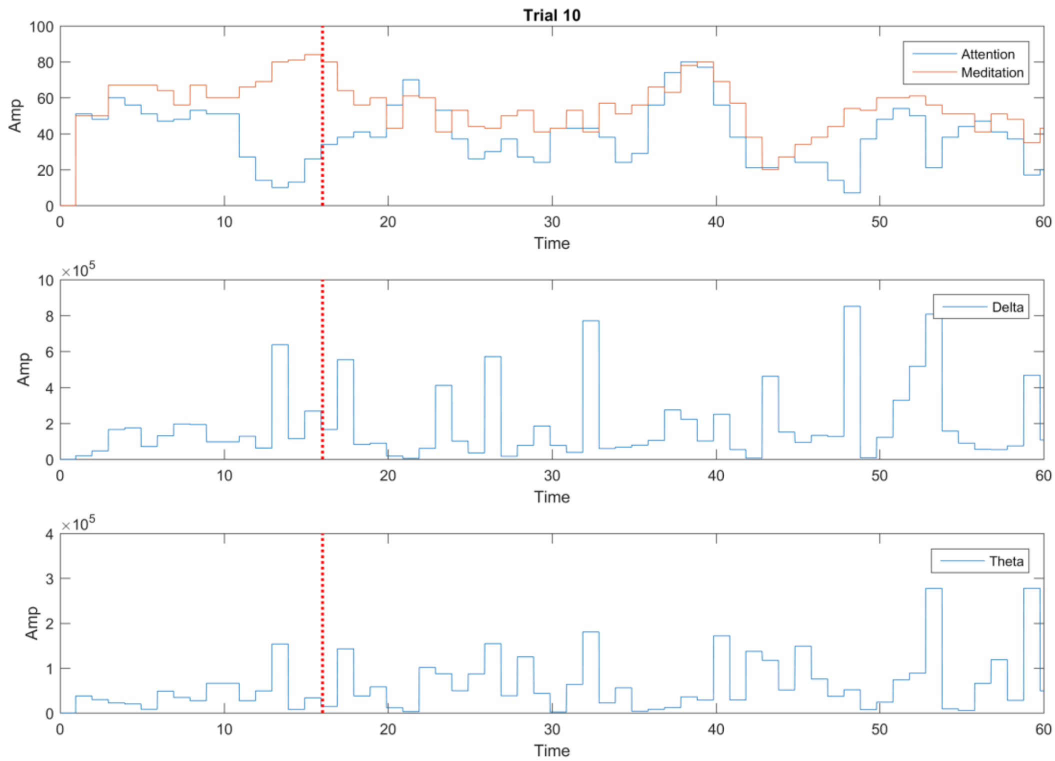

Figure 3-3: Raw Data of Natural Brainwave Response - I

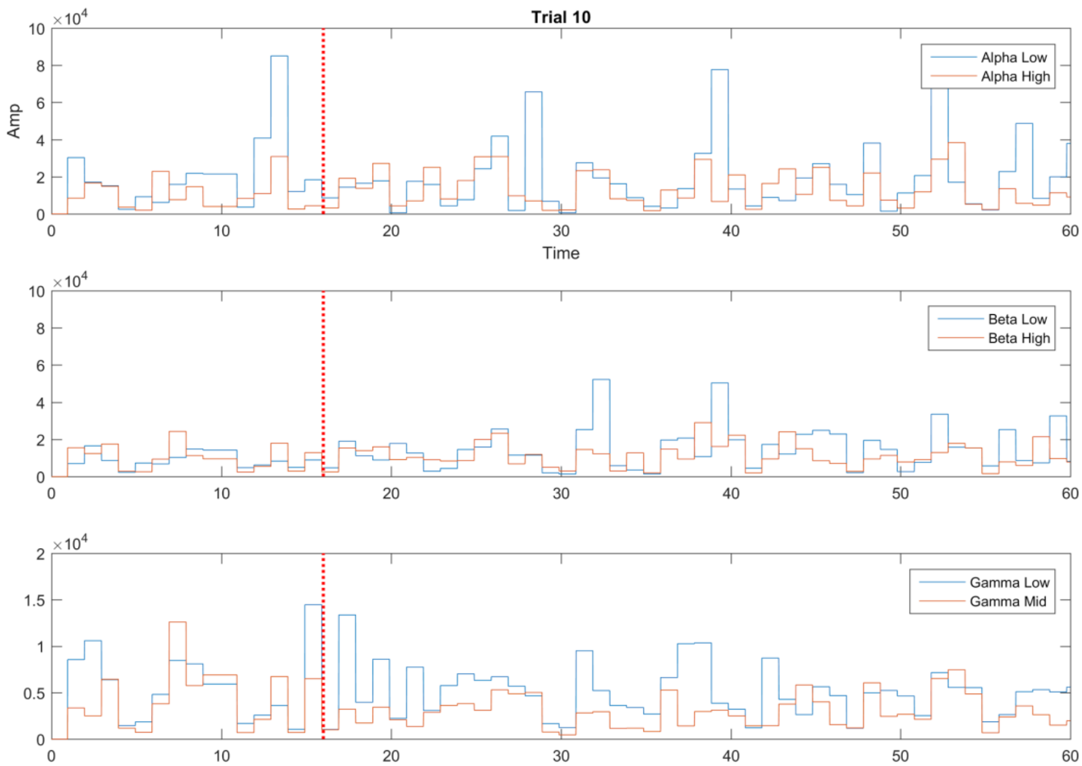

Figure 3-4: Raw Data of Natural Brainwave Response - II

3.3 Brainwave Control

- Brainwaves are difficult to control. Trying to increase attention or meditation is not easily done, but perhaps could be improved with more practice.
- We have a new matlab program that will allow us to display our own processing of the brain waves and the mindwave processed signals in real time. This will allow us to test our ability to control any of these waves more efficiently.

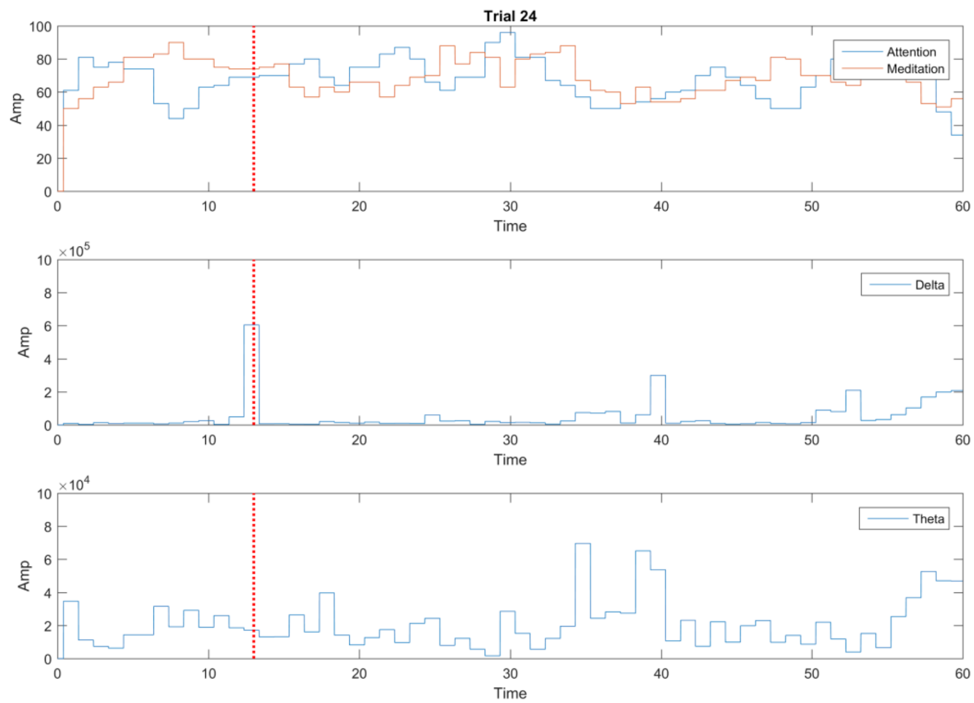

Figure 3-5: Raw Data of Attempted Brainwave Control - I

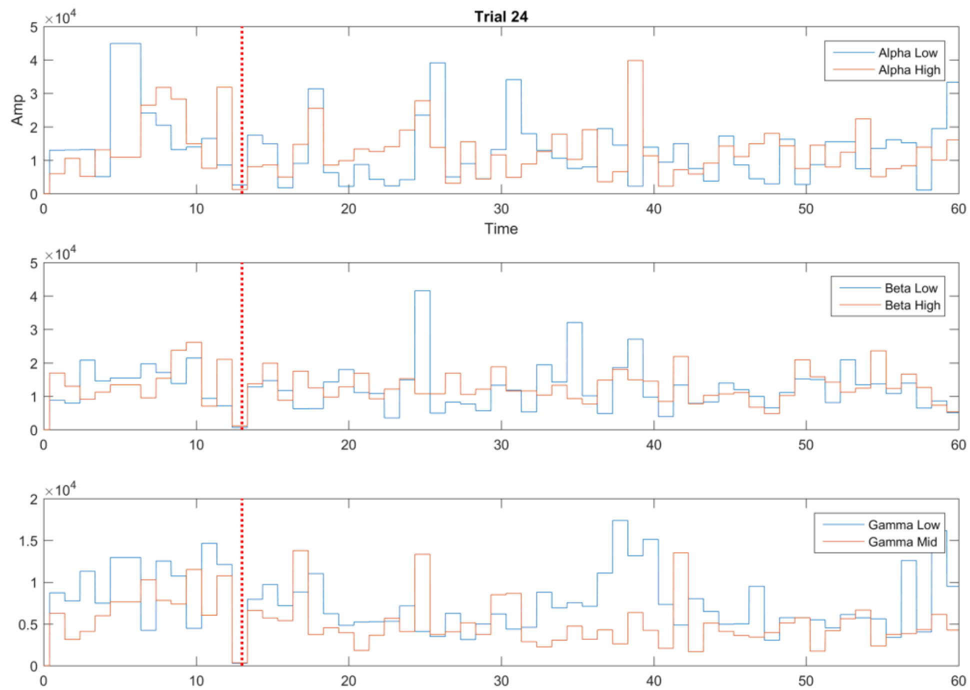

Figure 3-6: Raw Data of Attempted Brainwave Control – II

3.4 Steady State Visually Evoked Potential

We attempted to find an SSVEP response using the Neurosky Mindwave headset and stimulating frequencies between 4 and 80 Hz. Results for the 30 Hz test are shown as representative of the general results. First, we examined the power spectral density of each test using different estimators built in to Matlab. We used Welch's method for a moving average type estimate and Burg's algorithm for an auto-regressive estimate. As shown in Figure 3-6, the raw data has a very large low frequency component, decreasing power with increasing frequency, and no obvious spike in power at the stimulated frequency.

In order to suppress the high power in the low frequencies, we applied filters to the raw signal and re-examined the power spectral densities. Figure ** shows the results of a bandpass filter of 15 – 50 Hz and two highpass Butterworth filters of order 15 with cutoff frequencies of 10 and 15 Hz. The bandpass filter again shows no significant increase in power at the stimulated frequency. The locations of the peaks in the Burg algorithm estimate vary widely based on the number of poles used (order). The high pass filters show the same trends as the unfiltered data without the surge of power in the low frequencies when estimated by Welch's method. The Burg algorithm first peak seems to be near the stimulated frequency after the 15 Hz highpass filter, but it is a wide peak whose maximum varies by more than 10 Hz based on the number of poles used.

While it is possible to choose a filter and PSD algorithm combination that will give a significant increase in power at the stimulated frequency, that combination varies dramatically between tests and stimulation frequencies. Since our goal was to use SSVEP as the control for a Brain-Computer Interface, we would need a consistent processing algorithm that could distinguish between stimulation frequencies in real time, whether or not we can tease the frequencies out in later analysis. We concluded that the Mindwave headset raw data does not contain enough information to support a BCI using SSVEP.

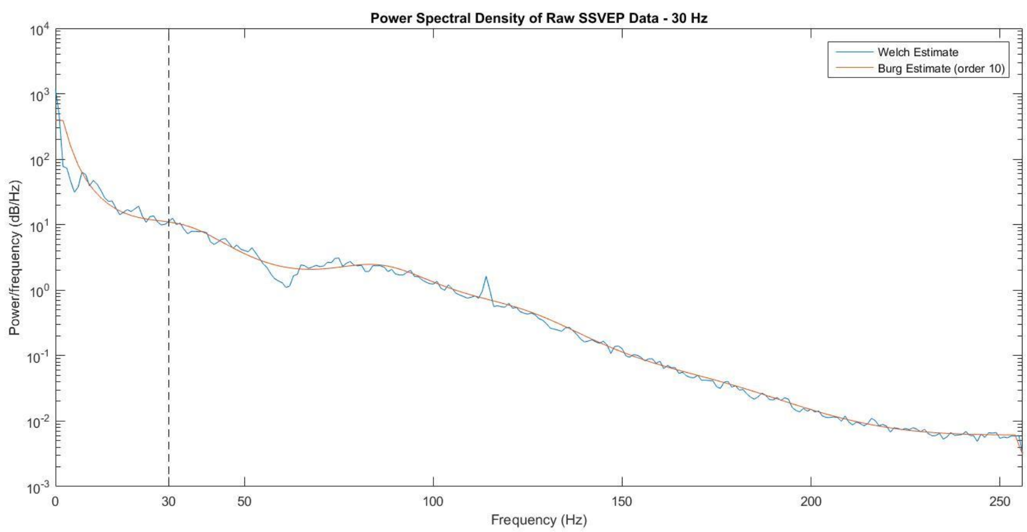

Figure 3-7: Power Spectral Density at 30 Hz

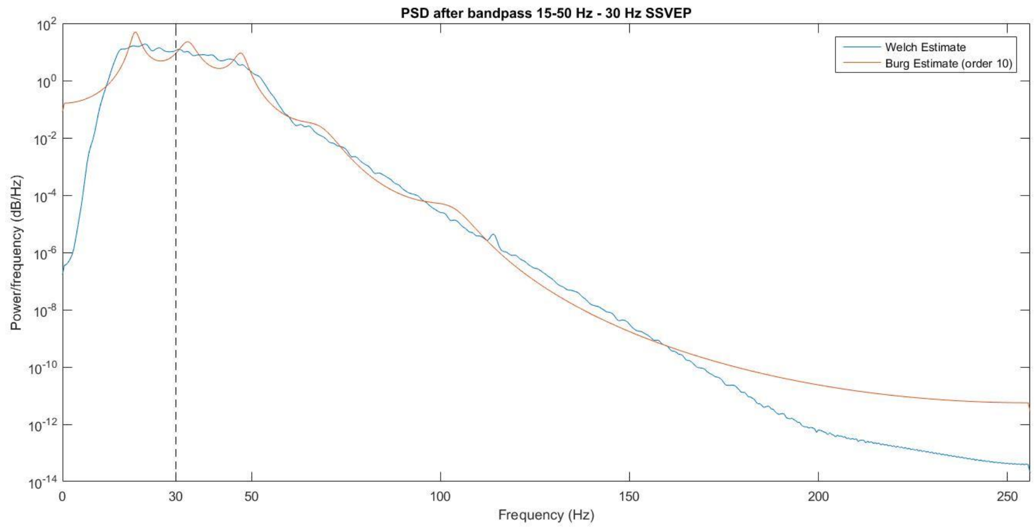

Figure 3-8: Power Spectral Density at 30 Hz with a bandpass of 15-50 Hz

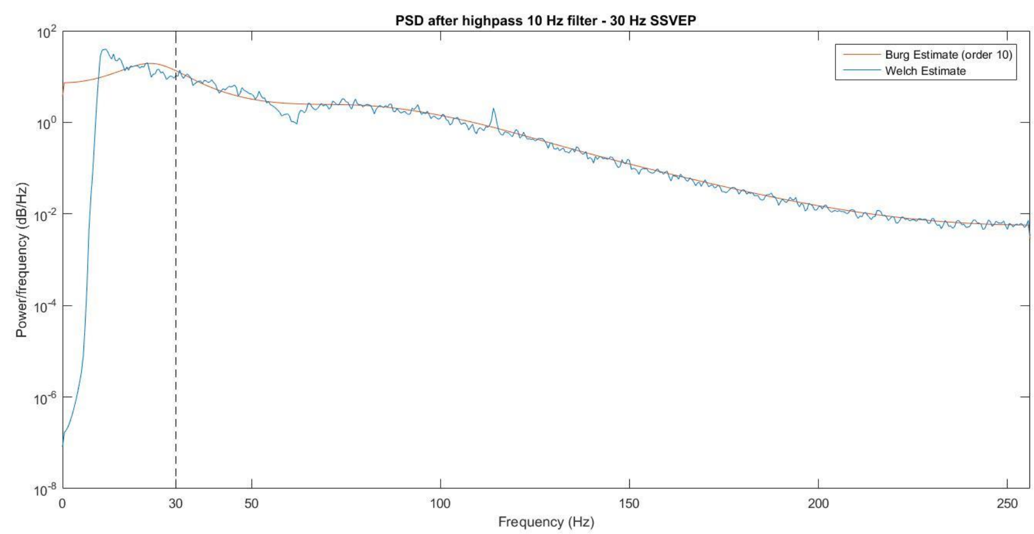

Figure 3-9: Power Spectral Density at 30 Hz with a highpass of 10 Hz

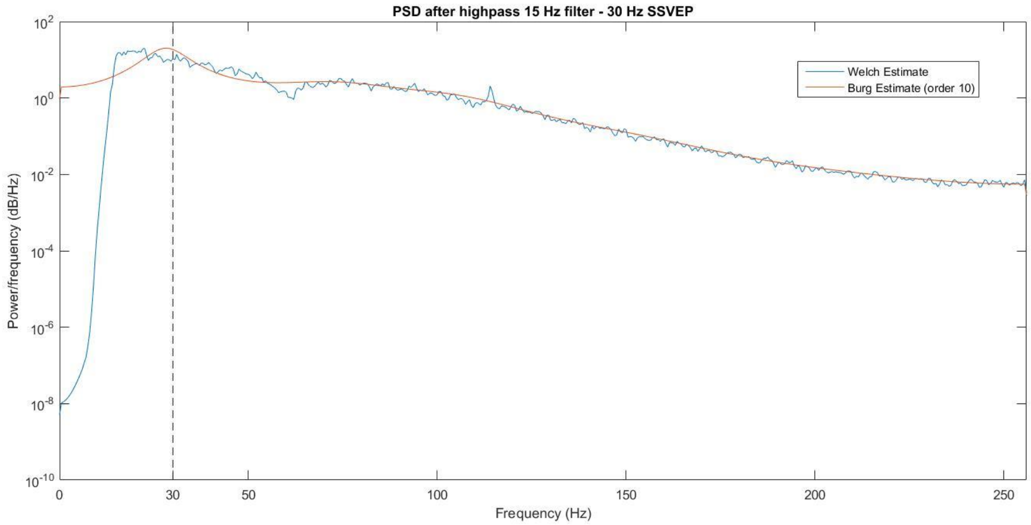

Figure 3-10: Power Spectral Density at 30 Hz with a highpass of 15Hz

3.5 Raw Data Algorithm Comparison

For our earliest investigations, we processed the raw signal data in two ways to compare it to the Mindwave outputs and try to deconstruct the Mindwave control parameters (attention and meditation). We were looking for any simple variations that we could use as control parameters for a Brain Computer Interface.

First we attempted to deconstruct the raw signal into individual brainwave signals. The raw signal was transformed to the frequency domain and then divided into the bands of the individual brainwaves. Each band was then transformed back to time domain. Unfortunately, this implies the use of an impossible filter, which we did not know at the time of analysis. The results seem to show waves at separated frequencies, but there are notable issues. For example, for the one second segment shown in Figure 3-7 the alpha wave is modulating at a much higher frequency than 12 Hz and the beta wave also has high frequency component riding on a lower frequency.

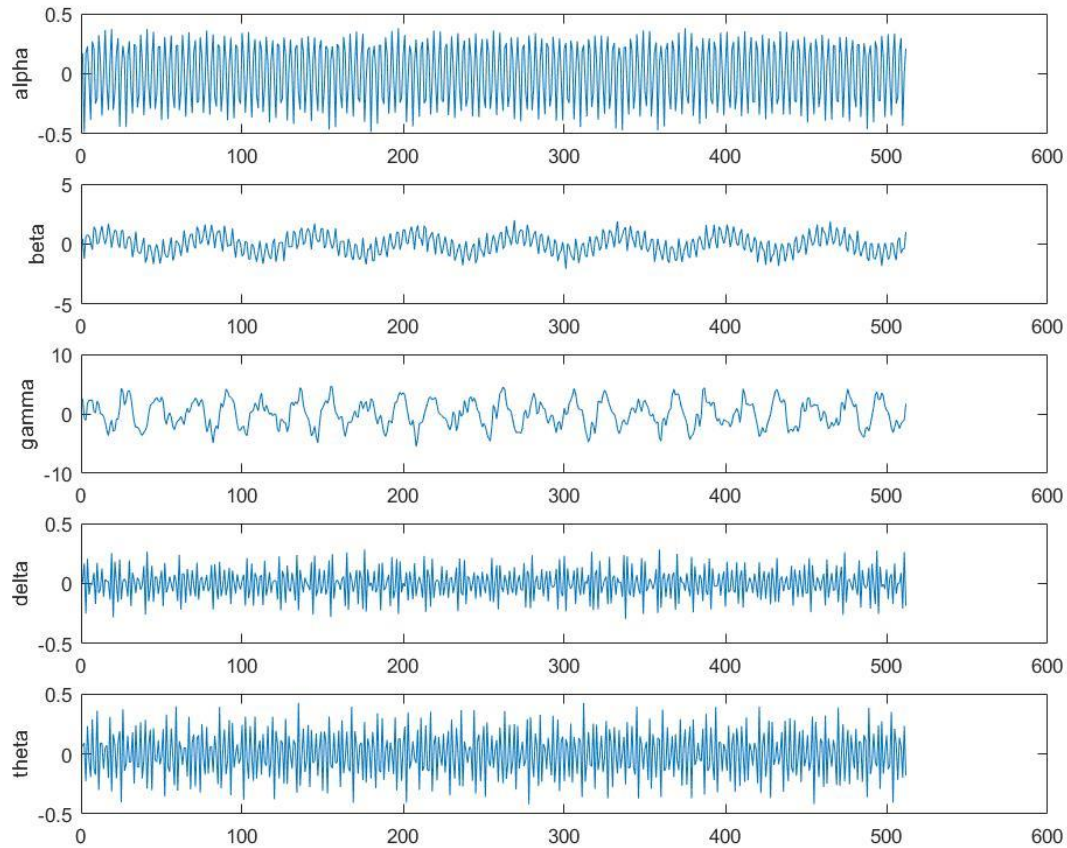

Figure 3-11: Brainwave Decomposition

Next we examined the bandpower for each frequency band at 1s intervals using the Matlab bandpower function. We compared these brainwave intensities to the mindwave outputs for each brainwave from the same time intervals and examined the mindwave attention and meditation parameters for the same intervals. The results showed some correlations, but again we were applying impossible filtering. Maybe by applying valid bandpass filters we could achieve a better correlation with the Mindwave outputs.

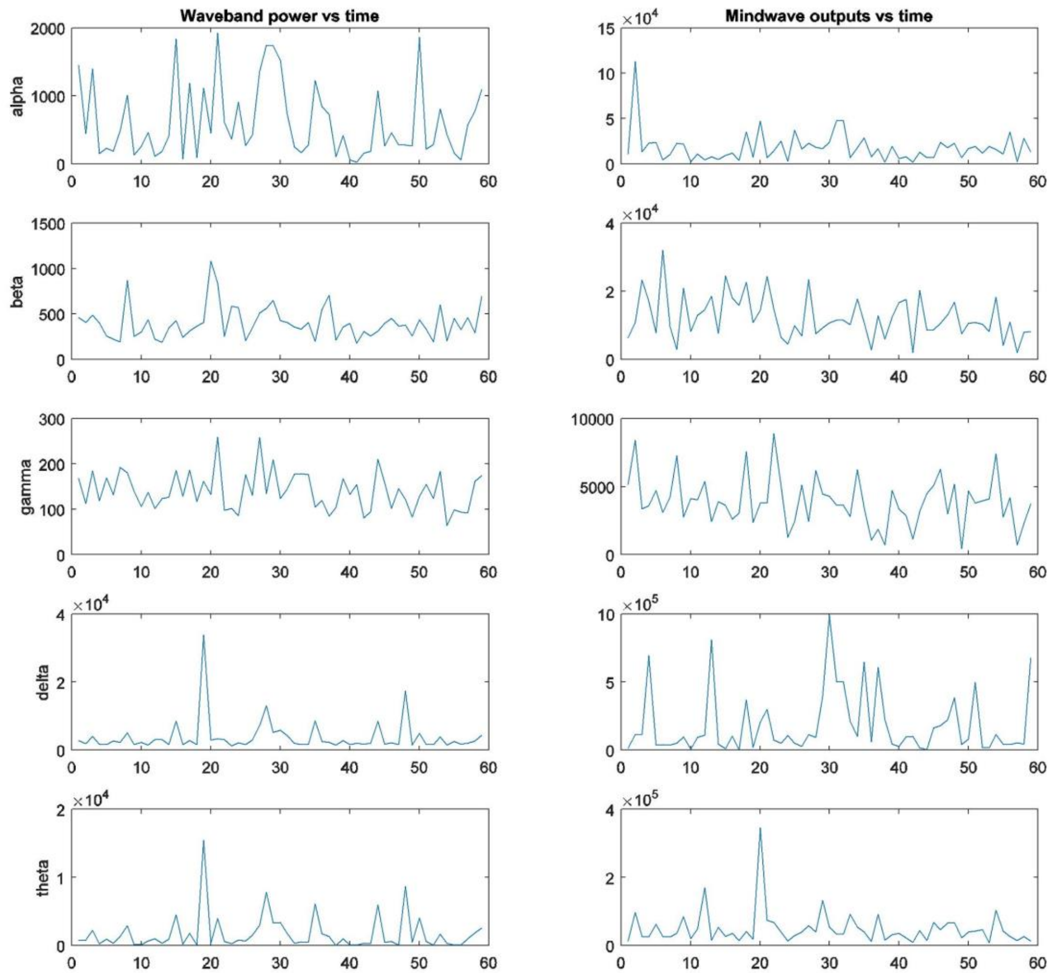

Figure 3-12: Evaluation of Output Algorithms

Overall our results of this investigative analysis were inconclusive: We were able to produce plots similar to the Mindwave individual brainwave outputs, but the attention and meditation parameters were not clearly correlated with any particular brainwave intensities. Since this data exploration step was so early in our project, the methods were a bit naïve. Finding no easy control parameters using our minimal signal processing skills at that point, we moved on to searching for the P300 and SSVEP responses. As these investigations also failed to work with the Mindwave headset, a possible future step would be to return to investigations of the individual brainwaves with improved signal processing knowledge. By examining the crosscorrelation of the individual brainwave intensities and the attention and meditation parameters, we might be able to find control parameters.

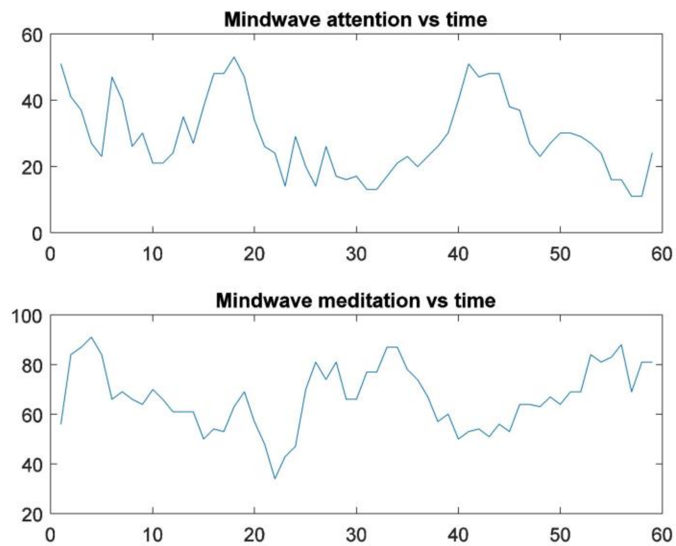

Figure 3-13: Attention and Meditation Algorithms

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