Using EEG to Demonstrate Alpha Wave Differences Between Eyes Closed and Eyes Open

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Abstract

In this study, we use EEG to help us understand the component waves of different frequencies that reflect our brain's response to certain stimuli or conditions. Neuroscience experiments have demonstrated that the conditions of having our eyes open and closed affects the activity of our brain waves. We therefore decided to investigate how specifically the alpha component of the EEG waveform is affected by the varying states of eyes open and closed. Using EEG and Fourier Transformation, we measured EEG signals and were able to break it down into alpha brain waves. The Fourier transform also provides a metric for the alpha wave known as power. We found that having eyes open suppressed alpha rhythm, showcasing decreased alpha wave amplitude and peak power compared to having eyes closed. These findings help us understand the role of alpha brain waves and the brain activities that are associated with it. As a result, we can learn more about our state of consciousness to treat psychological conditions such as depression and anxiety.

Introduction

In order to understand problems with brain function, we must study the details of its activity. The electroencephalogram, or EEG, records the electrical potentials that control cortical activity in the brain. This test measures brain waves and helps monitor for abnormalities. It is a medical intervention that can be used to dismiss or validate neurological conditions. Primarily serving as a tool for diagnoses, it allows for more efficient treatment of disorders.

The goal of this experiment was to detect and measure alpha wave activity from EEG signals. Alpha waves are a type of brain wave that exists as a component frequency among many others in the EEG waveform. EEG activity can be Fourier transformed to provide approximates for the power of alpha, beta, theta, and delta waves (Barry et al., 2007). The Fourier Transform is a mathematical technique that can break down an EEG waveform to its several components. This allows for the analysis of the types of waveforms as they each can tell us information about the current state of the brain.

Alpha waves are affected by eye-opening, eye-closing, and exerting mental effort. They are also defined as being between 8 to 13 Hz frequency. Overall, alpha waves are associated with an idle or resting mind. In their experiment, Barry et al. (2007) studied EEG signals in eyes-closed and eyes-open conditions, and how the resulting frequency components were affected. The purpose of this study is to test if the alpha brain wave components specifically are affected by these aforementioned conditions.

Methods

EEG and Recording Setup Preparation

The protocol for the EEG preparation and recording setup was followed until it got to the part of attaching the leads of the EEG flat electrodes. Instead of following the electrode placement in the provided figure, the Channel 1 “negative” electrode was placed on the middle of the forehead. The Earth electrode was also positioned half an inch to the left of the subject’s left eyebrow. After, the subject’s facial piercings and earrings were removed to prevent interference with the EEG recordings. An extra piece of medical tape was used to prevent the elastic bandage from unraveling. The subject was also instructed to lean their head into a Faraday cage while recording data. Phones, smartwatches, and laptops were cleared from the sitting area.

Alpha Wave Experiment

The subject sat down facing in a direction away from the computer and was told to relax while closing their eyes. It is also noted that the participant is well-rested prior to the experiment. The EEG signal recording was started and was displayed onto the LabChart application. Afterwards, they are told to open their eyes. Data was be recorded with their eyes open for a duration of 30 seconds. When the 30 seconds were over, they were then told to close their eyes for another 30 seconds while still recording. This procedure was repeated to obtain three sets of results in total.

Analyzing the EEG Data

The Marker tool and Waveform Cursor was used to measure the amplitude of the alpha waves. The amplitude is defined as peak-to-peak meaning it is the change between a wave’s crest and trough. Figure 1 and Figure 2 demonstrate how to derive the alpha wave amplitudes from EEG signals. The amplitudes of 10 waves were measured for each condition. A D’Agostino-Pearson test calculator from the web applet StatsKingdom was used to check for the normality of the data. If the data is normally distributed, the amplitudes would be reported with mean and standard deviation. Skewed data is reported with median and IQR.

A statistical comparison between the amplitude of eyes closed alpha waves versus eyes open alpha waves was performed using a one-tailed t-test for 2 independent means. This was done using the web application SocSciStatistics. It is important to note that this is only done if the data is normal. Non-normal data would use a Mann Whitney U test. A bar chart comparing these metrics was created using Excel.

LabChart was used to make PSD plots for the eyes closed versus eyes open conditions. The peak power of the alpha waves was determined by using the Waveform Cursor on a clear peak in the 8-12 Hz range of the PSD plot. The peak power was measured for each of the three trials for each condition. Since there are less than 10 data points, normality is assumed, and the average peak power is reported with the mean and standard deviation. LabChart was also used to create a spectrogram. Photoshop was used to make the spectrogram more presentable as it was taken directly from the LabChart application.

Results

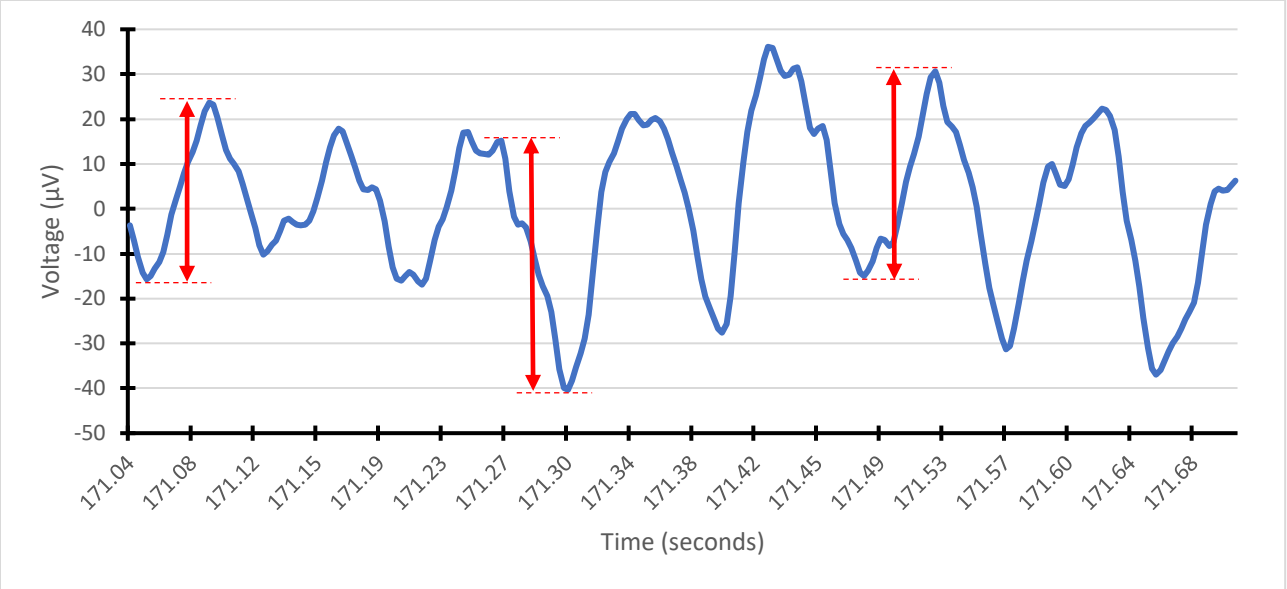

Figure 1. **Sample raw EEG signal with subject's eyes closed.** The EEG signals measured voltage potential (in microvolts) over time (in seconds) while the subject had their eyes shut. The red double-sided arrows demonstrate three examples of alpha waves and how their peak-to-peak amplitudes were determined.

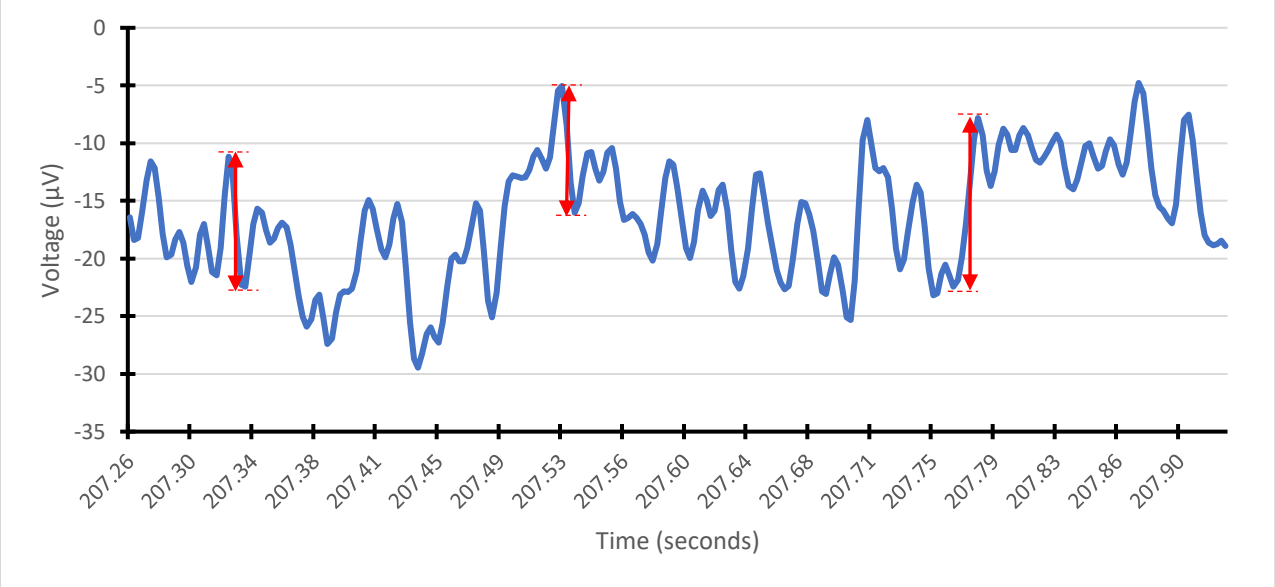

Figure 2. **Sample raw EEG signal with subject's eyes open.** The EEG signals measured voltage potential (in microvolts) over time (in seconds) while the subject had their eyes open. The red double-sided arrows demonstrate three examples of alpha waves and how their peak-to-peak amplitudes were determined.

Table 1. **Raw data showing amplitude of alpha waves with eyes closed vs. open.** Amplitudes of 10 waves were measured for each condition when the subject had their eyes closed and open.

Alpha wave amplitude was recorded in microvolts. The mean and standard deviation of the amplitudes were calculated.

	Alpha Wave Amplitude with Eyes Closed (μV)	Alpha Wave Amplitude with Eyes Open (μV)
Wave #1	59.1	14.9
Wave #2	59.9	13.4
Wave #3	48.8	12.4
Wave #4	54.5	9.0
Wave #5	43.3	10.4
Wave #6	41.0	13.0
Wave #7	49.7	13.2
Wave #8	44.3	10.0
Wave #9	50.2	7.8
Wave #10	49.4	11.8
Mean	50.0	11.6
Standard Deviation	6.3	2.2

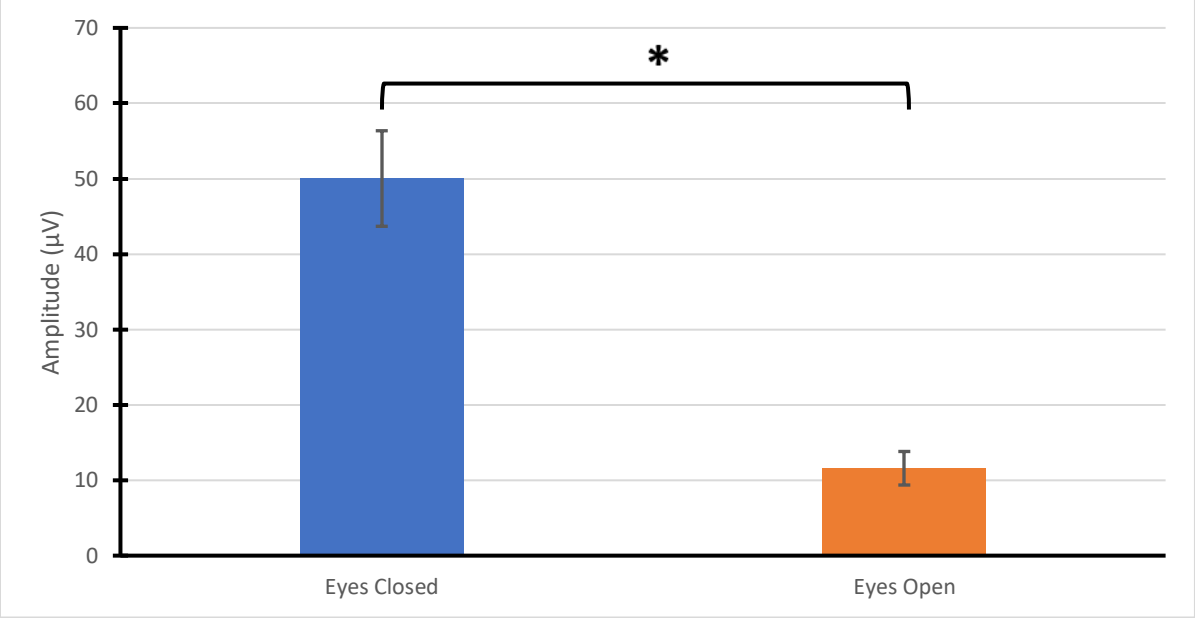

Figure 3. **Average amplitude of eyes closed alpha waves versus eyes open alpha waves.** A bar chart comparing the two average amplitudes, measured in microvolts, when the subject has their eyes closed (blue) and eyes open (orange). The average for each condition is calculated from the amplitudes of 10 different waves. For the experiment the bars represent mean ± SD. The reported mean amplitude for the eyes closed condition is $50.0 \pm 6.3\ \mu V$, and for the eyes open condition is $11.6 \pm 2.2\ \mu V$. $* p < 0.05$.

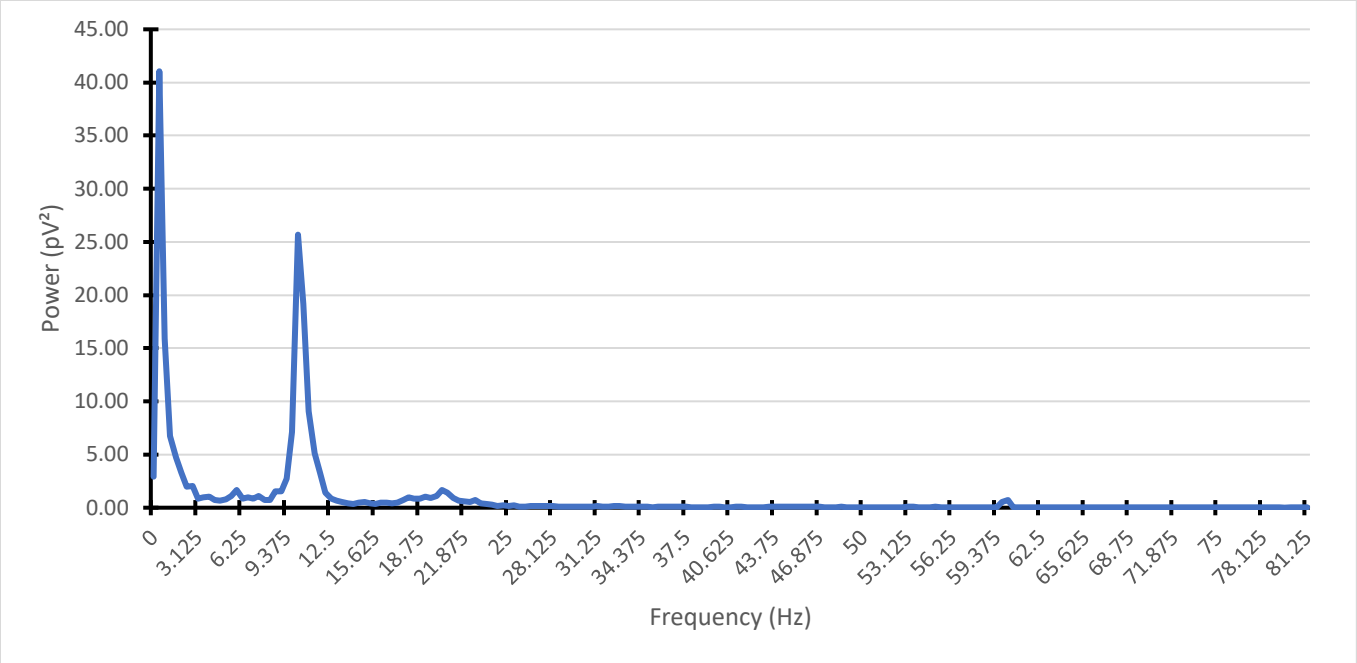

Figure 4. **EEG Power Spectrum Density plot when eyes are closed.** A PSD plot showing signal power (in pV^2) against frequency (in Hz) when the subject's eyes are closed.

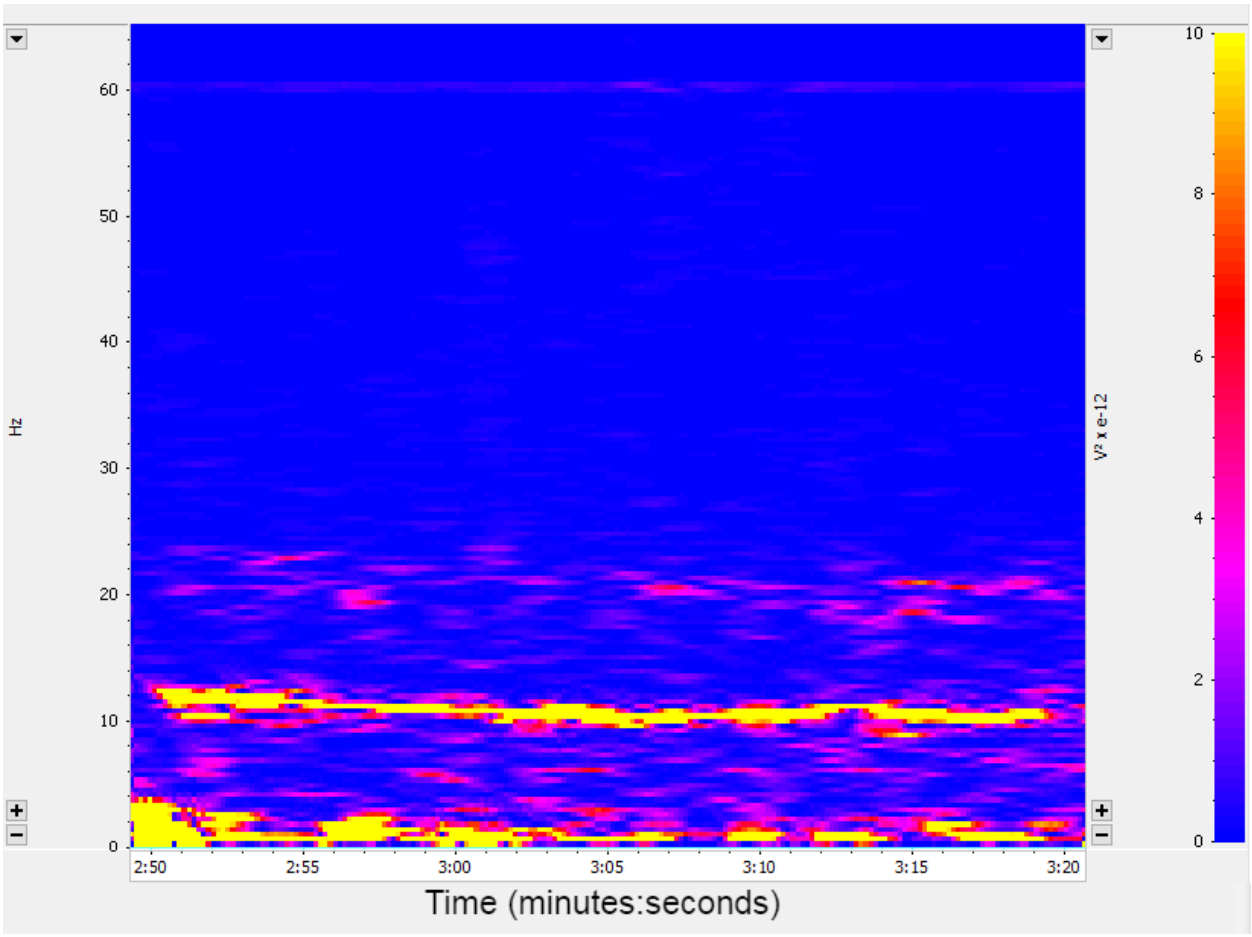

Figure 5. **EEG spectrogram image when eyes are closed.** A spectrogram plotting the power (in pV^2) in different frequency bands (in Hz) across time (in minutes:seconds) when the subject's eyes are closed.

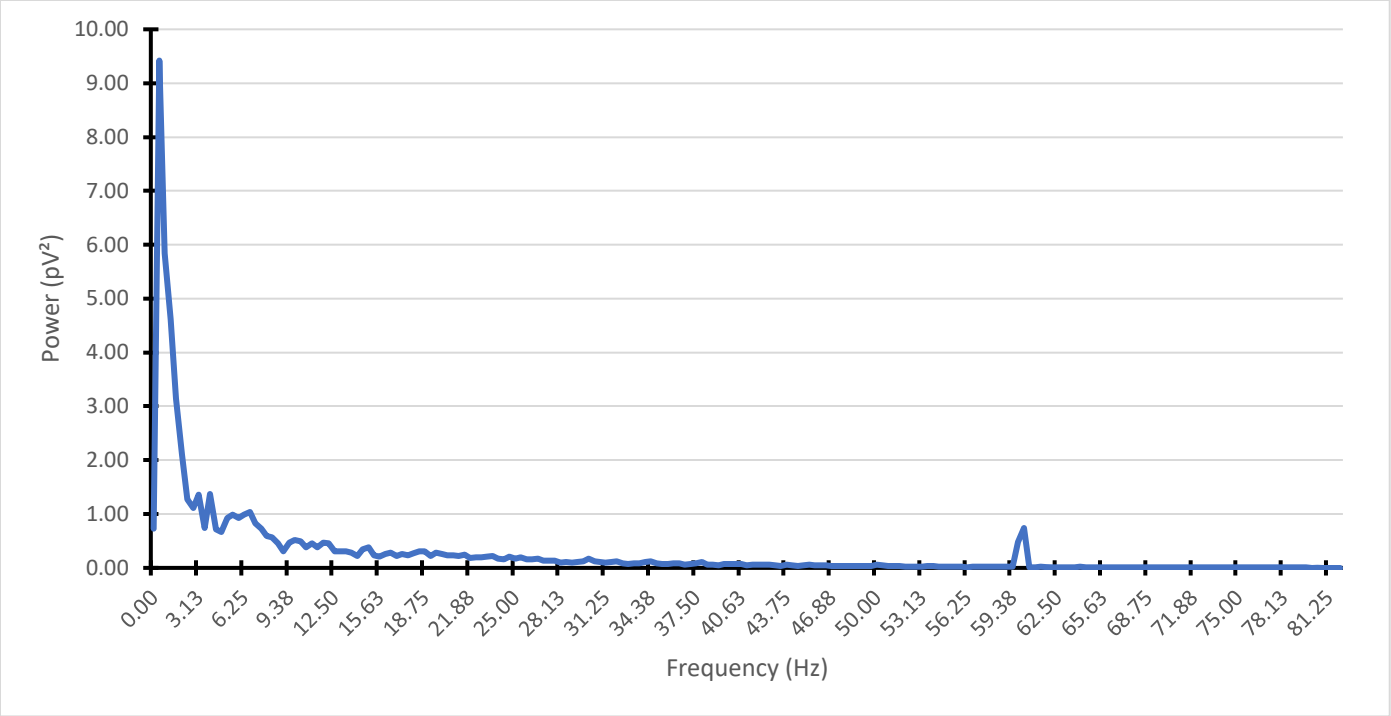

Figure 6. **EEG Power Spectrum Density plot when eyes are open.** A PSD plot showing signal power (in pV^2) against frequency (in Hz) when the subject's eyes are open.

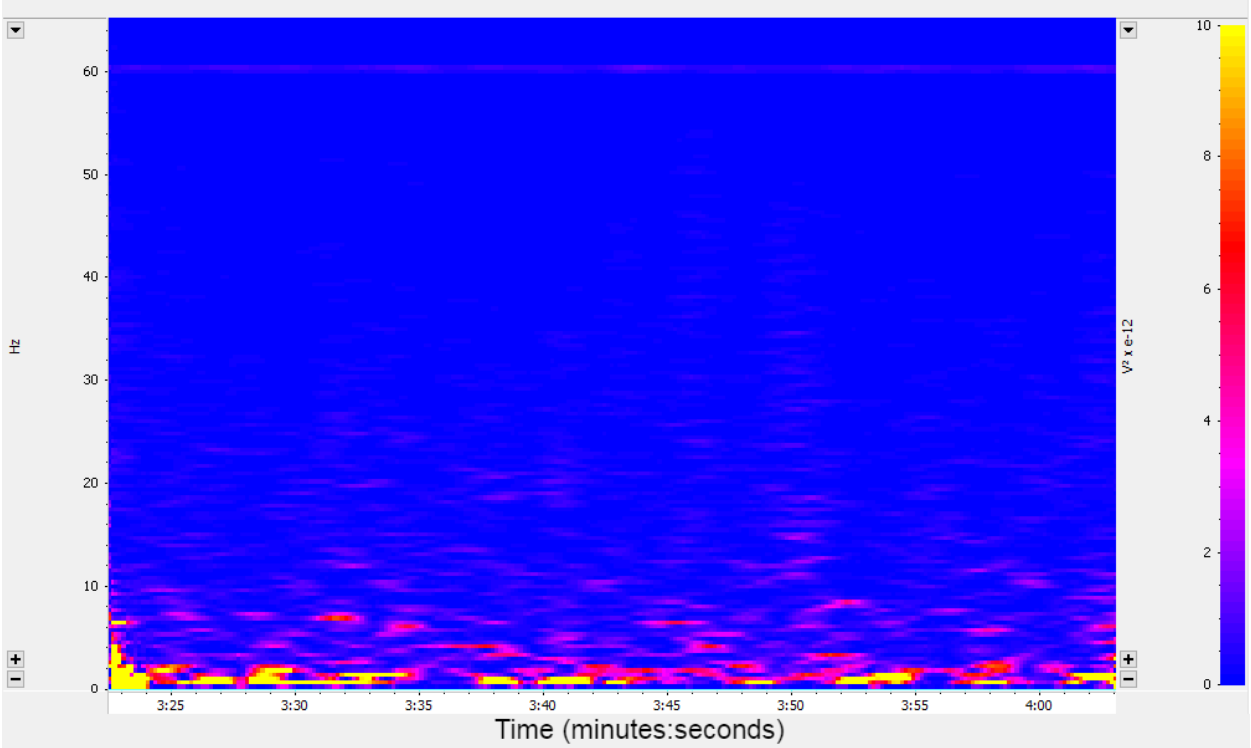

Figure 7. **EEG spectrogram image when eyes are open.** A spectrogram plotting the power (in pV^2) in different frequency bands (in Hz) across time (in minutes:seconds) when the subject's eyes are open.

Table 2. **Raw data showing peak power of alpha waves with eyes closed vs. open.** The peak power was measured for 3 trials for each condition: eyes closed and eyes open. The power was recorded in pV^2. The mean and standard deviation of the peak powers were calculated.

	Peak Power with Eyes Closed (pV^2)	Peak Power with Eyes Open (pV^2)
Trial 1	25.830	0.617
Trial 2	14.015	0.425
Trial 3	22.865	0.428
Mean	29.903	0.490
Standard Deviation	6.147	0.110

The D'Agostino-Pearson tests for the alpha wave amplitudes with eyes closed and open both indicated that there is a non-significant difference from a normal distribution. The p-value of the eyes open condition was 0.772, and the p-value of the eyes closed condition was 0.794. The average amplitudes would be reported as mean ± standard deviation.

With the eyes open condition, the subject displayed alpha wave amplitudes of $11.6 \pm 2.2\ \mu V$. In the eyes closed condition, the subject showed amplitudes of $50.0 \pm 6.3\ \mu V$. A one-tailed t-test for two independent means was used to statistically compare these two conditions. The resulting

t-value is 18.096 and the p-value is less than 0.05. We reject the null hypothesis and conclude that there is sufficient evidence to say that the eyes closed condition has a greater alpha wave amplitude compared to the eyes open condition.

The alpha wave peak power with eyes closed is reported to be $29.903 \pm 6.147\ pV^2$. The peak power with eyes open is reported to be $0.490 \pm 0.110\ pV^2$.

Discussion

In this experiment, we used an electroencephalogram test and the principle of the Fourier transform to detect and isolate a specific component frequency. The ability to study each brain wave can give us information about different brain activities and can aid in the diagnosis of psychological and neurological disorders. In the alpha wave experiment's eyes closed condition, the mean alpha wave peak power was reported to be $29.903 \pm 6.147\ pV^2$. The mean power of eyes closed is greater than the reported value of $0.490 \pm 0.110\ pV^2$ for the eyes open condition. This finding is partially in agreement with what was found in the experiments done by Barry et al. (2007), as it was shown that the alpha wave powers for the eyes closed condition are greater than the values for the eyes open condition. However, it is notable that the units for power are not the same. The Barry et al. (2007) paper uses μV^2, and not pV^2. What is interesting is that the mean and standard deviation values for the power of the eyes closed condition are very similar to each other despite them being in different units. This may possibly be due to the slight differences in the EEG Channel settings. Their experiment uses different bandpass filters and amplification settings. An experiment that could be conducted for next time is to test whether the settings can be manipulated to exhibit a conclusion that contradicts the shared observation between our experiment and the Barry et al. (2007) work.

In our experiment, we found that the alpha wave amplitudes when eyes are open is reported to be $11.6 \pm 2.2\ \mu V$. The amplitude when eyes are closed is $50.0 \pm 6.3\ \mu V$. The data for the eyes open condition are consistent with the findings from the Barry & De Blasio (2017) paper as their mean alpha amplitude is shown to be approximately $11\ \mu V$. A conclusion regarding the exact value for the alpha amplitude when the eyes are closed cannot be drawn as the scale in the figure only goes up to $22\ \mu V$. The Barry & De Blasio (2017) paper did not include any numerical data regarding the amplitudes but has only provided a heatmap of alpha wave activity.

The raw EEG signals collected for eyes closed and open are shown in Figure 1 and Figure 2, respectively. The waveforms depicted in the two figures are distinctive from each other. It is observed that the signals when eyes are closed are much taller compared to the signals when eyes are open. The Glass & Kwiatkowski (1970) paper presents figures that are identical to Figure 1 and Figure 2. The research notes that the alpha rhythm is suppressed when eyes are open. This is consistent with our observations of how the eyes open condition results in smaller alpha amplitudes compared to eyes open. The Glass & Kwiatkowski (1970) figure also presents their data with similar values for frequency and voltage potential.

References

Barry, R. J., Clarke, A. R., Johnstone, S. J., Magee, C. A., & Rushby, J. A. (2007). EEG differences between eyes-closed and eyes-open resting conditions. *Clinical Neurophysiology*, *118*(12), 2765–2773. https://doi.org/10.1016/j.clinph.2007.07.028

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Glass, A., & Kwiatkowski, A. W. (1970). Power spectral density changes in the EEG during mental arithmetic and eye-opening. *Psychologische Forschung*, *33*(2), 85–99. https://doi.org/10.1007/bf00424979