Recording Alpha and Beta Waves in the Brain in Response to Orchestral Music of Varying Tempos and Keys

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Abstract

In this investigation, we used EEG to help us understand the alpha and beta waves that reflected our brain's response to auditory stimuli or conditions. Neuroscience experiments have displayed that the different characteristics of sounds influences EEG signals. We therefore decided to investigate how specifically the alpha and beta component of the EEG waveforms are affected by varying musical stimuli of different tempos and keys. Utilizing EEG and the Fourier Transformation, we were able to record EEG signals and then break it down to its alpha and beta brain wave components. The Fourier Transform gave a metric for measuring the alpha and beta waves known as spectral power. We found that alpha and beta wave activity was unaffected by key and tempo. It was also observed that the positive control heavy metal stimuli and silence treatment were significantly different from the orchestral piece trials for the alpha wave tempo experiment. These findings provide insight into how we can assemble therapeutic interventions that utilize music. Understanding the characteristics of sound that induce relaxation on the human brain can be used to treat emotional disorders such as anxiety.

Introduction

To properly understand the multiple characteristics of music and its effects on the brain's state of relaxation, we must study the brain waves involved in this activity. The electroencephalogram, or EEG, records the electrical potentials from the pyramidal cells that control cortical brain activity. Alpha and beta waves are specifically examined to determine the brain's state of relaxation. Alpha waves are associated with the relaxed state of consciousness while beta waves are associated with active anxious thinking (Abdul et al., 2010). Analysis of these waveforms can tell us how to effectively create a therapeutic intervention involving music.

The goal of this experiment is to measure the alpha and beta wave peak powers for varying levels of musical tempo and key. In their experiment, Abdul et al. (2010) defined a higher alpha peak power value as more relaxation. With higher beta wave power, it would indicate greater attentiveness and focus. The music that will be used to study these variables are orchestral music pieces.

In the Hurless et al. (2013) paper, they tested for EEG signals with music genre preference, and they found that there was no clear trend how the tempo of a song affects alpha wave activity. They analyzed activity using alpha wave amplitude as a metric. Musical key and beta wave power were other factors that we were interested in. The purpose of this study is to test if there are differences in wave peak power for the different tempo and key conditions.

Methods

EEG and Recording Setup Preparation

A PowerLab 26T and LabChart software were set up to record EEG signals. The data will be collected from a single participant. Three EEG flat electrodes were utilized to record for brain activity. The Earth electrode was positioned on the left temple of the subject. This was exactly half an inch left from the eye. The Channel 1 negative electrode was placed on the right area of the forehead. Specifically, it was located above the middle of the right eyebrow. Finally, the positive electrode was placed on the crown of the head. Jewelry from the patient's face and neck was removed to minimize interference with the EEG recordings. An elastic bandage secured with medical tape was wrapped around the subject's head to ensure full skin-to-electrode contact. The participant wore wired earbuds connected to a laptop while leaning their head into the Faraday cage. Additional electronics not included in the experiment's procedure were cleared from the participant's seating area to reduce noise.

Music Stimulus and Treatment Groups Setup

The stimuli used in this experiment consists of seven different orchestral music pieces, a positive control, and a negative control. The orchestral pieces used in the experiment are listed in Table 1. The pieces used to test for differences in musical tempo are as follows: Fantasia in C, H.XVII No. 4; Symphony 3 (III); and Symphony 1 (IV). These songs present varying tempos with a constant key. In this case, the musical key that is held constant is C major. A slow tempo is defined as 79 beats per minute (BPM), medium as 106 BPM, and fast as 132 BPM. The pieces used to test for differences in musical key are as follows: Symphony 1 (IV); Cello Sonata No. 5 (II); Symphony 10 (III); Violin concerto in D minor; and Symphony 25 (I). These songs present varying keys with a similar tempo. The keys tested for are C major, D major, G major, D minor, and G minor. These pieces have a slow tempo around 80 BPM. As a positive control, the subject will listen to a random non-lyrical heavy metal song. The negative control for this experiment is exposing the subject to silence.

Part 1 consists of performing experiments for tempo. Portions of the experiment are done in sets. A set consists of a positive control treatment for 1-minute, negative control for 1-minute, and three randomized 1-minute clips from the list of pieces. In between each 1-minute time frame, there was a 30-second break to allow the subject some time to recover after the treatment. There were five of these sets in total. Also, a 2-minute break was given in between sets. Part 2 follows a similar procedure regarding the sets. The difference is that it is testing for key and that there are five randomized 1-minute clips from the list of pieces per set.

Table 1. **Orchestral music pieces used in trials.** Seven orchestral pieces used in the experiment with their musical keys, composer, and tempos (BPM) listed.

Title of music	Composer	Key	BPM

Fantasia in C, H.XVII No.4	Hadyn	C major	132
Symphony 3 (III)	Sibelius	C major	106
Symphony 1 (IV)	Beethoven	C Major	79
Cello Sonata No. 5 (II)	Beethoven	D major	82
Symphony 10 (III)	Mozart	G major	84
Violin concerto in D minor	Schumann	D minor	77
Symphony 25 (I)	Mozart	G minor	81

Alpha and Beta Wave Experiment

The subject sat down in a chair facing in a direction away from the recording computer and laptop. They were told to relax and to close their eyes. It is also important the subject is well-rested before the experiment. It is also important to note that the music was played at a constant volume level of 16%. On the first day of data gathering, Part 1 of the experiment was performed. Part 2 was done on the second day of data gathering. The EEG signal recording was displayed onto the LabChart application.

LabChart was used to make Power Spectral Density (PSD) plots for every 1-minute trial done. The Waveform Cursor on the LabChart software was used to measure the peak power and frequency of the alpha and beta waves. Figure 1 shows how to identify the peak ranges for alpha and beta waves. The Waveform Cursor was placed on a clear peak in the 8-12 Hz range of the PSD plot for alpha waves. For beta waves, the cursor was placed on the peaks in the 18-23 Hz range. Spectrograms were also made by Python to ensure the presence of alpha waves (Figure 2).

Excel was used to calculate the average peak power of 5 trials for each treatment. Since the number of trials is less than 10, we can assume normality. This means that the data can be represented as mean and standard deviation. One-way ANOVA tests were used to test for significance between group means. If there is a significant difference, a Post Hoc Tukey HSD is used to determine where the differences in the ANOVA test came from. These results are then graphed on bar charts using Excel.

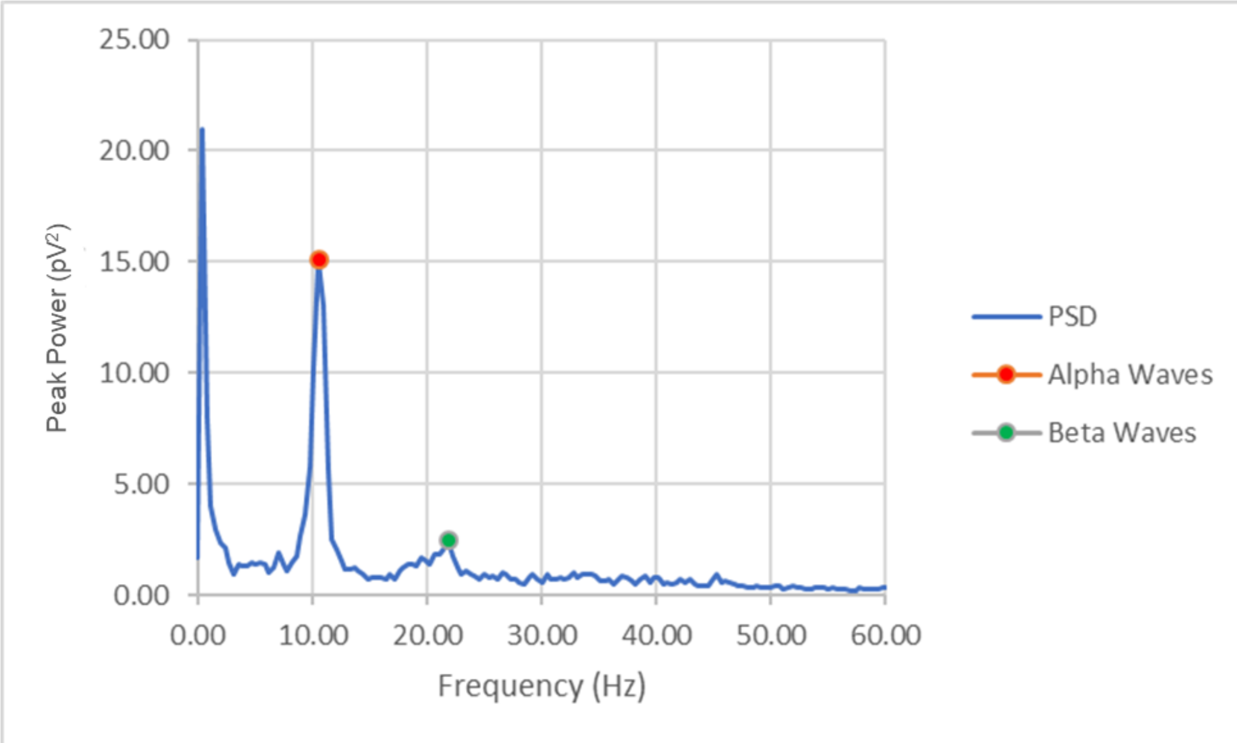

Figure 1. **Sample Power Spectral Density Plot of Silence Treatment.** An example plot is shown to identify the peak power and frequency of alpha (red marker) and beta waves (green marker). The y-axis measures peak power in picovolts squared. The x-axis measure wave frequency in Hz. The subject is exposed to the negative control in which they listen to silence.

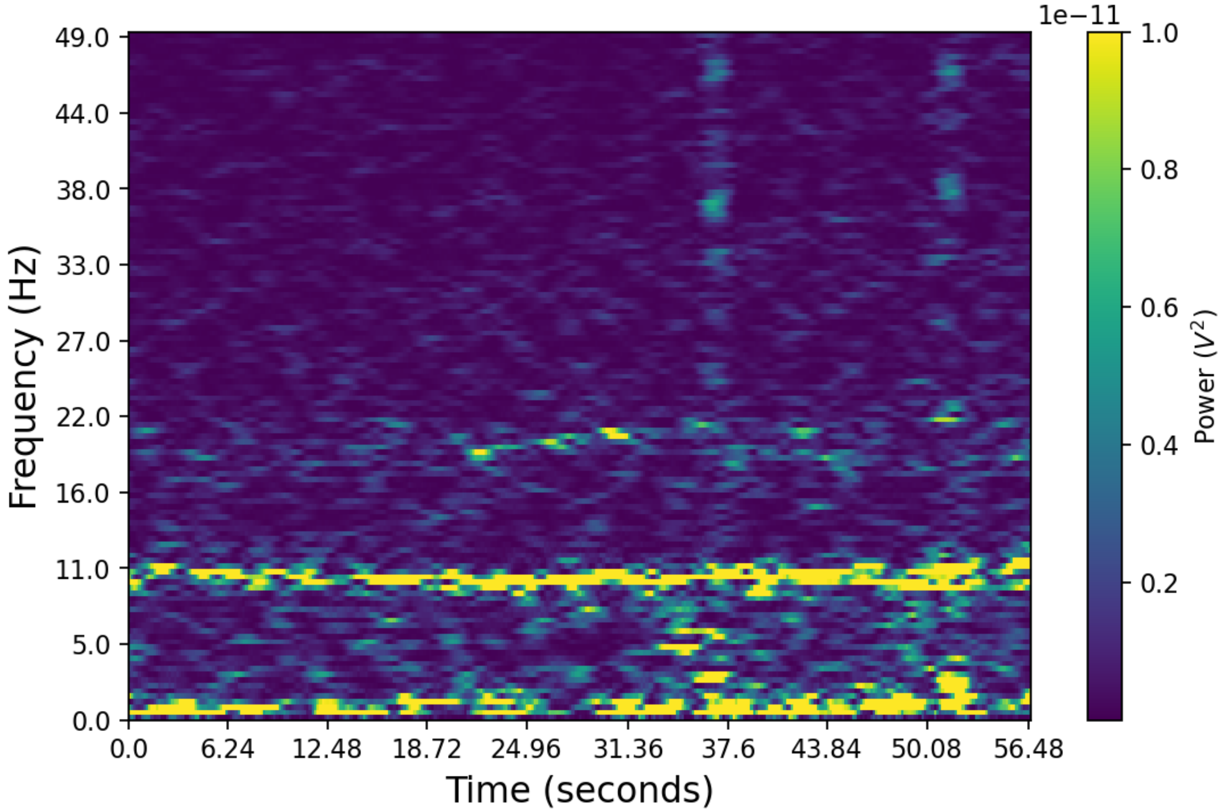

Figure 2. **Sample Spectrogram of Silence Treatment.** An example spectrogram is shown to ensure the presence of alpha waves. The spectrogram plots the power (in pV^2) in different frequency bands (in Hz) across time (in seconds) while the subject's eyes are closed. The subject is exposed to the negative control in which they listen to silence.

Results

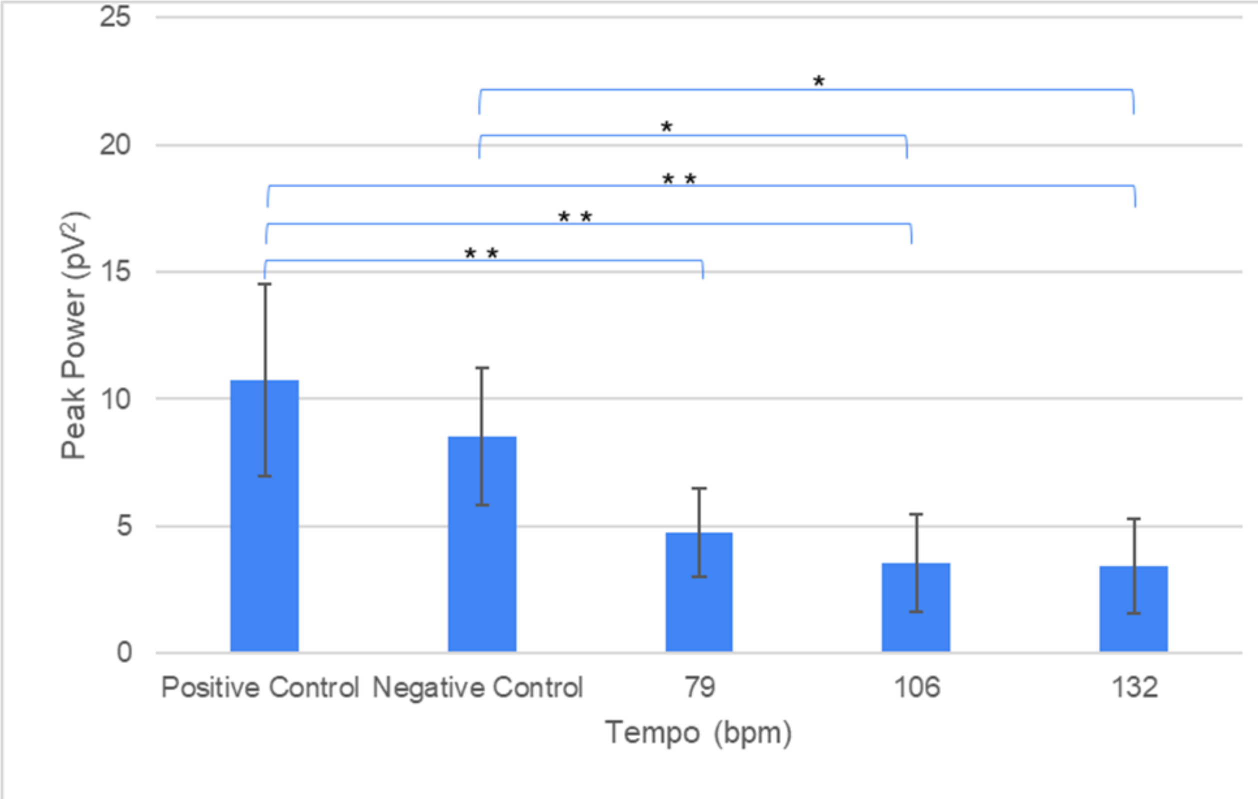

Figure 3. **Alpha Wave Peak Power with Varying Musical Tempo.** The average alpha wave peak powers (in pV^2) from a set of 5 trials was taken from each treatment for comparing tempo. The three tempos being tested for are 79, 106, and 132 beats per minute (BPM). Positive control is characterized as listening to heavy metal and negative control is listening to silence. The error bars represent mean ± standard deviation. The data was analyzed using a one-way ANOVA test and Tukey HSD. $*\,p < 0.05$, $**\,p < 0.01$

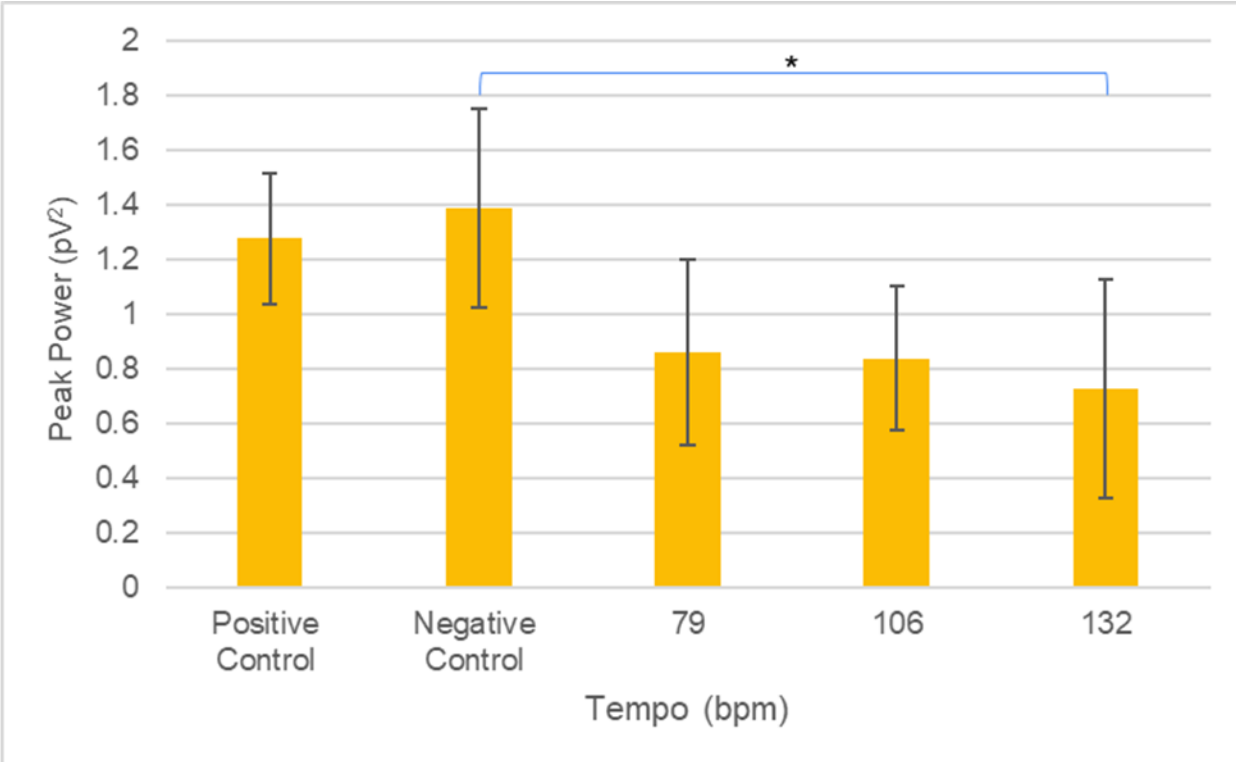

Figure 4. **Beta Wave Peak Power with Varying Musical Tempo.** The average beta wave peak powers (in pV^2) from a set of 5 trials was taken from each treatment for comparing tempo. The three tempos being tested for are 79, 106, and 132 BPM. Positive control is characterized as listening to heavy metal and negative control is listening to silence. The error bars represent mean ± standard deviation. Data was analyzed using a one-way ANOVA test and Tukey HSD. $* \, p < 0.05$

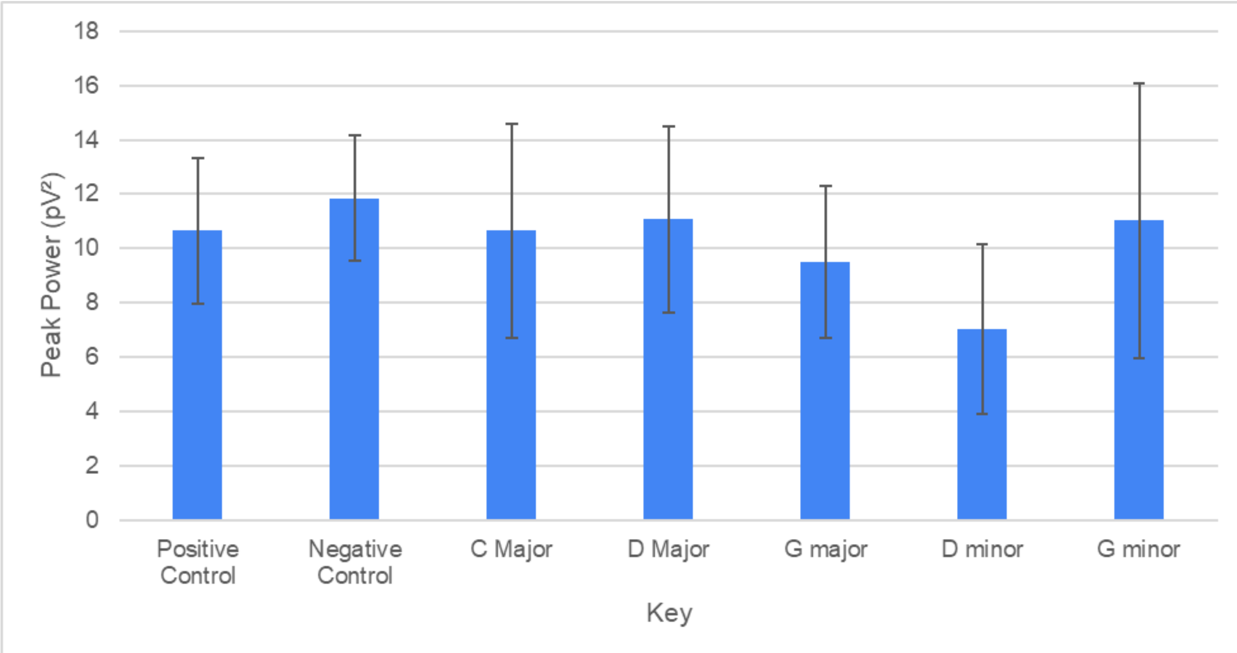

Figure 5. **Alpha Wave Peak Power with Varying Keys.** The average alpha wave peak powers (in pV^2) from a set of 5 trials was taken from each treatment for comparing keys. The five tempos being tested for are C major, D major, G major, D minor, and G minor. The positive control is characterized as listening to heavy metal and the negative control is listening to silence. The error bars represent mean ± standard deviation. Data was analyzed using a one-way ANOVA test.

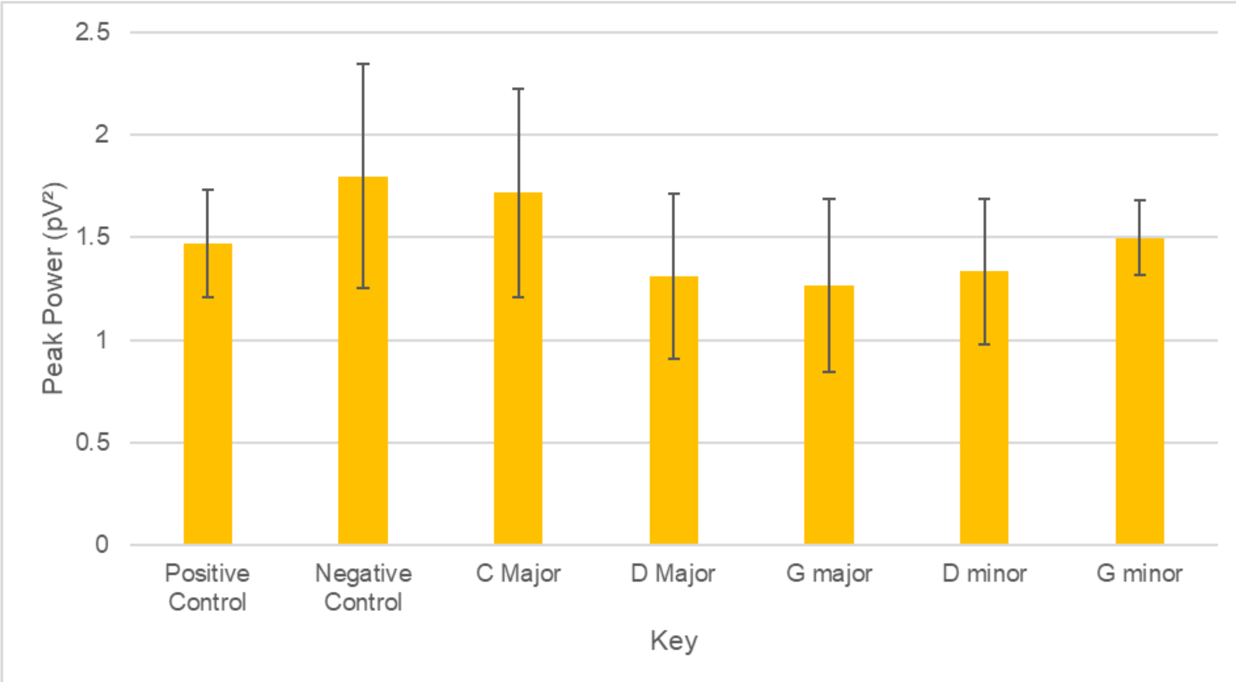

Figure 6. **Beta Wave Peak Power with Varying Keys.** The average beta wave peak powers (in pV^2) from a set of 5 trials was taken from each treatment for comparing keys. The five tempos being tested for are C major, D major, G major, D minor, and G minor. The positive control is characterized as listening to heavy metal and the negative control is listening to silence. The error bars represent mean ± standard deviation. Data was analyzed using a one-way ANOVA test.

In Figure 3, the minute variance in peak power between experiment treatments was observed by performing a one-way ANOVA test. The analysis of variance resulted in an F-statistic value of 8.52 and a p-value of 0.0004. Since the value is less than the significance level of 0.05, there is sufficient evidence to say that there is a statistically significant difference between the treatments' means. The Post Hoc Tukey HSD showed significant differences in Positive:79 BPM (p = 0.001), Positive:106 BPM (p = 0.002), Positive:132 BPM (p = 0.009), Negative:106 BPM (p = 0.03, and Negative:132 BPM (p = 0.04) for the alpha wave peak powers with varying musical tempo.

In Figure 4, a one-way ANOVA test resulted in a F-statistic value of 4.04 and a p-value of 0.02. There is sufficient evidence to say that there is a significant difference between the treatments' means. The Tukey HSD showed a significant difference between the Negative Control and the 132 BPM treatment group (p = 0.03) for the beta wave peak powers with varying tempo.

In Figure 5, a one-way ANOVA test resulted in a F-statistic value of 1.09 and a p-value of 0.39. There is not sufficient evidence to say that there is a significant difference between the groups' means.

In Figure 6, the one-way ANOVA test gave a F-statistic value of 1.28 and a p-value of 0.30. There is not sufficient evidence to say that there is a significant difference between the treatments' means.

Discussion

In this experiment, we used an electroencephalogram test to record alpha and beta waves under a variety of auditory stimuli in the pursuit of understanding how the brain responds to music. The experiment performed had the goal of investigating the degree to which different levels of tempo and key influence the brain's state of relaxation. Studies done relating to this subject could possibly provide evidence supporting music as a plausible form of therapy for emotional disorders such as anxiety. Overall, it was found that the subject's alpha and beta wave activity was unaffected by musical key and tempo. In the investigation involving recording alpha wave power with tempo, all the orchestral music trials were observed to be significantly different compared to the positive control. Specifically, it appears that there is a difference in alpha wave peak power between the orchestral music genre and the heavy metal genre. However, this is not seen in the alpha wave power trials involving key as there is no observed difference between the treatment groups. Our results from our observation with tempo can somewhat be supported by the findings in the Abdul et al. (2010) paper as they also state a difference in EEG metrics between listening to different genres. The result of their experiment found that naysaid music induces greater alpha wave power compared to rock music. In our experiment, we expected orchestral music to have a higher alpha wave power than heavy metal music as we believed that orchestral pieces are stereotypically more relaxing compared to metal rock. In a future experiment, music that is more similar should be used. For example, we would test for varying tempos with the music from the same artist. The musical characteristics and style of Beethoven and Hadyn are different and can result in varying emotions.

With the experiment conducted concerning key, there was no observed significant differences for the alpha and beta wave trials. The indifference of sound characteristics among alpha waves is not consistent with the findings in the Nishifuji & Miyahara (2008) paper as they found that differences in sound profiles had significant effects on alpha power. It is important to note that the paper tested for varying tones. Key and tones are characterizations that are used to describe sound. The key serves as the reference of the sound while tone represents the single frequency of the sound. In future experiments, a spectrogram that maps the frequencies of the music could be made to aid in this analysis.

In our experiment, it was observed that there were no significant differences between the varying tempos when recording alpha wave powers. This is consistent with the Hurless et al. (2013) paper as they also found no clear trend how the tempo of a song affects the activity of a subject's alpha waves. The EEG metric that they used were alpha wave amplitudes instead of alpha wave power. Future experiments recording for alpha wave amplitude can be done to test if other observations could be made. The plans for these proposed future experiments will assist in organizing an effective therapeutic intervention that has full understanding of different sound conditions and their effects.

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