Fourier Analysis of Biomedical Signals

IBEHS 3A03: Biomedical Signals and Systems

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Part A

Magnitude Spectra

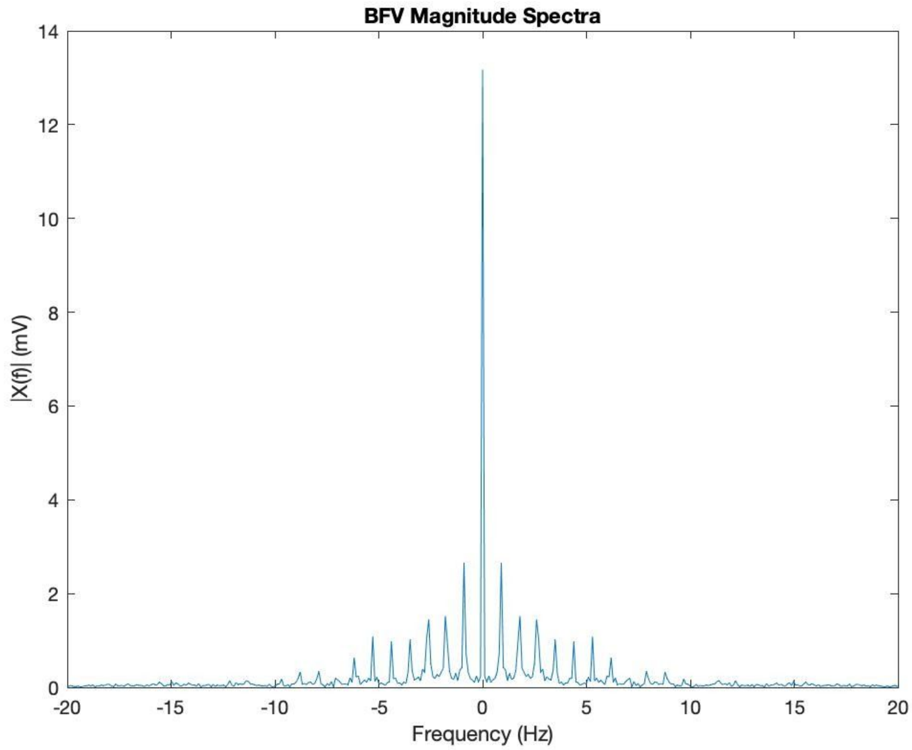

Figure 1: Graph Depicting the BFV Magnitude Spectra

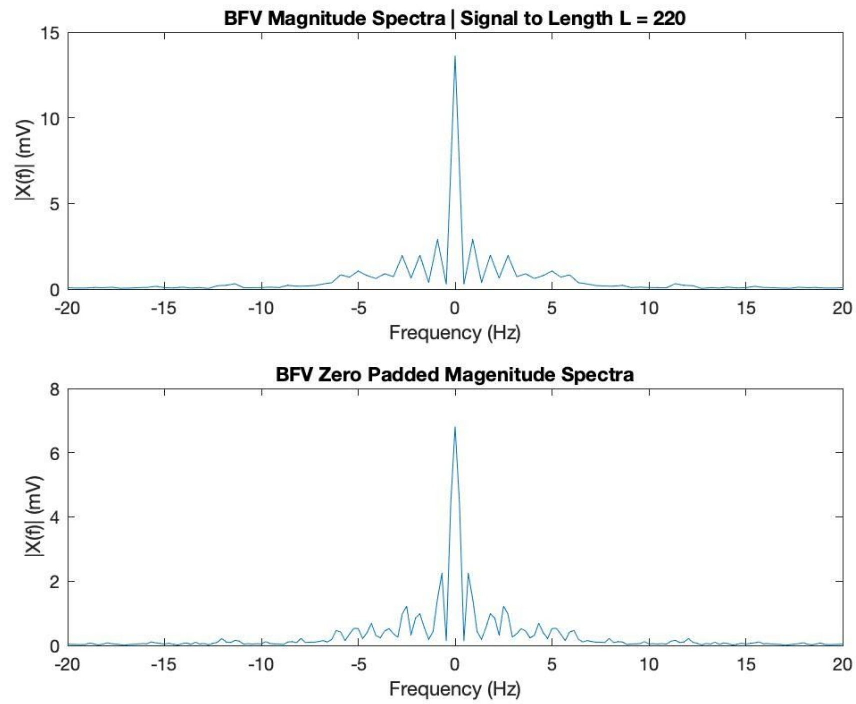

Figure 2: Graph 1 [top] Depicting BFV Magnitude Spectra with L = 220. Graph 2 [bottom] depicting BFV Magnitude Spectra with L = 220, 0 Padded.

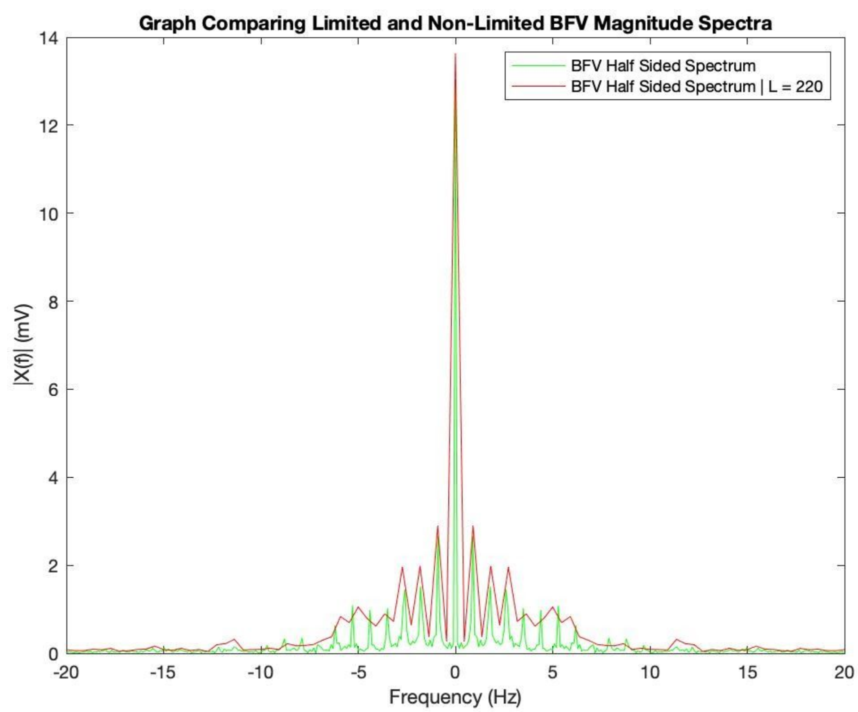

Figure 3: Graph Comparing Original BFV Magnitude Spectra and BFV Magnitude Spectra with L = 220.

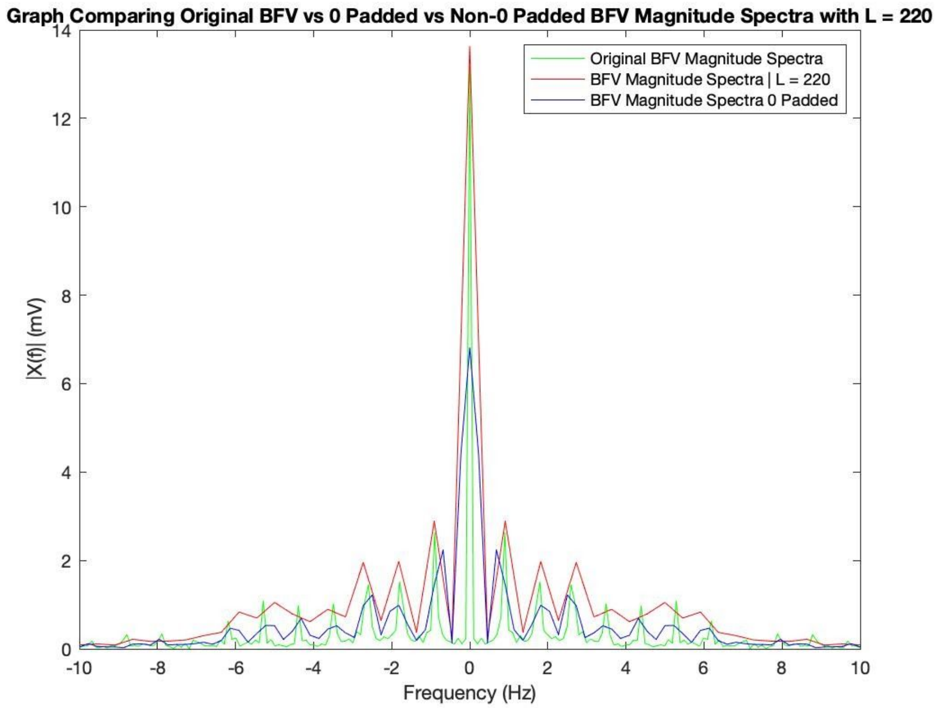

Figure 4: Graph Comparing Original BFV Magnitude Spectra, BFV Magnitude Spectra with L = 220, and BFV Magnitude Spectra with L = 220 & 0 Padded

BFV Analysis

After calculating and plotting the magnitude spectra found in figure 1 through 4, it can be seen that through trial and error the smallest value of *L* for which the harmonic structure observed in the spectrum of the entire BFV signal is ~220. *L* was defined as a vector beginning at element 1 and going up the *L* such that *L* is an integer less than the length *N* of the entire array.

The criteria used to determine the smallest *L* value was based on the signal modulation phenomenon. As we decreased the *L*, the resolution of the frequency was weakened. While testing for values below *L* = 220, the enveloping effect of the magnitude spectra was diminished, and the peaks began to combine into smoother lines (See Figure 2, Graph 1).

Figure 3 is a direct comparison plot between the magnitude spectra of the BFV signal at *L* = 220 and the magnitude spectra of the original BFV signal. As seen in the graph, the magnitude spectra at *L* = 220 continues to envelope many of the peaks found in the original magnitude spectra however, as the frequency increases, the magnitude spectra begins to encompass the peaks less and becomes a weaker representation of the harmonic structure observed in Figure 1 [1]. To combat this limitation, zero-padding was applied to the dataset from figure 2, making it a 440x1 vector [1].

Figure 2 showcases the magnitude spectra of the BFV signal limited to L = 220, and that same signal being zero-padded [1]. The graphs have been limited to from [-20 to 20] for the sake of comparison. Zero padding increases the accuracy of analysis for shorter DFT and FFT signals, by increasing the signal through adding 0's. A longer DFT/FFT, results in more frequency bins that are closely spaced in frequency [1]. Furthermore, it helps resolve the peak of a single isolated frequency that does not have any significant adjacent signals or noise in the spectrum. Finally, it helps with the computation of a large number of points [1].

To determine if zero-padding made the magnitude spectra plotted a better estimate of the entire signals spectrum when using the signal segment of length 220, a comparison graph was produced as seen in figure 4. Figure 4 compares the magnitude spectras of the original BFV signal, the limited (L = 220) BFV signal, and the zero padded BFV signal. As seen from frequency indexes 0 through 3, the entire signals spectrum is better estimated through the non-zero padded magnitude spectra. However, as we observe the frequency range of 5 through 12, we notice the effects of zero-padding more prominently. This can be seen below in figure 5.

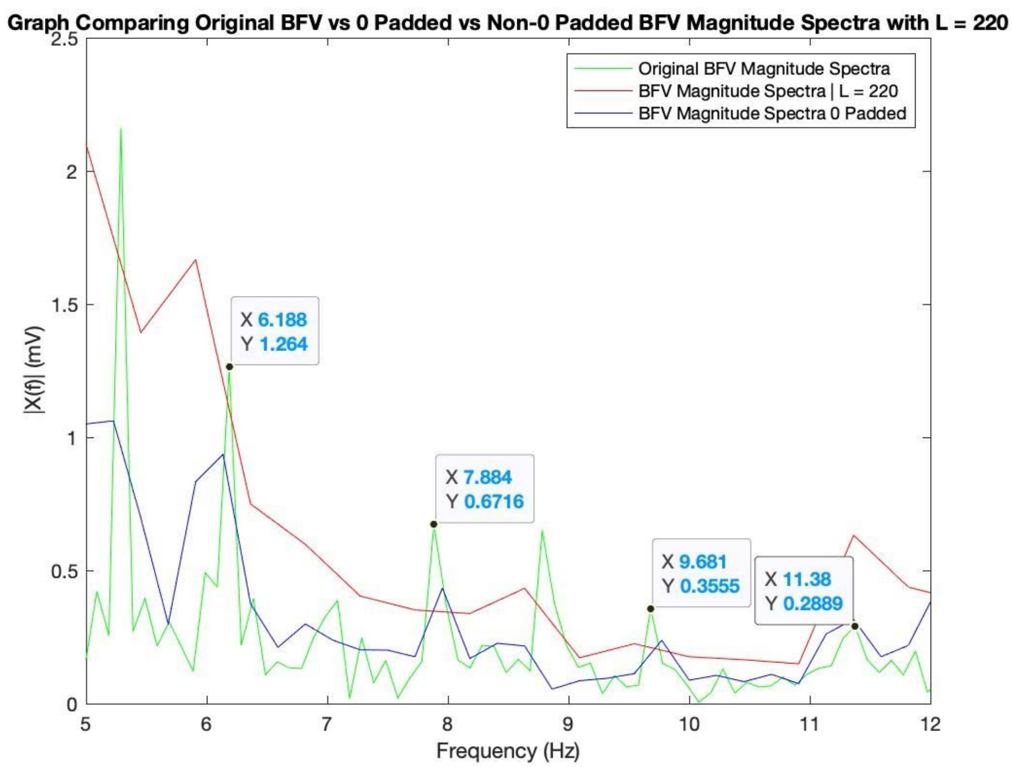

Figure 5: Graph Comparing Original BFV Magnitude Spectra, BFV Magnitude Spectra with L = 220, and BFV Magnitude Spectra with L = 220 & 0 Padded Limited From Frequency Range (5-12 Hz)

This graphical representation showcases how zero-padding can be used to resolve the peak of a single isolated frequency that does not have any significant adjacent signals or noise in the spectrum. As can be seen by the peaks located at frequencies 6.188, 7.884, 9.681, and 11.38, zero-padding helps resolve those lost peaks in the non-zero padded amplitude spectrum and makes them more prominent [1].

This increased level of accuracy demonstrated by zero-padding the magnitude spectra of L = 220, concludes that zero-padding provides a more accurate estimate of the original harmonic structure observed.

Part B

Magnitude Spectra

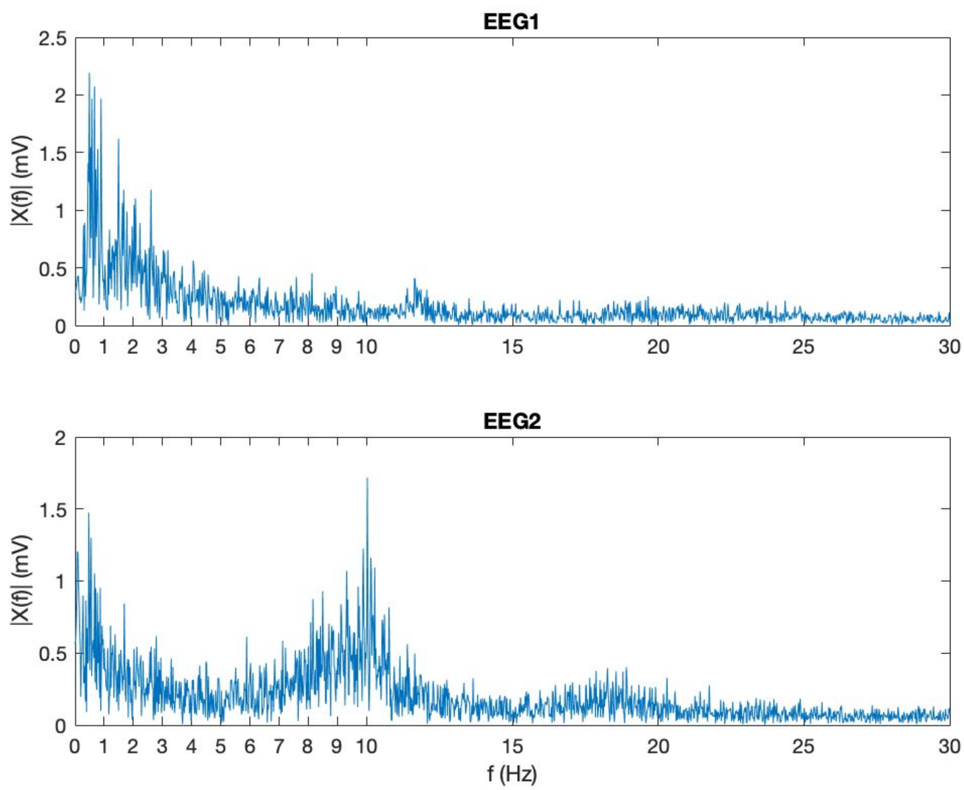

Figure 6: EEG1 and EEG2 Magnitude Spectra

Band Power

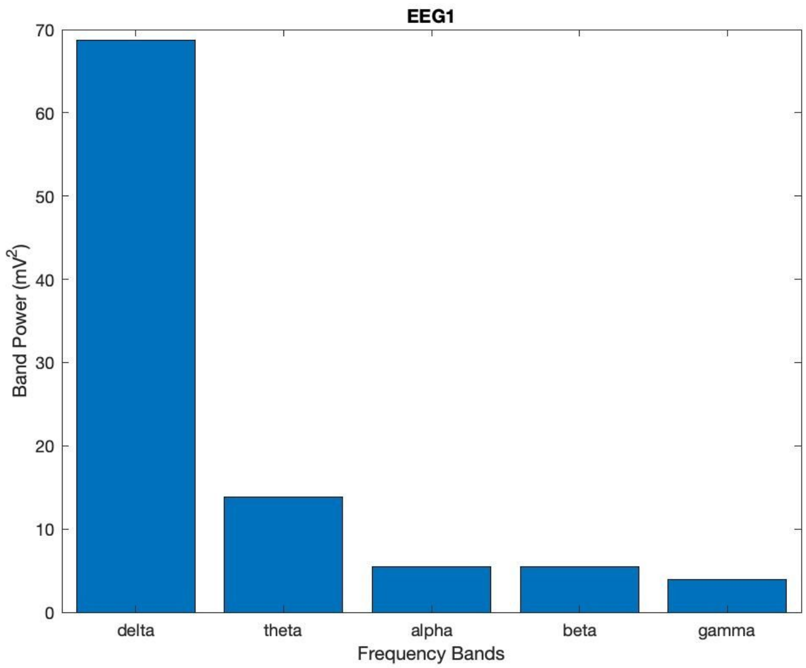

Figure 7: EEG1 Band Power Bar Graph

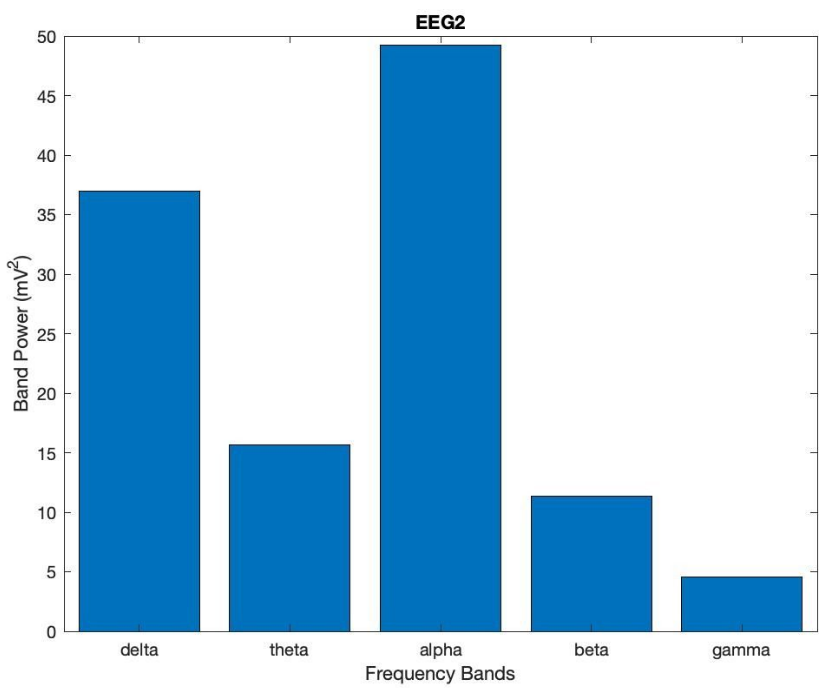

Figure 8: EEG2 Band Power Bar Graph

Normalized Band Power

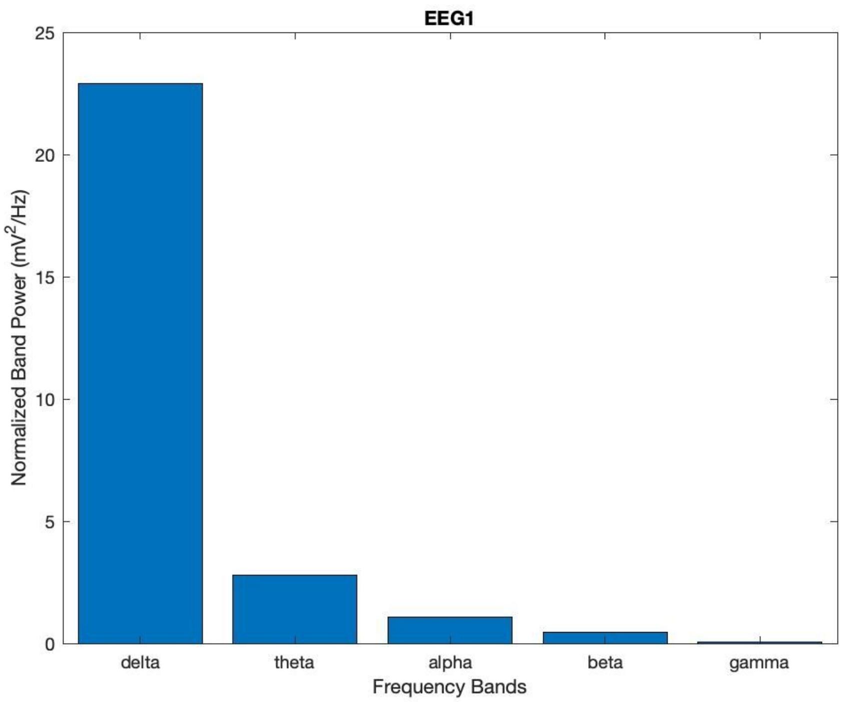

Figure 9: EEG1 Normalized Band Power

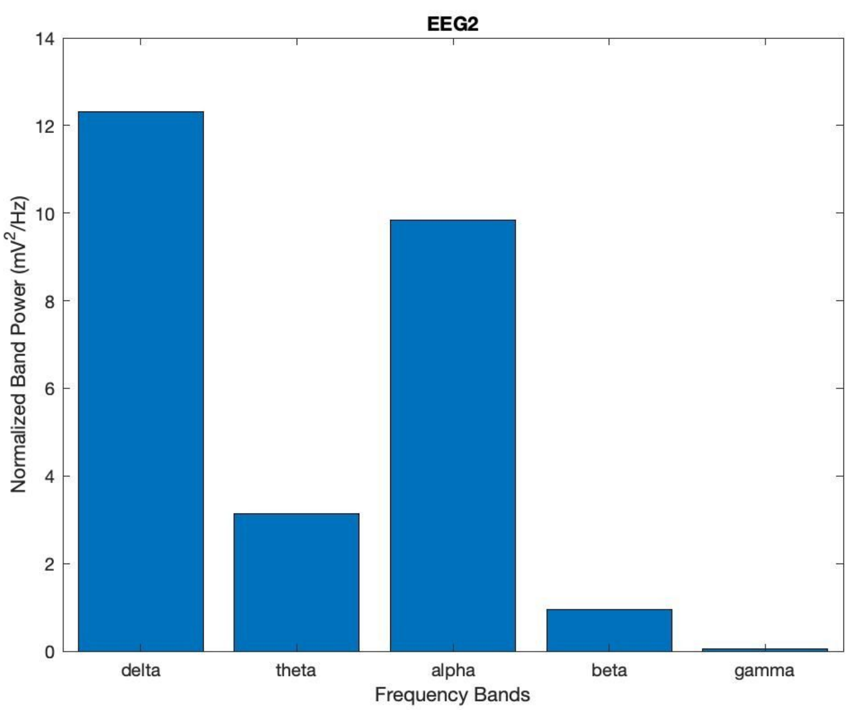

Figure 10: EEG2 Normalized Band Power

EEG Analysis

Upon analysis of the generated band power spectrums (both raw and normalized), the most significant delta is found between the alpha wave powers. This is seen in figures 7 through 10 above. To the question “which recording corresponds to a resting, eyes-closed state?”, this feature aligns perfectly with what is established in prior research.

Alpha waves are minimized in subjects with open eyes, drowsiness, or sleep (amongst other factors); conversely, with the eyes closed, alpha waves are amongst the strongest neural signals observed via EEGs [1].

Thus, we are led strongly to believe that EEG2 observes an eyes-closed state.

Spectrogram Analysis

BFV

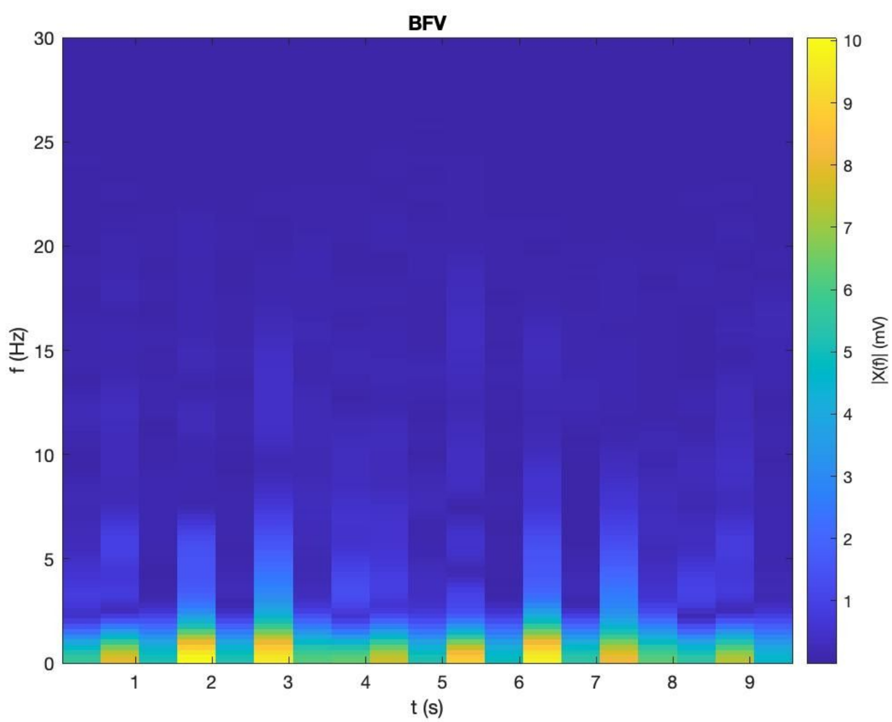

Figure 11: BFV Spectrogram Analysis

Spectrograms can be used to represent the signal strength over time for various frequencies. When analyzing the BFV spectrogram found in figure 11, the amplitude is fairly consistent for all frequencies. However, this consistency is contrasted at frequency 3 Hz and below. As seen in the figure above, at lower frequencies, the amplitude is far greater than at any other frequencies found in the spectrogram. In conclusion, the spectrogram analysis is fairly consistent meaning that the waves will persist in their state throughout the period measured. While the waves will change states near 3 Hz.

EEG

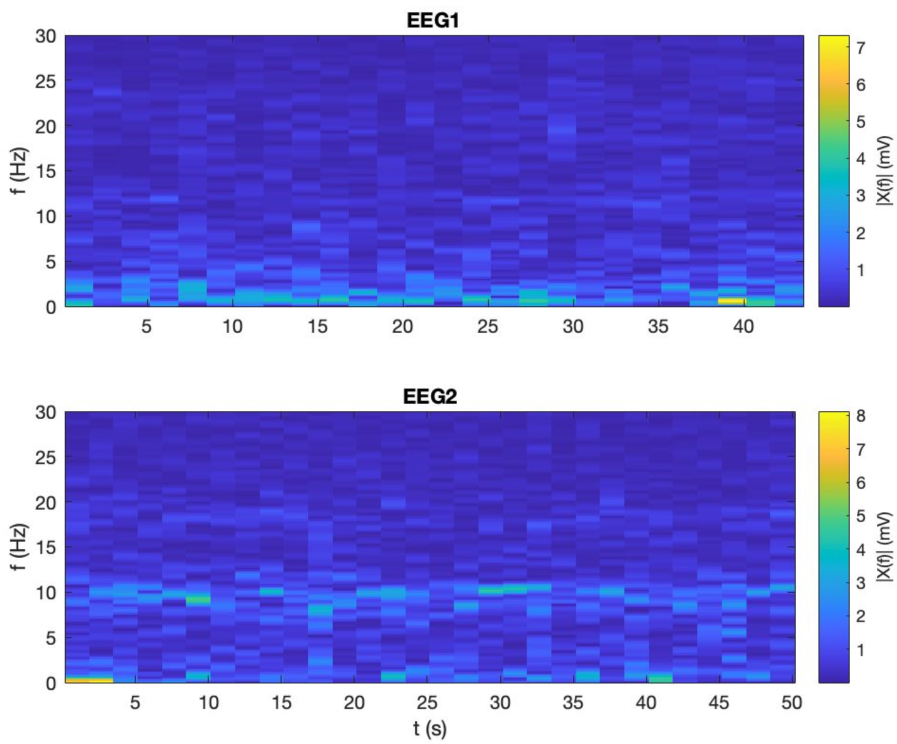

Figure 12: EEG1 and EEG2 Spectrogram Analysis

The spectrogram is useful for the Fourier analysis of potentially overlapping signals. We are also able then to visualize how the amplitudes of various frequency components may change over time. In the spectrograms of our EEG signals, we see fairly consistent amplitudes along our frequency levels. In EEG1, concentration about the low frequencies (delta waves). In EEG2, concentration again at those lower, delta frequencies, but even more so at moderate alpha waves. Across the x-axes, no significant fluctuations in signal intensity indicated by constant colours, suggests that these waves will persist in their state throughout the time periods measured.

References

[1] Kan, D.P.X., Croarkin, P.E., Phang, C.K. *et al.* EEG Differences Between Eyes-Closed and Eyes-Open Conditions at the Resting Stage for Euthymic Participants. *Neurophysiology* 49, 432–440 (2017). https://doi.org/10.1007/s11062-018-9706-6