BME445 NEURAL BIOELECTRICITY
Lab 2: THE ELECTROENCEPHALOGRAM (EEG)
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Purpose

The purpose of this lab is to record various brain rhythms in the frontal and occipital lobes using electroencephalogram (EEG) when the subject is performing activities such as blinking, chewing, closing the eyes and doing mental math to observe the variance in the brain signal. Using the built-in Electroencephalography II lab session in the CleveLab software, we have also observed how neurological disorders such as epilepsy can be detected by reviewing the EEG signals and learned about the characteristics of Grand Mal and epileptic seizures.

Results/Discussion

PART 1

1. Describe what happens to the EEG signal when the subject blinks or chews. Include a screen-shot of blinking/chewing and one without blinking/chewing.

As seen in *Figures 2 and 3,* in comparison to our baseline in *Figure 1* below, spike-like signals in short durations are introduced in the EEG signal when the subject blinks/chews. We can also observe the individual spikes distinctly in time domain analysis as the subject chewed rapidly in *Figure 5* and blinked rapidly in *Figure 6.*

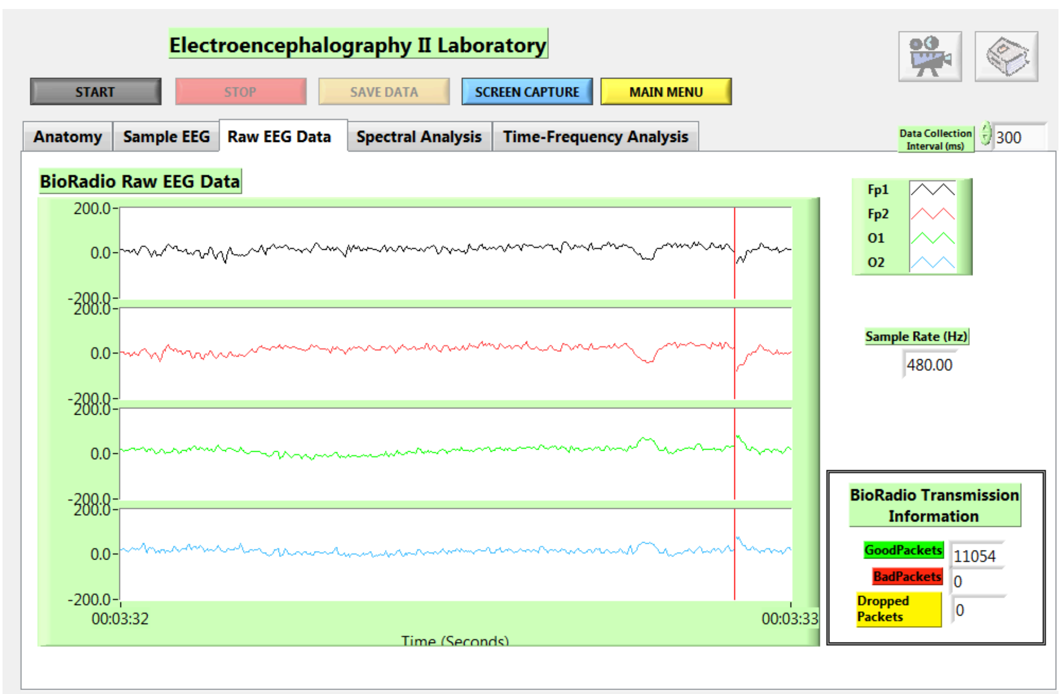

Figure 1: Baseline - Raw EEG signal for all channels when the subject is relaxed, eyes open and not performing any activity such as chewing or blinking.

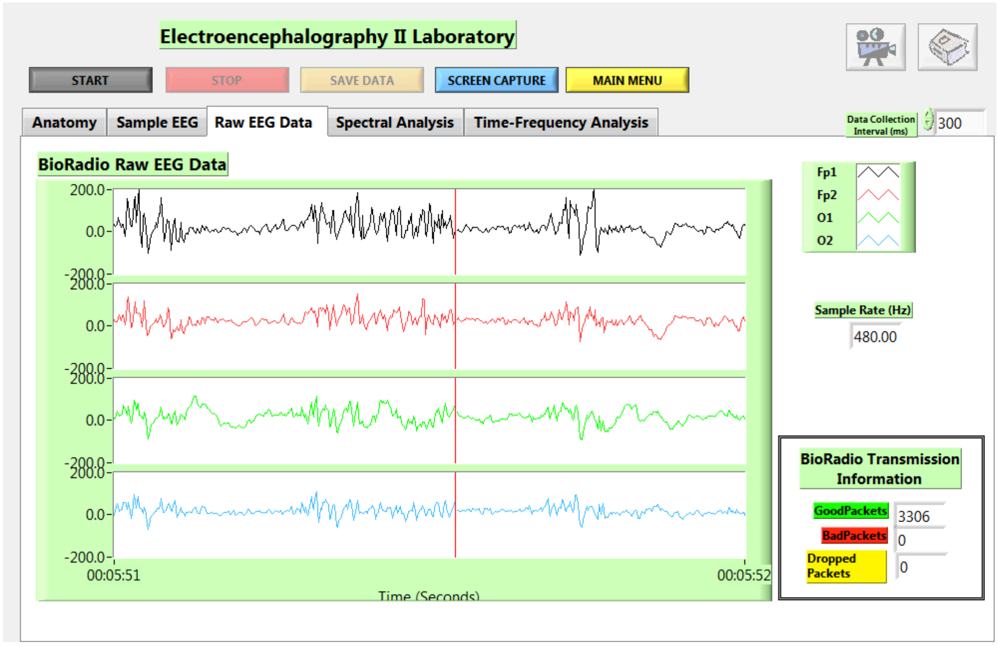

Figure 2: Chewing - Raw EEG signal for all channels during rapid chewing activity.

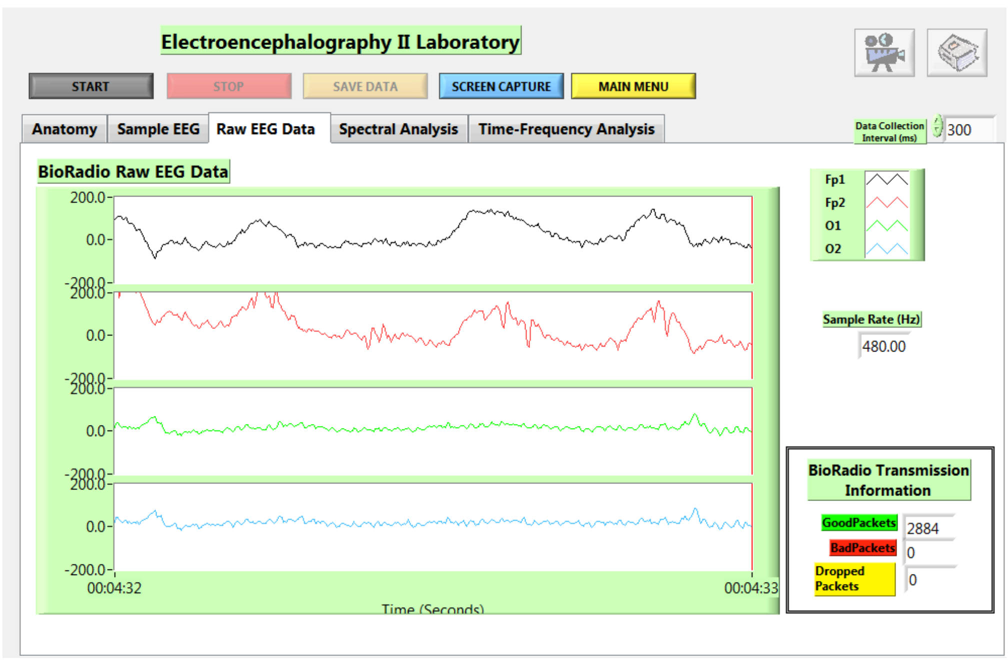

Figure 3: Blinking - Raw EEG signal for all channels during rapid blinking activity.

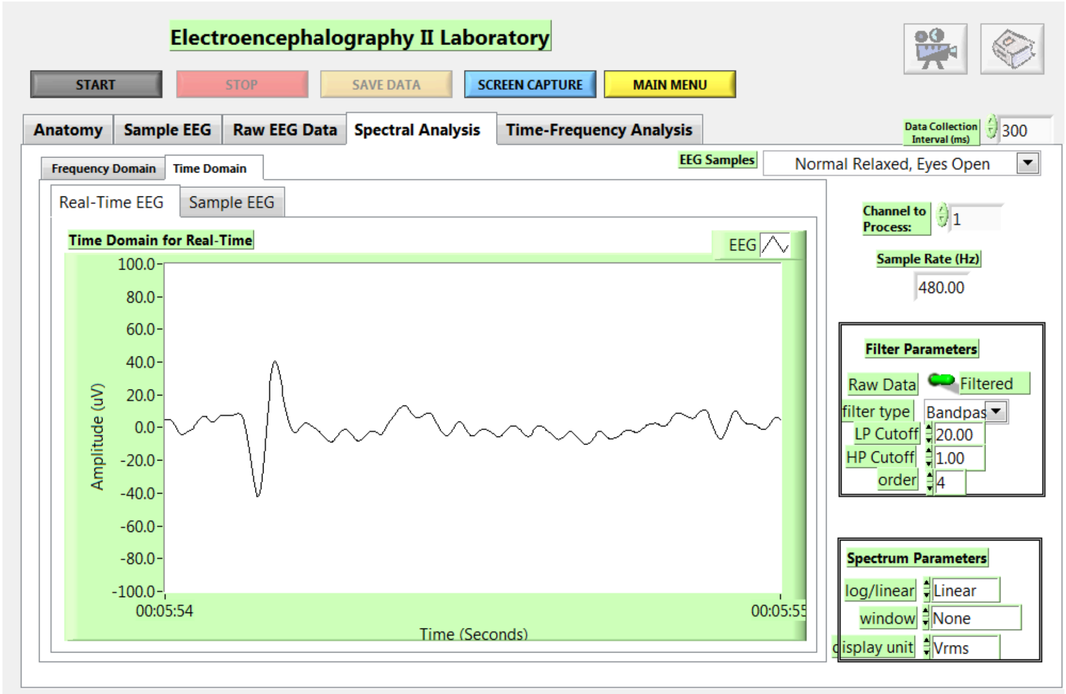

Figure 4: Baseline - EEG signal (Channel 1) observed in time domain.

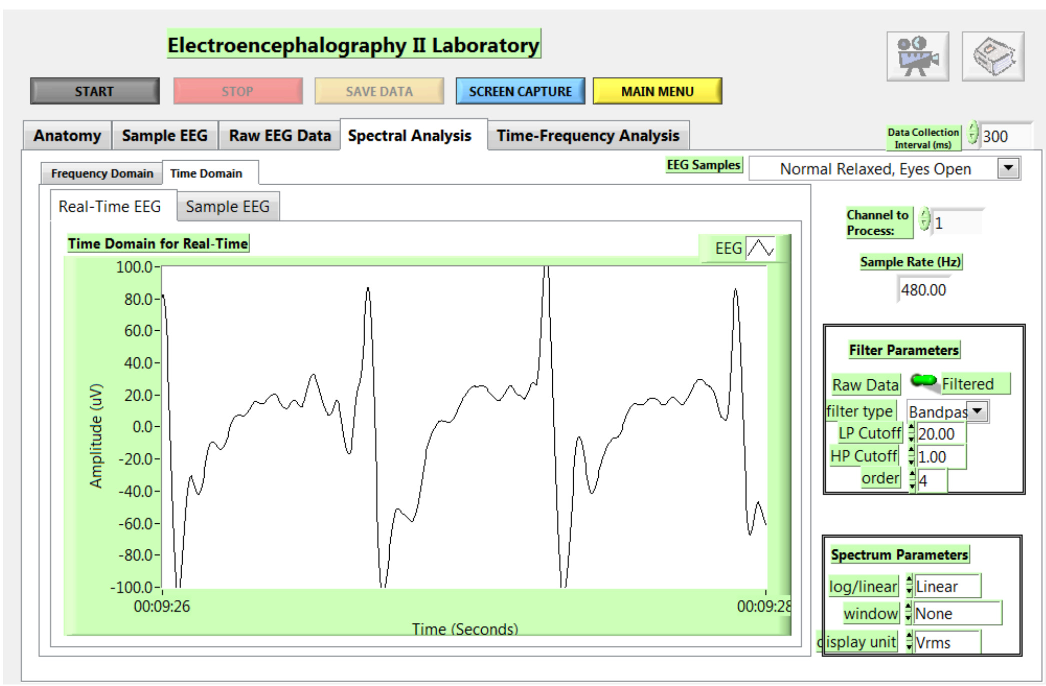

Figure 5: Chewing - EEG signal (Channel 1) observed in time domain during chewing activity.

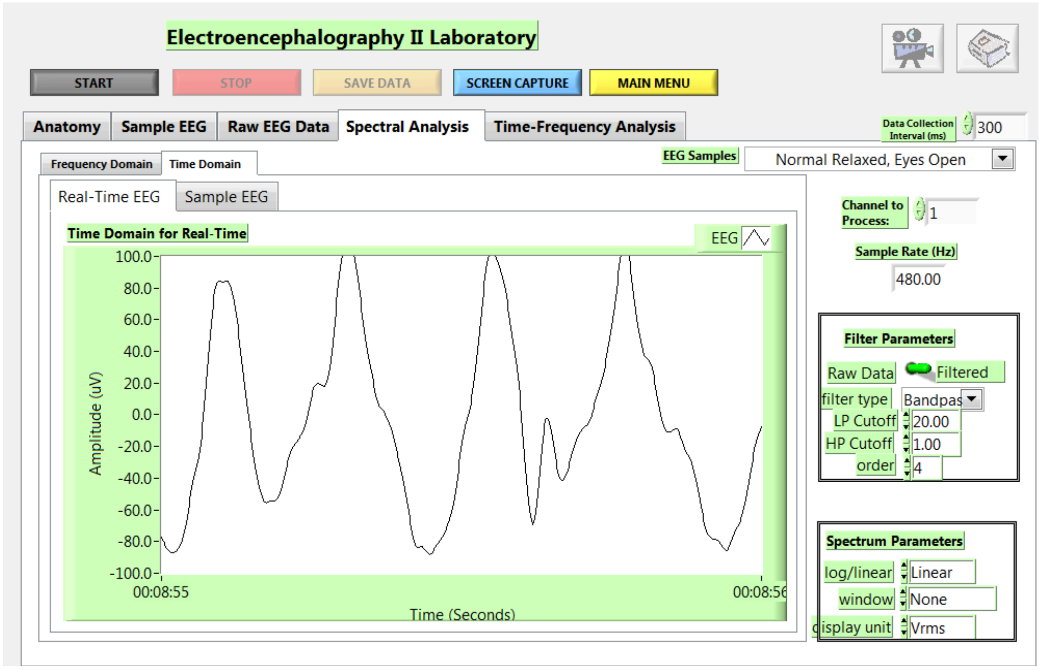

Figure 6: Blinking - EEG signal (Channel 1) observed in time domain during blinking activity.

2. Which channel gives you the best alpha rhythm? What type of filter (high pass, low pass, or band pass) and what settings should be used to emphasize the alpha rhythms? Include a screen-shot.

Alpha rhythms are maximal over the occipital lobe. In *Figure 7,* we can observe periodic sine wave-like rhythms in channel 3 (which correspond to electrodes placed in O1). Therefore channel 3 gives the best alpha rhythm. Since alpha waves are typically measured between 8-13 Hz, using a band pass filter with low-pass (LP) cutoff frequency of 13 Hz and high-pass (HP) cutoff frequency of 8 Hz to only allow the signals within 8-13 Hz frequency range. The EEG signal of channel 3, after the filtering is applied, observed in the frequency domain can be seen in *Figure 8.*

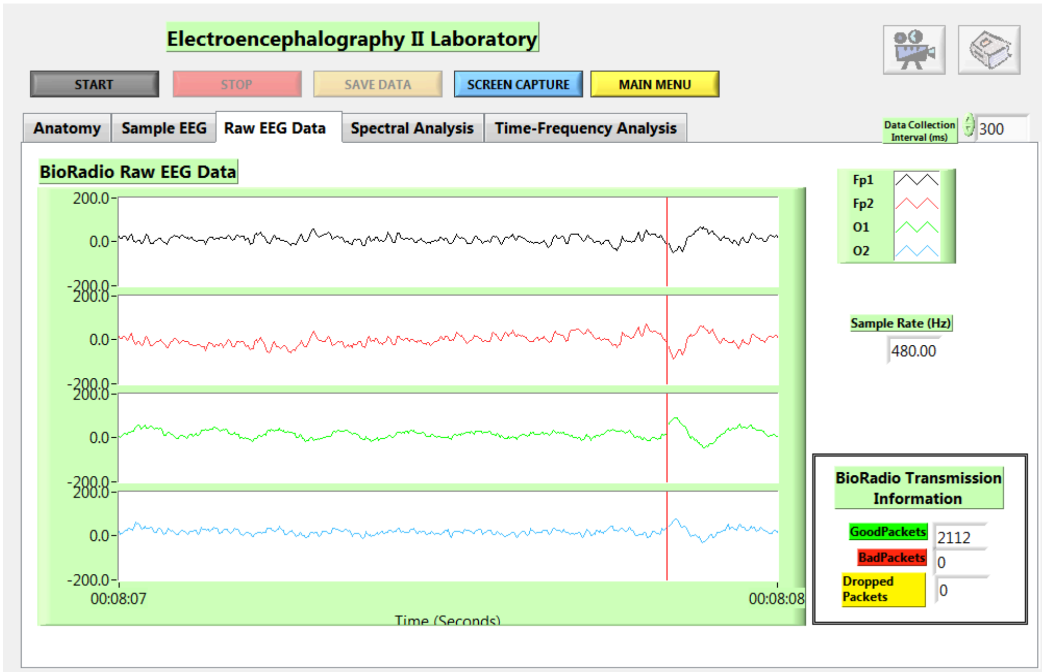

Figure 7: Eyes Closed - Raw EEG signal for all channels when the subject is relaxed and their eyes are closed.

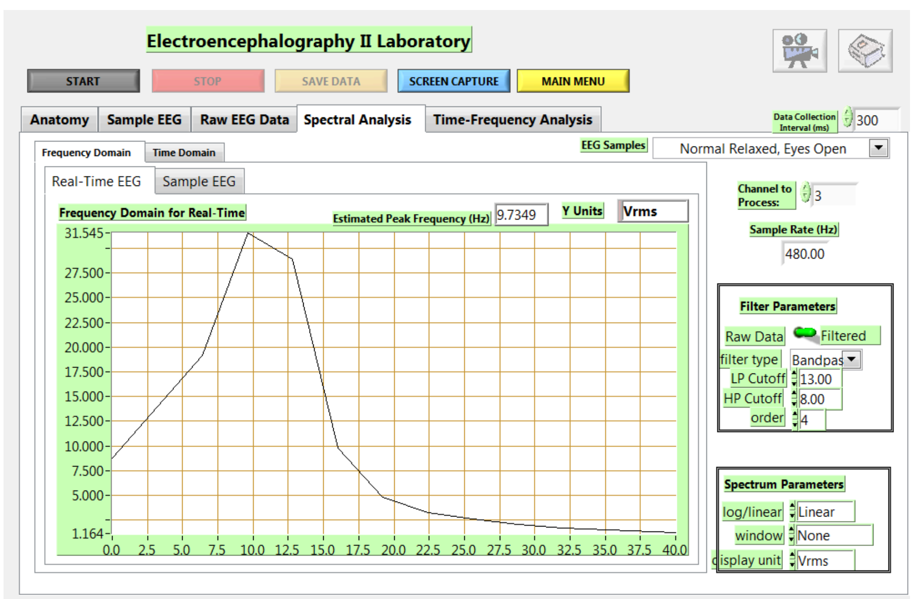

Figure 8: Eyes Closed, Alpha Waves with Band Pass Filter - EEG signal (Channel 3) observed in frequency domain when a band pass filter with HP 8 Hz and LP 13 Hz is applied to only allow for alpha waves.

3. What is the frequency range for eyes closed experiments? What is the major difficulty in obtaining this range?

Experimentally, we have found the frequency range to be around 9.3 - 11.8 Hz for eyes closed experiments based on the estimated peak frequency values in *Figures 9 and 11*. Since alpha activity in EEG is dominant during an eyes closed experiment, these results fall within the expected range of 8-13 Hz. The major difficulty in obtaining this range is that since the brain performs multiple functions at any point in time, there is no way to ensure other waves won't interfere with the measurement of alpha waves. For example, spending an extended period with your eyes closed may increase drowsiness or daydreaming, which may result in theta waves.

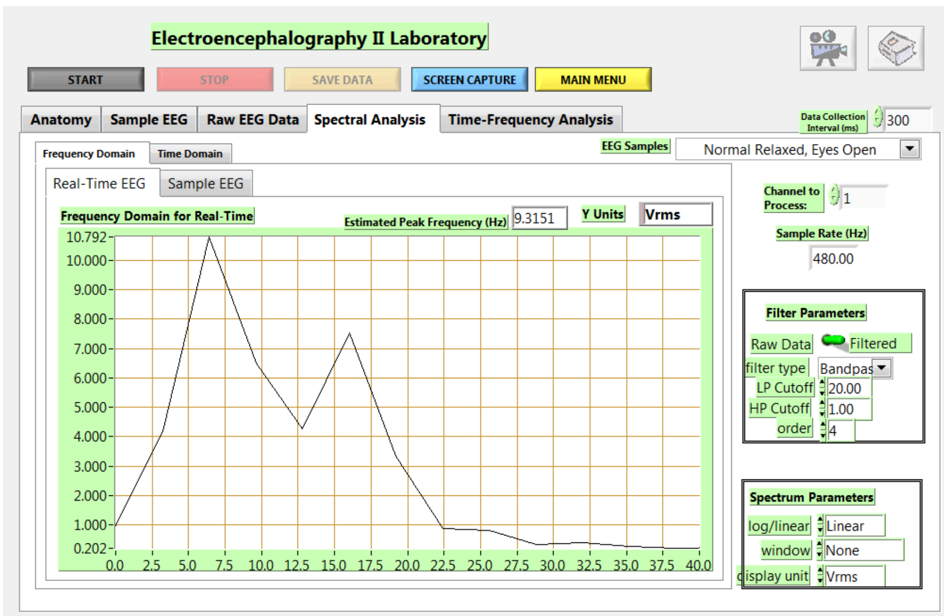

Figure 9: Eyes Closed, Channel 1- EEG signal observed in frequency domain.

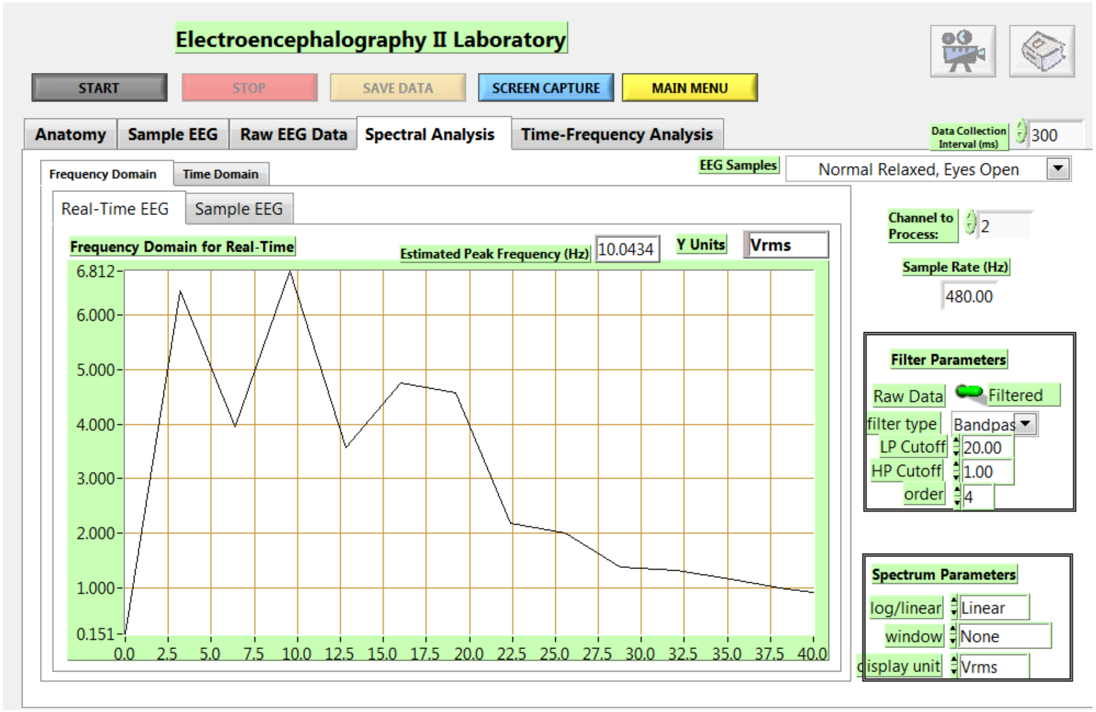

Figure 10: Eyes Closed, Channel 2- EEG signal observed in frequency domain.

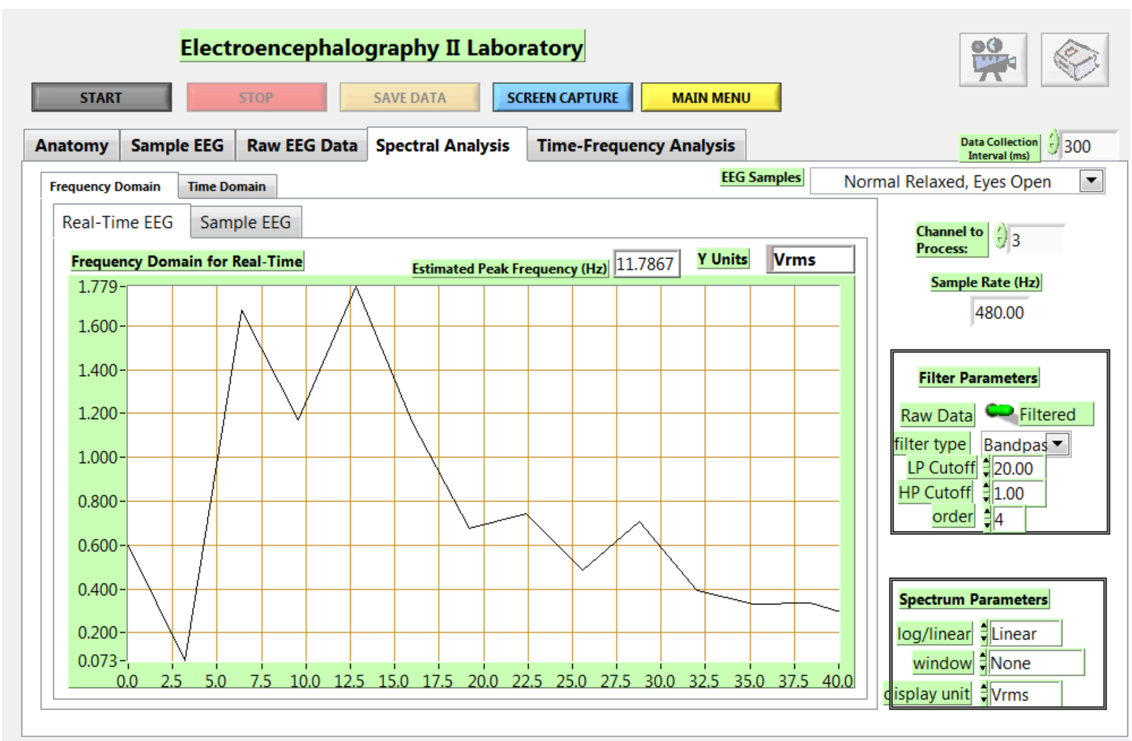

Figure 11: Eyes Closed, Channel 3- EEG signal observed in frequency domain.

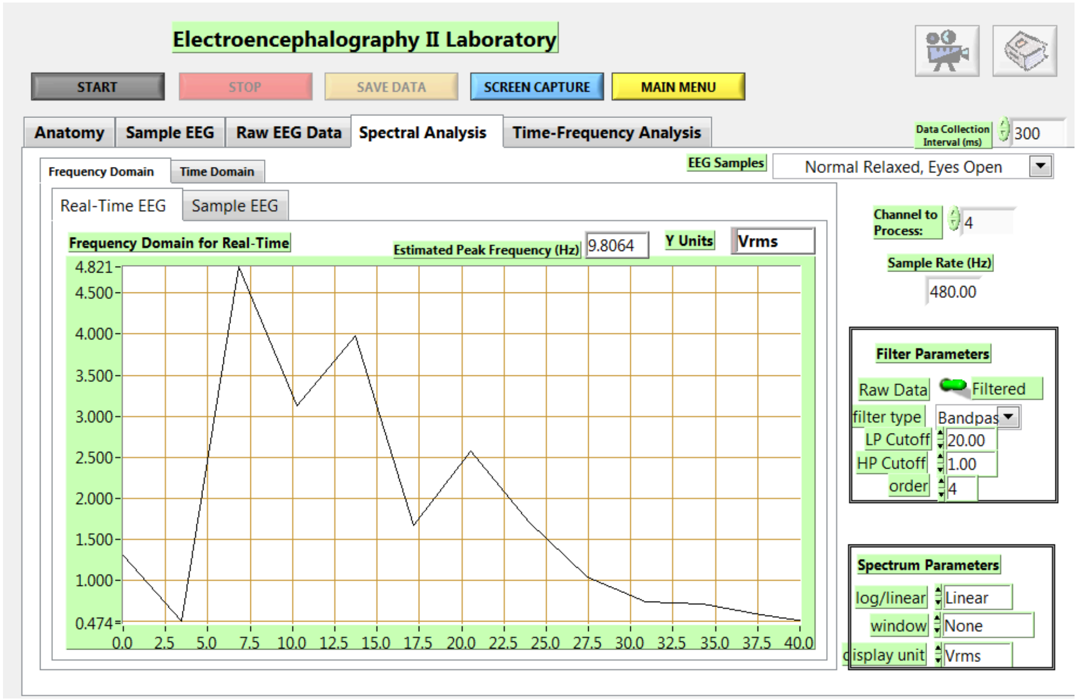

Figure 12: Eyes Closed, Channel 4- EEG signal observed in frequency domain.

4. Compare no mental math and mental math. Can you observe any difference?

In comparison to *Figure 7*, where the eyes were closed and the subject was relaxed, we observe the reduction in alpha waves in channel 3 in *Figure 13*. By performing frequency domain analysis, we observe that the estimated peak frequency is increased to ~20 Hz in *Figure 14*, which corresponds to a value within the beta wave range of 13-22 Hz.

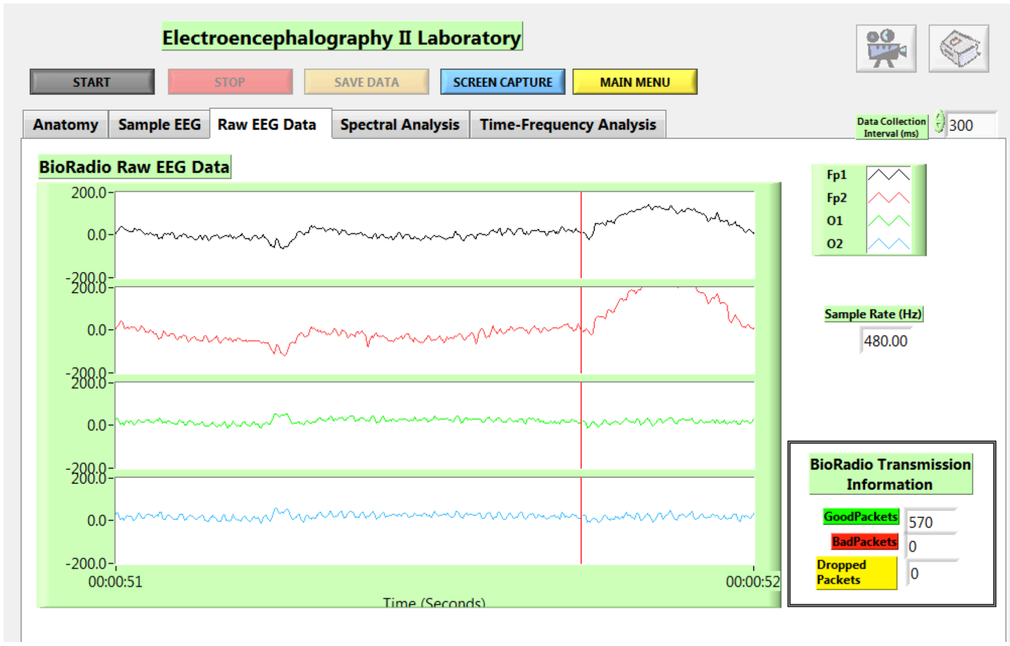

Figure 13: Eyes Closed, Mental Math - Raw EEG signal for all channels when the subject is performing mental math when their eyes are closed.

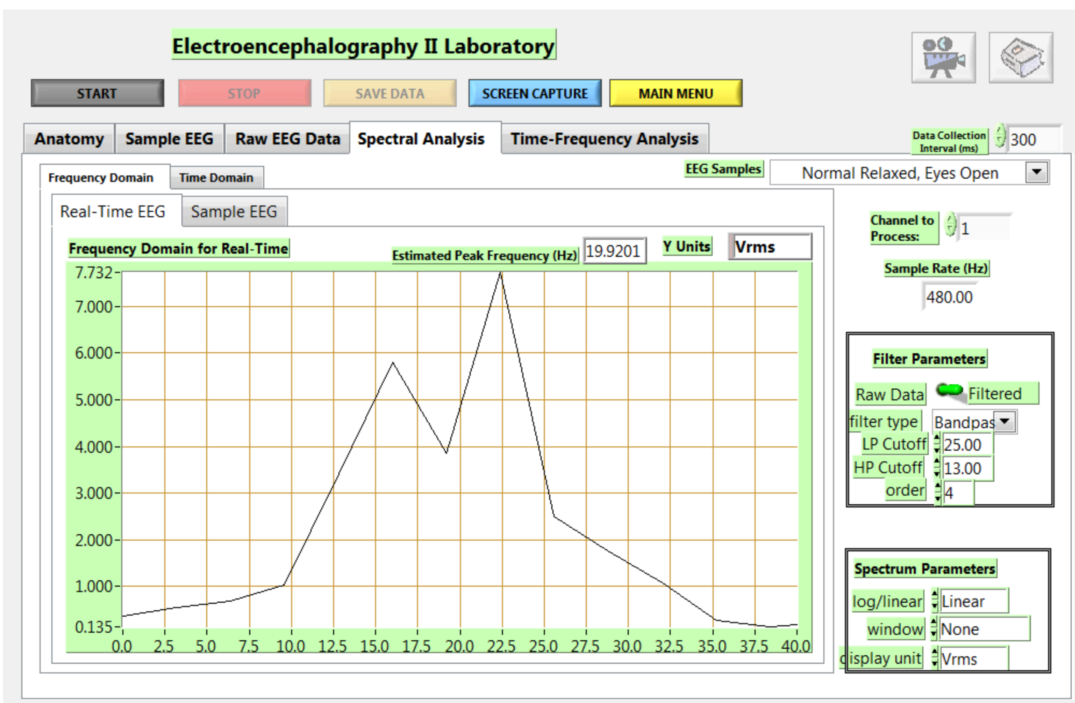

Figure 14: Eyes Closed, Mental Math - EEG signal (Channel 1) observed in frequency domain when the subject is performing mental math when their eyes are closed, with Bandpass filter applied to allow only for beta waves.

5. What type of filter (high pass, low pass, or band pass) and what settings should be used to emphasize the beta rhythms?

Band pass filter with low-pass (LP) cutoff with 22 Hz frequency and a high-pass cutoff with 13 Hz frequency should be used to emphasize the beta rhythms.

6. Why are gold cup electrodes used to record EEG instead of the snap electrodes (as in EMG and EKG)?

The material from which gold cup electrodes are made prevents the generation of additional noises and, in comparison to snap electrodes, does not significantly distort the signal in the recording range of electroencephalograms (EEG).

Additionally, given that gold lacks reactivity to chemicals, gold cup EEG electrodes maintain their effectiveness over time and decrease the risk of metal-related skin reactions.

7. Why did the EEG signal become more rhythmic when eyes were closed?

The occipital rhythm is enhanced (synchronized) when a subject closes their eyes. This synchronization occurs because of the blocking of the visual input to occipital areas. With eyes open, the brain constantly processes visual stimuli, leading to desynchronization of the alpha rhythm. We can observe the rhythmic EEG signal in *Figure 7,* especially in channels 3 and 4, which correspond to the signals obtained from electrodes placed in O1 and O2.

8. Compare the measurements between eyes open and the mental math section. Why are they so similar?

By comparing the raw EEG signals in *Figures 1 and 13,* we can observe the similarities in the EEG signal, where we see that alpha rhythms are no longer visible in channels 3 and 4.

In *Figure 14*, where the subjects' eyes were closed and they were performing mental math we observe the estimated peak frequency to be 19.92 Hz. In *Figure 15,* where the subjects’ eyes were open we observed the estimated peak frequency to be 15 Hz. Both of these frequencies fall within the beta wave frequency range of 13-22 Hz. These measurements are taken from channel 1, which corresponds to the signal that is obtained by the electrode placed in Fp1.

When the eyes are open, our brain receives visual input from our surroundings. Since the brain is processing this data constantly when the eyes are open, it is in an active state. Similarly, when performing mental math, the brain is concentrated on the task. This concentration disrupts the relaxed state and results in a reduction in alpha wave signals. During mental activation, we observe beta signals in both cases, most prominently arising in the frontal lobes.

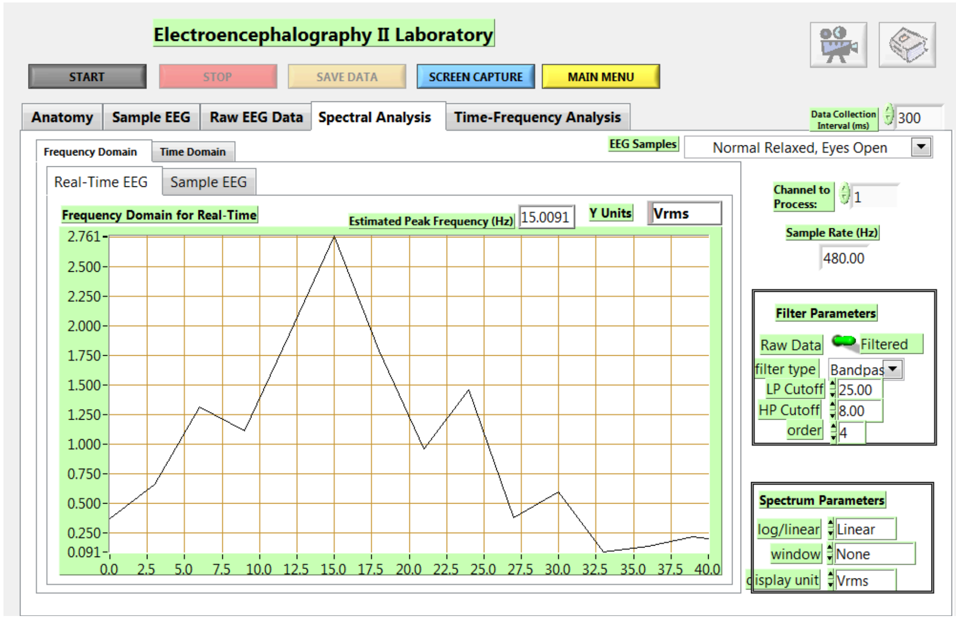

Figure 15: Eyes Open, Channel 1 - EEG signal observed in frequency domain.

9. Other than blinking, explain two (2) other sources of noise that exist in the experiment. Also suggest two (2) methods for eliminating sources of noise, and what problems may occur with those methods?

1. Environmental sources of noise such as AC power lines, lighting, other electronic equipment such as computers, are a source of noise that exist in the experiment. The most effective method for eliminating these kinds of sources of noise would be removing any unnecessary electro-magnetic (EM) noise from the recording room, and if possible replacing equipment using direct current, or using a Faraday cage. Although very effective, it is not very feasible since EM insulation requires advance planning and could be costly.
2. Physiological noise can be caused by other sources than blinking, such as cardiac signal, movement artifacts caused by muscle contraction. ECG signal is not preventable, however it has a low effect on the EEG signal. EMG noise can be avoided by instructing the subject to avoid talking and moving. In some cases, where these movements cannot be avoided, we can try to conduct the experiment in intervals where the periods of movement do not interfere with critical periods of data collection. This may result in the omission of certain interval.

10. Some hospitals have programs for automated EEG analysis to detect seizures or spiking activity that occur during data acquisition. How might a noisy recording affect these automated programs?

Noise in EEG recordings can lead to false positive detections, as these automated programs may interpret noise and artifacts as seizure-like activity, leading to inaccurate results and potentially unnecessary clinical interventions. More significantly, the noise in the EEG recordings can lead to false negatives, that is, actual seizure activity goes undetected because the noise obscures the relevant patterns. This can be very dangerous, as it may go unnoticed or create a delay in medical attention. Therefore, the noise in the EEG recordings impacts the sensitivity and the specificity of the detection algorithm.

11. Where would you place gold cup electrodes on the head to measure alpha waves? Beta waves? Theta waves? Delta waves?

To measure alpha waves, we would place the electrodes over the occipital lobe (ex: O1, O2), which is associated with visual processing.

To measure beta waves, we would place the electrodes at the frontal lobe (ex: FP1, FP2, F3, F4), which is associated with motor planning, thinking, active concentration, alertness, problem-solving, and decision-making.

To measure theta waves, we would place the electrodes at the midline and anterior scalp locations (ex: Fz, Cz, Pz), since theta waves tend to be more widespread and have a more midline distribution across the scalp.

To measure delta waves, we can place the electrodes at central and posterior scalp locations (ex: C3, C4, P3, P4), which is associated with breathing, heart rate, and deep-sleep.

12. During what types of physiological activities are alpha, beta, theta and delta waves elicited in the EEG? Give at least one physical correlation for each frequency band.

Alpha waves are primarily observed in relaxed wakefulness with closed eyes and during states of calmness and meditation. When we close our eyes and relax, alpha waves become more prominent, indicating a state of restful awareness.

Beta waves are most prevalent during active, alert wakefulness in activities such as problem-solving, decision-making, and focused cognitive tasks. When we engage in more mentally demanding activities, such as solving complex math problems and making decisions, our minds become more active and alert, characterized by increased beta wave activity.

Theta waves are observed during drowsiness, daydreaming, light sleep, and certain stages of meditation. They are associated with states of reduced external awareness and increased internal focus. They may signify transitions between different states of consciousness. Theta waves also appear to be involved in implicit learning or during "autopilot" like when we pick up on things without deliberate attention, like riding a bike or swimming.

Delta waves are prominent during deep, restorative sleep, particularly in slow-wave sleep stages. They are linked to the deepest stages of sleep, when the body undergoes physical repair or memory consolidation.

13. Both action potentials and post-synaptic potentials create the EEG. Explain the difference between these two signals.

The action potential refers to brief, rapid, all-or-nothing electrical signal propagating through the neuron, while the postsynaptic potential refers to the changes of transmembrane potential following the release of neurotransmitters at the end of a presynaptic axon, where the signal propagates to another neuron.

Postsynaptic potentials require activation of chemically (ligand) gated ion channels located on the postsynaptic membrane, whereas action potentials require activation of voltage-gated ion channels located.

PART 2

14. Describe the temporal characteristics of the three EEG samples (Grand Mal, Eyes Open, and Seizure Activity).

Grand Mal seizure sample observed has a sudden and unpredictable onset. They began abruptly and without warning. The signal sample exhibits high-amplitude/high-voltage due to synchronous electrical activity, including spikes and sharp waves during onset.

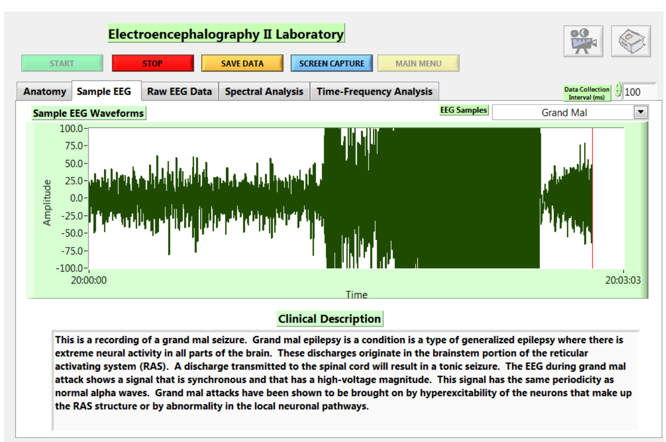

Figure 16: Sample EEG waveform of Grand Mal

The EEG signal appears to be inherently variable, with eyes open. There are ongoing asynchronous fluctuations in the signal reflecting the brain is focused various different information through cognitive and sensory processing.

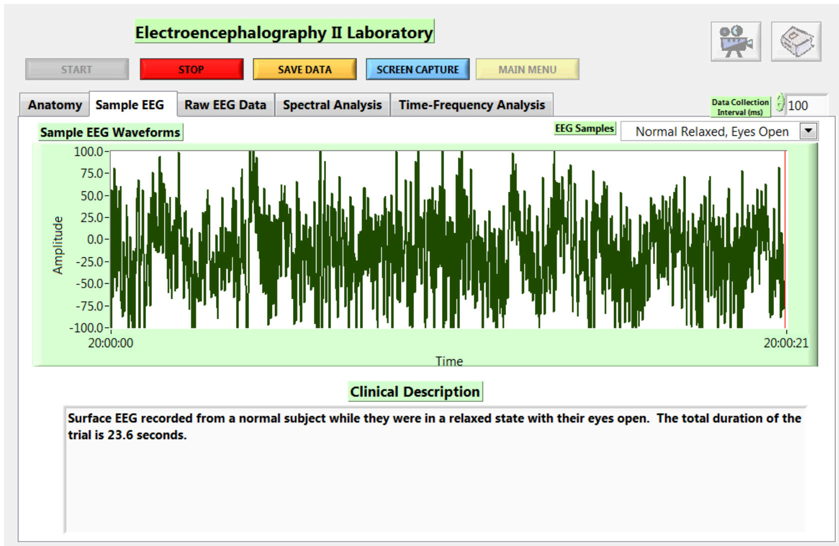

Figure 17: Sample EEG waveform of Normal Relaxed, Eyes Open

Seizure activity sample appears to be marked by abnormal and high-amplitude patterns, including spikes and sharp waves. Additionally, the electrical activity is highly synchronized during the seizure.

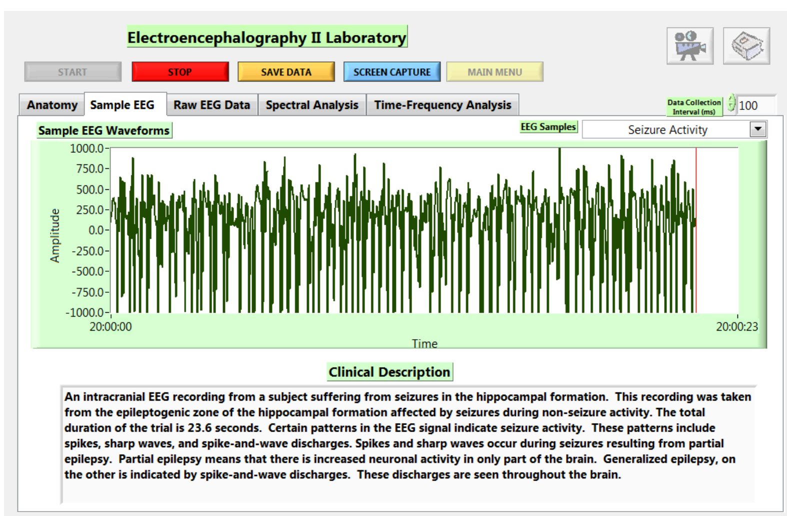

Figure 18: Sample EEG waveform of Seizure Activity

15. Describe the spectral JTFA characteristics of the three EEG samples (Grand Mal, Eyes Open, and Seizure Activity)

This seizure in *Figure 19* manifests as broadband spectral activity, with high-amplitude, irregular fluctuations across a wide range of frequencies. A sudden increase in intensity in the spectrogram is observed, as it jumps from 0 to 38 dB (a change from green to red colors). It also suddenly ends. We can also observe that the highest intensity spectrogram (darkest red) is at the intersection between highest amplitude in the time domain and between 5-10Hz in the spectral domain. This confirms that Grand Mal has the same periodicity as the alpha waves.

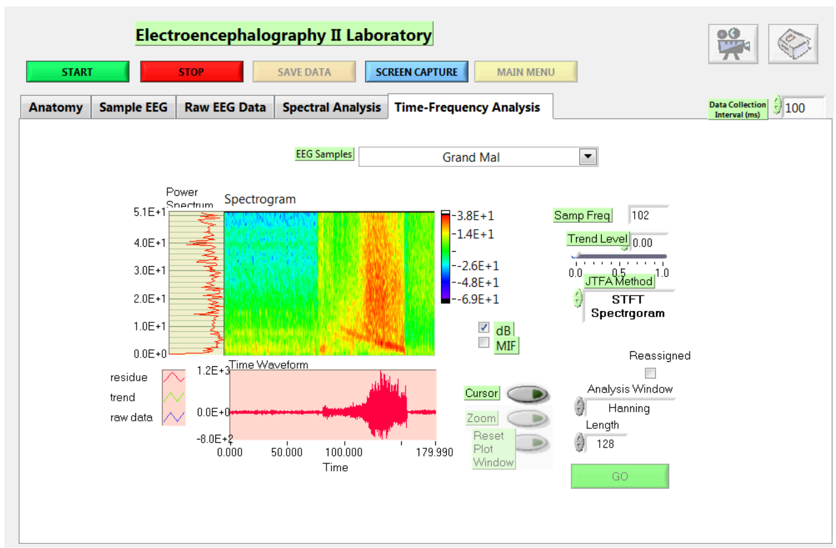

Figure 19: Grand Mal - JFTA STFT Spectrogram

In *Figure 20,* when relaxed and eyes are open, a relatively stable and consistent spectrogram is observed, with no sudden changes in intensity.

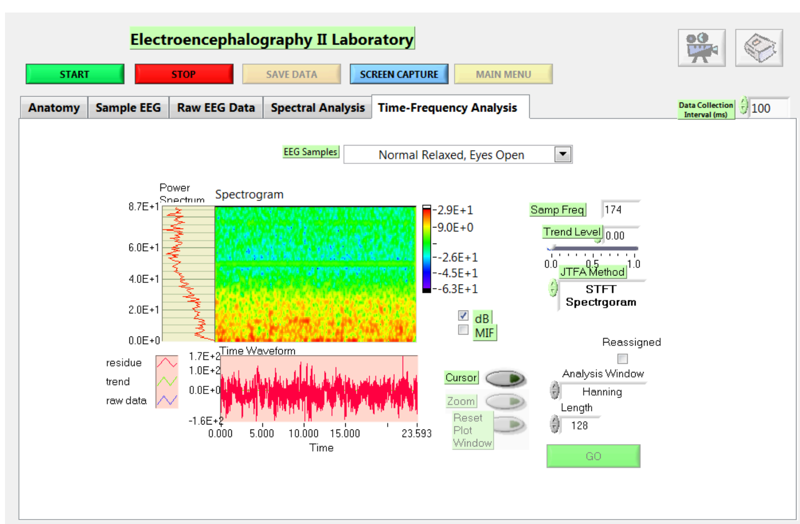

Figure 20: Normal Relaxed and Eyes Open - JFTA STFT Spectrogram

In *Figure 21*, during seizure activity, JTFA reveals high intensity bursts in the time-frequency domain. Seizure activity here exhibits highly synchronized characteristics. We see a similar pattern in this spectrogram compared to *Figure 20,* yet it consistently reaches higher intensities of 45dB, due to increased neural activity.

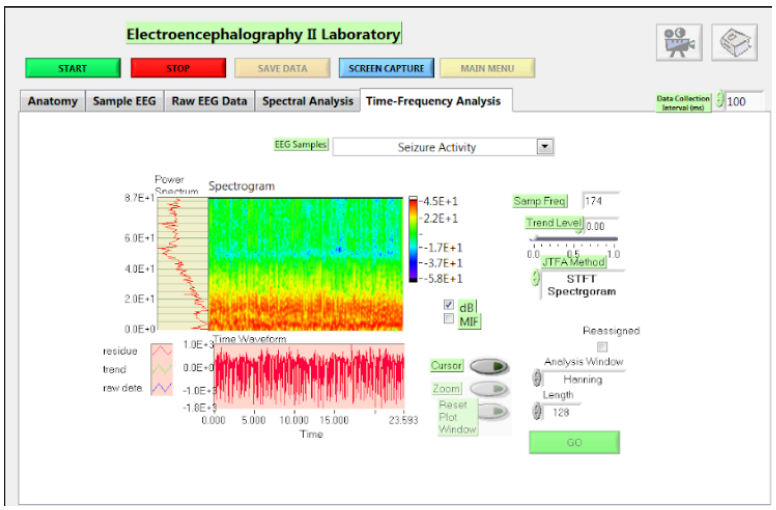

Figure 21: Seizure Activity - JFTA STFT Spectrogram

16. Why is it important to use EEG recordings to confirm non-convulsive seizures?

Non-convulsive seizures do not typically involve the visible convulsions or physical movements typically associated with convulsive seizures, making them difficult to diagnose based solely on clinical observations. Non-convulsive seizures primarily affect a person's mental state, behavior, or awareness with an absence of motor movements. Therefore, EEG can detect abnormal electrical activity in the brain that is characteristic of seizures, providing a definitive diagnosis.

17. Is it difficult to distinguish seizure activity from certain types of noise that can exist in an EEG recording? If so, why?

It is difficult to distinguish between seizure activity and certain types of noise in EEG recordings. This presents a significant problem because EEG signals are often affected by noise, artifacts, or other brain activities that can be mistaken for seizure activity. These artifacts include muscle activity, such as movement or jaw clenching, eye movements, electrical interference from nearby devices, and electrode-related issues. These artifacts can either mimic seizure activity or obscure seizures. This happens because seizures may exhibit similar waveforms to noise, or prolonged periods of noise can hide the short-lasting seizures. In addition, seizure signals are complex and vary depending on the type of seizure and the location in the brain where it originates, making it difficult to identify quickly with certainty.

Furthermore, when trying to identify absence seizures, blinking or eye movement artifacts can occur during absence seizures, making it challenging to differentiate between the characteristic spike-and-wave pattern of absence seizures and artifacts caused by these eye movements or blinks.

18. What are the benefits of using a JFTA method to analyze data compared to only using a spectral or temporal analysis technique alone?

JTFA shows frequency and time domains simultaneously, allowing us to view the frequency content of a signal changes over time. JTFA is particularly useful for capturing transient or non-stationary events in data. This method is especially useful for analyzing seizures, where events have rapidly changing frequency components, as it can analyze the evolution of signal characteristics. Whereas, these rapid changes could easily be missed with traditional temporal or spectral analysis.

Summary of Results & Discussion

In Part I of this lab, we collected electroencephalogram (EEG) signals, which record the electrical activity in the brain, by placing electrodes on the scalp of our subject. Using the CleveLabs software, we were able to observe the signals being generated in different parts of the brain with varying frequencies. We instructed our subject to perform various actions, such as closing eyes, chewing and solving math problems, to observe the effect of these activities in particular brain regions. Through filtering techniques, we were able to get waveforms with less interference. In Part II of this lab, we analyzed a set of provided EEG signal recordings of epileptic seizures. Through the CleveLabs software, we were able to observe the sudden changes in brain signals during epileptic seizures.