THE ELECTROENCEPHALOGRAM (EEG)

PART 1

OBJECTIVE:

This lab covers the electroencephalogram (EEG). Students will apply electrodes to a subject's scalp to measure and record EEG. Various brain rhythms will be examined under conditions such as eyes-open, eyes-closed and limb movements. Specific instructions for the lab report are designated with the  symbol.

INTRODUCTION:

The electroencephalogram (EEG) is a recording of electrical activities generated by the cerebrum in the brain. More specifically, it records the action potentials and the postsynaptic potentials of cortical cells. EEG data may look like a random, noisy signal, but signal processing techniques have been developed to separate different components of the brain waves. In this lab, you will be using the BioRadio to detect the electrical activities of neurons in the cerebral cortex and apply simple analysis to interpret the data.

BACKGROUND:

The Brain:

The human brain is a part of the central nervous system and is comprised of more than 100 billion nerve cells (neurons). The brain consists of three major sections known as the cerebrum, the cerebellum and the brain stem. The cerebral cortex, which is the largest part of the brain, is organized in such a way that functionally similar neurons are found in localized regions (FIGURE 1). For example, visual information is processed in the occipital lobe, motor planning is performed in the frontal lobe, and the temporal lobe is responsible for processing auditory information.

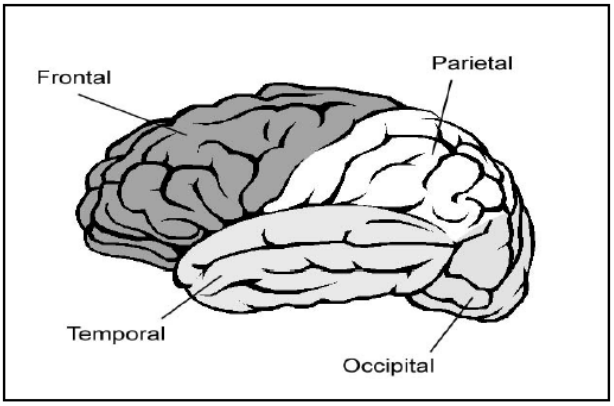

FIGURE 1: A diagram of the cerebral cortex, with the various lobes specialized for performing different functions.

Earlier, we alluded to the fact the EEG is a produced by the postsynaptic currents of neurons in the brain. This is due to the geometry of the brain, and the organization of neurons within the brain. The action potential refers to the 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. Individual action potentials and synaptic potentials of individual neurons in the brain are too weak to be detected by electrodes placed on the scalp.

An EEG recording is rather a measure of the summation of the electrical signal produced by many neurons firing over a period of time. Depending on the state of the brain and the task being performed, the neurons may be firing synchronously or asynchronously at particular frequency of interest. Neurons that are firing synchronously will have their potentials rise and fall at the same times. Therefore, the peak values will add, resulting in a relatively large signal. You can visualize this by thinking of adding two identical sine waves. The amplitude will double and the frequency of the signal will remain the same. Conversely, asynchronous firing neurons may or may not have signal peaks occur at the same time. Again, visualize the addition of two sine waves, but with different phases (i.e. a time shift). There may be an increase or decrease in amplitude depending on how the signals line up in time.

EEG components:

Rhythm	Typical Frequency (Hz)	Typical Amplitude (μV)
Alpha	8-13	2-100
Beta	13-22	5-10
Delta	0.5-4	20-100
Theta	4-8	10

EXPERIMENTAL SETUP:

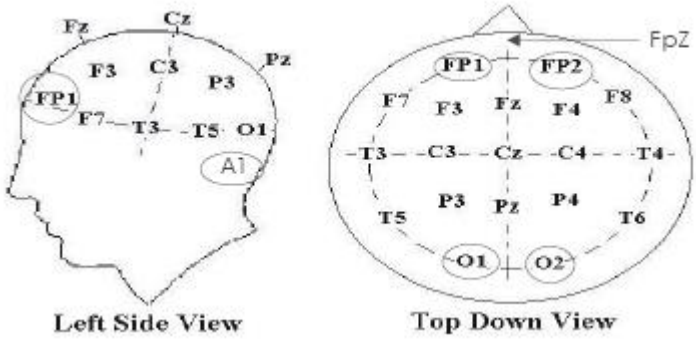

FIGURE 2: EEG setup

- If possible, the subject for this laboratory should be a person with shorter hair. The subject also should have their scalp free of any types of hair gel. You will need seven gold cup electrodes for this laboratory. Gold cup electrodes will be placed at locations O1, O2, Fp1,

and Fp2 (Figure 2) to measure EEG, on each mastoid as references, and at FpZ for the ground. The mastoid processes are the bony structures that you can feel behind the ears (Figure 3). Before applying electrodes to the subject it is important to properly prepare and clean the electrode sites.

- Now the gold cup electrodes can be attached. Generously fill a gold cup electrode with the provided Elefix gel, allowing some gel to fill over the top of the cup. Push aside the hair and place the electrode on the back of the subject's head at position O1. Some of the electrode gel should exude out of the electrode. Take a cotton ball and press it on top of the electrode and into the excess gel. Then tape the cotton ball and electrode down onto the head. Repeat for the other gold cup electrode at locations. The electrode placements for O1 and O2 are illustrated in Figure 4 without the cotton balls.

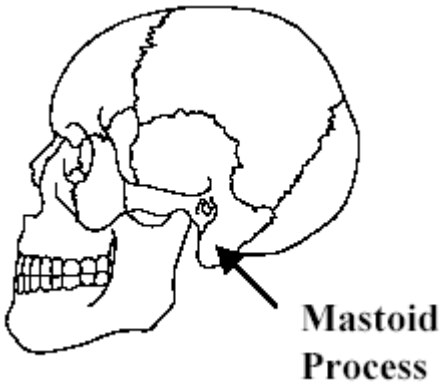

FIGURE 3: The mastoid processes are the bony structures located behind the ears.

FIGURE 4: Two of the six gold cup electrodes will be placed at O1 and O2 to monitor EEG.

- Connect gold cup leads to the harness inputs channels 1, 2, 3, 4, references, and the ground (shown in Figure 5). The harness leads are stackable allowing one lead to be plugged into more than one connector lead. The left side view of the head is symmetrical to the right side view as seen in the top down view.
- Connect the universal harness to the BioRadio transmitter and turn the transmitter on.

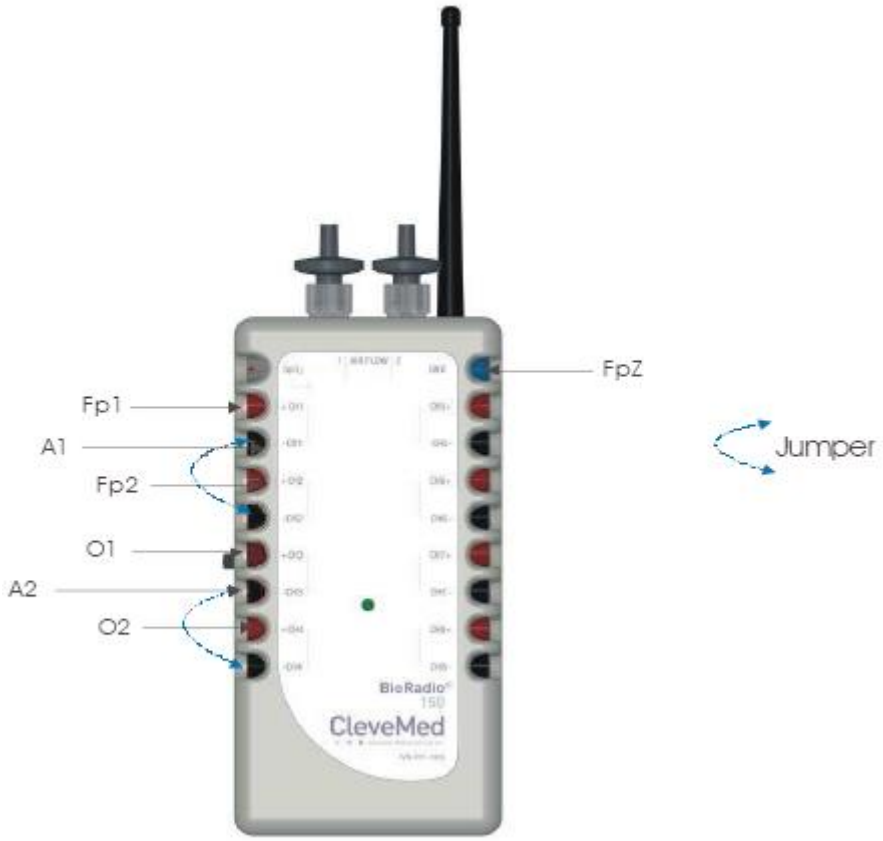

FIGURE 5: Bioradio connections used in this particular setup.

PROCEDURE:

- Run the CleveLabs Course software. Log in and select the "Electroencephalography II" laboratory session under the Advanced Physiology subheading and click on the "Begin Lab" button.
- Make sure the receiver is properly connected to the serial port on the computer and is powered on. Make sure your transmitter is connected to the universal harness. Turn the transmitter ON.
- Set the data collection interval to be 300ms, and then click on the green "**Start**" button.
- You should begin to see four channels of EEG scrolling across the screen. They may not look like normal EEG yet because you have not filtered out the artifacts. In fact, if there is a lot of 60Hz noise in the room, then the signal may even look like the plot of pure 60Hz oscillation before filtering.

- Set the time scale on the time domain plot to be 1 second. Click on the Spectral Analysis Tab.
- Instruct the subject to look at the screen. Under filter parameters, set the switch to filtered data, try filter type of bandpass, with highpass cutoff to 1Hz and the low pass cutoff of 20Hz, filter order can be set to 4.
- Instruct the subject to begin blinking rapidly and note what happens to the EEG signal.
- Instruct the subject to begin to chew and note what happens to the EEG signal.

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.*

- Select channel 1. After a few seconds, instruct the subject to close their eyes and relax. You are attempting to record alpha waves from the subject (8- 13Hz waves). You should see these waves show up as soon as the subject closes their eyes.
- Repeat previous step with the channel to process set to 2, 3, and 4.

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.*

- Do not change the parameters, but now click on the frequency domain plot tab. Examine what the estimated peak frequency is when the subject's eyes are open and when they are closed. When they are open, the estimated peak frequency should be fairly random. However, when the eyes are closed, this frequency should remain within a certain range. Record this range, as you will need it later.

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

- In order to illicit beta waves, you should ask your subject to solve math problems in their head at your command. You should as them questions quickly such as "What's 9*2?, What's

9+5?, What's 17-96?, What's 13*14?" Ask them in a quick manner and have the subject just mentally figure out and think the answer, they should not say it out loud. Make sure you ask the questions quickly, so that they are continually solving math problems in their head. You should do this experiment with the subject's eyes closed and attempt to abolish the alpha waves with the mental activity. You may need to change your filtering parameters for this application.

4. *Compare no mental math and mental math. Can you observe any difference?*
5. *What type of filter (high pass, low pass, or band pass) and what settings should be used to emphasize the beta rhythms?*

You may disconnect and clean the electrodes from part 1 before continuing on to the second part of today's lab.

6. *Why are gold cup electrodes used to record EEG instead of the snap electrodes (as in EMG and EKG)?*
7. *Why did the EEG signal become more rhythmic when eyes were closed?*
8. *Compare the measurements between eyes open and the mental math section. Why are they so similar?*
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?*
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?*
11. *Where would you place gold cup electrodes on the head to measure alpha waves? Beta waves? Theta waves? Delta waves?*
12. *During what types of physiological activities are alpha, beta, theta **and** delta waves elicited in the EEG? Give at least one physical correlate for each frequency band.*
13. *Both action potentials and post-synaptic potentials create the EEG. Explain the difference between these two signals.*

PART 2

INTRODUCTION:

Several neurological disorders exist that can have an impact on brain function. Often these disorders can be examined by reviewing the electroencephalograph, or EEG signal. Quantitative features of the EEG signal in both the temporal and spectral domain can be used for diagnosis. One important clinical disorder that can be diagnosed using the EEG signal is seizures. Seizures and status epilepticus can be potentially life threatening conditions. For convulsive seizures, visual observation is usually used in the emergency department setting to establish the diagnosis. However, non-convulsive seizures (NCS) may produce altered mental state or behavior with only subtle, ambiguous, or absent motor components. Thus, clinicians are left with only a vague hint that a seizure may be occurring, but not a diagnosis. The only way to definitively diagnose NCS is by EEG recordings, rather than by clinical observation.

BACKGROUND:

As stated above, an important application of the EEG is to diagnose neurological disorders. Epilepsy is a disease of the nervous system that is characterized by uncontrolled activity of part or all of the central nervous system. There are different kinds of epilepsy, such as grand mal, petit mal, and focal epilepsy. Epileptic seizures are characterized by usually synchronized neural activity, resulting in abnormally large amplitude EEG activity during an attack.

Grand mal epilepsy involves neuronal discharges in all areas of the brain, including the cortex, the deeper parts of the cerebrum, and even the brain stem and thalamus. Generally, grand mal attacks last anywhere from a few seconds to a few minutes. During grand mal the individual may lose control of visceral and motor control. Petit mal involves the basic thalamocortical brain activating system. Often referred to as absence epilepsy, an individual suffering from a petit mal attack will lose consciousness for up to thirty seconds, experience several twitch-like contractions in the head and neck regions, and then resume previous activities. Occasionally, a petit mal attack can initiate a grand mal attack. Focal epilepsy usually results from localized organic lesions or abnormalities such as scar tissue. Multi-channel EEG recordings can be used to identify the location of the earliest component of the seizure activity. Such a trigger zone may be removable by surgery to eliminate the seizure disorder.

Seizure Activity

Certain patterns in the EEG signal indicate seizure activity. These patterns include spikes, sharp waves, and spike-and-wave discharges. Spikes and sharp waves occur during seizures resulting from partial epilepsy. Partial epilepsy means that there is increased neuronal activity in only part of the brain. Generalized epilepsy, on the other hand, is indicated by spike-and-wave discharges. These discharges are seen throughout the brain.

Grand Mal

Grand mal epilepsy is a condition that is a type of generalized epilepsy where there is extreme neural activity in all parts of the brain. These discharges originate in the brainstem portion of the reticular activating system (RAS). A discharge transmitted to the spinal cord will result in a tonic seizure. The EEG during grand mal attack shows a signal that is synchronous and that has a high-voltage magnitude. This signal has the same periodicity as normal alpha waves. Grand mal attacks have been shown to be brought on by hyperexcitability of the neurons that make up the RAS structure or by abnormality in the local neuronal pathways.

Electroencephalography Analysis Methods

Several tools are available to provide quantitative analysis of temporal and spectral components of the EEG signal. In addition, this laboratory session will introduce a joint time-frequency analysis (JFTA). This method allows users to analyze signals in both the time and frequency domains simultaneously (Fig 4). It is a useful tool to analyze non-stationary signals. Essentially, this method yields which frequencies are occurring at what times. A graphical representation illustrates how the signal power spectrum changes over time. The basic approach is to divide the signal into several discrete intervals that can be overlapped. A Fourier transform can then be applied to each block of data to illustrate the frequency components of each block. The size of the discrete intervals determines the time accuracy. In other words, the smaller the discrete

blocks of time is, the better the time resolution. However, there is a tradeoff to this method. The frequency resolution is inversely proportional to the time resolution. This is known as the window effect. The smaller the discrete interval of time, the less resolution of frequency is provided. The algorithm described above is known as a short-time Fourier transform (STFT).

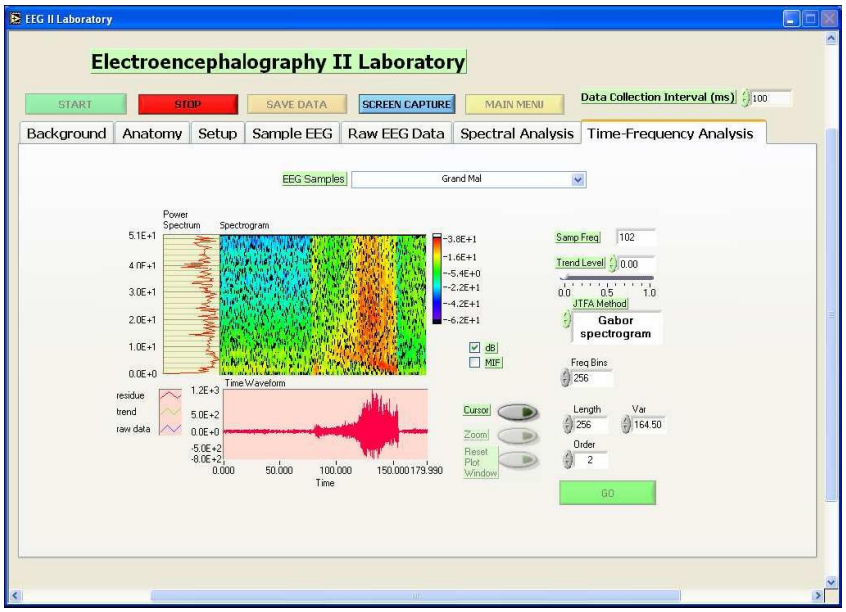

Figure 7: Joint Time-Frequency Analysis

- Log in and select the "Electroencephalography II" laboratory session.

- Click on the tab labeled "Sample EEG". From the drop down menu select the Grand Mal signal from the sample database and examine its temporal characteristics as it scrolls on the screen. Each signal is approximately one minute long and will repeat when it finishes.
- Repeat the above for the Eyes Open and Seizure Activity EEG Samples.

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

- Click on the tab labeled "Time-Frequency Analysis". This section will allow you to complete a joint time frequency analysis on the data file. Select the same three sample EEGs from above. Choose the STFT JTFA method. Click on the "Go" button. This will produce a JTFA in the window for each sample.

*15. Describe the **spectral** JTFA characteristics of the three EEG samples (Grand Mal, Eyes Open, and Seizure Activity)*
16. Why is it important to use EEG recordings to confirm non-convulsive seizures?
17. Is it difficult to distinguish seizure activity from certain types of noise that can exist in an EEG recording? If so, why?
18. What are the benefits of using a JFTA method to analyze data compared to only using a spectral or temporal analysis technique alone?

Lab Write-up Format

title/date	Laboratory title and date the experiment was performed
name	Names of everyone in the laboratory group [one (1) lab report is to be submitted by each lab group]. Include full names and all student numbers.
purpose	One or two sentences identifying the objective or purpose of the investigation
results/discussion	All questions from the lab investigation and write-up section should be answered here. Any additional observations, analysis performed during the laboratory may be included. In addition, a simple one paragraph explanation of what you did and what you found out should be included at the end of the observations/discussion section. Write this paragraph as if you were explaining your results to someone who is not familiar with the laboratory topic (i.e. someone who hasn't taken this course before). **(maximum of 200 words for this paragraph)**
figures	Print out and include all figures and/or screen shots (All figures/screen shots requested in the lab investigation and write-up section must be included, along with any additional figures that may complement your observations/results).