LABORATORY PROJECT
Study of Sleep Neural Dynamics via EEG

Adhyayan Mamgain (2018A1PS0955G)

f20180955@goa.bits-pilani.ac.in

Shrilaxmi Patil (2018B5A80889G)

f20180889@goa.bits-pilani.ac.in

Course ID: PHY F366

Instructor: Dr Gaurav Dar

December 10, 2020

Abstract

In this report we look at brain activity during sleep. We first studied the method of EEG and the different domains of EEG analysis. Then we looked at rhythms of brain waves and the classification of sleep stages based on these brain wave frequencies. We processed our sleep data implementing a multi-taper spectrum and obtained time-frequency plots. The hypnograms show the different stages of sleep as studied. The power spectrum obtained shows the dominant frequencies in different sleep periods. The data analyzed was found be regular and the sleep stages as well as the transitions between them were found to be regular as indicated by literature.

Contents

1 Introduction

1.1 What is EEG?

The electroencephalogram (EEG) is a technique to record the brain's electrical activity. The procedure involves placing electrodes along the scalp which measure voltage fluctuations. Generally the focus is either on event related potentials (ERP) or the spectral content of EEG. ERP looks at potential fluctuations that are time locked to an event whereas analyzing spectral content involves looking at the kinds of 'brain waves' that can be observed in EEG signals. [1]

1.2 EEG Data Analysis

In order to interpret the results obtained in the form of EEG signals one should be familiar with the data analysis of EEG. Usually, the data scroll obtained from the EEG apparatus has a a significant amount of noise, hence, it is essential that this noise is filtered. Here, we did a study on sleep EEG signals, where the brain wave frequency range was 0-35Hz. Therefore a 30 Hz low pass filter was used to remove all the signals above 30 Hz, as it was the range of interest.
EEG Analysis can be broadly classified into the following three domains.

1.2.1 Time Domain Analysis

Time Domain Analysis of EEG provides visual data about the change in brain waves signals with respect to time. It is commonly use in the study of Event Related Potentials (ERP). In a typical ERP study the brain wave response due to a stimulus is plotted using the EEG data. A simple example of measuring ERP would be where, say, a person is subjected to a visual stimulus in the form of flashing of the letter 'X' on a screen at a certain frequency. The goal is to see how the brain responds to this stimulus.

1.2.2 Frequency Domain Analysis

Probably the most important data analysis technique of the three, without which the study of EEG will be incomplete. The goal of frequency domain analysis is to find the amplitude of different frequencies present in a EEG signal. By applying Fourier Transform on a time series we can find the frequency domain plot of the signal. The frequency domain helps us to find the noisy components, these noisy components can then be removed and an

inverse Fourier transform can be done to get a noise free signal. And this is why frequency domain analysis is so important in EEG data analysis. However, one disadvantage about it is that all information about time is lost.
The fourier transform of a time signal $f(t)$ can be found as:

$$f(t) = \sum_{-\infty}^{\infty} c_n e^{\frac{in\pi t}{T}} \tag{1.1}$$

where $\omega = \frac{n\pi}{T}$ is the angular frequency, and $\Delta\omega = \pi/T$
Then,

$$f(t) = \sum_{-\infty}^{\infty} c_n e^{in\Delta\omega t} \tag{1.2}$$

Let $c_n = \frac{\Delta}{\sqrt{\omega\pi}} g(n\Delta\omega)$
Then,

$$g(n\Delta\omega) = \frac{1}{\sqrt{2\pi}} \int_{-T}^{T} f(t) e^{-in\Delta\omega t} dt \tag{1.3}$$

If $T \to \infty$

$$f(t) = \frac{1}{\sqrt{2\pi}} \int_{-T}^{T} g(\omega) e^{i\omega t} d\omega \tag{1.4}$$

$$g(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-T}^{T} f(t) e^{-i\omega t} dt \tag{1.5}$$

Where $g(\omega)$ is the Fourier transform of $f(t)$. In MATLAB usually the Fast Fourier Transform (FFT) is used, which is an inbuilt function.

1.2.3 Time-Frequency Domain Analysis

In signal processing, time–frequency analysis comprises of those techniques that study a signal in both the time and frequency domains simultaneously, using various time–frequency representations. One advantage of using this technique over frequency domain analysis is that information about time isn't lost and dominant frequencies can be detected in a certain time window, which gives more insight into brain wave activity. The Event Related Spectral Power (ERSP) is one of the most sought after data analysis tools in EEG study as it plots the spectral power of the component frequency with respect to time. This helps us in determining the dominant frequencies in the signal. In case of sleep data analysis, a time-frequency plot is called the hypnogram. However, a ERSP plot is more insightful than the conventional hypnogram as it provides more information about the spectral power of the component frequencies.

1.3 EEG in sleep research

The science of sleep has evolved greatly due to Hans Berger's invention of EEG which enables us to go from merely observing sleeping individuals to analyzing their brain activity in great detail. Today, EEG is the most common tool used in sleep research and has helped our understanding of the complexity of the brain activities characterizing sleep and wake states. Spectral analysis of sleep EEG recordings shows that sleep goes through structured and organized stages in several cycles. [2]

2 Sleep Data Analysis

Humans spend about one-third of their lives asleep, yet most individuals know little about sleep. Sleep is a universal need of all complex higher order life forms, the absence of which has serious health consequences. Therefore, we thought it would be interesting if we could study neural dynamics while one is asleep. Before analyzing the data one should be familiar with the basics of sleep physiology which describes the different sleep stages, classified as REM and NREM sleep. The following sections will be about the different brain-wave frequencies and the stages that they are dominant in.

2.1 Brain waves

Depending on neuron activity different brain wave frequencies obtained via the EEG provide insight into the working of the human brain. Slow brain waves are seen in conditions such as sleep, coma, brain death, depression, autism, brain tumors, obsessive–compulsive disorder, attention deficit hyperactivity disorder, and encephalitis, while rapid waves are reported in conditions such as epilepsy, anxiety, post-traumatic stress disorder, and drug abuse. Here we list the different brain wave frequencies:

- **Beta rhythm (13-35 Hz)**
  This wave is related to consciousness, brain activities, and motor behaviors. This wave is recorded when the eyes are open.
- **Alpha rhythm (7-13 Hz)**
  This wave was among the first rhythmic waves documented and named by Hans

Berger. It originates from the occipital lobes during wakeful relaxation, but has higher amplitude on the dominant side.

- **Theta rhythm (4-7 Hz)**

  This rhythm is recorded during low brain activities, sleep, or drowsiness.

- **Delta rhythm (0-4 Hz)**

  This wave is recorded during very low activities of the brain and deep sleep.

2.2 Sleep stages

Based on these brain wave frequencies sleep is classified into different stages, which are as follows.

- **Wake (Stage W)**

  First is the wake stage or stage W. During eye-open wakefulness, there are alpha and beta waves present, predominantly beta. As individuals become drowsy and their eyes close, the alpha rhythm is predominant. An epoch is stage W if it contains greater than 50% alpha waves and eye movements associated with wakefulness.

- **N1 (Stage 1)**

  This is the lightest stage of sleep and starts when more than 50% of the alpha waves are replaced with low-amplitude mixed-frequency (LAMF) activity. There is muscle tone present in the skeletal muscle and breathing tends to be regular. This stage tends to last 1 to 5 minutes, consisting of around 5% of the total cycle.

- **N2 (Stage 2)**

  In this stage the heart rate and body temperate drop. Sleep spindles, K-complexes, or both are present. Sleep spindles activate the superior temporal gyri, anterior cingulate, insular cortices, and the thalamus. The K-complexes show a transition into a deeper sleep. They are single, long delta waves only lasting for a second. Stage 2 sleep lasts around 25 minutes in the initial cycle and lengthens with each successive cycle, eventually consisting of about 50% of the cycle.

- **N3 (Stage 3)**

  This is the deepest stage of sleep with predominantly delta waves. This stage is the most difficult to awaken from and if someone is awoken, they will experience 'sleep inertia' where mental performance is moderately impaired for 30 minutes to an hour. This is the stage when the body repairs and regrows its tissues, builds bone and muscle, and strengthens the immune system. As people age, they tend to spend less time in this stage.

- **REM Sleep**
  This is the stage associated with dreaming. Interestingly, the EEG is similar to that of an awake individual, but the skeletal muscles are atonic and without movement, with the exception of the eye and diaphragmatic breathing muscles. Breathing is erratic and irregular. This stage usually starts 90 minutes after you fall asleep, with each successive cycle being longer. The first period is typically 10 minutes long, and the final one can last up to an hour.

After knowing the basics of sleep physiology, we are now in a stage to analyze sleep data. Sleep Data was taken from Physoinet.org [3].The data was collected by recording EEG data and the experiment was performed on two healthy subjects Bob and Alice. This sleep data was recorded over a period of 7 hours.

3 Results

The data taken from Physionet.org [3] was plotted, which had extra EMG (Electromyogram), EOG (Electrooculography) channels along with EEG data channels. EMG records the muscle activity, whereas, EOG records the occipital activity. This provides additional information which in turn gives better results.

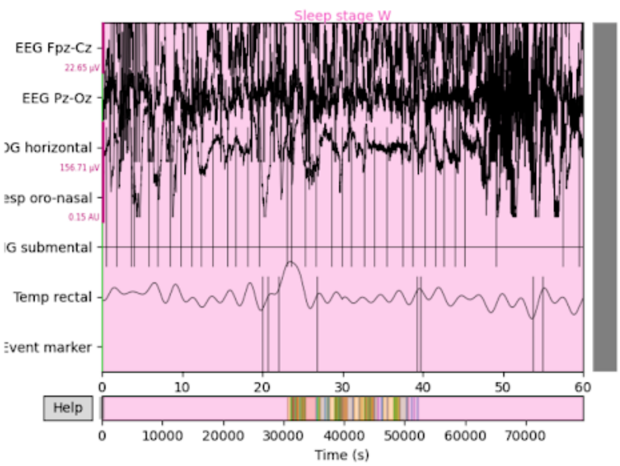

Figure 3.1: Data scroll shows that the data comprises of EEG, EOG and EMG data

The data was processed in MNE python [4]. It was first cleaned by overlapping windows to obtain an averaged signal to remove noise. The Multi-taper Spectrum was implemented while doing this (MNE provides a direct way of doing this using the library functions). Event ID's were also created to plot he hypnogram as well. The following time-frequency plots were obtained (Figure 3.2 & Figure 3.3)

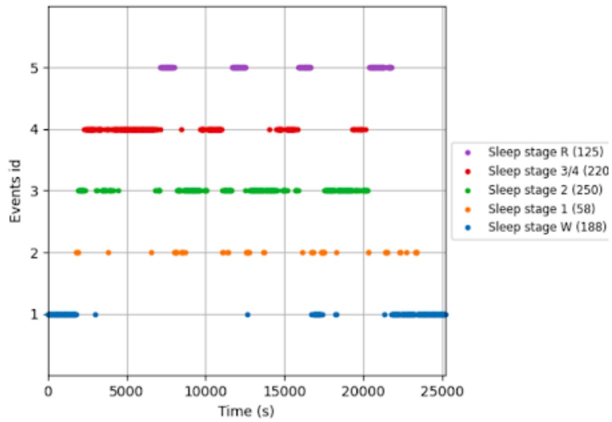

Figure 3.2: Hypnogram classifying stages of sleep

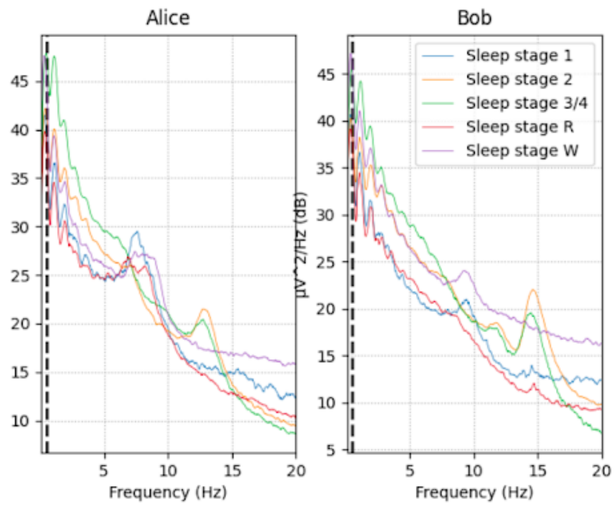

Figure 3.3: Spectral Power for both Bob and Alice

4 Discussions

Sleep data was recorded over a period of 25000 seconds which is equal to 7 hours. In figure 3.2 we can clearly see that the first event id (blue) denotes the wake period, meaning the subject is just going to sleep, with eyes opening and closing intermittently. This is followed by sleep stage 1 (orange), which then shifts to sleep stage 2 (green). This then transitions to

sleep stage 3 (red) which occurs after almost 45 minutes and is the deepest stage of sleep. Sleep stage 3 is the dominant stage from almost 45 minutes to almost 2 hours into the sleep. This is the deepest stage of sleep and the first deep sleep stage lasts for around 1 hour 20 minutes. This is followed by intermittent occurring of sleep stage 1 and sleep stage 2. As discussed before sleep stages 1 to 3 are labelled as the NREM sleep stages, where stage 3 is the deep sleep stage. However, the most interesting characteristics of sleep is the REM sleep stage, in which brain activity is akin to the active state, and it usually occurs after 90 minutes. Here the first REM period was observed after 125 minutes and lasted for about 16-20 minutes. It is generally observed that each successive REM sleep period is longer than the previous one, but here so wasn't the case. Only the last REM sleep period appears to be longer than the previous ones, the first three being almost similar in length. After the last REM period brain waves transition to the first sleep stage and finally to the wake stage. The last wake stage (blue) lasts for around 1 hour after which the subject wakes up and gains lucidity.
Additional insight is also provided by the power spectrum in figure 3.3. This figure shows the bursts of powers of different frequencies in terms of peaks. These peaks correspond to the sleep periods in which they are the dominant frequencies.

5 Conclusion

The the sleep data analysis results can be summarised as:

- The sleep pattern of the subjects Bob and Alice are normal as no abnormality was observed in the sleep pattern while studying the hypnogram.
- The transition in sleep stages was similar to what we expected. Thorough literature survey gave us the same indications as well. [5]
- Sleep stage 3 which is the deep sleep period occurred after almost 45 minutes and the first deep sleep period was the longest (1 hour 20 minutes), which is usually the case.
- REM sleep is supposed to occur after 90 minutes, but here according to the hypnogram it occurred after almost 125 minutes. However, one must be careful and not consider this as a sleeping disorder as the onset of REM sleep varies from person to person.

- Sleep stages 1 and 2 occurred intermittently, which is usually the case.
- Finally, the hypnogram ends with the dominant wake period (blue) which signifies that the subject is waking up.

The hyponogram obtained displays the sleeping pattern of a healthy individual, as is evident from the distribution of REM and NREM sleep stages. The duration of these sleep stages and there intermittent occurring shows that the subject has no sleeping disorders as well. The power spectrum provides information about the dominant frequencies in these stages, which is in accordance with the hypnogram plot.

6 Further work

Since we now have a detailed analysis of the average night of sleep, we can further expand this research to analyze the sleep data of people during periods of stress. [6]As stress is known to be a major contributor to sleeping disorders, gaining more insight in the same might give us some interesting results. Students are often stressed out during examination periods and thus we can collect sleep data of students during these times and see if stress during exams alters the regular sleeping pattern. However, one must select a sizeable pool of healthy students with no sleeping disorders to conduct the experiment. In order to analyze the EEG data one must first process the data in EEGlab and convert it to a MATLAB file (in the form of an array). Once we have the MATLAB file we can perform any possible MATLAB operation on it like the FFT or Welch power spectrum. The multi-taper spectrum analysis code [7] can also be used for better interpretation of data, and we strongly suggest that this multi-taper spectrum analysis is used to obtain the ERSP. The results might show us something interesting indeed.

References

[1] Minow F et al. Light GA, Williams LE. Electroencephalography (eeg) and event-related potentials (erps) with human participants. Curr Protoc Neurosci.; Chapter 6:Unit-6.25.24, 2010.

[2] Anilkumar AC. Nayak CS. Eeg normal sleep. https://www.ncbi.nlm.nih.gov/books/NBK537023/, 2020.

[3] Sleep database. https://archive.physionet.org/cgi-bin/atm/ATM.

[4] Mne python for eeg analysis. https://mne.tools/stable/index.html.

[5] Aakash K. Patel; Vamsi Reddy; John F. Araujo. Physiology, sleep stages. https://www.ncbi.nlm.nih.gov/books/NBK526132/, 2020.

[6] Insop Shim Kuem Sun Han, Lin Kim. Stress and sleep disorder. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3538178/, 2012.

[7] Michael J. Prerau. Beyond the hyponogram: Multitaper spectogram analysis of sleep eeg. https://prerau.bwh.harvard.edu/multitaper/, 2019.

[8] Steven J Luck. *An introduction to the event-related potential technique*. MIT press, 2014.