# Classification and Analysis of EEG Signals

## End – Semester Report

Submitted in complete fulfilment of course

**INSTRF266 STUDY ORIENTED PROJECT**

By

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## Acknowledgement

I would like to express my thankfulness to all those who have helped me and supported me during the course of the project. I would like to express my deepest gratitude to Dr. Anurag Nishad for giving me the opportunity to do this project and for his help and useful guidelines during the course of this project and also for helping me in writing this report.

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# Abstract

The brain activity produces the different kinds of signals like electrical and magnetic signals. This activity can be recorded using different kind of approaches, which are normally classified as invasive and noninvasive. In invasive methods surgical intervention are made to implant certain device in the brain whereas in noninvasive methods no such intervention is made. Among the different noninvasive methods, Electroencephalography is one of the most commonly used methods to record the brain signals. EEG is regarded as direct and simple noninvasive method to record the brain electrical activity, represented as voltage fluctuation resulting from current flow within the neurons of the brain [1].

Electroencephalography (EEG) is the neurophysiologic measurement technique which measures and record the electrical activity of the brain of the electrical activity of the brain using surface electrodes placed on the scalp. The method is known as the electroencephalography whereas the recorded signal which is the recorded oscillations of brain electric potentials is called electroencephalogram. Measuring and studying the EEG doctors and clinicians can get the information about the brain activities which help them not only to study the normal brain activity but also to diagnose a number of brain diseases and neurological disorders. In 1924, the German psychiatrist Hans Berger first recorded the human EEG [2].

The original Rechtschaffen and Kales sleep scoring manual of 1968, commonly known as the R and K rules, was used until 2007, at which point the American Academy of Sleep Medicine (AASM) updated the scoring manual in what is commonly known as the AASM scoring manual. The Rechtschaffen and Kales method divides sleep into five distinct stages: non–rapid eye movement (non-REM [NREM]) stages 1, 2, 3, and 4 and stage REM sleep. The AASM scoring manual recognizes four sleep stages: Stage N1 (formerly stage 1 sleep), stage N2 (formerly stage 2 sleep), stage N3 (formerly stages 3 and 4 sleep), and stage R sleep (formerly stage REM sleep) and apart from these, there is also stage Wakefulness [5].

# Introduction to EEG

Electroencephalography (EEG) is a measurement of potentials that reflect the electrical activity of the human brain. It is a readily available test that provides evidence of how the brain functions over time. The EEG is widely used by physicians and scientists to study brain functions and to diagnose neurological disorders. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain. Clinically, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time, as recorded from multiple electrodes placed on the scalp. Diagnostic applications generally focus either on event-related potentials or on the spectral content of EEG. The former investigates potential fluctuations time locked to an event, such as 'stimulus onset' or 'button press'. The latter analyses the type of neural oscillations (popularly called "brain waves") that can be observed in EEG signals in the frequency domain. As the voltage fluctuations measured at the electrodes are very small, the recorded data is digitized and sent to an amplifier. The amplified data can then be displayed as a sequence of voltage values [1].

## EEG Potentials

EEG signal can be classified as two types depending on the generation of the bran signals such as Event related potentials (ERPs) and Spontaneous or freerunning EEG [1].

1. **Event related potentials (ERPs) or Evoked Potentials:** It is the measured brain potential signal which is directly generated as a stereotyped electrophysiological response to a stimulus such as a specific sensory, cognitive, or motor event. The evoked potentials are generated and recorded by the patient's brain by applying a stimulus, such as a flash light or loud click to the sensory system of the patient.
2. **Spontaneous or free-running EEG:** It is the found naturally produced and rhythmic brainwaves which are generated by outside activity.

## The most common applications of EEG signals are –

- Distinguish epileptic seizures
- Characterizing seizures for the purposes of treatment
- Investigating epilepsy and locate seizure origin
- Testing epilepsy drug effects
- Monitoring cognitive engagement
- Monitoring the depth of anaesthesia, coma and brain deaths
- Monitoring for non-convulsive seizures/non-convulsive status epilepticus
- Locating areas of damage following head injury, stroke and tumour

- Producing biofeedback situations
- Controlling anaesthesia depth (servo anaesthesia)
- Monitoring the brain development
- Testing drugs for convulsive effects
- Investigating sleep disorders and physiology
- Investigating mental disorders
- Providing a hybrid data recording system together with other imaging modalities

This list confirms the rich potential for EEG analysis and motivates the need for advanced signal processing techniques to aid clinicians in their EEG interpretation. The EEG patterns are very important for understanding brain activities by identifying morphological features or examining frequency bands associated with different mental activities or conscious states [2].

## Advantages and Disadvantages of EEG Signals

### Advantages –

- Provides a lot of information about the brain activity.
- EEG is very suitable and efficient for diagnosing some brain diseases like epilepsy.
- It is very effective and efficient to detect sleep disorders, coma, encephalopathies, and brain death.
- Most inexpensive methods of neuroimaging.
- EEG high temporal resolution (millisecond range).
- No harmful side effect of this process on human health is reported.
- EEG procedure indeed measure electrical voltages which is generated naturally in the brain dose not inject any electrical signal.
- No voltage goes out from the measuring device.

### Disadvantages –

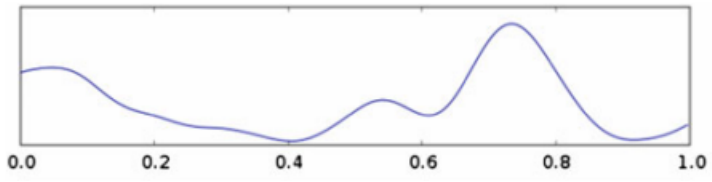
- EEG is less helpful than imaging techniques in determining the location of tumor, injuries and the precise nature for some diseases like stroke etc.
- EEG is a signal measurement technique and hence does not provide the image of the brain cross sections.
- EEG cannot indicate the location of the brain activity on the surface of the brain very well.

# Characteristics and Nature of EEG Signals

Frequency is one of the most important criteria for assessing abnormalities in clinical EEGs and for understanding functional behaviours in cognitive research. Frequency refers to rhythmic repetitive activity (in Hz). The number of cycles in second is counted as frequency. With billions of oscillating communities of neurons as its source, human EEG potentials are manifested as aperiodic unpredictable oscillations with intermittent bursts of oscillations. In healthy adults, the amplitudes and frequencies of such signals change from one state to another, such as wakefulness and sleep. There are five major brain waves distinguished by their different frequency ranges.

## Delta Wave –

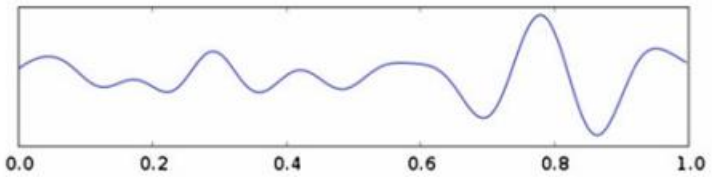
The delta wave lies between the range of 0.5–4 Hz and the shape is observed as the highest in amplitude and the slowest in waves. It is primarily associated with deep sleep, serious brain disorders and the waking state.



(Delta Wave)[4]

## Theta Wave –

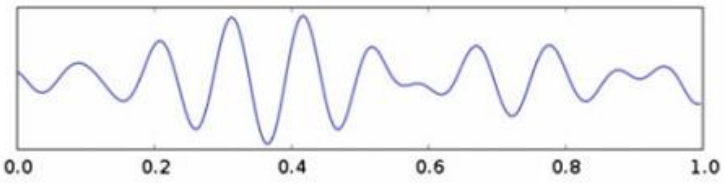
The theta wave lies between 4 and 8 Hz with an amplitude usually greater than 20 µV. The theta arises from emotional stress, especially frustration or disappointment and unconscious material, creative inspiration and deep meditation.



(Theta Wave)[4]

## Alpha Wave –

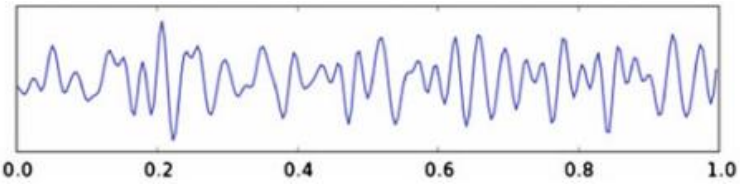
The alpha contains the frequency range from 8 to 13 Hz, with 30–50 m µV amplitude, which appears mainly in the posterior regions of the head (occipital lobe) when the subject has eyes closed or is in a relaxation state. It is usually associated with the intense mental activity, stress and tension. The alpha activity recorded from sensorimotor areas is also called mu activity.



(Alpha Wave)[4]

## Beta Wave –

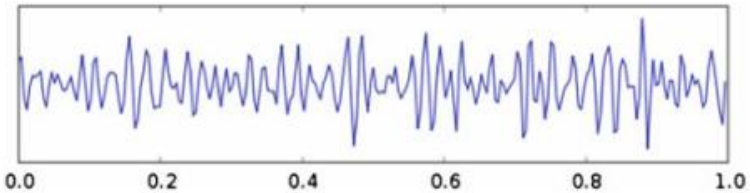
The beta is in the frequency range of 13–30 Hz. It is seen in low amplitude and varying frequencies symmetrically on both sides in the frontal area. When the brain is aroused and actively engaged in mental activities, it generates beta waves. These waves are characteristics of a strongly engaged mind. The beta is the brain wave usually associated with active things, active attentions and focusing on the outside world or solving concrete problems.



(Beta Wave)[4]

## Gamma Wave –

The gamma waves have the frequency from 30 Hz and up. This rhythm is sometimes defined as having a maximal frequency around 80 or 100 Hz. It is associated with various cognitive and motor functions.

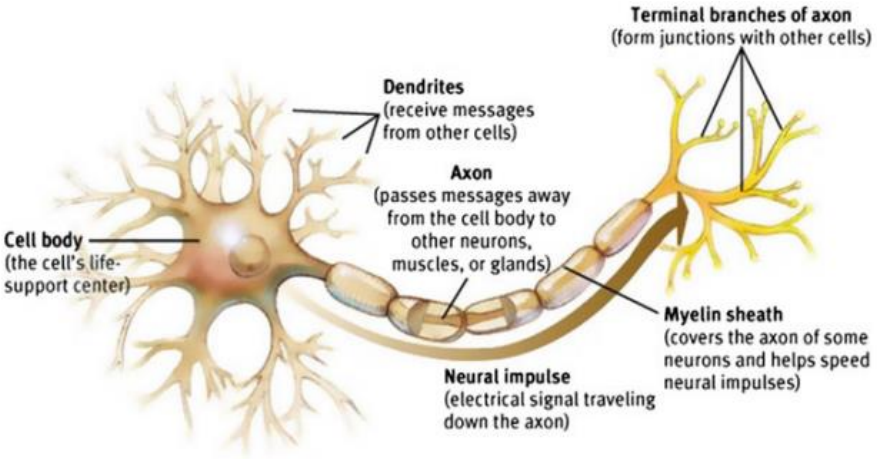


(Gamma Wave)[4]

# Generation Organism of EEG Signals in the Brain

The human brain consists of about 100 billion nerve cells called neurons and the electrical charges of the brain are maintained by these neurons. Neurons share the same characteristics and have the same parts as other cells, but their electrochemical character lets them transmit electrical signals and pass messages to each other over long distances. Neurons have three basic parts: cell body (soma), axon and dendrites shown in the figure below.

The cell nucleus is the heart of the cell giving instructions to the cell. The axon is a long, slender portion of the neuron that connects the nucleus of its own neuron to the dendrite of another. The dendrite is a short section of the neuron with many receptor sites for neurotransmitters that may be sent by a paired axon. Dendrites can be located on one or both ends of the cell. Through the axon–dendrite link, neurons can communicate between each other. This communication is made possible through the action potential [1].




(neuron)[1]

The action potential is an event where the ion pumps along the outside of an axon, rapidly changing the ionic makeup of the axon, allowing an electrical signal to travel quickly through the axon to the next dendrite. As a result of this rapid change in ionic charge, a voltage is generated, both on the inside and the outside of the cell membrane of the neuron. These neurons emit a chemical called neurotransmitters. The interneuron communication system is depicted in figures that the current flow that contribute to the surface EEG during a net excitatory input. When neurons are activated by means of an electrochemical concentration gradient, local current flows are produced. The electrical activity of neurons can be divided into two subsets; action potentials (AP) and postsynaptic potentials (PSP). If the PSP reaches the threshold conduction level for the postsynaptic neuron, the neuron fires and an AP is initiated.

The electrical potentials recordable on the scalp surface are generated by low frequency summed inhibitory and excitatory PSPs from pyramidal neuron cells that create electrical dipoles between the soma and apical dendrites (see figure below). These PSPs summate in the cortex and extend to the scalp surface where they are recorded as the EEG. Nerve cell APs have a much smaller potential field distribution and are much shorter in duration than PSPs. APs therefore do not contribute significantly to either scalp or clinical intracranial EEG recordings. Only large populations of active neurons can generate electrical activity recordable on the scalp. The voltage, when generated by a single cell, is typically too small to be accurately measured with present-day technology hence an amplifier is used to measure accurately [1].

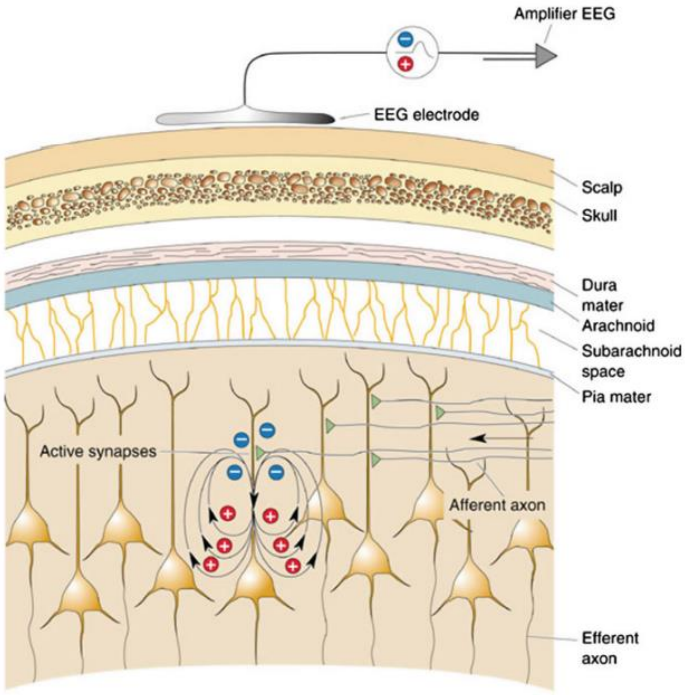
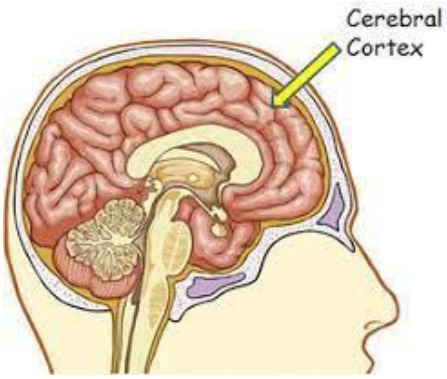



**Fig. 1.9** Illustration of generation of very small electrical fields by synaptic currents in pyramidal cells. The EEG electrode measures the signal through the thick layers of tissues. Only if thousands of cells simultaneously their small voltages can the signals become large enough to be seen at the surface of the scalp (Freeman 2004a, b)

[1]

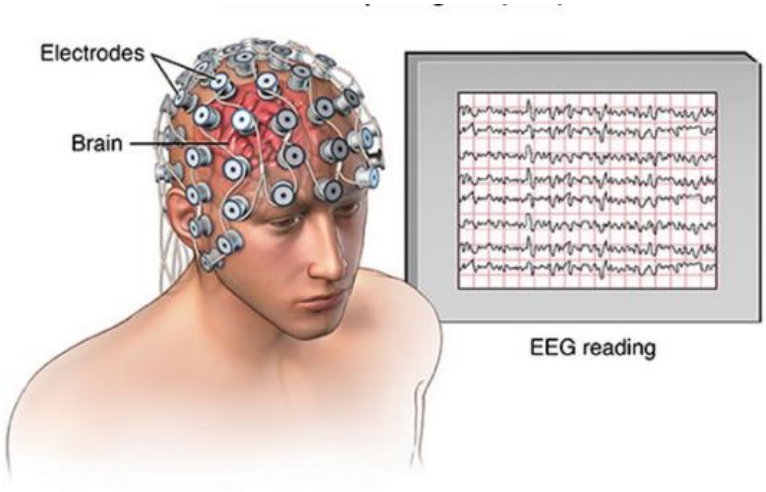



In the EEG measurement, the cerebral cortex is the most relevant structure as it is responsible for higher order cognitive tasks, such as problem solving, language comprehension, movement and processing of complex visual information. Due to its surface position, the electrical activity of the cerebral cortex has the greatest influence on EEG recordings.

(Human brain)[10]

## Recording the EEG Signals

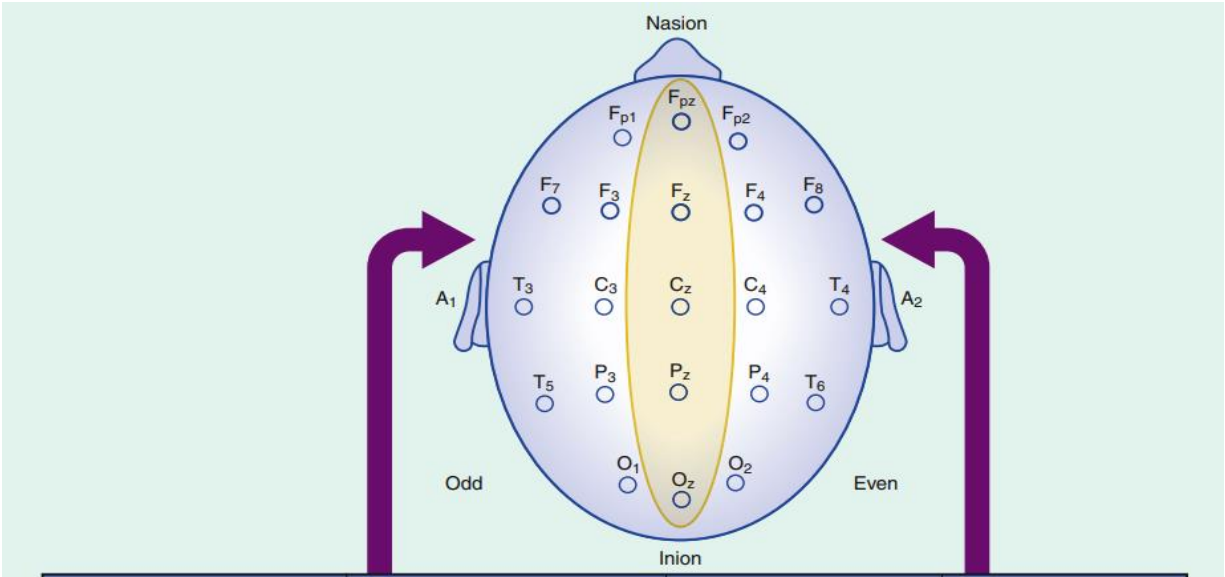
During the EEG test a number of small disks called electrodes are placed in different locations on the surface of the scalp with temporary glues. Each electrode is connected to an amplifier (one amplifier per pair of electrodes) and an EEG recording machine. Finally, the electrical signals from the brain are converted into wavy lines on a computer screen to record the results. Figure below presents an example of how electrodes are placed on the scalp during the recording of EEG signals and EEG signals are displayed on a computer screen. The electrodes detect tiny electrical charges that result from the activity of the brain cells. The charges are amplified and appear as a graph on a computer screen, or as a recording that may be printed out on paper. An expert then interprets the reading. EEG recordings, depending on their use can have from 1 to 256 electrodes recorded in parallel. This is called multichannel EEG recordings. One pair of electrodes usually makes up a channel. Each channel produces a signal during an EEG recording [9].




(Recording Setup)[9]

There are two types of EEGs, depending on where the signal is taken in the head**: scalp or intracranial**. For the **scalp EEG**, small electrodes are placed on the scalp with good mechanical and electrical contact. Special electrodes implanted in the brain during the surgery result in **intracranial EEG**. On the other hand, the EEG measured directly from the cortical surface using subdural electrodes is called the **electrocorticogram (ECoG)**. The amplitude of an EEG signal typically ranges from about 1 to 100 µV in a normal adult, and it is approximately 10–20 mV when measured with subdural electrodes such as needle electrodes. Since the architecture of the brain is non-uniform and the cortex is functionally organized, the EEG can vary depending on the location of the recording electrodes.

The question of how to place the electrodes is important, because different lobes of cerebral cortex are responsible for processing different types of activities. The standard method for the scalp electrode localization is the international 10–20 electrode system (Jasper 1958). The “10” and “20” represent actual distances between neighbouring electrodes are either 10 or 20% of the total front-back or right-left distance of the skull. The positions are determined by the following two points; nasion, which is the point between the forehead and the nose, level with the eyes, and inon which is the bony prominence at the base skull on the midline at the back of the head. Figure below presents the electrode position on the brain according to the international 10–20 system. Each location uses a letter to identify the lobe and a number to identify the hemisphere location. The letters F, T, C, P and O stand for Frontal, Temporal, Central, Parietal and Occipital, respectively. A “z” refers to an electrode placed on the midline. Even numbers refer to electrode positions on the right hemisphere, whereas odd numbers refer to those on the left hemisphere [5].




| Brain area | Left | Midline | Right |
|---|---|---|---|
| Frontal pole | Fp1 | Fpz | Fp2 |
| Frontal | F3 | Fz | F4 |
| Inferior frontal | F7 | | F8 |
| Anterior temporal | T1 or F9 | | T2 or F10 |
| Midtemporal | T3 | | T4 |
| Posterior temporal | T5 | | T6 |
| Central | C3 | Cz | C4 |
| Parietal | P3 | Pz | P4 |
| Occipital | O1 | (Oz) | O2 |

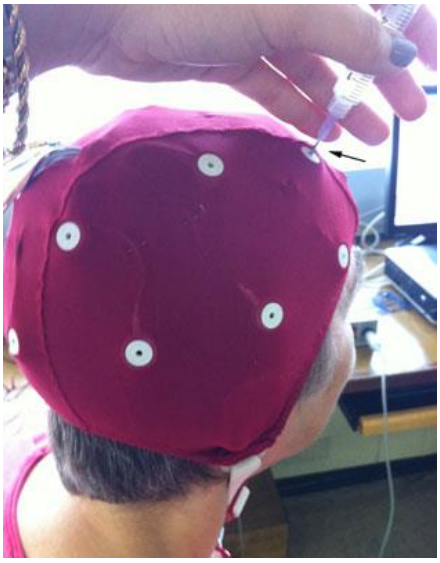
(Position of electrodes)[5]

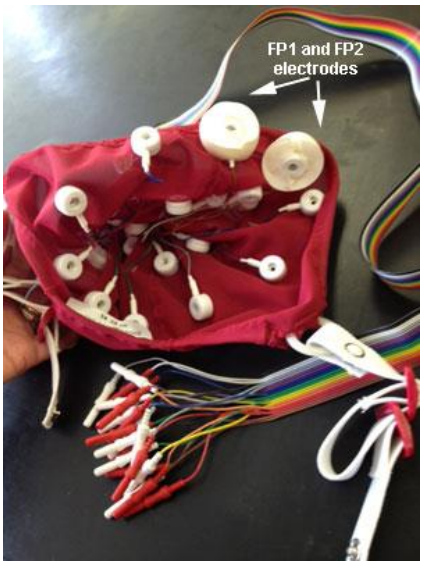
## Equipments

**EEG Electrodes –** Small metal discs usually made of stainless steel, tin, gold or silver covered with a silver chloride coating. They are placed on the scalp in special positions. These positions are specified using the International 10/20 system. EEG cables shown below are the disc electrodes to which electrode gel is applied and applied to the subject's scalp [6].

(Electrodes)[6]

**Electrode Gel –** It acts as a malleable extension of the electrode, so that the movement of the electrodes cables is less likely to produce artifacts. The gel maximizes skin contact and allows for a low-resistance recording through the skin. The electrolytic gel is injected into each cavity until a small amount comes out the hole in the mount. With a moderate amount of downward pressure, the syringe with a blunt needle is rapidly rocked back and forth.






(Electrodes Cap)[6]

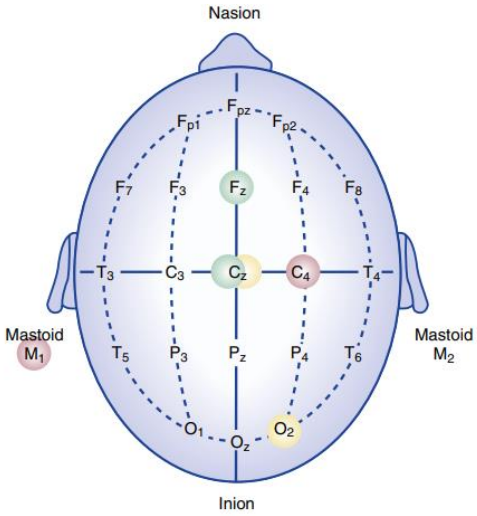
Many recording systems use a cap into which electrodes are embedded; this facilitates recordings when high density arrays of electrodes are needed or when comparing recording sites. The image to the right shows the inside of such a cap [6].

# EEG Sleep Signals

Sleep is not a uniform state of being. Instead, sleep is composed of several different stages that can be differentiated from one another by the patterns of brain wave activity that occur during each stage. These changes in brain wave activity can be visualized using EEG and are distinguished from one another by both the frequency and amplitude of brain waves. Sleep can be divided into two different general phases: REM sleep and non-REM (NREM) sleep. Rapid eye movement (REM) sleep is characterized by darting movements of the eyes under closed eyelids. Brain waves during REM sleep appear very similar to brain waves during wakefulness. In contrast, non-REM (NREM) sleep is subdivided into four stages distinguished from each other and from wakefulness by characteristic patterns of brain waves. The first four stages of sleep are NREM sleep, while the fifth and final stage of sleep is REM sleep. In this section, we will discuss each of these stages of sleep and their associated patterns of brain wave activity [7].

## EEG Recording

Wakefulness and sleep are determined by the characteristic patterns of the scalp EEG signals and are of fundamental importance in interpreting PSG studies. EEG records electrical potentials generated by the cortex but can reflect the influence of deeper brain structures, such as the thalamus. Measurement of the EEG signal is possible because of the relative difference in potential between two recording electrodes in grid 1 and grid 2 of the channel. A negative discharge in grid 1 relative to grid 2, by convention, is represented by an upwardly deflecting wave in grid 1 of the channel. The PSG references the left or right electrodes to electrodes on the opposite right and left ears (A2, A1) or mastoids (M2, M1). The general rule is to read only from the right cortical channel. However, when this channel develops artifact or the validity of the signal is suspected, comparison is made with the left channel [5].




(Arrangement for attaching electrodes)[5]

Electroencephalographic Recording criteria –

- Minimum paper speed of 10 mm/sec. One page equals 30 seconds and is defined as one epoch.
- Time constant of 0.3 seconds or low-frequency filter of 0.3 Hz.
- Pen deflections of 7.5 to 10 mm for 50μV are recommended.
- Electrode impedances should not exceed 5000 Ω.

## Electroencephalographic Activity during Wakefulness and Sleep

Here are the EEG wave patterns used to differentiate wake and sleep states and classify the sleep stages [5] –

**Alpha Activity –** 8 to 13 Hz rhythm, usually most prominent in occipital leads. Thought to be generated by cortex, possibly via dipole located in layers 4 and 5. Used as a marker for relaxed wakefulness and CNS arousals.

 [5]

**Theta Activity –** 4- to 8-Hz waves, typically prominent in central and temporal leads. Sawtooth activity (shown in figure) is a unique variant of theta activity (containing waveforms with a notched or sawtooth-shaped appearance) frequently seen during REM sleep.

 [5]

**Vertex Shape Waves –** Sharply contoured, negative-going bursts that stand out from the background activity and appear most often in central leads placed near the midline.

 [5]

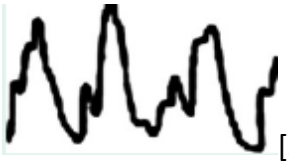
**Sleep Spindles –** A phasic burst of 11- to 16-Hz activity, prominent in central scalp leads; typically last for 0.5-1.5 seconds. Spindles are a scalp representation of thalamocortical discharges; the name derives from their shape (which is spindlelike).


[5]

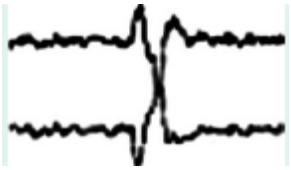
**K Complexes –** Recently redefined in the AASM manual as an EEG event consisting of a well delineated negative sharp wave immediately followed by a positive component standing out from the background EEG with total duration ≥ 0.5 seconds, usually maximal in amplitude over the frontal regions.


[5]

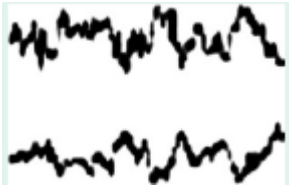
**Slow Wave Activity –** High-amplitude (≥75 μV) and low-frequency (≤2 Hz) variants of delta (1-4 Hz) activity. Slow waves are the defining characteristics of stage N3 sleep.


[5]

**Rapid Eye Movement (REM) –** Rapid eye movements are conjugate saccades occurring during REM sleep correlated with the dreamer's attempt to look at the dream sensorium. They are sharply peaked with an initial deflection usually.


[5]

**Slow Eye Movement (SEM) –** Slow eye movements are conjugate, usually rhythmical, rolling eye movements with an initial deflection usually ≥0.5 second in duration.


[5]

# Stages of Sleep

## Stage Wake (W) –

Typically the first several minutes of the record will consist of wake (W) stage. Stage W is recorded when more than 50% of the epoch has scorable alpha EEG activity. The EEG will show mixed beta and alpha activities as the eyes open and close, and predominantly alpha activity when the eyes remain closed. As the patient becomes drowsy, with the eyes closed, the EEG will show predominant alpha activity. If the patient moves in bed or rolls, the record will reflect this as a paroxysmal event characterized by high-amplitude activity with sustained increased artifact. The patient may enter stage N1 sleep for one or two epochs and then reawaken. Transitions may be difficult to score. From stage W, patients typically proceed to stage N1, but infrequently they may enter REM sleep or stage N2 sleep directly if the pressure to do so is high (reflecting a state of pathological sleep deprivation) [8].

[8]

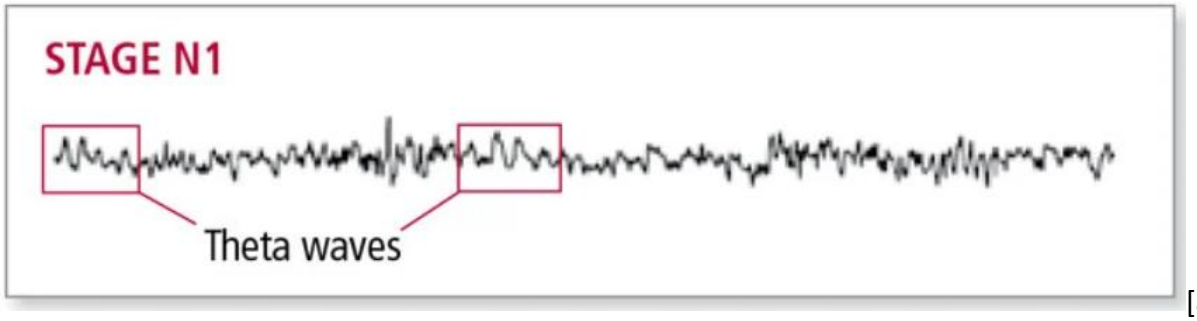
## Stage N1 NREM Sleep –

Stage N1 NREM sleep may also be termed transitional sleep or light sleep. Transition into sleep occurs following stage W sleep. Stage N1 NREM sleep is a transitional state characterized by low-voltage, fast EEG activity. The EEG patterns may be quite variable and may shift rapidly, making it sometimes difficult to interpret. Stage N1 sleep is scored when more than 15 seconds (≥50%) of the epoch is made up of theta activity (4 to 7 Hz), sometimes intermixed with low-amplitude beta activity replacing the alpha activity of wakefulness. Amplitudes of EEG activity are less than 50 to 75 μV. The alpha activity in the EEG drops to less than 50%. Stage N1 is of very short duration, lasting for 1 to 7 minutes.

Vertex sharp waves may occur toward the end of stage N1, but sleep spindles or K complexes are never a part of stage N1 sleep and neither are rapid eye movements. Vertex waves have a characteristic high-voltage sharp surface negative followed by surface positive component and are maximal over the Cz electrode. Arousals are paroxysms of activity lasting 3 seconds but less

than 15 seconds. If an arousal occurs in stage N1 sleep, and if the burst results in alpha activity for greater than 50% of the record, then the epoch is scored as stage W [5].

During drowsiness and stage N1 sleep, the eyes begin to slowly roll—SREMs. Sometimes eye movements during drowsiness and stage N1 NREM sleep may be jerky, irregular, or gently rolling. Theta activity may start to enter. Physiologically the patient's breathing becomes shallow, heart rate becomes regular, blood pressure falls, and the patient exhibits little or no body movement. This portion of sleep is distinguished by drifting thoughts and dreams that move from the real to the fantastic, along with a kind of floating feeling. The sleeper is still easily awakened and might even deny having slept. In general the time spent in Stage N1 increases with age [8].



[8]

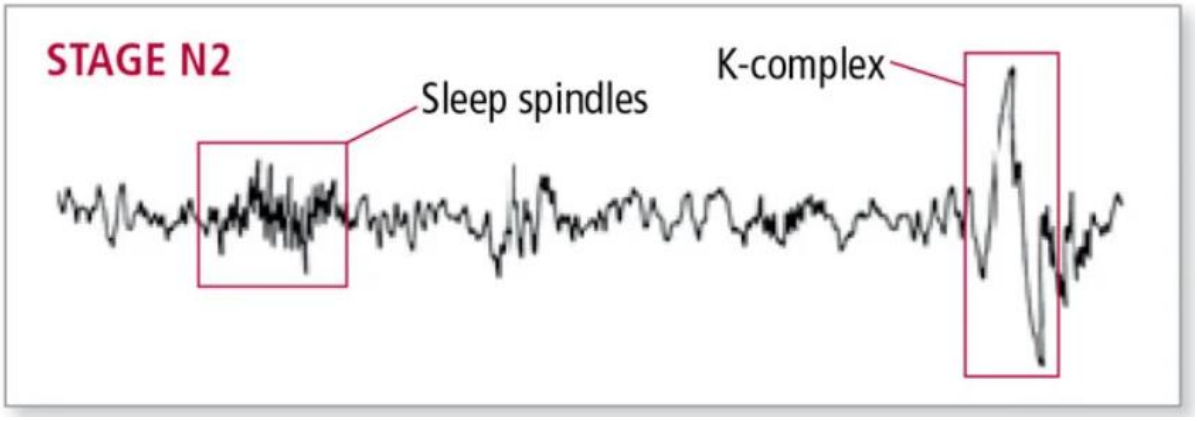
## Stage N2 NREM Sleep –

Stage N2 NREM sleep may also be termed sigma, spindle, or intermediate sleep (see Fig. 3.7). It is an intermediate stage of sleep, but it also accounts for the bulk of a typical PSG recording (up to 50% in adult patients). It follows stage N1 NREM sleep and initially lasts about 20 minutes. It is characterized by predominant theta activity (4- to 7-Hz EEG activity) and occasional quick bursts of faster activity. The EEG may show minimal alpha activity. Amplitude may increase from that seen in stage N1 sleep. Delta activity is only allowed to occur for less than 20% of the epoch. The threshold triggering slow wave sleep scoring is reached if 20% of the epoch consists of delta activity. K complexes and sleep spindles occur for the first time and are typically episodic.

K complexes (see figure below) are sharp, monophasic or polyphasic slow waves, with a sharply negative (upward) deflection followed by a slower positive (downward) deflection. K complexes must persist for at least 0.5 seconds. K complexes, even without the presence of sleep spindles, are sufficient for scoring stage N2 sleep. They are predominantly central vertex in origin. K complexes may occur with or without stimuli and in this respect they may represent a form of cortical evoked potential in a brain still minimally responsive to external stimuli. Sleep spindles (see figure below), which are also termed sigma waveforms, may appear here. They are generated in and controlled by activity within the midline thalamic nuclei (reticular thalamic

nucleus) and represent an inhibitory activity. Sleep spindles in the central vertex region and must persist for at least 0.5 seconds (i.e., six to seven small waves in 0.5 seconds), but are rarely longer than 1 second. Normal variant for scoring human sleep is the appearance in stage N2 sleep of low K complex quantity and high-amplitude spindle activity [5].

Stage N2 sleep is associated with a relative diminution of physiological bodily functions. Blood pressure, brain metabolism, gastrointestinal secretions, and cardiac activity decrease. The patient descends deeper into sleep, becoming more and more detached from the outside world and progressively more difficult to arouse [8].



[8]

## Stage N3 NREM Sleep –

Stage N3 NREM sleep may also be termed deep sleep, slow wave sleep (SWS), or delta sleep. The new AASM stage N3 includes R and K stages 3 and 4 together and does not make a distinction between them because such distinction probably does not have clear clinical significance. SWS is marked by high-amplitude slow waves. SWS constitutes the deepest, most refreshing and restorative sleep type, which tends to diminish with age.

Physiologically a patient going through SWS has the highest threshold for arousal. SWS may be associated with diffuse dreams (20% of dreams), and many parasomnias (sleep terrors, sleepwalking) manifest themselves here. Eye movements may cease altogether in this stage of sleep. Physiologically SWS is often linked with a peak in growth hormone secretion [5].

The arousal threshold of this stage of sleep is far greater than in stage N1 or N2 sleep. Both K complexes and sleep spindles may be seen in stage N3 sleep. If the patient wakes up from slow wave sleep, he or she may appear confused or disoriented. The patient may experience “sleep inertia” or “sleep drunkenness,” seeming unable to function normally for several minutes. The duration of sleep inertia depends on prior sleep deprivation and CNS-active medications [8].

[8]

## Stage REM Sleep –

Stage R or REM sleep may also be termed paradoxical sleep or active sleep. REM sleep typically occurs about 90 to 120 minutes after sleep onset in adults. It typically occupies 20% to 25% of the major period of sleep and is characterized by relatively low-amplitude, mixed-frequency EEG theta waves, intermixed with some alpha waves, usually 1 to 2 Hz slower than wake (see figure below). Brain waves are small and irregular, with pronounced bursts of eye activity (rapid eye movements).

Unlike the progressive relaxation noted during the NREM sleep stages, physiological activity during REM sleep is significantly higher. Blood pressure and pulse rate may increase dramatically or may show intermittent fluctuations. Breathing becomes irregular, and brain oxygen consumption increases. The body seems to have abandoned its effort to regulate its temperature during the REM phase and resembles a state of poikilothermy, drifting gradually toward the temperature of the environment [5].

Pathologically short REM sleep latency may point to a state of acute or cumulative sleep deprivation, may be caused by abrupt discontinuation of REM sleep–suppressing agents (such as antidepressants), narcolepsy-cataplexy syndrome, and may also suggest a major affective disorder. A variety of sleep disorders are strongly associated with REM sleep, including a variety of parasomnias (REM sleep behavior disorder, REM nightmares) and obstructive sleep apnea, which may be more pronounced during this sleep period [8].

[8]

## Sleep Stages Classification

A model is created which analyzes the dataset of the EEG signals of sleep stages and classifies the given signal as W, N1, N2, N3 and R signals accurately. For this, I wrote the code in python language in a jupyter notebook and implemented it in Google Colab. There are 4 stages is the model –

1. Environment setup
2. Loading the data
3. Feature engineering
4. Multi – class classification workflow

## Environment Setup

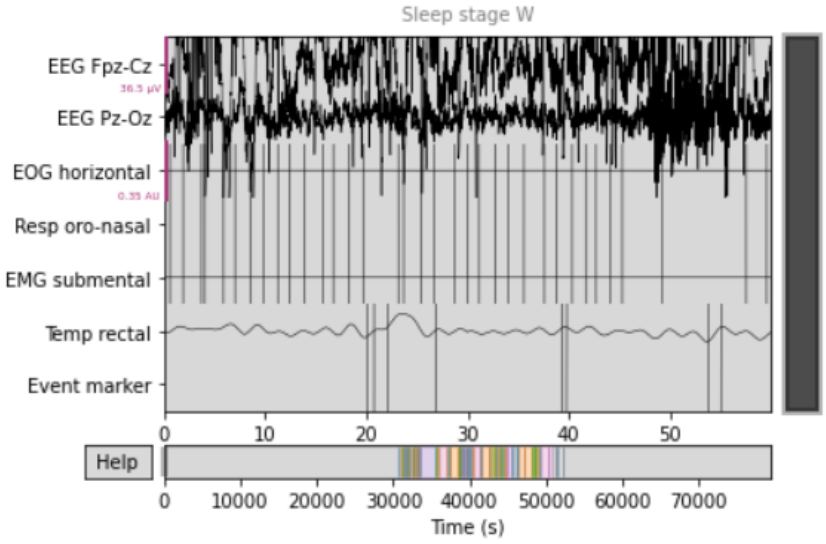
In this section, all the necessary libraries of python are imported and installed. The main libraries used here are –

- NumPy – For adding support for large, multi-dimensional arrays and matrices, along with a large collection of high-level mathematical functions to operate on these arrays.
- Matplotlib – Matplotlib is a cross-platform, data visualization and graphical plotting library for Python and its numerical extension NumPy.
- MNE – MNE-Python software is an open-source Python package for exploring, visualizing and analyzing human neurophysiological data such as MEG, EEG, ECoG, and more.
- SKlearn - The SKlearn library contains a lot of efficient tools for machine learning and statistical modeling including classification, regression, clustering and dimensionality reduction. [11]

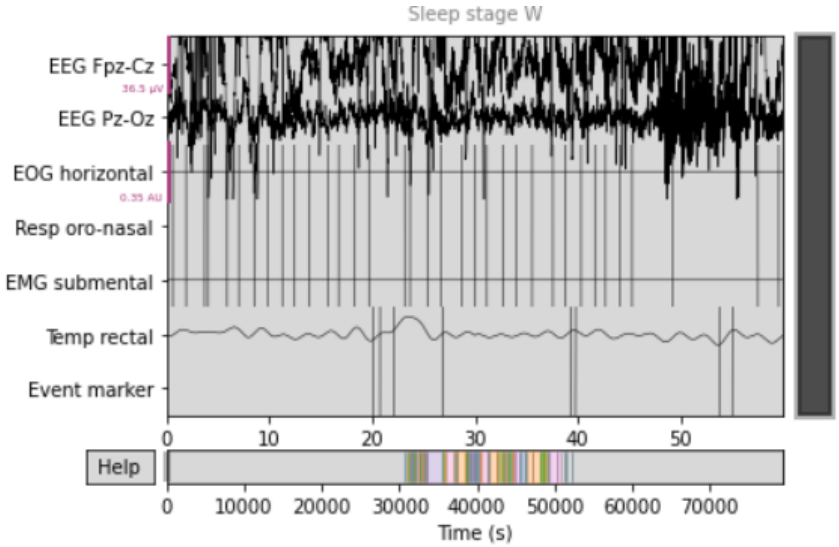
# Loading the Data

The dataset was downloaded from Sleep Physionet. This dataset has recordings of 2 subjects namely Alice and Bob. The intention is to predict the sleep stages of Alice's and Bob's data. This problem is tackled as supervised multiclass classification task. The aim is to predict the sleep stage from 5 possible stages for each chunk of 30 seconds of data. Alice's dataset and Bob's dataset were combined. Then a classifier algorithm was created and was run on this combined dataset to predict the sleep stages.

Firstly, the data was downloaded from the Sleep Physionet dataset using the function mne.datasets.sleep_physionet.age.fetch_data. [12]

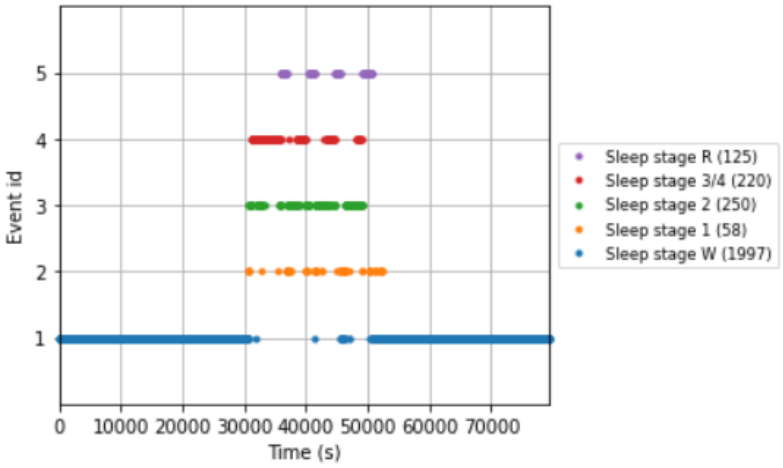



Alice's Data




Bob's Data

Then from this data, an epoch of 30 seconds of events was created only for the EEG signals. The other types of signals were labeled as 'miscellaneous'. The Sleep Physionet dataset is annotated using 6 stages of sleep but we will work only with 5 stages: Wake (W), Stage 1, Stage 2, Stage 3/4, and REM sleep (R). To do so, we use the event_id parameter in function mne.events_from_annotations to select which events are we interested in and we associate an event identifier to each of them. Here, I have merged Stage 3 and 4 into Stage 3.

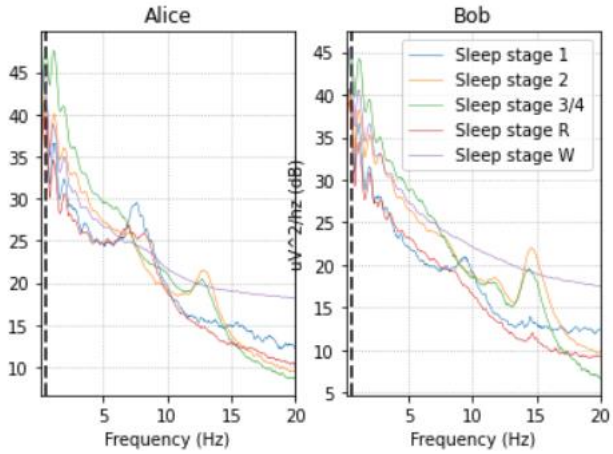



This image is the duration of each sleep stage in Alice's data.

The data set of Alice contains 2650 epochs and data set of Bob contains 2802 epochs of 30 seconds each.

## Feature Engineering

Observing the power spectral density (PSD) plot of the epochs grouped by sleeping stage we can see that different sleep stages have different signatures. These signatures remain similar between Alice and Bob's data.




PSD Plots of Alice's and Bob's epoch.

After this, a function is created to extract EEG features based on relative power in specific frequency bands to be able to predict sleep stages from EEG signals. A scikit-learn transformer from a Python function was designed as well to read the frequencies from the graphs in order to be able to classify them into the stages shown below as per the frequency value. 1400 epochs each from Alice's and Bob's dataset were taken for classification.

```
# specific frequency bands
FREQ_BANDS = {"delta": [0.5, 4.5],
              "theta": [4.5, 8.5],
              "alpha": [8.5, 11.5],
              "sigma": [11.5, 15.5],
              "beta": [15.5, 30]}

psds, freqs = psd_welch(epochs, picks='eeg', fmin=0.5, fmax=30.)
```

Screenshot of code for making frequency bands.

## Multi – class classification workflow

Here, the 2 key features of sckit-learn: Pipeline and FunctionTransformer were used. For classification of the sleep stages, Random Forest classifier was used.

Scikit-learn pipeline composes an estimator as a sequence of transforms and a final estimator. The pipeline's steps process data and they manage their inner state which can be learned from the data. "fit" to learn on the data and acquire state and "transform" (or "predict") to actually process the data and generate a prediction.

The FunctionTransformer converts a python function in an estimator compatible object. As the name suggests, it takes an argument and returns the result of the function.

Random forest consists of a large number of individual decision trees that operate as an ensemble. Each individual tree in the random forest spits out a class prediction and the class with the most votes becomes the model's prediction.

```
pipe = make_pipeline(FunctionTransformer(eeg_power_band, validate=False),
                     RandomForestClassifier(n_estimators=100, random_state=42))

# Train
y_train = epochs_train.events(train = 0.2, [:, 2])
pipe.fit(epochs_train, y_train)

# Test
y_pred = pipe.predict(epochs_test)
```

Screenshot of code of the classifier algorithm run on the epochs.

## Results

### Confusion Matrix

| | W | N1 | N2 | N3 | R |
|---|---|---|---|---|---|
| W | 1853 | 0 | 0 | 1 | 0 |
| N1 | 91 | 3 | 6 | 5 | 5 |
| N2 | 119 | 12 | 385 | 34 | 12 |
| N3 | 0 | 0 | 4 | 101 | 0 |
| R | 89 | 30 | 19 | 0 | 32 |

### Classification Report

| | precision | recall | f1-score | support |
|---|---|---|---|---|
| Sleep stage W | 0.86 | 1.00 | 0.92 | 1854 |
| Sleep stage 1 | 0.06 | 0.03 | 0.04 | 109 |
| Sleep stage 2 | 0.93 | 0.68 | 0.79 | 562 |
| Sleep stage 3/4 | 0.78 | 0.96 | 0.84 | 105 |
| Sleep stage R | 0.67 | 0.19 | 0.29 | 170 |
| accuracy | | | 0.84 | 2800 |
| macro avg | 0.65 | 0.57 | 0.57 | 2800 |
| weighted avg | 0.83 | 0.85 | 0.82 | 2800 |

- “true positive” for correctly predicted event values.
- “false positive” for incorrectly predicted event values.
- “true negative” for correctly predicted no-event values.
- “false negative” for incorrectly predicted no-event values.

$$Precision = \frac{TP}{TP + FP} \qquad Recall = \frac{TP}{TP + FN}$$

$$F1\ Score = 2 * \frac{Precision * Recall}{Precision + Recall} \qquad Accuracy = \frac{TN + TP}{TN + FP + TP + FN}$$ [13]

**The overall accuracy of the model is 84.64%.**

# References and Bibliography

For preparation of this report and the presentation, I referred the following sources –


1. Siuly Siuly, Yan Li, Yanchun Zhang - EEG Signal Analysis and Classification - Techniques and Applications, 2016.
2. Aboul Ella Hassanien, Ahmad Taher Azar, Brain-Computer Interfaces, 2015.
3. Patrick Cunningham Keith Lang Brian Mearns Lee Russell Stephen Sanchez, EEG Brain-Computer Interface Project, April 2007.
4. Mohammadshakib Moshfeghi, Aliye Tuke Bedasso, Jyoti Prasad Bartaula, Emotion Recognition from EEG Signals using Machine Learning, Bachelor Thesis Electrical Engineering, March 2013.
5. Raman K. Malhotra, Alon Y. Avidan, Sleep Stages and Scoring TechniqueI, Chapter 3, 2017.
6. Bryn Farnsworth, What is EEG and how does it work, 13th July 2021 https://imotions.com/blog/what-is-eeg/
7. Stages of Sleep, https://courses.lumenlearning.com/wsu-sandbox/chapter/stages-of-sleep/
8. A Harvard Health article, The Science of Sleep: Stages and Cycles, https://www.helpguide.org/harvard/biology-of-sleep-circadian-rhythms-sleep-stages.htm
9. Electroencephalography, https://en.wikipedia.org/wiki/Electroencephalography
10. Hafeez Ullah Amin, Wajid Mumtaz, Ahmad Rauf Subhani, Aamir Saeed Malik, Classifications of EEG Signals Based on Pattern Recognition Approach, Front. Comput. Neurosci., 21 November 2017 https://www.frontiersin.org/articles/10.3389/fncom.2017.00103/full
11. B Kemp, AH Zwinderman, B Tuk, HAC Kamphuisen, JJL Oberyé. Analysis of a sleep-dependent neuronal feedback loop: the slow-wave microcontinuity of the EEG. IEEE-BME 47(9):1185-1194 (2000).
12. Goldberger AL, Amaral LAN, Glass L, Hausdorff JM, Ivanov PCh, Mark RG, Mietus JE, Moody GB, Peng C-K, Stanley HE. (2000) PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Resource for Complex Physiologic Signals. Circulation 101(23):e215-e220
13. Chambon, S., Galtier, M., Arnal, P., Wainrib, G. and Gramfort, A. (2018)A Deep Learning Architecture for Temporal Sleep Stage Classification Using Multivariate and Multimodal Time Series. IEEE Trans. on Neural Systems and Rehabilitation Engineering 26: (758-769).