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Analysis of Electroencephalography (EEG) Signals and Its Categorization – A Study

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Abstract

Human brain consists of millions of neurons which are playing an important role for controlling behavior of human body with respect to internal/external motor/sensory stimuli. These neurons will act as information carriers between human body and brain. Understanding cognitive behaviour of brain can be done by analyzing either signals or images from the brain. Human behaviour can be visualized in terms of motor and sensory states such as, eye movement, lip movement, remembrance, attention, hand clenching etc. These states are related with specific signal frequency which helps to understand functional behavior of complex brain structure. Electroencephalography (EEG) is an efficient modality which helps to acquire brain signals corresponds to various states from the scalp surface area. These signals are generally categorized as delta, theta, alpha, beta and gamma based on signal frequencies ranges from 0.1 Hz to more than 100 Hz. This paper primarily focuses on EEG signals and its characterization with respect to various states of human body. It also deals with experimental setup used in EEG analysis.

Keywords: Electroencephalography; brain signal; modality; brain states

1. Introduction

Brain is a significant part of human which controls entire parts of human body. Brain can be viewed as collection of interconnected neurons which decides human behavior [12]. Understanding functional and cognitive behavior of human brain is an interesting area for medical researchers to find out better solution for various brain related issues [41] [26]. Medical doctors and radiologists perception, left side of brain is responsible for controlling right side of the human body and right side of the brain controls left side of human body. Brain images/signals can be acquired by using modalities such as, Computed Tomography(CT), positron Emission Tomography(PET), Magnetic resonance Imaging(MRI) and functional Magnetic resonance Imaging(fMRI) [42] [43] [24]. Each method has its own merits and demerits. Electroencephalography (EEG) is another modality which helps to analyze brain and its behaviors based on respective frequency of a signal. A significant characteristics of EEG includes, non destructive, pain less, side effect less and accurate interpretations for some brain diseases such as, epilepsy, memory loss, Alzheimer and autism[11][15] [21][22][25].. EEG signals are classified based on

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signal frequencies for different states/stimuli such as eye ball movement, eye open, eye close, finger clenching etc[44][23].These signals are associated with specific frequency ranges from 0 Hz to 100 Hz. Some signals have more than 100 Hz in frequency. This signal based analysis with respect to different states helps medical researchers for better understanding of functional and behavioral characteristics of complex brain structure.

This paper is organized as follows. Section 2 deals with relationship between EEG phenomena and lobes of brain. Section 3 explains EEG device and its characteristics. EEG atlas with respect to the lobes of brain and signal acquisition directions is discussed in section 4. Pre and post processing phases of EEG signal analysis is given in section 5. Section 6 deals characterization of EEG signals based on its frequency and section 7 discusses experimental design for eye movement of epilepsy patient. Section 8 concludes the paper.

2. EEG and Lobes of Human Brain

Brain is the most important functional organ, which controls and coordinates other muscles and nerves in our body. Brain is divided into two hemispheres known as left hemisphere and right hemisphere [1]. Each hemisphere is further divided into four lobes such as, Frontal, Temporal, Parietal and Occipital lobes. Frontal lobe is the largest lobe which is located behind the forehead. The left frontal lobe is responsible for speech and language. It concerned with planning, organizing, problem solving, memory, impulse control, decision making, selective attention and controlling behavior and emotions. Frontal lobe gets damage it may affect emotions, languages and memory [20][33][34].

Temporal lobe is located on the sides of the brain under parietal and behind frontal lobe. This is responsible for sound and speech in various aspects of memory. It may create hearing, language and sensory problems during damage. Occipital lobe is placed at the lower back of the head which relates perception and process visual information. It creates visual and perception defects after getting injury on this part [2][36]. Behind the frontal lobe, Parietal lobe is located which integrates sensory information from different parts of body. It may create the inability problem for recognize and locate parts of the body [see Fig. 1].

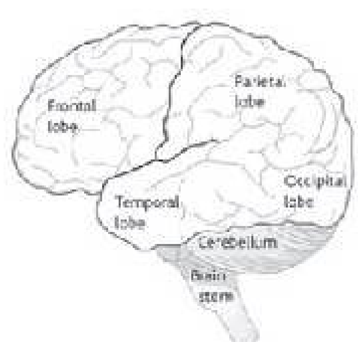


Fig.1. Structure of human brain and its Lobes

From the medical history, It is well known that specific action/ activity/states are controlled by particular part of the brain. For example, table 1 represents cranial nerve and its associative functionalities. Functional behavior of brain and their associated location are helpful to determine electrode positions for EEG recordings.

Table 1 Functions of Cranial nerves

S.No.	NAME	FUNCTION
1.	Olfactory	Smell
2.	Optic	Vision
3.	Oculomotor	Eye movement
4.	Trochlear	Eye movement
5.	Trigeminal	Facial sensation
6.	Abducent	Eye movement
7.	Facial	Face movement
8.	Vestibulocochlear	Hearing and balance
9.	Glossopharyngeal	Taste
10.	Vagus	Involuntary muscles
11.	Accessory	Voluntary neckmuscle
12.	Hypoglossal	Tongue movement

3. EEG Device and Its Characteristics

Electroencephalography is a technique that reads electrical potential from the brain and measured using special device called Electroencephalogram (EEG). This device comprised of electrodes, conductive gel, amplifiers and Analog to Digital converter as shown in fig. 2. The electrodes or leads are used to conduct electrical activity from the scalp of the brain. Different types of electrodes are used in general for EEG analysis. One type of electrode is reusable disk. These electrodes placed on the scalp with small amount of conductive gel (Ag-Cl) applied under the disk [13]. Disk will be with gold, tin and silver compositions. The cost of the electrode is low and life may depend upon metal used on disk and insulating medium on wire. These electrodes have chance to fall down from the scalp which leads higher chances of artifacts[18]. EEG cap is another type, which is having facility to choose different number of electrodes and types of electrodes. EEG cap is also available with reusable disks where conductive gel will be injected on the holes of the cap. It is preferred for multi channel recording but a complex issue in this cap is that one electrode gets fail results in changing the whole cap and it is also difficult to trace the failed one[17].

Fig.2. (a) ElectroEncephaloGram ; (b) Structure of Electrode

4. EEG Atlas Versus Lobes of Human Brain

The electrodes are arranged according to 10-20 standards for EEG placement [6]. These electrodes are labeled by letters (ie. F-Frontal, T-Temporal, C-Central, P-Parietal, O-Occipital) which indicates the lobes of the brain. Midline region is referred by a label with 'z'. Odd numbers indicates left hemisphere and even numbers are used to indicate right hemisphere. For example, C3 is located on left central lobe. An additional sensor is used to record special applications such as, heart rate, skin conductance, eye movements, and respiration.

EEG atlas with respect to electrode position is given the fig.3. Cortex around Cz, C3 and C4 locations deals with sensory and motor functions. Pz, P3 and P4 are related to cognitive processing. T4 and T6 represent emotional memory while T3 and T5 stands for verbal memory functions. Oz, O1 and O2 deals with visual processing stimuli. Fz is placed near intentional and motivational centers, F8 and F7 are located close to emotional and verbal expressions. F3 and F4 are located at motor planning activities. FPz, FP1 and FP2 deals with attention and judgment impulses [16], [Fig. 3].

The positioning of electrodes also referred as Montages follows two methods such as, Referential [35] or bipolar [38] electrodes. In Referential method, each electrode records the potential difference compared to reference electrode. The reference electrode is not perfect while placing it on nose tip or foot. Reference electrodes are placed on both Ear lobes called as linked ear lobes[37][31]. In bipolar method, potential differences are recorded between paired active electrodes. It connects the electrode in sequential manner and forms chain in Longitudinal or Transverse form. Signals acquired in bipolar and monopolar methods are shown in table 2.

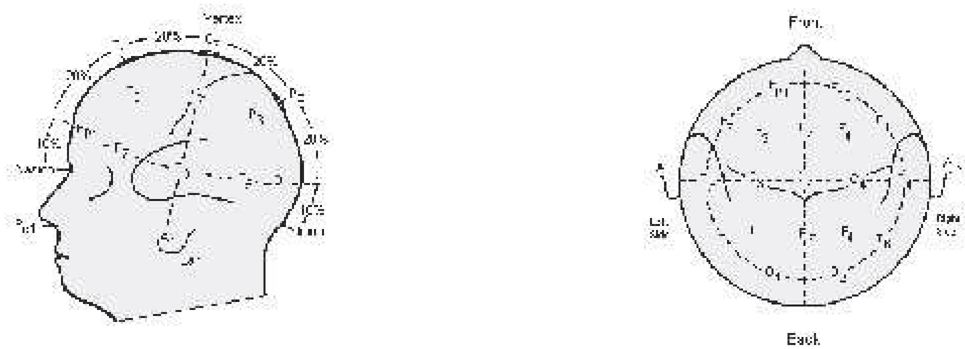


Fig.3. Point labels of 10-20 electrode placement systems (courtesy : google images)

Referential Montage (Linked ear lobes)	Bipolar Montage (Longitudinal)	Bipolar Montage (Transverse)
FP2 – A2	FP2 – F4	F8 – F4
F4 – A2	F4 – C4	F4 – Fz
C4 – A2	C4 – P4	Fz – F3

Table 2. Types of Montages

P4 – A2	P4 – O2	F3 – f7
F8 – A2	FP2 – F8	T4 – C4
T4 – A2	F8 – T4	C4 – Cz
T6 – A2	T4 – T6	Cz - C3
O2 – A2	T6 – O2	C3 – T3
FP1 – A1	FP1 – F3	T6 – P4
F3 – A1	F3 – C3	P4 – Pz
C3 – A1	C3 – P3	Pz – P3
P3 – A1	P3 – O1	P3 – T5
F7 – A1	FP1 – F7	T6 – O2
T3 – A1	F7 – T3	O2 – Pz
T5 – A1	T3 – T5	Pz – O1
O1 – A1	T5 – O1	O1 – T5

5. EEG Signal Analysis and its phases

EEG framework with frequently used modules in most of the EEG analysis is shown in fig. 4. In EEG Signal Acquisition phase, raw EEG signals will be collected directly from the scalp of the brain. Second phase is a preprocessing stage which consist of two processes such as, artifact removal [11] and data filtering [12]. Identification and removal of artifact is a challenging phase in signal acquisition and analysis. Artifacts may be triggered due to various factors such as, head motion during signal acquisition, physical problems in electrode/channel/lead, and connectivity issues between head and device. These artifacts will also create signals with abnormal frequency and shapes. Fig. 5 shows an artifact signal due to motion artifact during EEG experimental analysis of eye boll movement after 47th second[28][29]. Next phase in signal analysis is feature extraction where feature of the signal can be derived using various signal processing techniques like Fourier Transform, Wavelet, Principal Component Analysis and meaningful features are extracted (abnormal/normal)[15]. The most popular automated method is Fourier transform, which basically categorize the signals into four frequency bands- Delta (<4 Hz), Theta (4-8 Hz), Alpha (8-13Hz) and Beta (13-30 Hz) [5]. Fast Fourier Transform (FFT) method will not be suggestible for higher noise ratio in EEG signals. For that, Parametric Spectrum Estimation methods like Autoregressive (AR) used to reduce spectral loss and gives better frequency resolution. Parametric method is not suitable for non-stationary signals like EEG signal [6]. Classification is another significant phase uses extracted features for getting target observations [4]. Feature Extraction and Classification are the two critical problems encountered in time domain analysis.

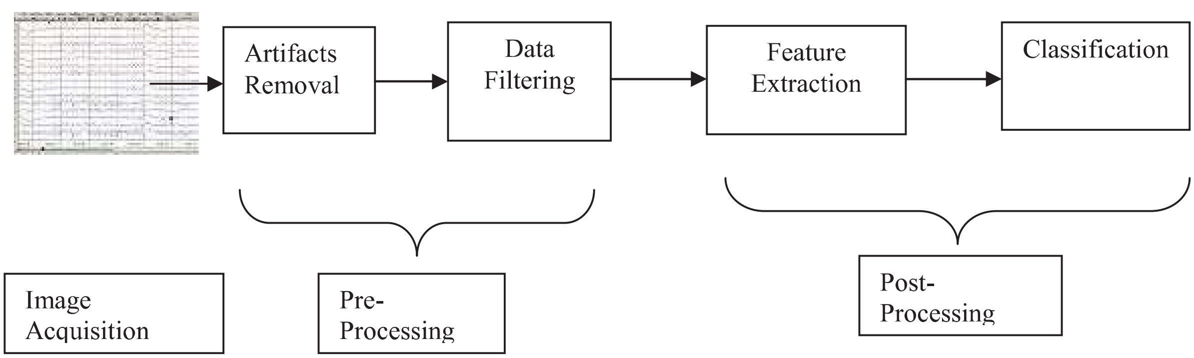


Fig.4. EEG signal processing stages

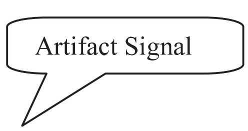
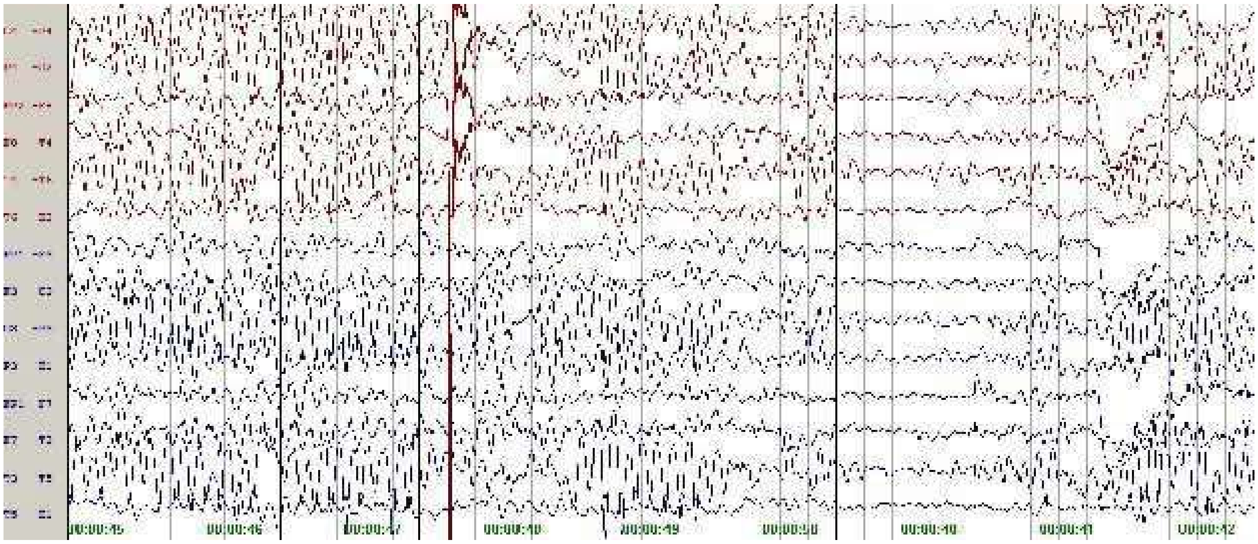


Fig. 5. Artifact signal in eye stimuli experiment



6. Signals and its characterizations

EEG waveforms are generally classified according to their frequency, amplitude, shape as well as position of the electrodes on the scalp. Frequency (Hertz, Hz) is the basic unit used to determine normal or abnormal rhythms. The familiar classification of waveforms such as, alpha, beta, theta, delta and gamma are based on signal frequency. Some waves are recognized based on their shape, head distribution and symmetry property[27]. Certain pattern of waveform is normal at specific age, state of alertness and sleep. The continuous rhythms of the brain or brain waves are categorized by frequency bands. Brain wave frequency differs corresponds to different behavior and mental states of the brain[14][32], [39].

6.1 Delta (0.1 - 4 Hz)

Delta wave is highest in amplitude and slowest wave. It represents the grey matter of the brain. This slowest brain wave activity is found in all stages of sleep especially in stage 3 and 4. It is normal and is dominant rhythms in infants and rarely observed by experienced mediators. Delta waves are abnormal for adults who are awake and it also induces growth hormone(see fig. 6).

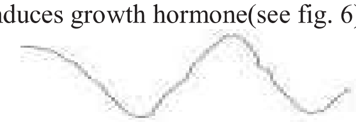


Fig. 6. Delta wave

6.2 Theta (4 – 8 Hz)

Theta waves are ranges from 4 to 8 Hz which are related to subconscious activity. These types of brainwaves are observed in deep relaxation and meditation. These signals influences on spiritual related researches in terms of getting extrasensory skills observed through meditations by reaching theta activity level. Psychotics can also gather awareness information by using this level. It is abnormal in adults but it is normal for children under 13 years. It encourages the production of human growth hormone, serotonin hormone that increase relaxation and get relief from pain, cortical hormone which helps for memory and learning(see fig. 7).

Fig. 7. Theta Wave

6.3 Alpha (8 – 13 Hz)

Alpha waves are seen in all age groups commonly found in adults who is awake but relaxed with closed eyes. It occurs on both sides of the head but slightly higher amplitude in non dominant side and recorded from the occipital and parietal regions of the brain. It represents white matter of the brain. It acts as a bridge between conscious and subconscious mind. Alpha induces the production of serotonin, a chemical reactor that increases relaxation and relief from pain. An abnormal case is alpha coma, caused by hypoxic ischemic encephalopathy of destructive process in the pons(see fig. 8).

Fig. 8. Alpha Wave

6.4 Beta (13 - 30 Hz)

Beta waves are concerned with behavior and actions. It is related to the sense of what we see, touch, hear, smell and taste. It is usually seen in both sides of frontal and parietal lobes. Beta waves induces the production of Cortisol, which is the major age accelearting hormone within the brain and also interface with learning and memory. These waves are occurred in conscious state like talking, problem solving, judgment, and decision making. These waves are located around cortical activity and it is also having an ability to think and access(see fig. 9).

Fig. 9. Beta Wave

6.5 Gamma (30 -100 Hz)

Gamma waves are associated with perception and consciousness which falls around 30 – 70 Hz. This wave is analyzed after the development of digital EEG as analog is restricted to record and measur rhythms lesser than frequency of 25 Hz. These waves are occurred during hyper alertness and integration of sensory inputs. Gamma properly combines the senses and memory together for an ultimate experience(see fig. 10).

Fig. 10. Gamma Wave

Table 3 represents some more states related to various signals and respective regions in brain.

6.6 Signal categorization based on Morphological Structure

Morphology refers shape of a waveform/rhythm. Some rhythm based on shape includes, K complex, V waves, Lambda waves, sleep spindles, Spike waves and Mu waves are recognized by their shape than by their frequency. It may be abnormal in some persons and normal in others.

Table 3 Brain wave frequencies with their characteristics

Type	**Frequency (Hz)**	**Behavioral /Psychological State**	**Neurotransmitter/ Hormone**	**Location**
Delta	0- 4	Deep rest, dreamless sleep	Human Growth Hormone, Melatonin	Frontally in adults, Posteriorly in children
Theta	4 – 8	Deeply relaxed	Serotonin, Acetylcholine, Anti-cortisol, Endorphins,Human Growth Hormone	Thalamic region
Alpha	8 – 13	Day dream, calm	Serotonin, Endorphins, Acetylcholine	Posterior regions
Beta	13 – 30	Alert, active thinking, anexity, panic attack, focus, concentration	Adrenaline, Cortisol, Norepinephrine, Dopamine	Frontal and Parietal
Gamma	30 - 100	combination of two senses	Serotonin, Endorphins	Somatosensory cortex

6.7 Mu Waves

These waves have specific shape and occur in the range of 8-13 Hz and associated with motor cortex and in parasagittal regions. Morphological structure of Mu waves shows consecutive 'V' representation in rhythmic form(see fig. 11).

Fig. 11. Mu Wave

6.8 K-Complex

K-Complex wave is often occurred in a run of theta waves with high amplitude followed by an arousal response. It also occurred with noise or other stimuli especially in sleep stage 2. K-Complex waves are large amplitude delta frequency waves with sharp apex(see fig. 12).

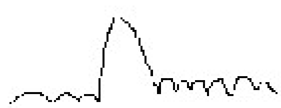


Fig. 12. K-Complex Wave

6.9 V Waves

V waves occur in two sides of parasagittal areas and mostly occur during sleep. These signals appear after sleep disturbances and like K complex, it may present during brief semi arousals. It is easy to recognize(see fig. 13).

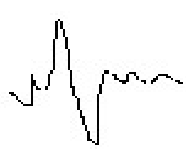


Fig. 13. V Wave

6.10 Lambda Waves (λ)

They are sharp transient occur over the occipital region of walking person during visual exploration. It is triangular in shape and occurs when the eyes stare at blank surface. Lambda waves occur when reading or watching Television It is normal waveform and can occur as single wave/short runs/long runs (see fig. 14).

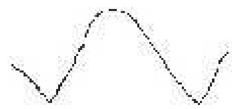


Fig. 14. Lambda Wave

6.11 Spike Waves

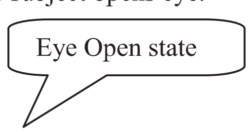
Spike wave is seen in all ages of people preferably in children. It has large amplitude slow wave with 3 Hz usually in delta wave and originate from thalamic structures. These signals may occur synchronously and systematically in the generalized epilepsies or focally in parietal. This wave occurs more usually with brain injury and the Lennox- Gas taut syndrome.

6.12 Sleep Spindles (σ)

It is also called as sigma activity which ranges up to 11-15 Hz range in upper level of alpha or lower level of beta. Spindles are group of waves that occur during sleep stages but particularly in stage 2. It is seen mostly in parasagittal regions.

7. Experimental Design

EEG experiments are best suitable for brain issues such as, epilepsy[19],Alzhemeir[3], seizure disorder[11], attention deficit disorder[8], learning disabilities[5], anxiety disorders[7], fetal alcohol syndrome[4], autism[40], chronic pain[9], insomnia, dyslexia[10] etc. These issues are sensitive to the brain signals with specific frequency. Experimental setup primarily based on some factors which include type of study, pre and post state analysis, number of electrodes/channels used etc. The subject is instructed to have electrodes with conductive gel medium on scalp surface either in the form of electrode cap or an individual electrode. Initial signal artifacts due to head motion will be generally ignored in the analysis. Experiment will be scheduled based on specific time series with respect to the type of study. Signals from neurons are acquired with the help of collection of electrode which in turn connected with electroencephalogram device. Signals responsible for eye open and eye close on frontal, temporal, occipital, central and parietal lobes of the brain are shown in figures 15 and 16. Signals from this study are closely related with alpha activity for eye open, eye close, eye blinking and eye boll movement with the frequency ranges from 8 to 13 Hz. Few beta signals are also influencing along with alpha signals due to the impact of other states when the subject opens eye.



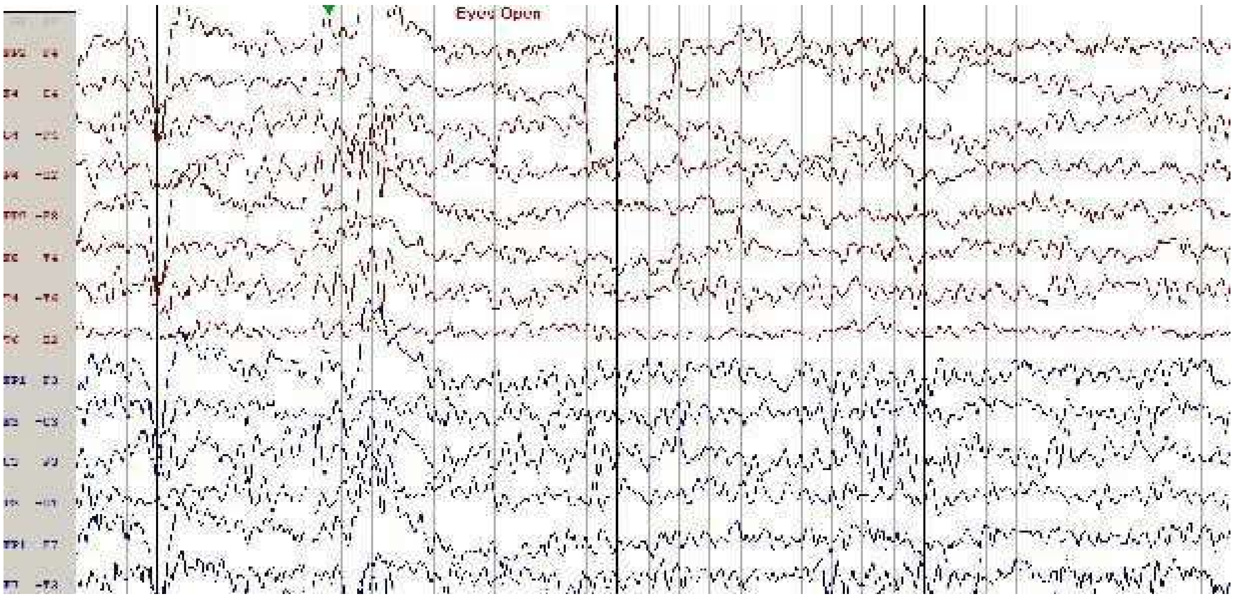


Fig. 15. Alpha activities responsible for eye open on frontal, temporal, occipital, central, and parietal lobes of the brain

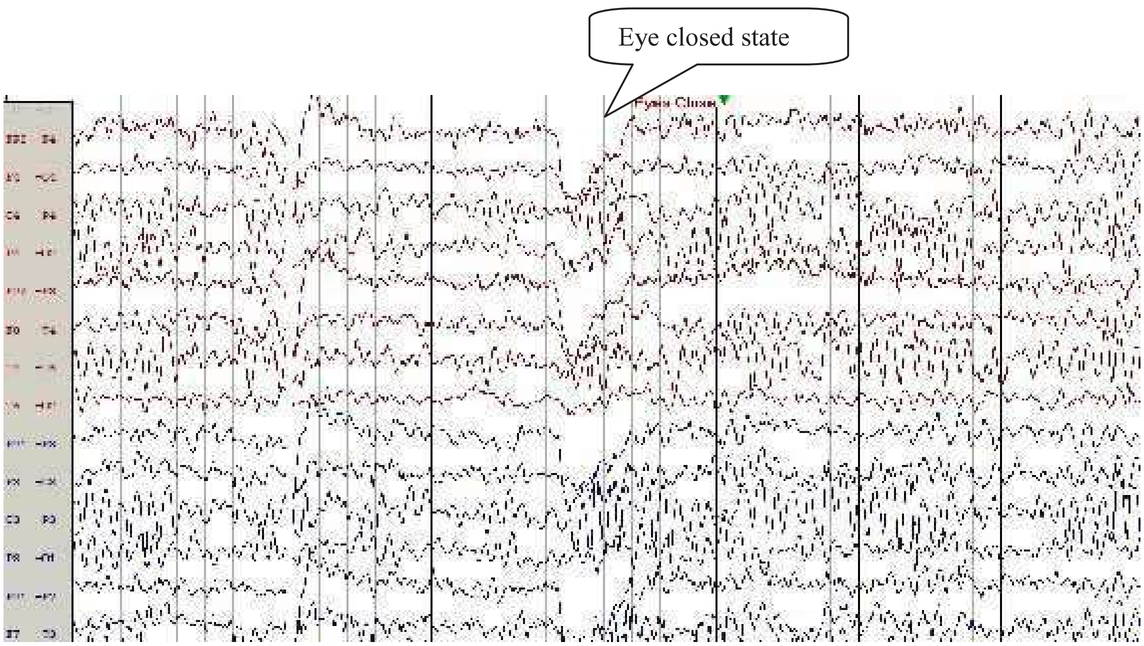


Fig. 16. Alpha activities responsible for eye close on frontal, temporal, occipital, central, and parietal lobes of the brain

8. Conclusion

The rapid advancements in biomedical technology for analyzing bio medical signals are an important research area. One such technology is Electroencephalogram (EEG), which is to measure the brain potential in order to help the disabled people and obtain accurate diagnosis of diseases. EEG records brain waves with respect to specific frequency by placing metal electrodes on the scalp. This paper explains Importance and categorization of EEG signals and its characteristics based on various states. It also focuses on experimental setup, materials and methods used in EEG analysis.

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