Difference of Brain Electrical Activity Mappings in Sleep Stages

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Abstract. According to a survey by the World Health Organization, the proportion of people who has difficulty in sleeping is up to 27%. Detecting the cause of these sleep disorders needs an elaborate analysis of the physiological signals of different sleep stages. Analyzing and comparing the brain electrical activity mapping energy difference of normal subjects and subjects who have the disease of nocturnal frontal lobe epilepsy is introduced in this study. The brain electrical activity mapping is from the independent component analysis (ICA) of the Electroencephalograph (EEG) waveform. The EEG data set is coming from the CAP sleep database. The control group uses the data of n3, n10, and n11. The experimental group uses the data of nfle1, nfle2, and nfle3. The EEGLAB, a toolbox in MATLAB, is used to preprocess the EEG waveform and locate the area where signals are generated in the brain. The preprocessing steps include channel locations, selecting data, filtering, re-referencing the data, ICA, and artifact rejection. After the preprocessing, there are 13 electrodes retained and the energy difference of the brain electrical activity mapping will be compared between the control group and the experimental group by observation.

Keywords: Sleep Stage; Brain Electrical Activity Mapping; EEG.

1. Introduction

Sleep is a basic physiological behavior of human beings and has linked to not only physical health but also mental health. Based on the standard of classification provided by AASM (American Academy of Sleep Medicine), sleep time is divided into five phases, which include the awake phase (W), non-rapid eye movements (NREM), and rapid eye movements (REM). Among these, NREM is divided into three smaller phases (N1, N2, N3) [1]. Our research is based on the theory of sleep stages.

With the discovery of EEG, the study of sleep diseases associated with sleep stages has entered a new era. Electroencephalogram (EEG) is a method of recording brain activity using electrophysiological indicators. Whenever the brain is working, the electrical signal that occurs synchronously in a mass of neurons is integrated and formed. Actually, it records the changes in electrical waves during brain activity and is the overall reflection of the electrophysiological activity of brain nerve cells on the surface of the cerebral cortex or scalp [2].

An electroencephalography brain map is a topographic map that presents an image of the spatial distribution of quantitative EEG data on the scalp surface through graphics and color differences. That spatial distribution can visually display EEG signals or typical parameters. For example, it vividly illustrates the distribution of a certain frequency scope of power or the distribution of peak latency. [3]

There can be significant differences in the frequency and amplitude of brain waves according to the various stages of sleep. It has been confirmed by the medical field that the abnormal signals of each sleep phase are related to sleep disorders. For example, patients who suffer from sleep apnea syndrome (SAS) usually have a relatively low proportion of N3 and REM phases during the whole night [4]. In this regard, analyzing sleep stages by classified brain wave states can be a wonderful method to diagnose some sleep-related diseases. In addition, figuring out the characteristic of waveforms and the differences between them can benefit understanding the periodic rhythms of sleep,

controlling the sleep process and treating sleep-related diseases, and facilitating further study in the sleep domain [5]. In conclusion, it's meaningful to recognize the characteristic of brain waves and give contrastive analysis among the ones of different phases.

Independent component analysis (ICA) is a computational method that decomposes a multivariate signal into addable subcomponents in signal processing. It is achieved by assuming subcomponents with statistically independent and non-Gaussian signals [6, 7]. From the Internet, free and publicly available data sets were found so that they could be used to analyze the EEG mapping of different people and to complete our comparison of differences in EEG mapping between people during sleep. By using the EEGLAB tool (free and publicly available at http://www.sccn.ucsd.edu/eeglab/) in Matlab to analyze and visualize the data as well as process ICA. This is the most important tool in our experiment [8].

Nocturnal frontal lobe epilepsy is an epileptic syndrome that mainly occurs during sleep and the symptom suggests the origin is located in the frontal lobe [9].

In this study, the point is to focus on this disease because symptoms during sleep are not easy to observe and it is difficult to distinguish them from sleep disorders and pseudocysts seizures,[10] but there are visible differences between normal individuals and patients in Electroencephalography brain map. In this study, the electroencephalography brain map was examined to determine the spatial distribution of energy intensities in different cerebral sites. At last, the results will be produced through comparative methods. The control group (sleep data selected from normal individuals) and the experimental group (data selected from patients who suffer from nocturnal frontal lobe epilepsy) were manually analyzed and compared.

2. Methods

2.1 The Data Source

The input EEG signals for this study were derived from a famous data set. The data set used in this study is free and publicly available from the CAP sleep database on the physionet website (https://physionet.org/content/capslpdb/1.0.0/). This database is designed to provide representative examples of detailed annotations of CAP in various pathophysiological contexts, for the development and evaluation of automated CAP analyzers, and to support basic research on CAP dynamics. The file is in edf format, which includes an entire night's sleep polysomnography. The data set contained information on 16 healthy people who were not using any medications that affect the central nervous system. There were also 40 patients with NFLE, 22 with RBD, 10 with PLM, 9 with insomnia, 5 with somnolence, 4 with SDB, and 2 with bruxism. There were 92 cases in total [11]. In this study, n3, n10 and n11 were used as the data of the control group, and nfle1, nfle2 and nfle3 were used as the data of the experimental group.

2.2 Preprocessing

EEGLAB is a toolbox of MATLAB. It's mainly used for importing EEG data, data visualization, preprocessing, independent component analysis (ICA), and so on [12]. In this study, the data from the CAP sleep database was processed and analyzed using EEGLAB. Considering the small amount of data (three data in each group) analyzed, the group analysis method is used in this paper, which means that the average of three data is analyzed in the control and experimental group. After loading all the data, we will preprocess multiple datasets together. The preprocessing steps include channel locations, selecting data, filtering, re-referencing the data, ICA, and artifact rejection. The flow chart of the whole preprocessing of the control group is shown in Figure 1. Since the preprocessing of the experimental group is the same and the subtlety is the different data (nfle1, nfle2, nfle3) used, its flow chart is omitted.

The CAP sleep database's electrode configuration follows the 10-20 International Standard Lead System, which is included in EEGLAB's own standard _BEM folder. There are 13 electrodes (Fp2, F4, C4, P4, F8, T4, FP1, F3, C3, P3, F7, T3, Cz) retained, and the rest of them are deleted. The graph

of the 2-D channel location is shown in the following Figure 2. Band-pass filtering is used to filter the noise of EEG waveforms, eliminate undesired background signals and also select the appropriate frequency range. The frequency range of clinical EEG analysis is about 0.1~100Hz, especially between 0.3~70Hz. Sleep stage signal has the traits of low frequency and obvious frequency domain. It is mainly composed of four kinds of basic rhythm waves, which are the Alpha wave(8-12Hz), Beta wave(13-30Hz), Theta wave(3-7Hz), and Delta wave (0.1-3Hz). To better analyze the data we need, we choose the following frequency as our pass band. The lower edge of the frequency pass band is 0.5 Hz and the higher edge of the frequency pass band is 30 Hz. After the filtering, it's clear that the waveform was becoming more gradual than before. What EEG waveform records are the potential difference between two electrodes, so it's essential to re-reference the data. We assume that the sum of the recorded electric field intensity from all scalp electrodes was always zero, so we adopt an average reference. The average reference takes the average value of all collected electrode potentials as the reference signal. It's an effective way to conduct the re-reference step.

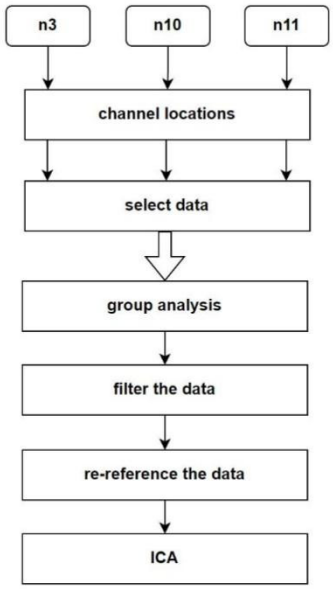


Fig 1. Flow chart of the preprocessing of the control group

The abbreviation of independent component analysis is ICA. ICA is a signal processing method to separate independent sources linearly mixed in several sensors. Why do we serve ICA as a necessary procedure? If we want to extract data from a specific brain area, the electrode penetrated in that place receives signals not only from the target location but also from the location nearby to some extent. For instance, imagine that there is a symphony performance in the theater and the audience only wants to recognize the sound of one instrument but fails because it turns out to be a mixture of different instruments. In other words, the signal coming from elsewhere spoils the purity of the collection. ICA includes an algorithm to extract and separate the data, attempting to make the output as statistically independent as possible and restoring the original sources maximally. What's more, we can only inspect the electroencephalography brain map after applying ICA and the topographic map is of paramount importance in our research.

ICA in EEGLAB is now widely used in the EEG research domain, most often to recognize and remove some artifacts such as the stereotyped eye, line noise, and muscle artifacts [4].

Our group uses ICA to purify the brain data automatically to eliminate the ill effects. We can see the oscillogram photographs change a little bit after this procedure, which proves ICA is a necessary procedure in preprocessing.

During recording, the person being monitored, some unavoidable activities may occur that will produce eye movement artifacts, EMG artifacts, motion artifacts, ECG artifacts, vascular wave

artifacts, 50Hz, and electrostatic interference. In this study, artifacts were removed by observing whether the EEG topography showed obvious symmetry, or whether the brain appeared mostly active and inactive areas. Through observation and analysis, there are three apparent ocular artifacts graphs in the experimental group, which are the third, fourth, and thirteenth graphs. They will not be considered in the following analysis and comparison.

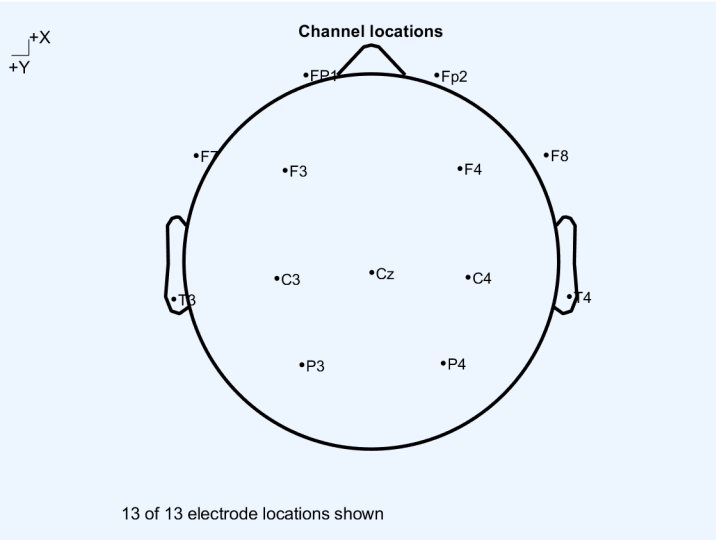


Fig 2. 2-D channel location

2.3 Analysis

In this study, we use the data n3, n10, and n11 from the CAP database as the control group. The subjects in this group don't have any sleep problems. The experimental group includes the data nfle1, nfle2, and nfle3. The subjects in this group have the disease of nocturnal frontal lobe epilepsy. We will compare the energy difference of the brain electrical activity mapping between the control group and the experimental group by observing the difference in color strength and locating the area where signal generation is most active in the brain. The red color of some areas in the map is relatively deep, which means the brain electrical activity in this area of the brain is more active than in other areas. The darker the color, the higher the relative energy, and therefore the stronger the electrical response.

The analyses were divided into two types, analysis in the group and analysis between the group. First, the control group and the experimental group were analyzed separately to exclude inappropriate images. The images were analyzed by increasing brain activity from blue to green to yellow to red. Then the appropriate images are compared and analyzed to get the result.

3. Results

3.1 Analysis of the Group

3.1.1 The Control Group

The brain electrical activity mappings of the control group are shown in Figure 3 on the left and the color bars of each independent components are placed on the right as the same order as the left one. All images are reasonable, so here is an analysis of the 13 images. In the first image, it is obvious that the Fp2 region is very blue and the upper part of the Cz region is yellow. This indicates that the upper central part of the brain is more active at this time. For both the second and third images, C4 was the inactive part, but their active part was concentrated in P4 and FP1, and Fp2 regions, which correspond to the brain Parietal and Frontal Pole, respectively. The fourth image shows that the frontal regions of the brain are inactive, but at C4 and P4, which correspond to the Central and Parietal regions, they are very active. Next, the fifth image shows that it is not active in T4; the other areas are in the intermediate state and not particularly active. The inactivity in images 6 and 7 was similar

in F3 (Frontal) and C3 (Central Frontal), respectively. However, the former active region was concentrated in Fp1 (Frontal Pole), while the latter was concentrated in P3 (Parietal). The active areas in the eighth image are concentrated in T3 (Temporal), but they are not obvious. In the ninth and tenth pictures, there was no particularly active area, and the inactive area was concentrated in F7 (Inferior Frontal) and Fp2 (Frontal Pole), respectively. Next, as shown in the eleventh picture, both C3 (Central) and P3 (Parietal) regions are inactive, while other regions are basically in the intermediate state. Finally, the twelfth and thirteenth pictures show the opposite. The former was inactive in F4 (Central) but active in C4 (Central). The latter is the opposite of the former. In general, normal people's brain activity during sleep is concentrated in the middle of the brain, with little activity in the limbic regions. Two areas, Frontal and Central, vary significantly, sometimes active and sometimes inactive. This can be used as a basis to determine whether sleep is normal.

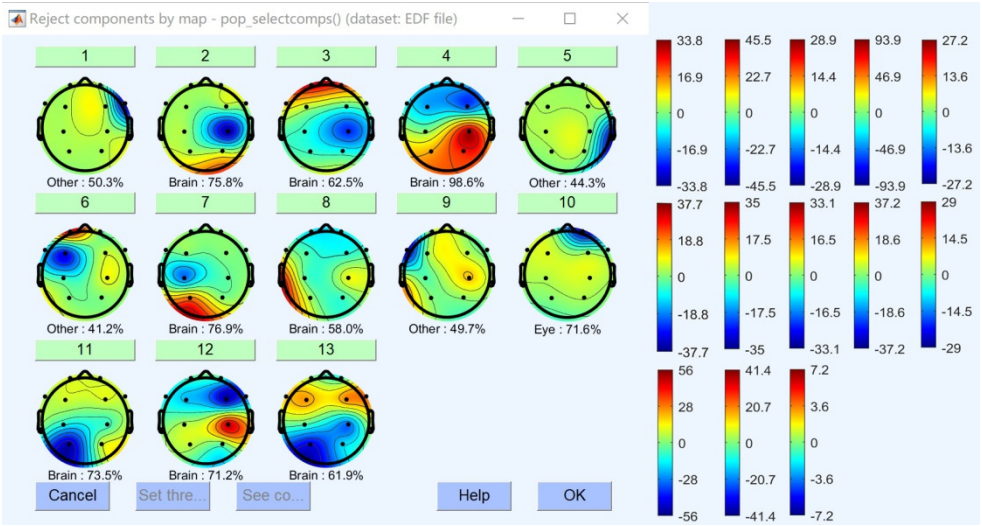


Fig 3. Brain electrical activity mappings and the corresponding color bars of the control group

3.1.2 The Experimental Group

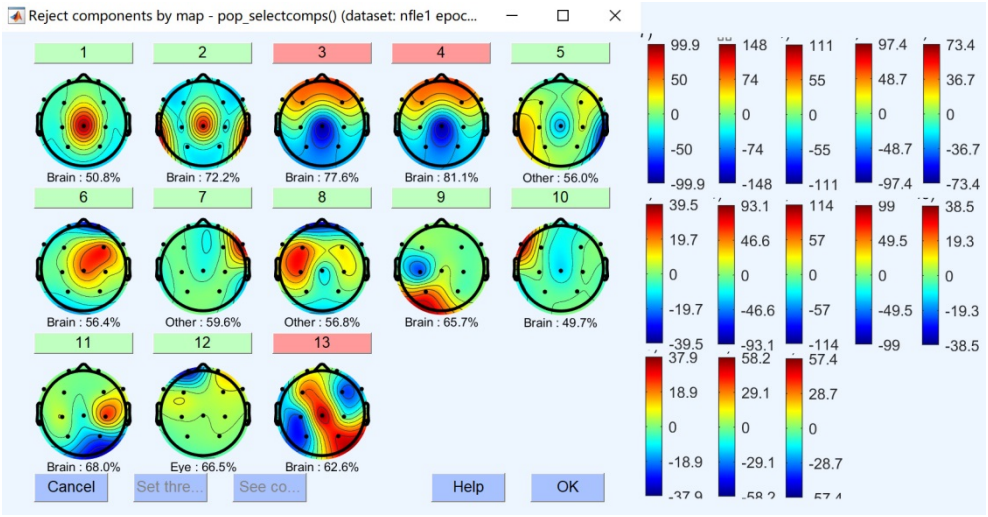


Fig 4. Brain electrical activity mappings and the corresponding color bars of the experimental group

The brain electrical activity mappings and the corresponding color bars of the experimental group are shown in Figure 4. The third, fourth, and thirteenth images were excluded as ocular artifacts are apparent. Comparing and analyzing the remaining ten images, the red color is significantly concentrated in the central area around the electrode Cz in the first and second images. In the sixth and eighth images, the deepest red area is around electrodes F3 and F4, which represent both the left and right frontal lobes in the brain. In addition, the active areas relatively focus on the right parietal lobe and central area of our brain respectively in the ninth and eleventh images, around the electrodes

P3 and C4. In conclusion, it shows that during the whole sleep stage, in people with nocturnal frontal lobe epilepsy, the areas in their brain where brain electrical signals generate most actively are mainly in the central area, the left frontal lobe, the right frontal lobe, and the right parietal lobe. However, due to the insufficient amount of data used for analysis, the commonality and accuracy of these results still need to be verified.

3.2 Contrastive Analysis between Two Group

Given the strong ocular artifacts that occurred in images 3, 4, and 13 in the experimental group, we'll only give contrastive analysis between the rest ten of both groups. First of all, there is no apparent discrepancy between pictures 5, 9, and 10 in each group.

As for image 1, 2, and 6, a distinguishing feature is that an obvious red zone around the electrode Cz can be observed in the experimental group compared to the control group, which indicate that patients who have nocturnal frontal lobe epilepsy go through hyperactivity in the central zero. Apart from this significant feature, there are still some subtle differences. For example, mid-temporal lobes on both sides are noticeably more active in the experimental group according to image 2. And another slight difference is hyperactivity in the right frontal lobe according to image 6, experimental group.

We can see an active zone around the right part of the central sulcus in the experimental group according to image 11, but this area isn't active compared to the control group in image 12. In image 8, the active zone is concentrated on electrode T3 in the control group, in other words, the left mid-temporal lobe in individuals without sleep disorders is normally active, but this active zone is moved forward to the left frontal lobe in the experimental group. There is a noticeable active zone in the occipital lobe in the control group according to image 7. Amazingly, we can't find this red zone in the experimental group, as an alternative, abnormal hyperactivity can be witnessed in the right anterior temporal lobe.

4. Conclusion

In this paper, the toolbox EEGLAB of MATLAB is used to preprocess the data in the CAP sleep database. The data is divided into two groups, which are the control group and the experimental group. To sum up, the following conclusions come up: In the control group, the electrical signals generated during the whole sleep phase were mainly concentrated in the central region, with no significant activity in the limbic regions of the brain. There were no particularly active areas in the control group, and the brain movement was less intense than in the experimental group. During the whole sleep stage in the experimental group, the brain's electrical signals generate in most active areas are mainly in the central area, the left and right frontal lobe, and the right parietal lobe. Finally, compared to the control group, the cases in the experimental group tend to have more active zones in the brain, including both sides of the frontal lobe and the region around the central sulcus. However, due to the insufficient amount of data used for analysis, the commonality and accuracy of these results still need to be verified.

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