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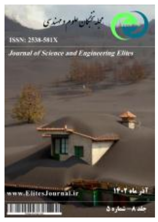

A Review of Electroencephalogram (EEG) Patterns on Cognitive Processes Based on Brain Waves

Pegah Kamankesh [1*], Zahra Ghayedi [2]

1- M.A. Student of Cognitive Psychology, Tarbiat Modares University, Tehran, Iran
2- M.A. of Clinical Psychology, Department of Psychology, Islamic Azad University, Marvdasht Branch, Marvdasht, Iran

*pegahkamankesh@yahoo.com

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Abstract

The brain's functions hinge on millions of neurons' activities, tied to cognitive aspects like memory and perception. Studying brain performance via non-invasive technologies stands as a pivotal aspect of neuroscience. Analyzing brain waves during rest versus cognitive tasks offers practical insights for modeling research. Results indicate regions linked to cognition align with cognitive duties. Brain waves dynamically vary, revealing diverse responses to emotions in distinct brain regions.

Key words: Electroencephalogram (EEG) Patterns, Cognitive Processes, Brain Waves, Neurons, Memory, Neuroscience.

1- Introduction

Understanding the secrets underlying the brain functioning would be the noble achievement of this era. Learning how the brain learns would be the milestone to guide the researchers of artificial intelligence, neurology and psychology [1]. Brain function relies on the interplay of millions of these neurons. Many aspects of brain functions and behavior of the human body can only be discussed based on how information is transmitted from neuron to neuron. All cognitive processes inside a brain are carried out with neuronal activity comprising of synapsing and spike generation in a network of neurons. Every cognitive process within the brain is executed through neuronal activity, involving the formation of synapses and the generation of spikes within a network of neurons [2].

The activated brain regions observed align with established principles in cognitive science pertaining to learning, memory, comprehension, and other aspects of rational judgment. The innovative approach of intricate network analysis entails an examination of the mathematical cognitive processes involved in recitation, thereby establishing a robust research foundation for investigating the correlation between brain cognition and human proficiency in learning and memory. The topological characteristic of the cerebral network is intricately linked to cognitive behavior. Alterations in the brain network occur during cognitive processes or engagement in activities, manifesting distinct patterns corresponding to various cognitive tasks. Consequently, the construction and examination of cerebral functionalities during task performance constitute a prominent focus in neuroscientific research [3]. The matching of cognitive load and working memory is the key for effective learning, and cognitive effort in the learning process has nervous responses which can be quantified in various physiological parameters. Therefore, it is meaningful to explore automatic cognitive load pattern recognition by using physiological measures [4].

Brain consists of millions of brain cells also called neurons. The neurons in our brain function to communicate with each other via electric impulse waves; especially for the communication in the nervous system, the neurons are interconnected with each other by forming into neural nets, related through a passage called 'synapse' which allows activities. When the activity of these neurons occurs, current flows locally produced. In this activity, jointly driven by an electric current flow from one neuron to neuron to another, and it will produce wave patterns (waves), and is known as the wave of the brain (brain waves). Brain waves can be used to analyze human emotions and artificial intelligence based on these waves can be designed that can recognize human emotions quickly and easily [5]. Cognitive activity is the ability of the human brain to manipulate information about the surrounding environment and includes thinking, learning, memory, problem solving and can be recognized by the interaction of the neuron network [6]. Numerous studies have delved into the examination of cognitive states and cognitive processes and cognitive tasks by some non-invasive technologies like EEG (Electroencephalography) MEG (Magnetoencephalogram) and MRI (functional Magnetic Resonance Imaging) [7]. EEG administration may also be a more tolerable process than fMRI for certain populations (e.g. children, individuals with heightened sensory sensitivity, and those who fear confined spaces) [8].

Wang, et al. (2015), investigated brain functional networks in cognitive by EEG; their results revealed that Cognitive processes have a strong connection to word learning and memory [3]. The activation of prefrontal, parietal, occipital, and temporal regions during cognitive processes aligns with findings in cognition research. Specifically, the activation of the frontal and prefrontal areas is closely tied to human understanding, thinking, and rational discrimination [8].

Dahal, et al. (2011), examined new approach modeling in cognitive, their results revealed that utilizing diverse parameters extracted from EEG responses to various stimuli can serve as a metric in cognitive modeling research [1]. Collaborative efforts involving neurologists, mathematicians, psychologists, and engineers have the potential to refine models, elucidating how individuals organize knowledge and exhibit intelligent behavior in the future [3].

Valentim, et al. (2021), studied an EEG exploration dataset involving patients engaged in arithmetic subtractions to gain insights into potential trends and the correlation between changes in the randomness pattern of the signal, They compared the EEG signal for subjects at rest and during activity, attempting to identify any indications of the subjects' performance, their results revealed that upon initial analysis, the rest and activity datasets appear similar; however, the overall picture shifts when considering the power levels associated with each type of brain wave (theta, alpha, beta, and gamma) [9].

Cheng, et al. (2022), offer systematic guidance on computing the cognitive status of construction workers based on EEG data, their results revealed that EEG provides scholars and project managers with insights into the cognitive status of construction workers from a neuroscience perspective. The included studies validate EEG's potential to measure various cognitive aspects, including vigilance, mental fatigue, stress, attention, mental workload, and emotional state. The findings suggest that a thoughtful EEG experiment design should consider factors like participant selection, device and electrode selection, task design, and label selection to enhance the quality of obtained EEG signals. Data preprocessing, including artifact removal, is essential for accurate computation of construction workers' cognitive status. Extracting time-domain, frequency-domain, and time–frequency-domain features can yield rich cognitive information about construction workers [10].

Park, et al. (2011), explored the influence of stress during memory recall and mental calculation, and their results reveal that Noises, considered a physical stress factor, and memory recall, identified as a mental stress factor, resulted in a decrease in the relative power of the alpha wave in the parietal and occipital lobes. Additionally, the mental stress factor led to an observed increase in the relative power of the theta wave [11].

The aim of current study is to delve into the intricate relationship between brain activity and cognitive functions, exploring the nuances of EEG patterns to provide a comprehensive understanding. By synthesizing the existing literature, This scholar aspire to contribute valuable insights into how specific brain wave patterns correlate with various cognitive processes, paving the way for a deeper comprehension of neurocognitive mechanisms.

2- Methodology

In the current paper first of all try to review each of the foremost methods of each paper carefully, for this reason, the methods used by each scholar are as follows:

Wang, et al. (2015), applied electroencephalography (EEG) to collect data from subjects given four different mathematical cognitive tasks and they analysis some variable parameters including four visual stimuli cognitive tasks and analyzes BFN property parameters, validating that the four types of BFNs constructed in the experiment exhibit small-world properties [3].

Ismail, et al. (2016), appraised electroencephalography to detect or identify human emotion via the study of brain waves and they analysis some variable parameters including cope with emotions through the classification process, brain waves as electricity flows of human emotion and the relationship between understanding human emotion through facial and brain waves [5].

Valentim, et al. (2021), conducted Power spectral densities (PSDs) and ARIMA and ARFIMA Models to explores extant electroencephalogram (EEG) signals in search of patterns that could differentiate subjects undertaking mental tasks and reveals insights on said data and they analysis some variable parameters including 1) significant differences between the electrical activities for subjects at rest and during activity, 2) categorising subjects' performance groups (good, average, and poor) based solely on EEG data, 3) checking for differences in the activity of different brain areas [9].

Cheng, et al. (2022), considered data analysis approach to Measuring and Computing Cognitive Statuses of Construction Workers Based on Electroencephalogram and they analysis some variable parameters including mental workload, mental stress, mental fatigue, vigilance, attention and emotional state [10].

Park, et al. (2011), provided Electroencephalography (EEG) data from 34 healthy subjects while they were at memory test interrupted by noises to investigate the appearance of brainwaves due to mental stress and they analysis some variable parameters including noise as the major factor of stress and regarding the problem presentation or explanation for answers as one of the stress factors [11].

3- Result and Discussion

Wang, et al. (2015), investigated brain functional networks in cognition based on EEG and they founded that the Brain Functional Network (BFN) includes brain regions such as the frontal, parietal, and occipital lobes, which are associated with cognitive functions related to attention, thinking, understanding and other cognitive tasks also in terms of Figure 1, and for the four types of cognitive tasks, the maximum number of connections and shortest path length value for the BFN is for the task involving counter-clockwise letters also supported by Figure 2 [3].

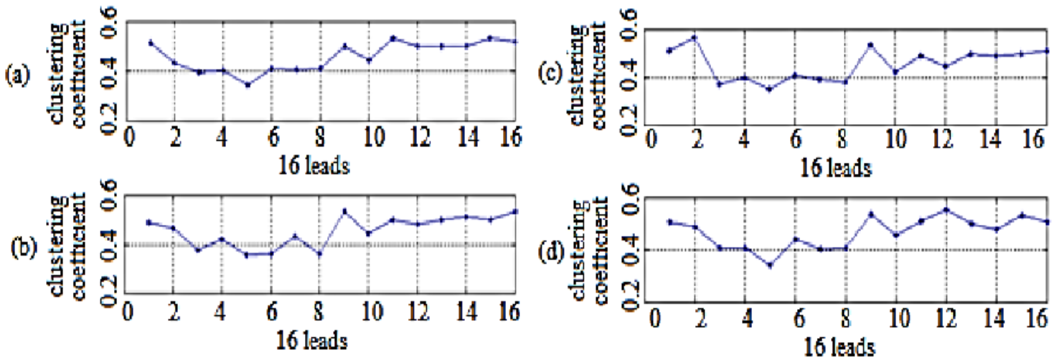

Figure 1- Clustering coefficient of (a) clockwise numbers, (b) counter-clockwise numbers, (c) clockwise letters, and (d) counter-clockwise letters

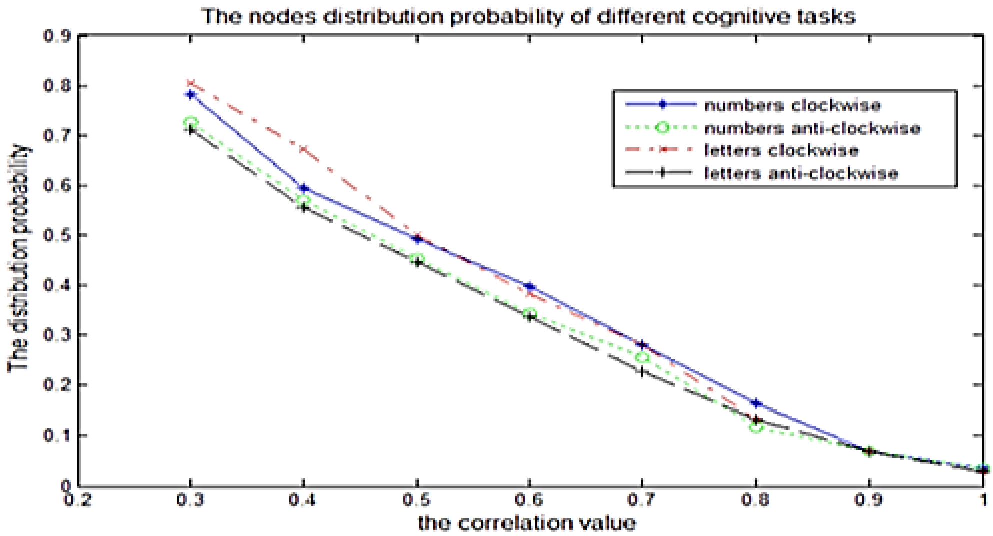

Figure 2- The nodes distribution probability of different cognitive tasks

Ismail, et al. (2016), examined human emotions by EEG, and they realized that for each emotional responses brain waves changed. They founded that the wave of angry emotional reactions are very clear on the right side of the brain and theta wave is visible when the emotion of anger occurs also in terms of Figure 3. In a sad reaction the high response occurred in waves of Theta and the reaction at the Delta waves was insignificant supported by Figure 4. In happy reactions brain wave activity shows a very noticeable in the middle part of the brain that are on Alpha waves and this is also evident in Figure 5. The most obvious answer in the surprised reaction can be seen is in the Delta and Theta waves reflected in Figure 6 [5].

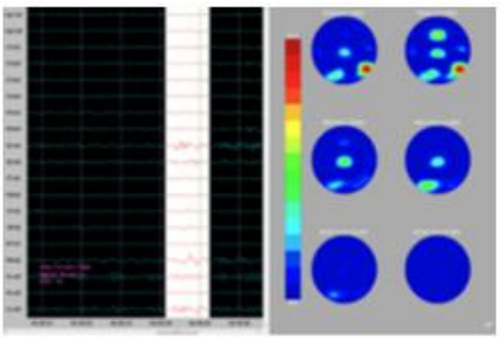

Figure 3- wave of emotion sad

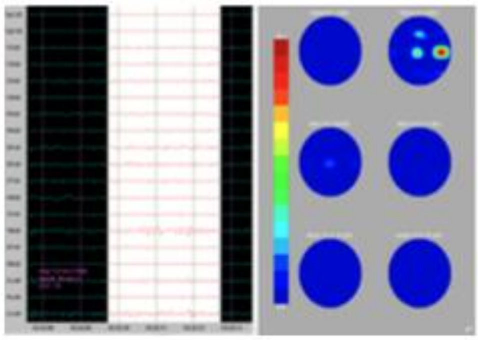

Figure 4- wave of emotion anger

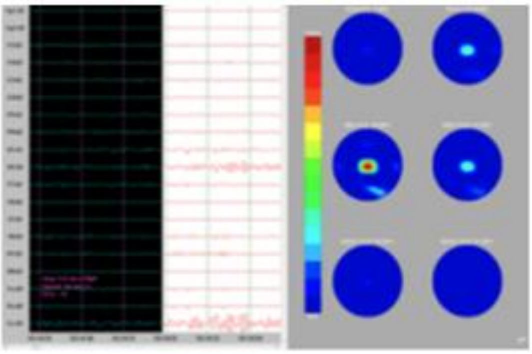

Figure 5- wave of emotion happy

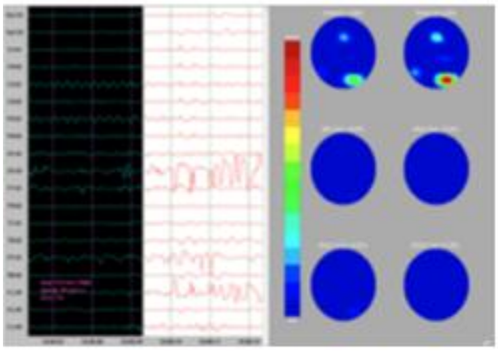

Figure 6- wave of emotion surprised

Valentim, et al. (2021), estimated electroencephalogram (EEG) signals to find patterns which could differentiate subjects undertaking mental tasks and reveals insights on said data. They recognized that regions O and P seem to show greater electrical activity in low frequency ranges, with noticeable peaks for the 10 Hz mark in all brain regions. As for differences between the two curves, although they seem very close, it is worth highlighting that these are semi-log graphs, indicating that the y-axis is on the log scale. Hence, although visually subtle, the differences might be significant also in terms of Figure 7 [9].

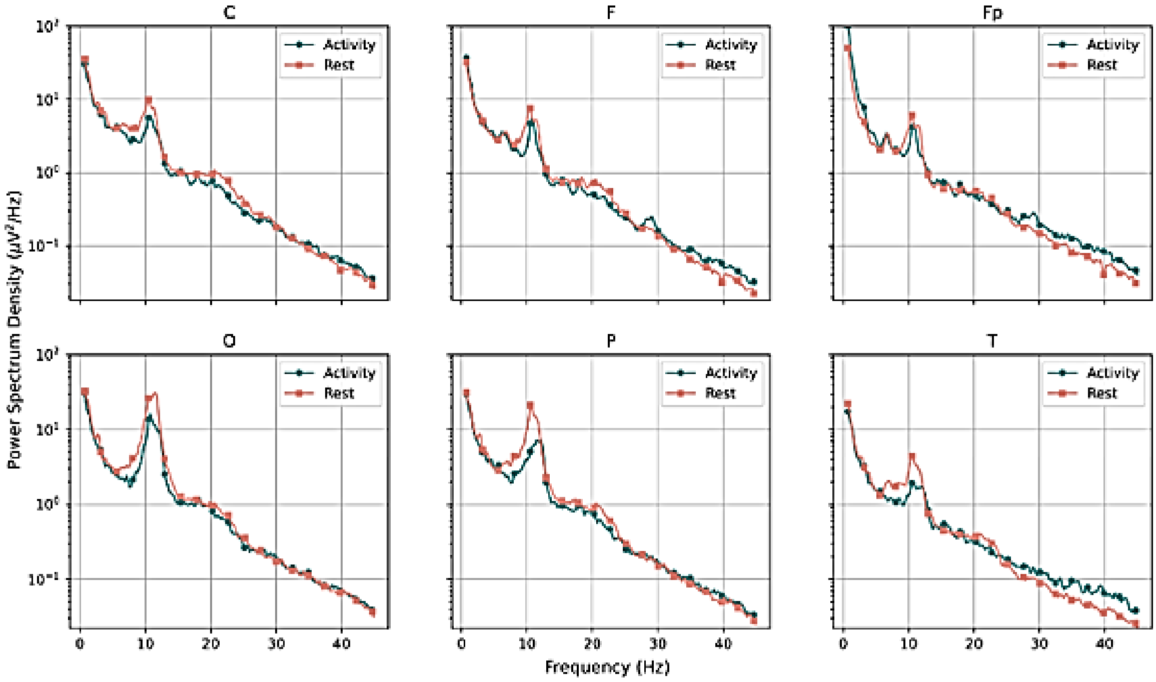

Figure 7- Comparison of the power spectral density between the activity and rest datasets

In a study on brain activity, all regions showed a peak in activity around the 45-second mark, even though the study design did not specify any significant events at that time and the T (temporal) region showed the most noticeable synchronous increases in signal power as shown in Figure 8. Good performers generally have curves below others, particularly in the higher-frequency range, Poor performers' curves tend to be highest in the beta band, with peaks around 29 Hz, while the average performers' curves are higher in the gamma range concerning Figure 9 [9].

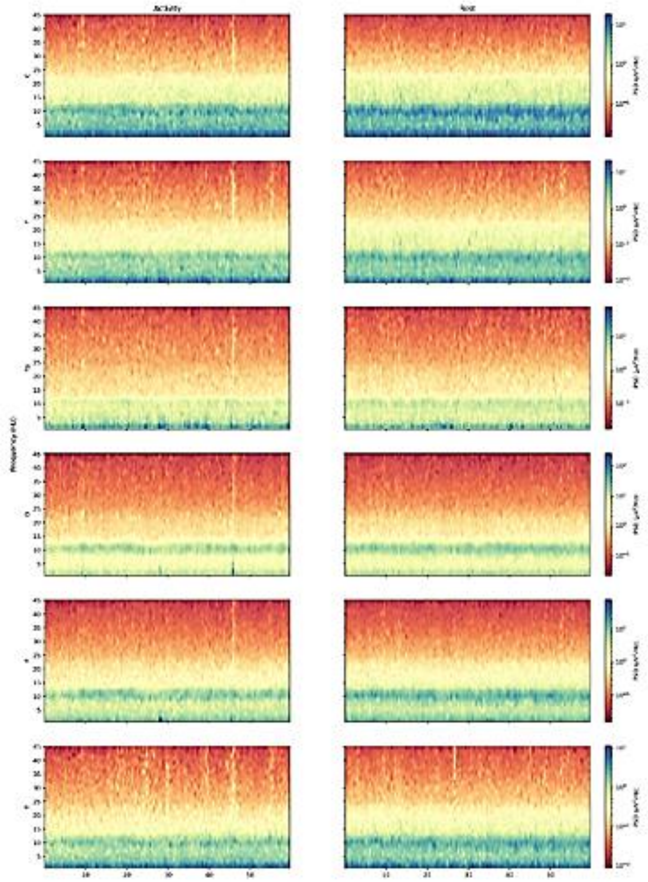

Figure 8- Comparison of the spectrograms between activity (left) and rest (right) datasets

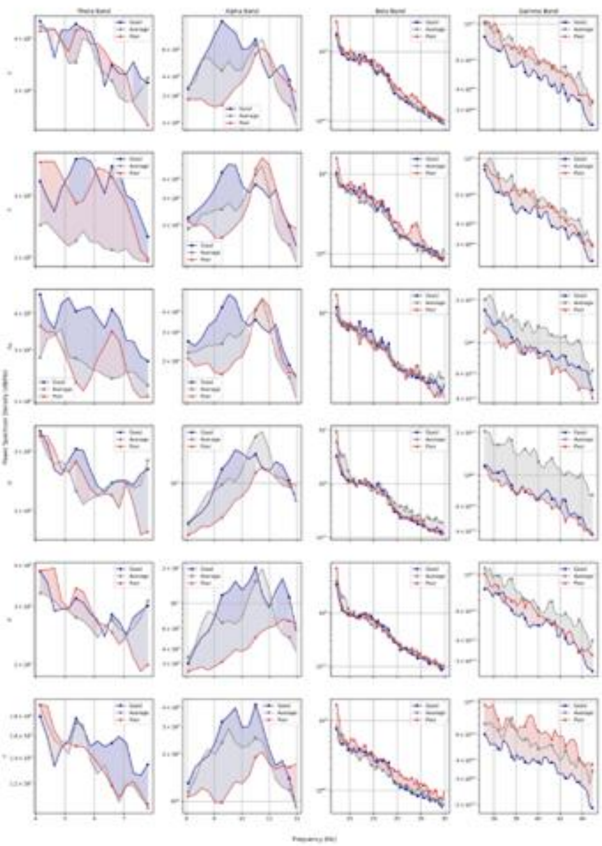

Figure 9- Comparison of the power spectral density between good, average, and poor performers

Park, et al. (2011), inquired how electroencephalography (EEG) patterns change in response to stress through noise and cognitive tasks. They figured out observable changes in the theta, alpha, and gamma waves in the posterior region of the brain in response to stress stimuli such as noise, problem presentation, and explanation of answers. As shown in Table 1, the relative power of the alpha wave was significantly decreased around the parietal and left central-parietal lobes as compared to the rest duration when noise was applied as shown in Figure 10 [11].

Table 1- Paired t-tests of noise state and rest state in the tests of number memorization

Variable	Method	Difference	p Value
P3, Pz, CP1, CP5, T5	Alpha	Number_Noise < Number_Rest Word_Noise < Word_Rest Picture_Noise < Picture_Rest	< .01

Number_ Noise represents the five noises of the number memorization; Number_Rest represents the rest of one minute of the number memorization; Word_ Noise represents the five noises of the word memorization; Word_Rest represents the rest of one minute of the word memorization; Picture_ Noise represents the five noises of the picture memorization; Picture_Rest represents the rest of one minute of the picture memorization.

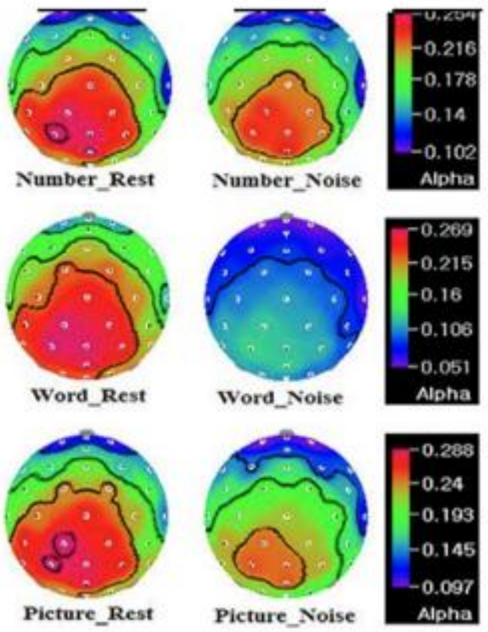

Figure 10- Brain-mapping of average relative power of alpha wave in noise state and rest state

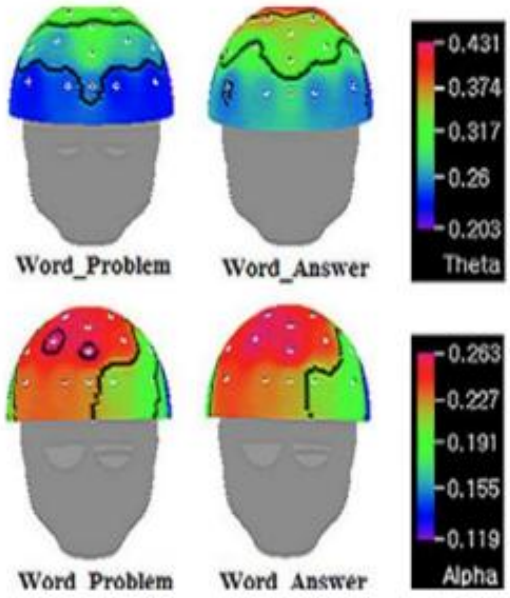

Figure 11- Brain-mapping of average relative power of theta and alpha waves in the memory recall of words

As shown in Table 2, in case of word memorization the relative power of the theta wave around the parietal, central-parietal and central lobe was significantly higher in the problem solving than the problem presentation, and the relative power of the alpha wave around the occipital, occipital-parietal and parietal lobe was significantly lower with regard to Figure 11 [11].

Table 2- Paired t-tests of problem presentation and explanation of problems in the memory recall

Variable	Method	Difference	p Value
T6,POz, C3, P4, CP2, CP5, CP6, Pz, P3, CP1, Cz, C4,	Theta	Word_Problem <Word_Answer	<.01
Oz, O1, Pz, CP2, P3, P4, POz	Alpha	Word_Problem >Word_Answer	<.01

Word_Problem represents the presentation of five problems of the word memorization. Word_Answer represents the solution of five problems of the word memorization.

As shown in Table 3, in case of picture memorization as well as word memorization, the relative power of the alpha wave around the occipital, occipital-parietal and parietal lobe was significantly lower in the problem solving than the problem presentation. This represented that the problem solving process was more unstable than the stimulated problem presentation and the relative power of the theta wave of each of problem presentation and the problem solving process is lower at the left occipital and left parietal in the problem presentation and significantly lower at the occipital, occipital-parietal and parietal in the problem solving as compared to the rest state was related with the increase of stress, and the decrease of relative power of the alpha wave at the occipital, occipital-parietal , and parietal was related with instability as shown in Figure 12. As shown in Table 4, in case of mental calculation, the relative power of the alpha wave around the occipital, occipital-parietal, and parietal lobe was significantly lower in the problem presentation as compared to the rest state, and the relative power of the gamma wave around the occipital and occipital-parietal lobe was significantly higher in terms of Figure 13 [11].

Table 3- Paired t-tests of problem presentation and rest state, explanation of problems and rest state, and problem and rest state, and problem presentation and explanation of problems in the memory recall of pictures

Variable	Method	Difference	p Value
O2, P4, POz, P3, CP5, T3, C3	Theta	Picture_Problem > Picture_Rest	<.01
Pz, C4, CP1,T6, Oz, Cz, C3, CP5,T3, O1, O2, POz, P3, P4	Theta	Picture_Answer > Picture_Rest	<.01
Oz, O2, POz, P3, CP1, T5,P4	Alpha	Picture_Answer < Picture_Rest	<.01
Oz, O1, O2, P3, CP2, POz	Alpha	Picture_Problem > Picture_Answer	<.01

Picture_Problem is regarding the presentation of five (5) problems of the picture memorization; Picture_Answer is regarding the solution of five (5) problems of the picture memorization.

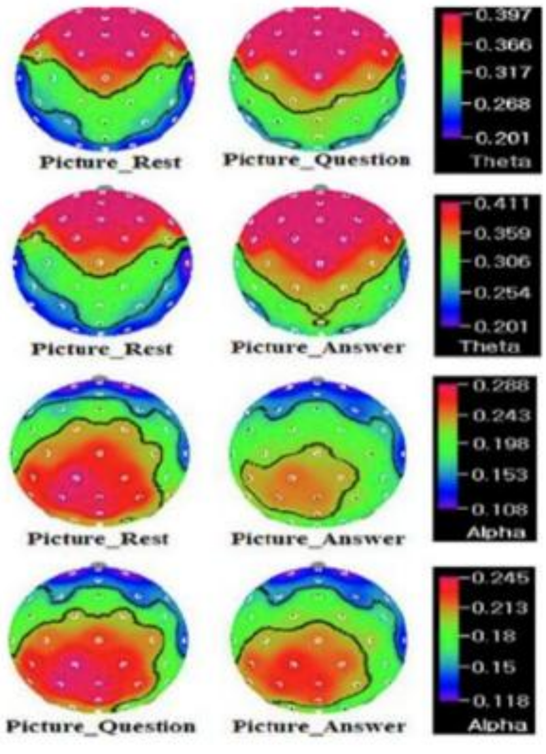

Figure 12- Brain-mapping of average relative power of theta and alpha waves in the memory recall of pictures

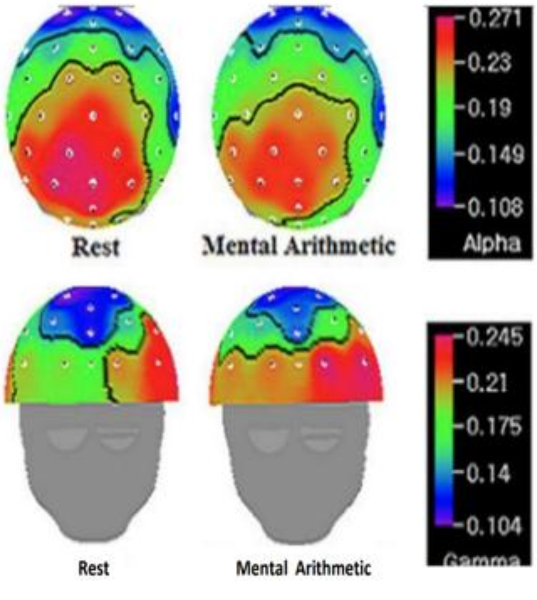

Figure13- Brain-mapping of average relative power of alpha and gamma waves in the mental calculation

Table 4- Paired t-tests of the mental calculation process and rest state in the mental calculation test

Variable	Method	Difference	p Value
Oz , POz, P3, CP1, T6, O2, P4	Alpha	Mental Calculation_Problem < _ Rest	<.001
O1, POz, O2, Oz	Gamma	Mental Calculation_Problem > _ Rest	<.01

_ Rest is the average of each rest of the three (3) rests, that is, word, number and picture memorization; Mental Calculation_Problem is regarding the presentation of five (5) problems of the mental calculation.

Table 5 showed the deviation of noise the deviation of noise, only one side of the left or right state increased or decreased in the left-right asymmetric case against the relative power of four EEGs in the 90% confidence interval as a result of the paired-test of each stress and relevant rest section reflected. During mental calculation compared to a resting state, the theta wave's relative power against T3 and T4 showed significant side-to-side asymmetry, with an increase observed only in T4. The gamma wave also displayed asymmetry, decreasing solely in T4. Additionally, the beta wave exhibited side-to-side asymmetry against T5 and T6, with an increase observed only in T5. Furthermore, the theta wave's relative power was significantly asymmetric against CP5 and CP6, with an increase observed only in CP6, while the gamma wave displayed asymmetry, decreasing solely in CP6 regarding Figure 14 [11].

Table 5- Asymmetric deviation of noise state and rest state in the mental calculation test by the paired t-tests against the relative power of each of the theta, alpha, beta and gamma waves

Variable	Method	Difference	p Value
Oz , POz, P3, CP1, T6, O2, P4	Alpha	Mental Calculation_Problem < _ Rest	<.001
O1, POz, O2, Oz	Gamma	Mental Calculation_Problem > _ Rest	<.01

_ Rest is the average of each rest of the three (3) rests, that is, word, number and picture memorization; Mental Calculation_Problem is regarding the presentation of five (5) problems of the mental calculation.

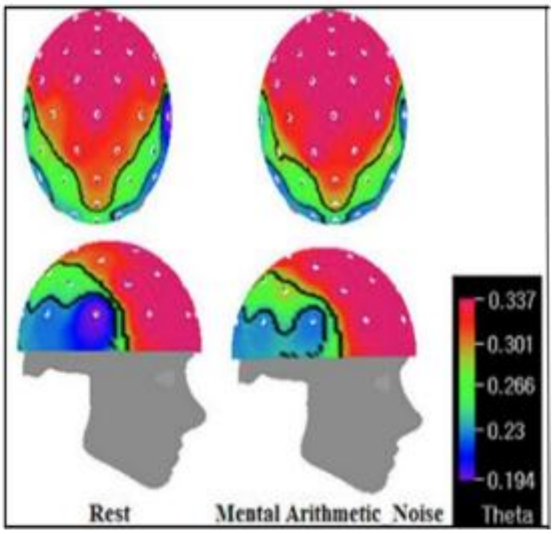

Figure 14- Brain-mapping of asymmetric deviation of noise state and rest state in the mental calculation test against the relative power of the theta wave

4- Conclusion

The exploration of EEG's application for emotion detection in medical and law enforcement fields illuminates its potential for revealing true emotions concealed by facial reactions. The study's use of frequency- and time-based methods to discern cognitive patterns sheds light on brain activity during mental tasks, offering insights into alpha and gamma wave activity. Furthermore, the analysis of noise-induced instability and stress-related wave variations underscores the significance of EEG in gauging cognitive stress factors. The study of brain functional networks and their association with cognitive processes emphasizes the activation of specific brain regions, aligning with established cognition research.

5-References

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