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Neurophysiological Insights into Memory: EEG Analysis of Young Adults During Cognitive Tests

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Abstract: ***Background: Detecting learners' cognitive profiles is a key step towards individualised and customised instruction. Our aim is to Explore the relationship between EEG brainwave activity during memory tasks and the activity of alpha and theta waves in parietal and frontal area of cerebral cortex was compared to scores on the P.G.I memory scale. Methods: While wearing an EEG headset, the participants take a Battery of memory test- P.G.I memory scale to evaluates their entire cognitive profile. Second, the memory scores are calculated out. After that, frequency-domain characteristics are retrieved from the gathered EEG data. Then Regional EEG Activity in Frontal Regions and Parietal Regions were used as outcome measures. Result: A Significant difference in Alpha and Theta wave activity between different memory performance groups are observed in frontal area (F3, F8, F7) Notably, Excellent performers had significantly higher Theta activity compare with alpha wave activity. F3 region (P< 0.04), F8 region (P<0.001), Above Average Memory(P<0.001), F7 region (P<0.004) Average Memory and in P3 Region significantly lower Theta wave and higher alpha wave activity can see in average memory group (P<0.07) also it is observed that Frontal areas show more significant higher theta activity and lower alpha activity compare with Parietal area during memory task. Conclusion: Theta wave activity appears to play a role in memory performance, with higher Theta power associated with better memory, particularly in the F3 and F8 frontal regions. and it is concluded that Frontal brain regions are more sensitive to memory performance differences than parietal region.***

Keywords: EEG, Electroencephalography, long-term memory, spectral analysis, cognition

1. Introduction

Whether we can learn and remember something depends on our ability to concentrate on the information at the time, as well as our ability to focus our attention on retrieving that information when we recall it later. This is true for people of all ages, from young adults to those in their sixties. Mainly cognition involves two processes Attention and memory.

Cognition
Cognition is an umbrella term used to describe the mental processes associated with understanding and acquiring knowledge (1). Cognitive ability is a set of mental processes that an individual applies to gather and analyse information from their environment (2)

Attention
The basic components of attention are focusing, concentration, and consciousness. Attention is best understood as a segmented system that has multiple subsystems that conduct distinct but interconnected functions (3).

Memory
Memory is a periodic feature of neurons and their connections that are retained in the brain through chemical modifications at the level of the neuron. It is one of the most crucial cognitive areas for routine function, and it refers to the method of archiving, encryption, and retrieving data. Various types of memory are known, notably sensory-related, long-term, short-term, as well as working memory (4). Attentional activities are considered of as the doorway for learning and memory, and they are essential for completing any task at hand (5). The type of message that should be stored in long-term memory and the method by which it can be obtained are determined by attention. People receive a variety of knowledge every day, but not all of it is encoded and retained in memory (6,7)

Attention and memory interact simultaneously, as objectives, segments, and concepts stored in memory influence choice of focus and alertness. These bidirectional relationships can be observed in various types of memory and within their fundamental neural systems (8).

Brain and EEG:
The human brain represents one of the most massive and most complicated organs in the body. It is made up of billions of neurons that link together and create synapses to interact with one another (9). Distinct brain functions are linked to different lobes of the brain. According to research, the temporal lobe is associated with auditory stimuli, the occipital lobe processes visual information. frontal lobe is associated with High level executive functions, Prospective memory, Decision making (10). and the parietal lobe is associated with Sensorimotor planning, Learning, Language, Spatial recognition, Stereognosis (11).

Electroencephalography (EEG) is an electrical activity of brain neurons that can reveal the brain's normal and pathological conditions. It has been used to investigate brain waves in people with moderate cognitive impairment, memory loss, and dementia (12). EEG is a non-invasive brain-computer technology with advantages such as high temporal resolution, and good spatial distribution (13).based on the frequencies the brain waves are classified into alpha (α: 8–13 Hz), beta (β: 13–30 Hz), theta (θ: 4–8 Hz), gamma (γ: 30–150Hz), and delta (δ: 0.5–4Hz) In EEG assessment, alpha, theta, and gamma rhythms play an important role in human cognitive processes and neurological activity

(14).Furthermore, theta rhythm is correlated and related to memory and learning steps, particularly for both storage and retrieval periods in all types of memories (15).While doing a mental activity, various variations in the electroencephalogram (EEG) frequency bands are noted, and these are related to the type of cognitive processes that are taking place. The activity of electrodes placed over the frontal lobes of the brain differed during a memory task vs a simple sensory task (16). The study of frequency spectrum data collected during a working memory test in healthy people revealed that with an increase in the number of items required in memory, theta and beta band activity in the frontal areas increased (17). During spoken and sustained attention activities, delta activity increases. Another study found that the relative theta wave in the frontal lobe was considerably higher than in the control group. Changes in alpha and beta activity while doing various mental Working memory activities. Frontal alpha power changes can also be observed with tasks demanding enhanced cognitive engagement. Others discovered lower alpha power frontally in healthy adults and increase in theta power during a task measuring semantic memory performance, notably in the left hemisphere (18).

Decreased memory function leads to issues in daily life. However, no quick and simple method of assessing attentional function has yet been identified. As a result, we are looking for a quick and simple way to assess memory function. The purpose of this study was to collect fundamental data on electroencephalography (EEG) features during cognitive activities in order to develop a new method for evaluating attentional performance with EEG.

2. Objective

1) To explore the relationship between EEG brainwave activity and cognitive performance in memory tasks.
2) To check the activity of alpha and theta waves in parietal and frontal area of cerebral cortex during memory task.

3. Methodology

The study was conducted on 65 healthy volunteers age 20–22 years (mean ± SD, 20 ± 06). The objectives and procedure of the study were explained to the subjects. Ethical clearance for the study was taken from the ethics committee for human subjects. The experiment was performed at Srinivas hospital, Mukka, Mangalore. conducted in morning in a sound proof room in sitting position. The subjects were instructed to remain still as far as possible when the instrument is recording EEG. Single recording was taken if there is a recording error, then the electrodes were reapplied & measurement was repeated.

Table 1: Showing inclusion /exclusion criteria

S.no	Inclusion Criteria	Exclusion Criteria
1	Healthy individuals with no history of neurological or psychiatric disorders	Neurological or Psychiatric Conditions: History of epilepsy, traumatic brain injury, stroke, or other neurological/psychiatric disorders, sleep disorders
2	Normal cognitive function	Regular use of substances like alcohol, recreational drugs.
3	EEG Suitability	Regular Medication
4	Language Proficiency: Fluent in the language used during cognitive testing to ensure comprehension of tasks.	Any Visual or Auditory Impairments
5	Informed Consent: Willingness and ability to provide written informed consent.	Severe Anxiety or Discomfort

Memory Test: A standardized memory test battery was administered to assess different memory domains, such as short-term memory, long-term memory, and working memory.

Battery of memory test - The PGI memory scale (19) has 10 subtests assessing verbal and nonverbal memory, remote memory, recent memory, short-term memory, and long-term memory. The test was developed at Postgraduate Institute of Medical Education and Research, Chandigarh.

Study Design:

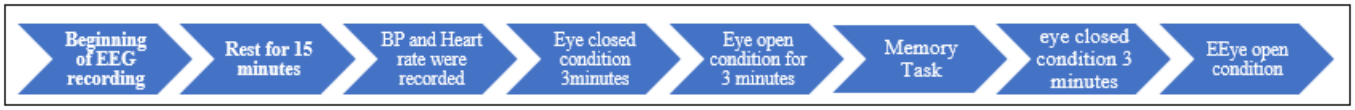

Figure 1: The sequence of activities during EEG recording.

EEG Signal Acquisition and Analysis:
EEG recording will be taken by using digitized Allengers virgo EEG machine. which has 18 channels, where 16 of them are used for collecting the EEG signals from different parts of the scalp and two are used as reference points. the Recording electrodes are placed by using paste electrolyte. the sensors measure EEG data from F7, F3, F4, F8, P3, P4 based on the 10–20 system EEG signals will be recorded (Fig.1) and raw data will be filtered using low & high frequency filter with cut-off frequency of 3-50HZ and sensitivity will be adjusted to 20mv. The noise will be eliminated through notch filter 50Hz.Signals were analysed offline. Visual identification of movement and eye blink artifacts led to the exclusion of the corresponding EEG stretch from the analysis. During the memory test, ten 4-second epochs were selected from an artifact-free region. Power Spectral Density (PSD) was performed to identify the energy and strength of the signal followed by the computation of the average PSD (20,21).

Statistical Analysis:
The demographic and baseline variables were summarized as descriptive statistics that is Mean, Median, standard deviation. also, inferential analysis paired t test was done in the software used for data analysis was SPSS version 25. P<0.05 will be considered as significant.

4. Result

1) Baseline Parameters:
65 young adults were participated in the analysis (Table 2), with Mean ± SD of age is 20±06, Systolic Blood Pressure(mmHg) and Diastolic Blood Pressure (mmHg) Mean and standard deviation of the study participants is 109± 10 (mmHg), 76±08 (mmHg), Respectively also Heart Rate(bpm) Mean and standard deviation of the study participants is 82±8 (bpm).

Table 2: Demographic and Baseline Variable

S. No.	Demographic and Baseline Variable	Mean ± SD
1	Age	20±06
2	Systolic Blood Pressure(mmHg)	109± 10
3	Diastolic Blood Pressure (mmHg)	76±8
4	Heart Rate(bpm)	82±8

Table 2: Shows Mean and standard deviation of Age Systolic Blood Pressure(mmHg) Diastolic Blood Pressure (mmHg), Heart Rate(bpm)

2) Analysis of EEG and task performance measures:
a) F3 Region: Significant differences in Alpha and Theta wave activity between different memory performance groups. Notably, Excellent performers had significantly higher Theta activity than other groups. (P< 0.04)
b) F8 Region: Excellent performers (P<0.001), Above Average Memory(P<0.001), Average Memory (P<0.004) performers exhibited higher Theta wave activity compare with alpha wave activity.
c) F7 Region: A significant difference in higher theta activity for the Above Average Memory group (P<0.004).
d) P3 Region: significantly lower Theta wave and higher alpha wave activity can see in average memory group (P<0.07). (Table 3)

Table 3: Comparison of Theta and Alpha Brain Wave Activity Across Memory Performance Categories

Region of Brain Areas	Categories (MEMORY TEST)	Theta	Alpha	P-value
		Mean (SD)	Mean (SD)	
Frontal area (F4)	Excellent	44±10	37±18	0.159
	Above Average Memory	46±13	48±21	0.661
	Average Memory	46±10	44±18	0.442
	Below Average Memory	49±11	39±27	0.463
Frontal area (F3)	Excellent	47±12	36±19	0.04*
	Above Average Memory	41±19	49±9	0.595
	Average Memory	45±10	40±20	0.229
	Below Average Memory	43±4	33±8	0.248
Frontal area (F8)	Excellent	41±8	29±14	0.000*
	Above Average Memory	48±11	28±14	0.000*
	Average Memory	47±13	32±16	0.004*
	Below Average Memory	51±6	32±14	0.235
Frontal area (F7)	Excellent	40±9	36±18	0.268
	Above Average Memory	46±8	32±13	0.004*
	Average Memory	42±11	39±19	0.591
	Below Average Memory	37±5	32±15	0.598
Parietal area (P3)	Excellent	41±8	44±21	0.426
	Above Average Memory	49±9	48±19	0.81
	Average Memory	43±7	52±21	0.07*
	Below Average Memory	47±10	51±15	0.646
Parietal area (P4)	Excellent	40±9	40±20	0.954
	Above Average Memory	46±11	45±23	0.897
	Average Memory	44±9	52±18	0.119
	Below Average Memory	37±1	58±10	0.099

Activity of alpha and theta waves in frontal and parietal area of cerebral cortex during memory task.

- Frontal areas (F3, F4, F7, F8) shows more significant higher theta activity with Mean and Standard deviation of 44.5 ±1.04 and lower alpha activity with Mean and standard deviation of 36.6 ± 2.5 based on memory performance (Fig .2)
- Parietal areas (P3, P4) show lower theta activity with Mean and Standard deviation of 43.3 ±3.01 and higher alpha activity with Mean and standard deviation of 49 ±5.2 based on memory performance (Fig 3)

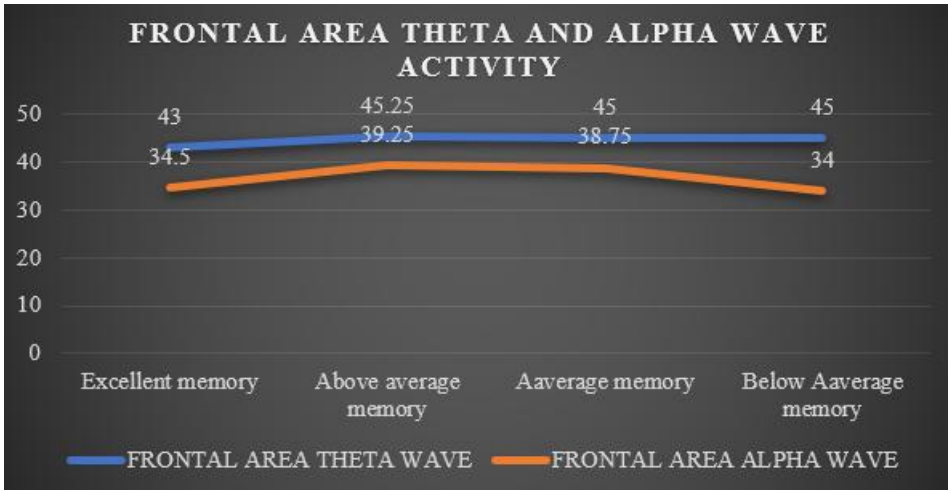

Figure 2: Frontal Area Theta and Alpha Wave Activity Across Memory Performance Levels. The graph represents the mean theta and alpha wave activity in the frontal brain regions for different memory performance groups.

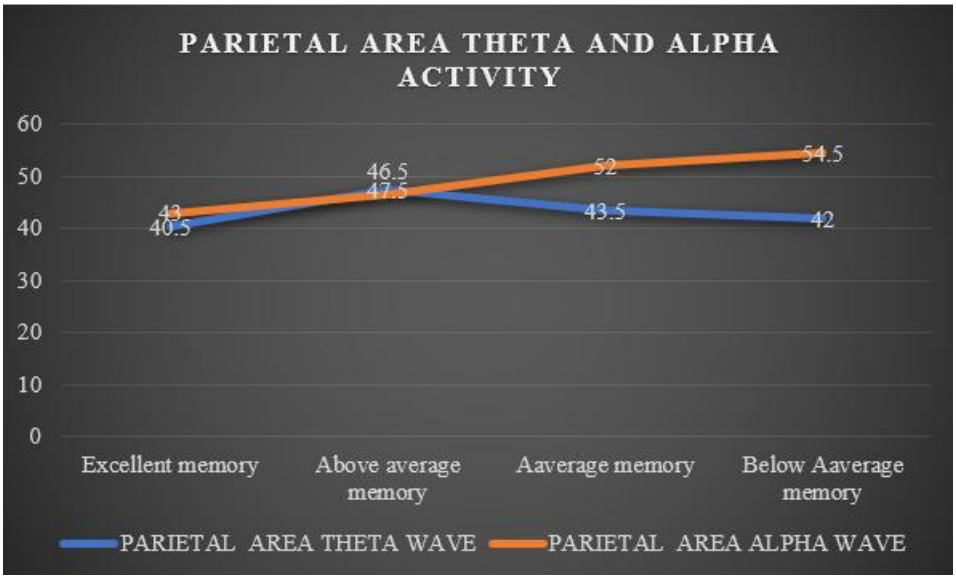

Figure 3: Parietal Area Theta and Alpha Wave Activity Across Memory Performance Levels. The graph represents the mean theta and alpha wave activity in the parietal brain regions for different memory performance groups.

5. Discussion

Human brain electric activity can be studied for the purpose of assessing the functional and structural integrity of the brain and gaining insight into cognitive processes.

This study examined EEG activity during memory task to identify baseline activity components and compare variations across groups over all frequencies.

As shown in table 2, excellent and above-average memory performers had higher theta frequency and lower alpha frequency in frontal regions (F3, F4, F7, F8), whereas mixed changes in theta and alpha frequency were detected in the parietal region (P3, P4). Stronger theta rises are associated with better encoding efficiency.

Plenty of studies have examined theta and alpha frequencies, which have long been linked to cognitive functions (22). The current study discovered that increased memory tasks were associated with an increase in frontal theta activity. Other studies discovered that theta frequency in the frontal brain is positively linked with increased cognitive workload (23). Alpha and theta operate in distinct and opposing ways. The essential findings are that when workloads increase, theta synchronizes whereas alpha desynchronizes. Animal studies have demonstrated that theta is an oscillating component of the hippocampus EEG that is linked to memory processing. From a functional perspective, a rise in theta band power indicates cortical stimulation, specifically an increase in the activity of the hippocampus medial prefrontal circuits (24). Some studies suggest that good performance is connected with a tonic increase in alpha but a decrease in theta power, and a significant phasic decrease in alpha but an increase in theta, depending on the kind of memory demand (25).

Other studies shows that A spike in Theta power indicates higher memory stress throughout the memory activity. Theta power rises significantly when working memory is required, remains constant throughout the memory task, and declines once working recall is no longer necessary (26).

In our study It is observed that Frontal areas show more significant higher theta activity and lower alpha activity and the relationship between theta activity and memory processes has been well documented in other research study (27). Theta

activity frequently rises with the level of difficulty. Higher theta power is noticed when tasks related to programming become more difficult. Increased theta power may indicate cognitive functions such as problem solving, memory retrieval, and mental exertion. Another study found reduced power in the upper alpha band and greater strength in the theta and lower alpha bands in the fronto-central region during the course of action (28). also, a gradual increase in theta (4-6 Hz) power in response to memory stress, which is consistent with prior findings on the neural basis of memory working ability as a contributing factor of task-related frontal midline theta variability in the Sternberg task (29). others Findings revealed that individuals with higher cognitive ability responded faster without sacrificing accuracy. These high-ability participants also exhibited larger late positive event-related potentials and increased frontal midline theta activity, suggesting better attention control and sustained focus (30, 31).

As our result shows Parietal area shows lower theta and higher alpha activity during memory task performance. Other findings indicated that the process of updating sensory information in working memory is associated with increased amplitude of the parietal P3 component and a positive slow wave in event-related potentials (ERPs) (32).

6. Conclusion

The study's findings may be dependent on context to the participants' perceptions of the P.G.I memory scale in lab conditions and EEG recording of Theta wave activity appears to play a role in memory performance, with higher Theta power associated with better memory, particularly in the F3 and F8 frontal regions. Alpha wave differences are observed in some regions but do not show a consistent pattern across all areas and it is concluded that Frontal brain regions (F3, F8) are more sensitive to memory performance differences than parietal regions (P3, P4). Our finding of brain networks during memory retrieval could serve as the foundation for a future quantitative EEG-based memory assessment system.

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Consent for Publication: The investigators informed all the participants before data collection that the data would be published as per the study objectives without participant details.

Ethical Approval and Consent to Participate:
This study was approved by the Ethics Committee of Srinivas University (Ethics Code:33/Ahs/2023) on 13 December 2023. All participants provided written informed consent prior to enrolment in the study. This manuscript has not been published, submitted, or accepted for publication elsewhere.

Declaration of Conflicts of Interest: 'The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article'

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