Research Article

Investigating the Relationship Between Resting-State EEG Gamma Power and Neuropsychological Performance in Healthy Adults

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Abstract

Aim: Resting-state gamma oscillations, less studied compared to task-related gamma activity, have increasingly been considered to reflect baseline cognitive processes and readiness for future cognitive demands. Previous research has largely focused on clinical populations, identifying aberrant gamma activity as a marker of cognitive dysfunction in conditions such as schizophrenia, Alzheimer's disease, and ADHD. This study investigates the relationship between resting-state EEG gamma power and neuropsychological performance in healthy adults. Specifically, it examines the associations between absolute and relative gamma power across different brain regions (frontal, temporal, parietal, and occipital) during resting-state and performance in cognitive domains such as working memory, verbal fluency, face recognition, short-term memory, and attention. **Material and Methods**: A total of 45 healthy individuals who underwent routine neuropsychiatric evaluations at NP Istanbul Brain Hospital and exhibited no pathological findings were included in the study. Resting-state EEG data, collected retrospectively, were analyzed to extract gamma power values, which were subsequently correlated with neuropsychological test scores. **Results:** The results revealed significant positive correlations between relative gamma power in the frontal and parietal regions and verbal fluency performance. This association suggests that specific brain regions contribute uniquely to cognitive functions during resting states, with gamma power providing insight into the neural substrates of language-related abilities. **Conclusion:** These findings highlight the relevance of resting-state gamma power in understanding individual differences in cognitive abilities. Future research should validate these findings with larger, more diverse samples and incorporate advanced techniques like MEG to better understand the neural mechanisms linking gamma oscillations to cognitive performance.

Keywords: *EEG, Gamma Oscillations, Neuropsychological Performance, Resting-State, Cognitive Functions*

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Introduction

The intricate and dynamic relationship between brain activity and cognitive performance has long intrigued neuroscientists, as it is essential for comprehending the systems that govern human cognition. Among the array of techniques available for probing this relationship, electroencephalography (EEG) stands out as a non-invasive, highly informative tool that captures the brain's electrical activity [1, 2]. Gamma band oscillations within the EEG spectrum, generally recorded between 30 and 100 Hz, are thought to arise from the synchronized action potentials of fast-spiking, parvalbumin-positive interneurons that contribute to the formation of both local and long-range cortical networks [3-5]. Neural activity in this frequency range tends to be intensified during processes such as sensory integration and complex cognitive tasks, including attention regulation, memory storage, executive decision-making, and language processing [6-8]. While much of the studies have sought to explore the significance of gamma power in task-related contexts, increasing attention has been directed towards examining the associations between resting-state gamma power and cognitive abilities in diverse populations [9].

Resting-state gamma oscillations, though less well understood, are thought to underline baseline cognitive processes and may serve as a preparatory mechanism for future cognitive demands [10]. Most of the studies on resting-state gamma activity have been conducted on clinical populations, including those suffering from schizophrenia, Alzheimer's disease and attention deficit hyperactivity disorder (ADHD) [11-13]. In schizophrenia, for instance, abnormalities in gamma oscillations are linked to difficulties in memory processing and regulatory cognitive functions. Building on this understanding, Tanaka-Koshiyama et al [14] investigated resting state EEG gamma power in schizophrenia patients and found heightened power in the theta, alpha, beta, and gamma frequencies, with no noticeable alterations in delta activity. Notably, a negative relationship was identified among verbal learning performance and gamma power, suggesting that increased resting-state gamma activity may contribute to memory impairments in schizophrenia. Similarly, memory deficits and neurodegenerative alterations have been tied with altered gamma activity in Alzheimer's

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disease [15]. In ADHD, reductions in gamma power during resting-state conditions have been related to challenges in sustaining attention and executive function regulation [13]. Such alterations in gamma activity in clinical populations emphasize the relevance of gamma oscillations as measures of cognitive dysfunction [16].

In contrast to the clinical focus, research on resting-state gamma activity in healthy populations is relatively limited. In a notable study conducted by Oswald et al [17], MEG was employed to examine the correlation between working memory (WM) and resting-state oscillatory activity in healthy adults. They found that spectral power, particularly in the alpha and gamma bands, positively correlated with verbal and visuo-spatial WM abilities, primarily in parietal and prefrontal regions, highlighting the role of resting-state oscillations in WM function. Additionally, McKeon et al [18] examined the developmental trajectory of gamma oscillations and their function in facilitating WM throughout adolescence. They found that while total gamma power decreases with age, gamma event patterns become more specific, enhancing neural efficiency and cognitive function.

Furthermore, Bennis et al [19] investigated how daily variations in theta and gamma activity in the salience-control executive network relate to cognitive differences observed in aging. They observed that elevated theta fluctuations were associated with poorer memory performance and higher neuroinflammation markers, while greater gamma fluctuations correlated with improved executive function and lower β-amyloid deposition. Lastly, Oswald et al [20] employed resting-state MEG to investigate verbal fluency and discovered gamma clusters in the inferior frontal gyrus of the left side related to processing of phonological sounds, while slower frequency groups in the opposite hemisphere related to executive monitoring. Together, these studies highlight the dynamic role of gamma oscillations across development, aging, and cognitive functions.

This study aims to investigate the relationship between resting-state EEG gamma power and neuropsychological performance across multiple cognitive domains in healthy adults. Unlike many studies that focus on clinical populations or specific age groups, this research explores gamma oscillations in a non-clinical population, examining how both absolute and relative gamma power across various brain regions correlates with cognitive performance. The study addresses several cognitive domains, including working memory, executive functions, visual recognition memory, verbal memory, and non-verbal memory, to provide a comprehensive understanding of how resting-state gamma power supports neuropsychological functioning. By employing a rigorous methodology that combines EEG data analysis with neuropsychological assessments, this research aims to bridge a gap in the literature and offer new insights into the neural dynamics underlying cognitive performance in healthy adults.

Materials and methods

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Study design

This research is a quantitative cross-sectional study designed to investigate the relationship between resting-state EEG gamma power and neuropsychological performance in healthy adults. The research does not involve any experimental manipulation; instead, it relies on pre-existing EEG and neuropsychological data obtained from healthy individuals. EEG recordings and neuropsychological assessments were retrospectively obtained from routine neuropsychiatric evaluations at NP Istanbul Brain Hospital. Although electrophysiological and cognitive assessments occurred in separate sessions, the precise intervals between these two procedures were not available to the researcher. However, in routine clinical practice, EEG recordings and neuropsychological tests typically take place within a short time frame, ranging approximately from several days to a few weeks, depending on individual appointment schedules and clinical availability. Following data collection, EEG recordings were preprocessed and analyzed to extract gamma power values from different brain regions (frontal, temporal, parietal, and occipital lobes), and these were correlated with cognitive performance scores derived from neuropsychological tests. The study aims to identify whether variations in gamma power are associated with performance differences in cognitive domains including working memory, executive functions, and memory.

Participants

The participants of this study were healthy adults who underwent routine neuropsychiatric evaluations at Üsküdar University NP Brain Hospital. The sample consists of 45 healthy adults, selected from the hospital's database, which contains resting-state EEG recordings and neuropsychological test results. Participants were eligible for inclusion if they were aged 18 years or older, had no prior diagnosis of neurological or psychiatric conditions, and exhibited intact cognitive functioning to ensure valid neuropsychological performance. Individuals with previous substance use issues or any factors that could interfere with the accuracy of neuropsychological assessments were excluded from the study. The study utilized convenience sampling, relying on the availability of existing data from the hospital's records.

Data collection tools

In this study, only age and gender data were accessible due to restrictions in the data access approval, and no additional demographic details were available. The EEG recordings were performed by trained technicians who provided periodic instructions to the participants, such as asking them to open and close their eyes at intervals, to ensure accurate resting-state data. The data were recorded with a 21-electrode setup following the international 10-20 system, using a sampling frequency of 120 Hz. These recordings lasted approximately 10 minutes and were provided in *.cnt* format as raw, unprocessed data for analysis.

Neuropsychological performance assessments were conducted and scored by clinical psychologists specializing in cognitive evaluation. Each domain of cognitive function was measured using specific tests:

Working memory and complex attention: The Digit Span Test, part of the Wechsler Memory Scale (3rd Edition, WMS-III), evaluates working memory by asking participants to repeat a sequence of digits in the given order (ahead) or in reverse order (backward) [21]. The test commences with brief sequences and progressively extends their length to assess the participants' capacity to retain and manage information in short-term memory. Performance is scored based on the longest sequence they can accurately repeat. In this study, results from the forward and backward digit repetition tasks were utilized to evaluate working memory and complex attention performance.

Executive functions: Verbal fluency was evaluated by the Controlled Oral Word Association Test (COWAT), in which participants were instructed to produce words commencing with designated letters (e.g., K, A, S) within a set time limit [22]. The overall count of accurately produced words in the COWAT was used for correlational analysis in this domain. The second test, the Stroop Color-Word Test (SCWT), measured participants' ability to inhibit automatic responses by naming the ink color of printed words that conflicted with the color's name [23]. This study employed the interference score, indicative of the disparity between the duration required to read words and the time needed to identify ink colors, as a variable for examining its association within the realm of executive function through correlation analyses.

Visual functioning: The evaluation of visual recognition memory was conducted through the Benton Face Recognition Test (BFRT), necessitating tat participants identify faces displayed under diverse lighting conditions and angles [24]. Participants viewed a target face and were then asked to select the matching face from an array of six options. The overall count of accurate matches was utilized for correlational analysis in this area.

Non-verbal memory: The Wechsler Memory Scale-Fourt Edition (WMS-IV) includes subtests that assess non-verbal memory, encompassing both visual short-term and long-term memory [25]. The subtests consist of tasks in which participants view a sequence of figures individually. After each figure is taken away, they are required to recreate the design from memory prior to the presentation of the next figure. The scores are based on the presence and accuracy of key elements within the reproduced drawings. In this study, both immediate recall and delayed recall performances were analyzed to explore potential associations between memory processing stages and resting-state gamma band activity.

Verbal memory: The Öktem Verbal Memory Processes Test (VMPT) is a word-list learning test designed to evaluate a person's capacity to acquire, remember, and identify verbal information [26]. In the initial phase, participants are provided with a list of words, followed by an immediate recall task where they attempt to remember and reproduce as many words as possible. Following a predetermined interval, participants are instructed to retrieve the identical word list, evaluating their long-term retention of verbal information. The VMPT encompasses a recognition task in which individuals are shown a combination of previously presented and novel words, requiring them to identify the word they learned earlier. In this study, scores derived from the VMPT were used for correlation analysis of verbal memory function, focusing on immediate recall, total learning, delayed free recall, and delayed recognition.

Data analysis

Resting-state EEG data were preprocessed utilizing MATLAB R2022b in conjunction with the EEGLAB toolbox. The EEG data, originally in ***.cnt*** format, were loaded and segmented into a time window of 0 to 180 seconds for each recording. A basic FIR filter was applied with a bandpass range of 0.5-50 Hz. The reference electrodes A1 and A2 were removed, and channel locations were added using standard electrode position files. Artifacts, such as those caused by eye movements and muscle activity, were manually detected and removed through the inspect/reject data by eye approach. Subsequently, Independent Component Analysis (ICA) was performed, and non-brain components (those labeled below 70% as brain activity) were rejected using the ICLabel plugin. After that, average referencing was applied, and the processed data were saved in ***.set*** format for each participant.

The analysis of gamma power was conducted within the EEGLAB environment using the Darbeliai plugin, allowing for precise extraction of gamma band values. The preprocessed EEG data in *.set* format were loaded into Darbeliai, where frequency intervals were set to encompass standard EEG bands, with the gamma band specifically defined from 30 to 50 Hz in the 'spectrum band' table. This frequency band was chosen due to the EEG recordings' sampling rate of 120 Hz, which limits reliable detection of gamma oscillations to frequencies below approximately 60 Hz (Nyquist frequency). Restricting analyses to 30–50 Hz thus ensured accurate measurement and minimized contamination from muscle artifacts that commonly emerge at higher frequencies. Gamma power extraction was conducted using a 2-second FFT (Fast Fourier Transform) window length with a spectral resolution of 10 points per Hz, balancing frequency resolution with temporal stability. Following this, absolute and relative gamma power values were extracted from selected electrodes (C3, C4, Cz, F3, F4, F7, F8, Fp1, Fp2, Fz, O1, O2, P3, P4, Pz, T3, T4, T5, T6) to capture gamma activity patterns across distinct cortical regions, and these values were exported for further analysis. Custom MATLAB scripts were subsequently used to compute the average gamma power across the major brain regions, including the frontal, temporal, parietal, and occipital lobes. The electrodes were grouped by region as follows: frontal region (Fp1, Fp2, F3, F4, F7, F8, Fz), temporal region (T3, T4, T5, T6), parietal region (P3, P4, Pz), and occipital region (O1, O2). The scripts computed both the average absolute and relative gamma power values for each lobe, which were subsequently used in correlation analyses with neuropsychological performance measures.

The statistical analyses were performed utilizing IBM SPSS Statistics version 29.0.2.0. Neuropsychological scores and gamma power values were entered into a data table along with available demographic information such as age and gender. Fundamental descriptive statistics, such as mean, frequency, and standard deviation, were computed for these variables. The assessment of data normality was conducted through Shapiro-Wilk test, revealing that the majority of the data didn't conform to a normal distribution. Consequently, Spearman's rank correlation was utilized to analyze the associations between gamma power levels and neuropsychological test scores. Statistical significance was defined as $p < 0.05$.

Results

This study involved 45 healthy adults aged between 24 and 69 years, with a mean age of 40.89 years (**± 10.76 years** *SD*). Of the participants, 64.4% were male ($n = 29$) and 35.6% were female ($n = 16$) (Table 1).

Table 1: Demographic features of the sample

Variable		n	%	
Gender	Female	16	35.6%	
	Male	29	64.4%	
Age	Min.	Max.	Mean	SD
	24	69	40.89	10.76

The descriptive statistics and Shapiro-Wilk normality test results for EEG gamma power values across different brain regions are presented in Table 2. Absolute and relative gamma power were analyzed, with their respective averages and standard deviations reported for the frontal, temporal, parietal, and occipital regions. Absolute gamma power values showed a range of means, with temporal absolute gamma power having the highest mean (M = 0.7513, SD = 0.6471) and parietal absolute gamma power having the lowest mean (M = 0.3538, SD = 0.1737). Relative gamma power values were smaller across regions, with frontal relative gamma power showing the smallest mean (M = 0.0239, SD = 0.1365). The Shapiro-Wilk test outcomes demonstrated that all gamma power variables deviated from a normal distribution (p < 0.05 for all variables), indicating that non-parametric tests would be more suitable for subsequent statistical analysis.

Table 2: Descriptive statistics and normality test results for EEG gamma power

Variable	n	Mean	SD	Shapiro-Wilk W	p-value
Frontal Absolute Gamma Power	45	0.4060	0.2731	0.765	< 0.001
Temporal Absolute Gamma Power	45	0.7513	0.6471	0.725	< 0.001
Parietal Absolute Gamma Power	45	0.3538	0.1737	0.905	0.001
Occipital Absolute Gamma Power	45	0.5977	0.3956	0.847	< 0.001
Frontal Relative Gamma Power	45	0.0239	0.1365	0.837	0.001
Temporal Relative Gamma Power	45	0.0329	0.0192	0.895	< 0.001
Parietal Relative Gamma Power	45	0.0192	0.1133	0.902	< 0.001
Occipital Relative Gamma Power	45	0.0172	0.1039	0.922	0.005

***p < .05* indicates a significant deviation from normal distribution according to the Shapiro-Wilk test.**

Table 3 presents the summary statistics for the neuropsychological test scores. The WMS-III Digit Span Forward test had a mean score of 5.84 (SD = 0.952), while the WMS-III Digit Span Backward test had a mean score of 4.27 (SD = 0.720), indicating performance in working memory tasks. COWAT Verbal Fluency showed a broader range of performance (Min = 10, Max = 74), with a mean score of 42.58 (SD = 13.314). Stroop Interference had a mean score of 42.76 (SD = 16.010), based on 33 participants, reflecting individual differences in executive functioning. Benton Face Recognition, a measure of visual recognition memory, showed a mean score of 47.73 (SD = 4.305). The memory assessments, comprising the WMS-IV Immediate Recall and WMS-IV Delayed Recall tests, yielded average scores of 11.98 (SD = 2.321) and 12.02 (SD = 2.808), respectively. The VMPT Total Learning score had the widest range, from 46 to 144, with a mean of 120.22 (SD = 21.303), suggesting variability in verbal memory performance.

Table 3: Descriptive statistics of neuropsychological test scores across cognitive domains

	n	Min.	Max.	Mean	SD
WMS-III Digit Span Forward	45	4	7	5.84	0.952
WMS-III Digit Span Backward	45	3	6	4.27	0.720
COWAT Verbal Fluency	45	10	74	42.58	13.314
Stroop Interference	33	14	89	42.76	16.010
Benton Face Recognition	37	35	54	47.73	4.305
WMS-IV Immediate Recall	45	3	14	11.98	2.321
WMS-IV Delayed Recall	45	2	14	12.02	2.808
VMPT Immediate Recall	45	3	11	7.02	2.039
VMPT Total Learning	45	46	144	120.22	21.303
VMPT Delayed Free Recall	45	6	15	12.80	2.768
VMPT Delayed Recognition	45	0	6	1.67	1.523

"Note: Cognitive domains measured include working memory and complex attention (WMS-III Digit Span), executive functions (COWAT, Stroop Interference), visual recognition (Benton Face Recognition Test), verbal memory (VMPT), and non-verbal memory (WMS-IV Immediate and Delayed Recall)."

Spearman's correlation analysis was carried out to assess the associations between absolute gamma power in the frontal, temporal, parietal and occipital regions and a range of neuropsychological test scores. The results are summarized in Table 4. Frontal absolute gamma power showed no significant correlations with any of the neuropsychological test scores. The highest observed correlation was with WMS-IV Immediate Recall (ρ = 0.182, p = 0.231), though this was not statistically significant. Temporal absolute gamma power exhibited a marginal positive correlation with WMS-III Digit Span Backward ($\rho = 0.269$, $p = 0.074$), though this result did not reach statistical significance. Parietal and occipital absolute gamma power did not show any statistically significant correlations with neuropsychological test scores. Overall, the correlation analysis revealed no significant relationships between absolute gamma power and neuropsychological performance ($p > 0.05$ for all variables), suggesting that absolute gamma power across brain regions was not meaningfully lined to cognitive performance in this sample.

Spearman's correlation analysis was also performed to evaluate the associations between relative gamma power in the frontal, temporal, parietal, and occipital regions and a range of neuropsychological test scores. The results are detailed in table 5. Higher frontal relative gamma power was significantly correlated with improved COWAT Verbal Fluency scores ($\rho = 0.466$, $p = 0.001$), indicating a positive association between two measures. Additionally, parietal relative gamma power was significantly correlated with COWAT Verbal Fluency ($\rho = 0.386$, $p = 0.009$). There were no significant associations between relative gamma power in any brain region and the scores for WMS-III Digit Span Forward or WMS-III Digit Span Backward. Benton Face Recognition, WMS-IV Immediate Recall, and WMS-IV Delayed Recall scores did not show any significant correlations with relative gamma power across any brain region ($p > 0.05$). Overall, significant correlations were mainly identified between relative gamma power localized in the frontal and parietal regions and verbal fluency, while no notable

Table 4: Spearman correlations between absolute gamma power in cortical regions and neuropsychological test scores

	Spearman's rho (ρ)	Frontal Absolute	Temporal Absolute	Parietal Absolute	Occipital Absolute
WMS-III Digit Span Forward	Correlation Coefficient	0.158	0.075	0.057	-0.052
	p-value (two-tailed)	0.299	0.623	0.709	0.733
	n	45	45	45	45
WMS-III Digit Span Backward	Correlation Coefficient	-0.002	0.269	0.135	0.145
	p-value (two-tailed)	0.991	0.074	0.378	0.341
	n	45	45	45	45
COWAT Verbal Fluency	Correlation Coefficient	0.103	-0.046	0.016	-0.166
	p-value (two-tailed)	0.500	0.766	0.917	0.277
	n	45	45	45	45
Stroop Interference	Correlation Coefficient	-0.120	-0.301	0.194	-0.197
	p-value (two-tailed)	0.506	0.089	0.280	0.273
	n	33	33	33	33
Benton Face Recognition	Correlation Coefficient	0.125	0.033	-0.015	0.028
	p-value (two-tailed)	0.461	0.844	0.928	0.869
	n	37	37	37	37
WMS-IV Immediate Recall	Correlation Coefficient	0.182	0.200	0.080	0.133
	p-value (two-tailed)	0.231	0.188	0.602	0.383
	n	45	45	45	45
WMS-IV Delayed Recall	Correlation Coefficient	0.165	0.262	0.179	0.281
	p-value (two-tailed)	0.278	0.082	0.238	0.062
	n	45	45	45	45
VMPT Immediate Recall	Correlation Coefficient	-0.063	0.029	0.047	0.049
	p-value (two-tailed)	0.682	0.850	0.759	0.752
	n	45	45	45	45
VMPT Total Learning	Correlation Coefficient	-0.159	0.088	-0.055	0.016
	p-value (two-tailed)	0.297	0.564	0.722	0.915
	n	45	45	45	45
VMPT Delayed Free Recall	Correlation Coefficient	0.073	-0.039	0.030	0.017
	p-value (two-tailed)	0.635	0.797	0.844	0.914
	n	45	45	45	45
VMPT Delayed Recognition	Correlation Coefficient	-0.007	0.051	0.046	0.025
	p-value (two-tailed)	0.962	0.738	0.762	0.870
	n	45	45	45	45

Table 5: Spearman correlations between relative gamma power in cortical regions and neuropsychological test scores

	Spearman's rho (ρ)	Frontal Relative	Temporal Relative	Parietal Relative	Occipital Relative
WMS-III Digit Span Forward	Correlation Coefficient	0.105	0.068	0.071	0.090
	p-value (two-tailed)	0.492	0.659	0.641	0.556
	n	45	45	45	45
WMS-III Digit Span Backward	Correlation Coefficient	-0.053	0.174	0.084	0.040
	p-value (two-tailed)	0.729	0.254	0.584	0.792
	n	45	45	45	45
COWAT Verbal Fluency	Correlation Coefficient	0.466**	0.137	0.386**	0.269
	p-value (two-tailed)	0.001	0.369	0.009	0.074
	n	45	45	45	45
Stroop Interference	Correlation Coefficient	-0.129	-0.186	-0.183	-0.123
	p-value (two-tailed)	0.474	0.300	0.308	0.496
	n	33	33	33	33
Benton Face Recognition	Correlation Coefficient	-0.035	0.009	-0.261	-0.031
	p-value (two-tailed)	0.837	0.958	0.119	0.854
	n	37	37	37	37
WMS-IV Immediate Recall	Correlation Coefficient	-0.172	-0.078	-0.232	-0.105
	p-value (two-tailed)	0.258	0.610	0.126	0.491
	n	45	45	45	45
WMS-IV Delayed Recall	Correlation Coefficient	-0.154	-0.021	-0.172	0.020
	p-value (two-tailed)	0.314	0.890	0.260	0.897
	n	45	45	45	45
VMPT Immediate Recall	Correlation Coefficient	-0.215	-0.224	-0.133	-0.087
	p-value (two-tailed)	0.156	0.139	0.385	0.571
	n	45	45	45	45
VMPT Total Learning	Correlation Coefficient	-0.064	0.008	0.068	0.057
	p-value (two-tailed)	0.674	0.959	0.685	0.710
	n	45	45	45	45
VMPT Delayed Free Recall	Correlation Coefficient	0.045	-0.036	0.000	0.114
	p-value (two-tailed)	0.770	0.813	0.998	0.456
	n	45	45	45	45
VMPT Delayed Recognition	Correlation Coefficient	0.011	0.031	0.037	-0.085
	p-value (two-tailed)	0.942	0.839	0.811	0.579
	n	45	45	45	45

Note: Correlation coefficients represent Spearman's rho (ρ). Gamma power values represent averages from electrodes grouped into frontal (Fp1, Fp2, F3, F4, F7, F8, Fz), temporal (T3, T4, T5, T6), parietal (P3, P4, Pz), and occipital (O1, O2) regions. Bold values indicate significant correlations ($p < 0.01$, two-tailed).

relationships were observed for other cognitive domains.

To further explore the relationships between relative gamma power and verbal fluency performance, scatter plots were generated to visually represent the significant correlations identified. Figure 1 illustrates the relationship between frontal relative gamma power and COWAT Verbal Fluency outcomes. The scatter plot shows a positive trend, suggesting that higher levels of frontal relative gamma power are associated with better verbal fluency performance. This is consistent with the significant Spearman's correlation result ($\rho = 0.466$, $p = 0.001$), indicating that increased gamma activity in the frontal region may contribute to enhanced verbal processing and fluency. Figure 2 depicts the correlation between parietal relative gamma power and COWAT Verbal Fluency scores. Similar to the frontal region, a positive trend is observed, indicating that as parietal relative gamma power increases, so do verbal fluency scores. This correlation was also statistically significant ($\rho = 0.386$, $p = 0.009$), highlighting the potential involvement of the parietal region in supporting verbal fluency tasks.

These scatter plots visually reinforce the positive relationships between relative gamma power in the frontal and parietal regions and verbal fluency performance. The generally monotonic trend observed aligns with the use of Spearman's correlation, capturing a consistent directional association without assuming strict linearity. Although a few outliers introduce slight variability, the overall positive association between relative gamma power and verbal fluency remains evident.

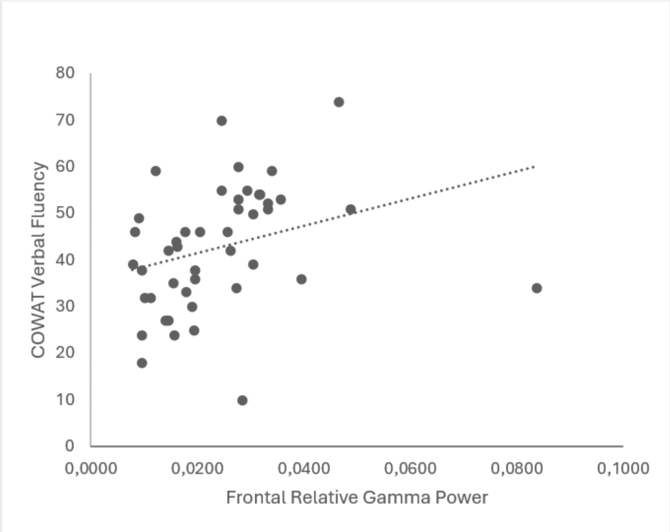

Figure 1: Scatter plot of frontal relative gamma power and COWAT verbal fluency scores

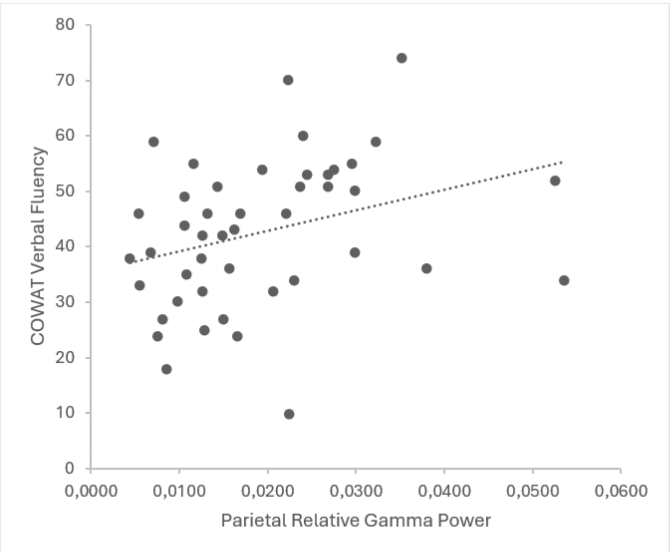

Figure 2: Scatter plot of parietal relative gamma power and COWAT verbal fluency scores

Discussion

This study aimed to investigate the relationship between resting-state EEG gamma power and neuropsychological performance across various cognitive domains in healthy adults. The results demonstrated a few significant correlations between relative gamma power in specific brain regions and cognitive performance, particularly in the domain of verbal fluency. However, the overall findings suggest that absolute gamma power was not significantly related to cognitive performance, and only relative gamma power in the frontal and parietal regions showed significant correlations with verbal fluency. These findings will be interpreted in the context of existing literature, with a focus on their potential implications and the limitations of the study.

The most notable finding was the significant positive correlation between frontal and parietal relative gamma power and COWAT Verbal Fluency scores. These findings are in line with previous studies investigating resting-state brain activity and its associations with cognitive processes including language processing and executive function. For instance, prior research demonstrated that verbal learning performance was inversely correlated with elevated resting-state gamma band power in schizophrenia patients, especially in the temporal and frontal regions [14]. Although that study examined a clinical population, the connection between gamma oscillations and language-related cognitive performance remains relevant here. Conversely, this study discovered that in healthy people, gamma power and verbal fluency were positively correlated, potentially reflecting the typical operation of gamma oscillations to promote progressed cognitive activities like language production. This opposing direction of correlation (positively in healthy adults versus negative in schizophrenia patients) may be reflective of the pathological nature of gamma oscillations in schizophrenia, where such activity is thought to contribute to cognitive impairments by acting as cortical noise [14].

The significance of gamma oscillations in cognitive functions associated with language is further substantiated by MEG research, which revealed that gamma-band activity in the left inferior frontal gyrus (LIFG) contributes a crucial role in phonological processing during tasks requiring verbal fluency [20]. This aligns with the present findings, as increased frontal gamma power in healthy adult participants was associated with enhanced performance on verbal fluency tasks. The LIFG, identified as a key region for speech production and word retrieval, showed gamma power enhancement in the MEG study, which underscores the relevance of this region for verbal fluency. This result further suggests that resting-state gamma activity may serve as an indicator of the brain's readiness to engage in language-related tasks, like the concept of gamma power being a marker for cognitive preparedness observed in other studies [20].

Additionally, the MEG study identified bilateral parietal regions as important for verbal fluency, with gamma oscillations in these areas contributing to phonological processing [20]. In a similar vein, this study revealed a correlation between gamma power in parietal regions, and verbal fluency performance, indicating that these areas may be instrumental in the integration of sensory-motor information essential for the production of fluent speech. The engagement of both frontal and parietal cortices indicates that verbal fluency requires complex cross-regional communication, a finding consistent with the notion that multiple brain regions coordinate during language production tasks [20].

Both studies emphasize that gamma-band oscillations support higher cognitive functions, particularly those related to verbal fluency and executive control. While resting-state gamma power in frontal areas was linked to better verbal fluency performance in the current investigation, gamma oscillations in the left inferior frontal gyrus were linked to phonological processing in the MEG study [20]. This convergence of findings suggests that gamma oscillations are a crucial component of the neural mechanisms underlying verbal fluency, regardless of whether the task involves active language production or reflects resting-state cognitive readiness. The findings indicate that resting-state gamma power might serve as an indicator of cognitive performance in non-clinical populations, as this study shows a positive association between gamma power and verbal fluency; mirroring the insights gained from MEG studies in other cognitive domains [20].

Despite these promising results, several limitations must be considered when interpreting the findings of this study. Firstly, due to restrictions on data access permissions, precise information regarding the exact time intervals between EEG recordings and neuropsychological assessments was not available to the researcher. Although these assessments typically occur within a short period—ranging from days to weeks—standard in routine clinical evaluations, the lack of exact interval data per participant introduces potential variability in cognitive performance. Factors such as transient cognitive fluctuations, mood variations, or fatigue could thus not be ruled out completely, potentially affecting the strength and consistency of correlations observed. Future prospective studies with clearly recorded intervals would help mitigate this limitation.

Furthermore, the modest sample size (N = 45) restricts statistical power and the generalizability of the current findings. The cross-sectional and retrospective nature of the study also limits the capacity to infer causal relationships between EEG gamma power and cognitive performance. Therefore, replication with larger and diverse cohorts in prospective studies is necessary to enhance external validity and establish clearer causal interpretations. Additionally, given the number of cognitive tests and EEG regions analyzed, there is an increased risk of identifying statistically significant relationships that may not reflect true underlying associations (Type I error). Although corrections for multiple comparisons (e.g., Bonferroni or False Discovery Rate adjustments) were not implemented here due to the exploratory nature of the analysis and modest sample size, incorporating such corrections in future confirmatory studies would strengthen the validity and reliability of the findings.

Moreover, regression analyses to control for demographic factors were not conducted. Although basic demographic data (age and gender) were available, additional demographic variables, including education level or socioeconomic status, could not be accessed due to data restrictions. Thus, comprehensive statistical control for potential demographic confounders was not feasible, limiting the ability to isolate the specific contribution of gamma power to cognitive performance. Future studies with broader demographic information should use regression methods to clarify the independent relationship between gamma oscillations and cognitive outcomes.

Another limitation involves the analysis of gamma oscillations within the restricted frequency band (30–50 Hz). Due to the EEG sampling rate of 120 Hz used in this study, gamma analyses were constrained to frequencies below the Nyquist limit (~60 Hz), making detection of higher gamma frequencies unreliable. Higher gamma frequencies, often observed during cognitive tasks or detected more clearly with methods offering higher temporal resolution such as MEG, could not be adequately evaluated. Future studies employing higher sampling rates or MEG recordings, which provide superior spatial and temporal resolution, could explore broader gamma frequency ranges, capturing gamma oscillations more precisely and potentially revealing stronger associations with cognitive performance.

Finally, the analysis grouped EEG electrodes into broad cortical regions (frontal, temporal, parietal, and occipital), which restricted the ability to examine subtle differences in cognitive functions between the left and right hemispheres (lateralization effects). Because EEG signals recorded from scalp electrodes reflect summed activity from relatively large cortical areas, this approach inherently limits precise localization of neural activity. Consequently, subtle hemispheric differences that might be important for specific cognitive processes may not be adequately captured. Future studies using EEG source localization methods or employing techniques with inherently higher spatial resolution, such as MEG, could more precisely investigate hemispheric lateralization and provide deeper insights into how lateralized brain activity contributes to cognition.

Conclusion

In conclusion, the association between gamma power and verbal fluency observed in this study aligns with existing research that links gamma-band activity to language production and executive functions. While previous studies have examined these relationships in clinical populations or using advanced imaging techniques such as MEG, the findings extend these insights to a healthy adult population, indicating that resting-state gamma power could potentially be crucial in facilitating cognitive readiness for verbal tasks. Nonetheless, these findings should be interpreted cautiously considering several methodological limitations, including the retrospective nature of data collection, modest sample size, limited control for demographic variables, restricted gamma frequency range, as well as the inherent spatial resolution constraints of EEG methodology. Future research employing larger prospective cohorts, regression analyses to control demographic confounders, statistical adjustments for multiple comparisons, and advanced imaging methods (e.g., MEG) will be essential to substantiate and expand upon the observed relationships, clarifying these associations.

Patient informed consent:

There is no need for patient informed consent.

Ethics committee approval:

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REFERENCES

1. Niedermeyer E, Lopes da Silva FH. Electroencephalography: Basic principles, clinical applications, and related fields. 5th ed. Lippincott

Williams & Wilkins; 2005.

2. Luck SJ. An introduction to the event-related potential technique. 2nd ed. MIT Press; 2014.
3. Uhlhaas PJ, Pipa G, Lima B, Melloni L, Neuenschwander S, Nikolić D, et al. Neural synchrony in cortical networks: history, concept and current status. Front Integr Neurosci. 2009;3:17. doi:10.3389/neuro.07.017.2009.
4. Bartos M, Vida I, Jonas P. Synaptic mechanisms of synchronized gamma oscillations in inhibitory interneuron networks. Nat Rev Neurosci. 2007;8(1):45–56. doi:10.1038/nrn2044.
5. Whittington MA, Cunningham MO, LeBeau FE, Racca C, Traub RD. Multiple origins of the cortical γ rhythm. Dev Neurobiol. 2011;71(1):92–106. doi:10.1002/dneu.20814.
6. Başar E, Başar-Eroğlu C, Karakaş S, Schürmann M. Brain oscillations in perception and memory. Int J Psychophysiol. 2000;35(2–3):95–124. doi:10.1016/s0167-8760(99)00047-1.
7. Buzsáki G, Draguhn A. Neuronal oscillations in cortical networks. Science. 2004;304(5679):1926–9. doi:10.1126/science.1099745.
8. Herrmann CS, Fründ I, Lenz D. Human gamma-band activity: a review on cognitive and behavioral correlates and network models. Neurosci Biobehav Rev. 2010;34(7):981–92. doi:10.1016/j.neubiorev.2009.09.001.
9. Raichle ME, MacLeod AM, Snyder AZ, Powers WJ, Gusnard DA, Shulman GL. A default mode of brain function. Proc Natl Acad Sci U S A. 2001;98(2):676–82. doi:10.1073/pnas.98.2.676.
10. Jensen O, Mazaheri A. Shaping functional architecture by oscillatory alpha activity: gating by inhibition. Front Hum Neurosci. 2010;4:186. doi:10.3389/fnhum.2010.00186.
11. Grent-'t-Jong T, Gross J, Goense J, Wibral M, Gajwani R, Gumley AI, et al. Resting-state gamma-band power alterations in schizophrenia reveal E/I-balance abnormalities across illness stages. eLife. 2018;7:e37799. doi:10.7554/eLife.37799.
12. Güntekin B, Erdal F, Bölükbaş B, Hanoğlu L, Yener G, Duygun R. Alterations of resting-state Gamma frequency characteristics in aging and Alzheimer's disease. Cogn Neurodyn. 2023;17(4):829–44. doi:10.1007/s11571-022-09873-4.
13. Tombor L, Kakuszi B, Papp S, Réthelyi J, Bitter I, Czobor P. Atypical resting-state gamma band trajectory in adult attention deficit/hyperactivity disorder. J Neural Transm (Vienna). 2021;128(8):1239–48. doi:10.1007/s00702-021-02368-2.
14. Tanaka-Koshiyama K, Koshiyama D, Miyakoshi M, Joshi YB, Molina JL, Sprock J, et al. Abnormal spontaneous gamma power is associated with verbal learning and memory dysfunction in schizophrenia. Front Psychiatry. 2020; 11:832. doi:10.3389/fpsyt.2020.00832.
15. de Haan W, Stam CJ, Jones BF, Zuiderwijk IM, van Dijk BW, Scheltens P. Resting-state oscillatory brain dynamics in Alzheimer disease. J Clin Neurophysiol. 2008;25(4):187–93. doi:10.1097/WNP.0b013e31817da184.
16. Herrmann CS, Strüber D, Helfrich RF, Engel AK. EEG oscillations: From correlation to causality. Int J Psychophysiol. 2016; 103:12–21. doi:10.1016/j.ijpsycho.2015.02.003.
17. Oswald V, Zerouali Y, Boulet-Craig A, Krajinovic M, Laverdière C, Sinnett D, et al. Spontaneous brain oscillations as neural fingerprints of working memory capacities: A resting-state MEG study. Cortex. 2017;97:109–24. doi:10.1016/j.cortex.2017.09.021.
18. McKeon SD, Calabro F, Thorpe RV, de la Fuente A, Foran W, Parr AC, et al. Age-related differences in transient gamma band activity during working memory maintenance through adolescence. NeuroImage. 2023;274:120112. doi:10.1016/j.neuroimage.2023.120112.
19. Bennis K, Eustache F, Collette F, Vandewalle G, Hinault T. Daily dynamics of resting-state EEG theta and gamma fluctuations are associated with cognitive performance in healthy aging. J Gerontol B Psychol Sci Soc Sci. 2024. doi:10.1093/geronb/gbae152.
20. Oswald V, Zerouali Y, Boulet-Craig A, Krajinovic M, Laverdière C, Sinnett D, et al. Magnetoencephalography resting-state correlates of executive and language components of verbal fluency. Sci Rep. 2022;12(1):476. doi:10.1038/s41598-021-03829-0.
21. Tulsky DS, Chiaravalloti ND, Palmer BW, Chelune GJ. The Wechsler Memory Scale, Third Edition: A new perspective. In: Tulsky DS, Saklofske DH, Chelune GJ, Heaton RK, Ivnik RJ, Bornstein R, et al., editors. Clinical interpretation of the WAIS-III and WMS-III. Academic Press; 2003. p. 93–139. doi:10.1016/B978-012703570-3/50007-9.
22. Espe-Pfeifer P, Wachsler-Felder J. Neuropsychological Interpretation of Objective Psychological Tests. Springer; 2000. p. 160. ISBN: 978-0-306-46224-5.
23. Stroop JR. Studies of interference in serial verbal reactions. J Exp Psychol Gen. 1992;121(1):15–23. doi:10.1037/0096-3445.121.1.15.
24. Benton A, Hamsher KD, Varney N, Spreen O. Contribution to neuropsychological assessment. Oxford University Press; 1983.
25. Wechsler D. Wechsler Memory Scale (WMS-IV) Technical and Interpretive Manual. Pearson; 2009.
26. Oktem O. Verbal memory processes test (WMPT) – A preliminary study. Arch Neuropsychiatry. 1992;29(4):196–206.