

Power Spectral Analysis of Alpha Waves in Alzheimer's Patients' EEG Datasets

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ABSTRACT: This study investigates how absolute spectral power and power ratios in the alpha frequency band in frontal and parietal regions, as measured through electroencephalograms (EEGs), vary in individuals with Alzheimer's disease compared to healthy controls. Identifying quantitative biomarkers of Alzheimer's is crucial because this would allow for greater objectivity and accuracy in diagnosis, as opposed to relying on questionnaires such as the Mini-Mental State Examination (MMSE), which may be influenced based on patient demographics. A dataset with the EEGs of 65 subjects (divided into control or Alzheimer's participant groups) published in 2023 on OpenNeuro was analyzed through MATLAB, calculating the absolute spectral power in the Fz and Pz electrodes as well as the Fz: Pz power ratios for each participant. Statistical analysis revealed significant differences between Alzheimer's and control groups in spectral power at the Fz ($p = 0.005$) and Pz ($p = 0.0006$) electrodes, as well as the power ratios between them ($p = 0.0025$). These findings demonstrate that reduction of alpha power and an increase of Fz:Pz ratio, suggesting a proportional increase of frontal activity or decrease of parietal activity in individuals with Alzheimer's, are notable trends and a potential biomarker of Alzheimer's disease.

KEYWORDS: Behavioral and Social Sciences, Neuroscience, Alzheimer's Disease, Electroencephalograms, Diagnostic Biomarkers.

■ Introduction

Alzheimer's disease (AD) is the most common form of dementia (a neurodegenerative disorder) affecting around 6.9 million Americans above the age of 65.¹ At its more severe stages, AD can degrade the quality of life of many individuals by impairing cognitive skills such as memory, complex thinking, communication, and the capacity to conduct daily activities. Current AD screening commonly involves cognitive tests evaluating memory, orientation, and attention, the most common being the Mini-Mental State Examination (MMSE). The MMSE has been a prominent tool in assessing patients for potential dementia, comprising 11 questions that, on average, take less than 10 minutes to complete. Though the MMSE has proven both accessible and efficient, its accuracy may be limited to only certain groups of individuals as a result of cultural, academic, and linguistic barriers, producing less reliable results for some patients.² This examination has also been shown to lack precision and nuance in diagnosing specific stages or progressions within AD.³ The MMSE and other cognitive tests, therefore, present numerous limitations because of insufficient standardization and a lack of specificity of diagnosis.

Thus, quantitative or biological metrics have shown promise in the diagnosis of neurodegenerative disorders. An electroencephalogram (EEG) is one test used to generate parameters/quantitative characteristics to detect and analyze disorders. To conduct an EEG, electrodes are placed on the scalp of the patient in a standardized 10-20 method, and the brain's electrical activity (brain waves) is recorded. Commonly assessed frequency bands of brain waves include delta (0.5-4 Hz), theta (4-7 Hz), alpha (8-12 Hz), and beta (13-30 Hz) waves.⁴ An increase in research of EEG applications in evaluating of neu-

rodegenerative disorders such as AD has been observed over previous years due to the technology's value as an accessible, quantitative resource easily facilitated by healthcare providers. One useful EEG measurement observed in studies is absolute spectral power, referring to the total power in microvolts present in a specific range of frequency. Absolute spectral power is a useful and notable measure because it allows for the individual analysis of each frequency band's objective power activity. Previously, studies have discovered deviations in spectral power measurements in AD patients compared with healthy controls, typically involving an increase of delta⁵⁻¹² and theta spectral activity^{5-9,11-14} and a reduction of alpha^{6,8-15} and beta power.^{5,6,8,11} Additionally, power ratios have been employed in previous works as common analytical measures in EEG studies for dementia and neurodegenerative disorders, furthering our understanding of how brain dynamics shift as disease progresses.¹⁶⁻¹⁹ Frontal and parietal regions may be particularly useful monitors for AD because of their individual roles in cognitive functioning. The frontal lobes are involved in processes of decision-making, adaptive reactions, and memory,²⁰ while the parietal areas drive linguistic abilities,²¹ attention,²² visual processing, spatial awareness, and orientation.²³ Considering the potential of power ratios as diagnostic measures and the common deterioration of AD patients' abilities to conduct higher-level functions governed by frontal and parietal regions, assessing spectral power dynamics (both individual spectral power and power ratios between regions) in frontal and parietal regions is a promising target area for research that motivated the present study. The Fz and Pz midline electrodes were selected to examine frontoparietal dynamics as a biomarker for AD to minimize the effects of lateralization, taking into ac-

count that previous studies show that hemispheric asymmetry varies from subject to subject based on handedness and other individual differences.²⁴

Despite these extensive findings, there is a lack of literature specifically analyzing how spectral power measures and power ratios vary in the alpha band for frontal and parietal electrodes in individuals with AD. In addition to this, the efficacy of using these particular EEG parameters (both spectral power and power ratios) as tools for AD diagnosis is unclear.

Therefore, in alignment with these prospects, the objective of the study was to examine the deviation in resting-state EEG spectral power and ratios of the alpha frequency band for AD individuals compared to controls. This reveals diagnostic differences in both the strength of the alpha wave and the proportional power of frontal and parietal regions of the brain in AD compared to healthy control subjects. In the examination of the relationships between these variables, the study aims to help identify quantitative biomarkers in the AD screening process, to aid in objectively and more specifically diagnosing individuals through quantitative analysis of spectral features.

■ Methods

Dataset Description:

To answer the research question, a dataset was identified to analyze the variation in the absolute spectral power of the alpha frequency band in AD patients compared with controls (CN). The data was found on OpenNeuro, published in 2023 by Andreas Miltiadous *et al.*,²⁵ containing the resting-state EEGs of 88 subjects. 36 of these individuals were diagnosed with AD, 29 were healthy controls, and 23 were diagnosed with frontotemporal dementia. The 23 individuals with frontotemporal dementia were excluded from the present study to maintain focus on the metrics of patients with AD. The mean MMSE score for the AD group was 17.75, ranging from 4 to 23, indicating inclusion of patients with cognitive decline ranging from mild to severe degrees. The control participants all maintained scores of 30, the maximum score possible on the examination. The average ages between groups were approximately matched, with the AD group's mean being 66.4 years (SD = 7.9) and the CN group's being 67.9 years (SD = 5.4).

Neurologists at the 2nd Department of Neurology of AHEPA General Hospital of Thessaloniki facilitated the recording collection. The EEGs were conducted in accordance with standard resting-state conditions (subjects sitting and closing their eyes) and the 10-20 system of electrode placement. The average recording for an AD subject was 13.5 minutes, while that of the CN group was 13.8 minutes. The data's sampling rate was 500 Hz, and its resolution was 10 μ V/mm.

Preprocessing:

The EEGs of the subjects were downloaded and uploaded to the EEGLAB toolbox within MATLAB for pre-processing and analysis. A zero-phase Hamming-windowed sinc Finite Impulse Response (FIR) band-pass filter with a lower edge of 8 Hz and a higher edge of 12 Hz was applied to all datasets to limit the signals recorded to the alpha frequency band. This filter is available in the graphic user interface (GUI) of MAT-

LAB's EEGLAB toolbox. Subsequently, the raw channel data were examined to identify artifacts, such as those caused by physiological processes (eye blinking, muscle movement) or external sources (poor electrode contact, technological lapses, electrode pops). The artifacts were then manually rejected to filter out these irregularities. The data was referenced to electrodes A1 and A2, which were placed over the mastoids, a commonly employed neutral reference point for EEGs.²⁶

Feature Extraction:

The absolute spectral power values for each subject were calculated using the Signal Processing Toolbox in MATLAB, offering the `bandpower` command. The command is written in the format `p = bandpower(x, fs, freqrange)`, where inputting the signal data `x`, the sampling rate `fs` (500 Hz), and the frequency range vector `freqrange` (8-12 Hz) yields the signal's power value of `p` in microvolts. It does so by taking the time series signal `x` and integrating the power spectral density (PSD) estimate calculated using a modified periodogram with a default Hamming window, returning the average absolute spectral power within the specified frequency range. Specifically, the powers for the Fz (electrode 17) and Pz (electrode 19) were calculated to assess the alpha band's spectral dynamics in the frontal and parietal lobes. A Fz: Pz power ratio was also calculated for each subject to assess the power activities between frontal and parietal regions within the alpha frequency band. Figure 1 shows the code box depicting this process.

```

1      %% Open EEGLAB
2      eeg_lab
3      %% Set Parameters
4      fs = 500 % Sampling frequency
5      freqrange = [8 12] % Frequency range
6      %% Load Structures of Data
7      subj1ch17 = EEG.data(17, :);
8      subj1ch19 = EEG.data(19, :);
9      bps1c17 = bandpower(subj1ch17, fs, freqrange);
10     bps1c19 = bandpower(subj1ch19, fs, freqrange);
11     %% Save variables
12     save(s1, 'subj1ch17', 'subj1ch19', '.mat')

```

Figure 1: A code box visualizing the computational sequence that was used to calculate the first subject's EEG data using code and commands. This was repeated for all 65 subjects. In setting appropriate parameters that fit the data (500 Hz sampling frequency and 8-12 Hz alpha frequency range) and calculating electrode power at specific channels (17 and 19), variables were successfully saved in EEGLAB for subsequent analysis and comparison of spectral power across subjects.

Statistical Tests:

After calculating the power values for all 65 subjects, an independent sample t-test was conducted to analyze the significance of the data between the AD group and the CN group. This type of test was selected because the data points of the same variable (alpha spectral power, alpha power ratios) were compared between two different groups that were independent of one another. Three t-tests were conducted comparing the AD and CN groups: the Fz electrode, the Pz electrode, and the Fz: Pz ratio. The t-tests returned the mean values, degrees of freedom (df), and p-values for these comparisons between the AD and CN groups.

The flow chart below conveys the collective data collection and analysis process, which was repeated for all 65 participants'

datasets for channels 17 (Fz) and 19 (Pz). Figure 2 shows a sample of how the code would function for the first subject.

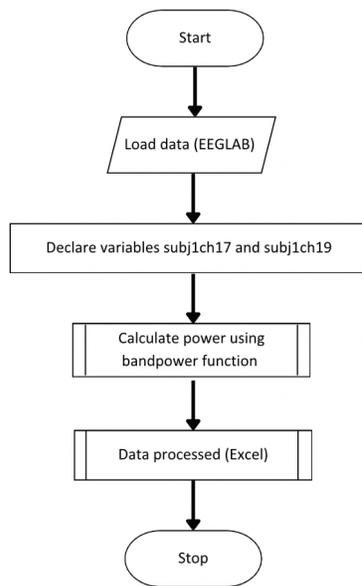


Figure 2: Flow chart depicting the process of computational feature extraction and analysis. After loading the data, establishing variables, and calculating spectral power, the data points were assessed for statistical significance in Excel.

■ Results and Discussion

Fz Electrode:

For the Fz electrode in the AD group, spectral powers between 7.2967 to 32.4324 microvolts were found, with the median at 11.1418 and the interquartile range (IQR) between 9.1962 and 13.8774. Additionally, for the CN group, the spectral power ranged from 9.6325 to 66.9747 microvolts, with a median of 17.0038 and an IQR between 10.6529 and 27.3586.

The independent sample t-test conducted for the Fz electrode between the AD and CN groups presented several statistics comparing the two groups' spectral measurements. The average spectral power of the AD group was 13.077, while that of the CN was 21.383. The df was found to be 37. Furthermore, a p-value of 0.005 was calculated. The spread of the datasets and the t-test are displayed in Figure 3.

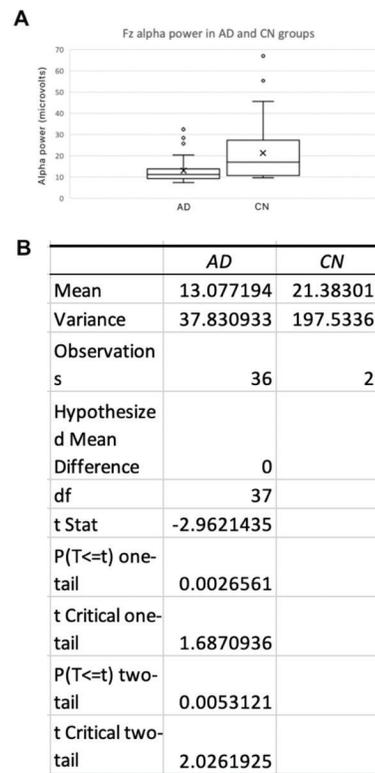


Figure 3: Data analysis of Fz alpha absolute spectral power (μv) in AD and CN groups. (A) Box plots depicting the spread of Fz spectral data in the AD and CN groups. (B) The independent sample t-test was used to compare the significance of the difference between the AD and CN groups. The test reveals a statistically significant reduction of alpha spectral power in the AD group compared to the CN group ($p=0.005$), which may also be seen in the box plot data.

Pz Electrode:

The AD patients exhibited spectral power values from 6.5408 to 35.393 microvolts in the Pz electrode, with a median of 10.4192 and an IQR from 8.5807 to 14.4895. On the other hand, spectral powers were within the range of 9.4289 to 90.5023 in the CN group, the median being 22.6552, and its IQR from 12.8027 to 40.9584.

Moreover, an independent sample t-test was also conducted for the Pz electrode. The mean powers were 13.346 for the AD participants and 29.42 for the CN participants. The df was 34, and a p-value of 0.0006 was calculated. Figure 4 represents the qualities of the data as box plots and the t-test as a table.

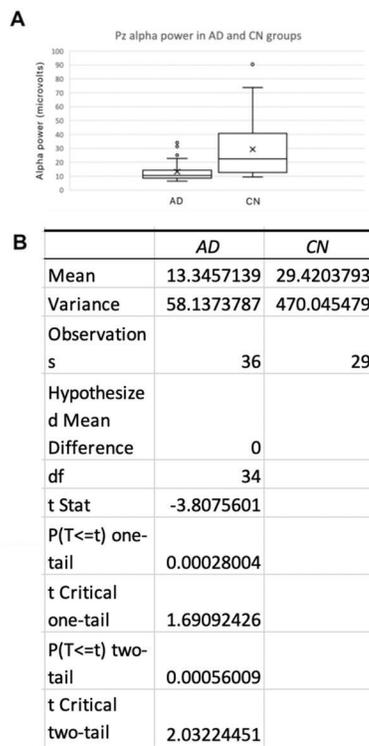


Figure 4: Data analysis of Pz alpha absolute spectral power (μV) in AD and CN groups. (A) Box plots demonstrating the spread of Pz spectral datapoints across the AD and CN groups. (B) The independent sample t-test was conducted to assess the significance of variations between the two groups of patients. The t-test reveals a statistically significant decrease in alpha spectral power in the AD group compared to the CN group ($p=0.0006$), which is also reflected in the box plot data.

Fz: Pz Power Ratio:

The ratios between Fz and Pz electrodes ranged from 0.5337 to 2.1847 for the AD participants and 0.3682 to 1.7823 for the CN participants. The AD group's median ratio was 1.0228, with an IQR from 0.86265 to 1.194475, while the CN group's median ratio was 0.79, with an IQR of 0.64305 to 0.96465.

The independent sample t-test conducted comparing the AD and CN ratios noted that the AD participants had an average Fz: Pz power ratio of 1.051, and the CN participants had an average of 0.825. The df equaled 61, and a p-value of 0.0025 was calculated. In Figure 5, the ratio dataset's characteristics and the t-test are visually represented.

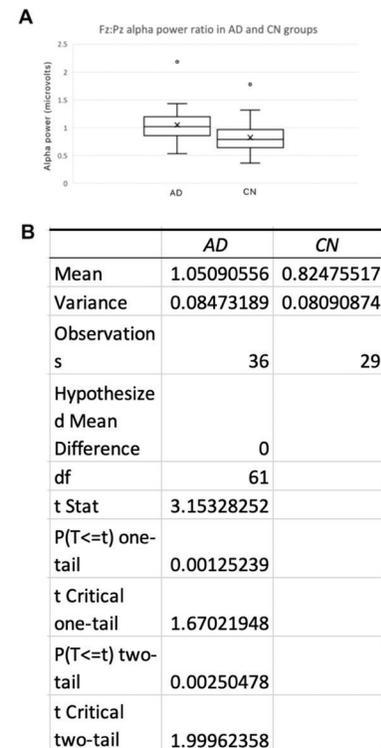


Figure 5: Data analysis of Fz: Pz alpha absolute spectral power ratios in AD and CN groups. (A) A box plot depicting the spread of Fz: Pz spectral ratios in the AD and CN individuals. (B) The independent sample t-test assesses the statistical significance of the ratio differences between the two sample groups. The t-test demonstrates a statistically significant increase in power ratio in the AD group compared to the CN group ($p=0.0025$), which can also be observed in the box plot data.

Discussion:

The present study was conducted to identify whether alpha power in individuals with AD, compared to CN subjects, could be used as a biomarker of AD. While earlier studies have explored alpha power reduction in patients with AD compared to CN subjects, they have not specifically evaluated the activity of frontal and parietal electrodes and the ratios of alpha power between them. The current study addressed these gaps in the field by thoroughly examining both absolute spectral power and the ratio of power between frontal and parietal electrodes in the alpha frequency band compared to healthy controls.

The results of the study demonstrated that there was a reduction of alpha spectral power in individuals and an increased Fz: Pz ratio with AD compared with their corresponding controls. With p-values less than 0.05 (alpha value), the t-tests suggested this reduction was significant in both the Fz ($p = 0.005$) and Pz ($p = 0.0006$) electrodes. These values, therefore, support the significance of alpha spectral power reductions in distinguishing between AD and CN individuals. Similarly, with a p-value of 0.0025 between the Fz: Pz ratios for the AD and CN groups, the t-test aligns with the notion of a significant increase in the Fz: Pz ratio for individuals with AD.

Based on this analysis, these conclusions align with the majority of previous findings. Many studies reported a significant decrease in spectral power in the alpha frequency band in subjects with AD compared with controls.⁸⁻¹⁵ Though no studies

to our knowledge have specifically maintained focus on the alpha power ratio between Fz and Pz electrodes, other reports have found significant associations between increased upper/low alpha power ratio and cognitive decline^{18,19} as well as increased alpha3/alpha2 ratio and incipient AD development.¹⁷ Studies have also shown abnormal fronto-parietal pairing of the delta and alpha rhythms in less severe AD,²⁷ demonstrating the significance of fronto-parietal alpha band activity in assessing AD. Thus, the current study was able to elaborate upon previous notions in specifically investigating alpha band dynamics in frontal and parietal regions. A reduced power in a higher-frequency brainwave, like the alpha band, which is connected to orientation, attention, and focus,²⁸ may indicate greater cognitive dysfunction. Observing this effect in individuals with AD is reasonable, as it may correlate with a decreased neurological aptitude for the higher-level processing activities that AD subjects often experience challenges with. Moreover, an increased Fz: Pz ratio may indicate proportionally increased frontal alpha activity or reduced parietal activity in individuals with AD. Both of these concepts align with common AD symptoms. Increased frontal alpha power is correlated with depressive moods, negative emotions, and self-consciousness.²⁹ Decreased parietal alpha power may be related to psychotic symptoms,³⁰ deteriorating motor abilities,³¹ and reduced attention and focus.³² Considering how approximately 40% of AD patients experience depression, 30% have psychotic symptoms, and many commonly experience motor problems in the later stages of AD³³ and attention difficulties during earlier periods of the condition,³⁴ the increase in Fz: Pz ratio may agree with numerous observed characteristics of AD.

There were a few limitations to this study. Greater categorization in dividing the total sample into various AD severity stages and age groups might have been able to reveal the effects of certain demographical nuances. Additionally, a larger sample size overall would have enabled this trend to be proven across groups worldwide. The small sample size may have affected the calculated p-values. Future studies should aim to explore multiple electrodes in the frontal and parietal regions, as well as how factors such as age, severity, education level, and other comorbidities may affect spectral power dynamics.

■ Conclusion

These findings, therefore, notably demonstrated that reduced alpha spectral power in the frontal and parietal regions (Fz and Pz electrodes) and increased Fz: Pz spectral power ratios may be significant biomarkers of AD ($p < 0.05$), presenting an alternative means of diagnosis on a quantitative basis. This research contributes significant data to an ongoing field investigating accessible and scientific methods for the diagnosis of neurodegenerative conditions, potentially holding clinical value and enabling earlier and more objective diagnosis.

■ Acknowledgments

I would like to acknowledge and thank my mentor, Dr. Amparo Güemes González, and my teaching assistant, Belquis Haider, for their continued guidance throughout this research project.

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