EEG Signal Analysis During Mental Arithmetics

Group Number: 17

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Abstract*— *In this study, we conducted an analysis of electroencephalography data from six subjects while they were engaged in a repeated subtraction mental arithmetic task. Our analysis, employing power spectral density and coherence measures, revealed significant increases in average power within the theta, alpha, and beta wave bands, particularly in the left frontal and left parieto-occipital regions. Additionally, we observed noteworthy functional connectivity in the frontal region within these frequency bands.

Keywords—electroencephalogram, power spectral density, cognitive engagement, mental task, coherence.

I. Introduction

The human brain engages in complex neural processing during mental arithmetic tasks. Electroencephalogram (EEG) offers a valuable means of examining these cognitive mechanisms on a broader scale. This paper presents a comprehensive analysis of EEG data collected during repeated mental subtraction, with a specific focus on examining power spectral density (PSD) and magnitude-squared coherence (MSC). The study investigates how different brain regions behave and interact with each other during the given mental task.

II. Material and Methods

The MATLAB programming language was used to implement all data analysis and visualization in this work. All the figures provided are vectorial, it is possible to digitally zoom to enhance resolution.

A. *Experiment Design*

The dataset was acquired to explore EEG correlates during a mental arithmetic task: serial subtraction. Participants were seated in a controlled, soundproof environment where they initially underwent a 3-minute period of adaptation, remaining in a relaxed state with closed eyes. Following this adaptation phase, a 3-minute EEG recording was obtained to capture baseline activity during rest. Subsequently, 4-digit minuend and 2-digit subtrahend were orally communicated to the participants who then engaged in a 4-minute mental arithmetic task, of which 1 minute was provided as data.

B. *Data Collection*

The EEG recordings were obtained with electrode placements conforming to the International 10-20 scheme. All channels were sampled at a rate of 500 Hz. The data was supplied in a partially preprocessed state, involving the application of a high-pass filter with a 0.5 Hz cut-off frequency, a low-pass filter with a 45 Hz cut-off frequency, and a power line notch filter set at 50 Hz.

C. *Data Preprocessing*

Upon conducting an initial visual analysis of each channel, our observations revealed the presence of artifacts, notably an excess of 1000 samples, which we subsequently decided to remove. To ensure the temporal stability and stationary nature of our stochastic signals, we adopted a methodology involving the extraction of a 45-second window from the middle portion of the available data. This approach was chosen to capture the most representative aspects of the two distinct neurological activities under investigation, avoiding alterations caused, for instance, by the transition between the stages of the experiment. Consequently, the signals were detrended.

D. *Power Spectral Density*

To examine the frequency characteristics of the signals, we employed PSD analysis utilizing the Welch method (window type: Hamming, size: 10 s, overlap: 0.1 s) according to provided relevant references [1]. For the sake of comparative analysis and to streamline the dataset by reducing its dimensionality, we opted to normalize the power spectral density of signals during cognitive engagement (the working state) with respect to the baseline (the rest state). To facilitate visual examination and interpretation, we applied a logarithmic scale transformation. **Figure II.**1 provides a concrete example of our approach.

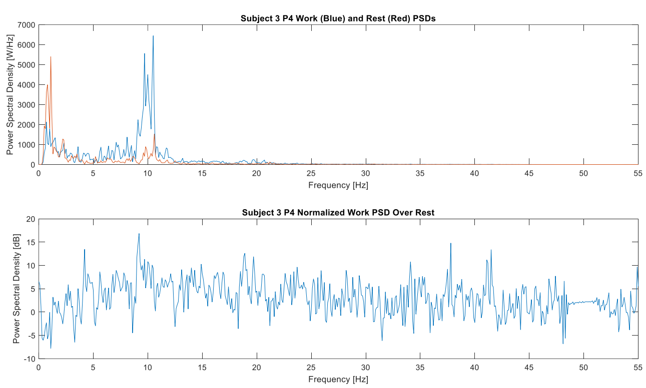

Figure II.1 Example of power spectral density baseline normalization

E. *Frequency bands*

To assess the specific contributions of distinct frequency bands to the overall power of baseline-normalized cognitive brain activity, we conducted integrations across relevant frequency ranges. These bands were the following: δ (1, 4) Hz, θ (4, 8) Hz, α (8, 13) Hz, β1 (13, 20) Hz, β2 (20, 30) Hz, γ (30, 40) Hz. Our selection was informed by foundational literature. Moreover, the partitioning of the beta band was assessed in relation to relevant references [1], enhancing the resolution for the identification of pivotal brain activity.

F. *Magnitude-Squared Coherence*

An effective metric for assessing functional connectivity between different brain regions is the magnitude-squared coherence (MSC) evaluated between each pair of electrodes. It ranges from 0 to 1 and indicates the correlation level for each frequency.

III. Results and Discussion

The topographical maps depicted in **Figure III.1** were generated using baseline-normalized power spectral density averaged across subjects, integrated over each frequency band. Additionally, **Figure III.2**, displaying boxplots, provides a comprehensive view of how band power varied among subjects over the anatomical lobes of the brain. These visualizations allowed us to draw the following conclusions:

A. *Frequency Band Activation*

Drawing from established literature [2], it is clear that alpha activity increases in response to cognitive load, especially during the retention phase of working memory tasks. This elevation in alpha activity correlates with the number of items held in working memory and is most prominent in the posterior and bilateral central regions. This phenomenon is likely attributed to the generation of the alpha rhythm near the parietal-occipital fissure. Our data aligns with these findings, as we observed a noticeable increase in average power density within the theta (θ) and alpha (α) bands in the parieto-occipital region during cognitive engagement.

Beta waves are involved in conscious thought and logical thinking. We observed a prominent increase in β1 power in the frontal region and a more modest one in β2 in the central-parietal region. These findings reflect cognitive behavior in optimal conditions, characterized by conscious focus, memory, and problem solving during stress-inducing mental tasks [3].

B. *Hemispherical Asymmetry in Workload*

It is interesting to notice the heightened involvement of the left hemisphere compared to the right. Scientific literature recognizes that the left hemisphere excels in executing practiced activities and applying familiar modes of comprehension when the task at hand no longer presents uncertainty [4].

C. *Coherence Among Channels*

Through empirical analysis, we determined a significant threshold of 0.4 for identifying inter-channel coherence. **Figure III.3** highlights the functional connectivity among brain regions during the mental task, showing strong interactions within and between the frontal, temporal, and central regions. This emphasizes the consistent behavior of brain areas engaged in cognitive tasks.

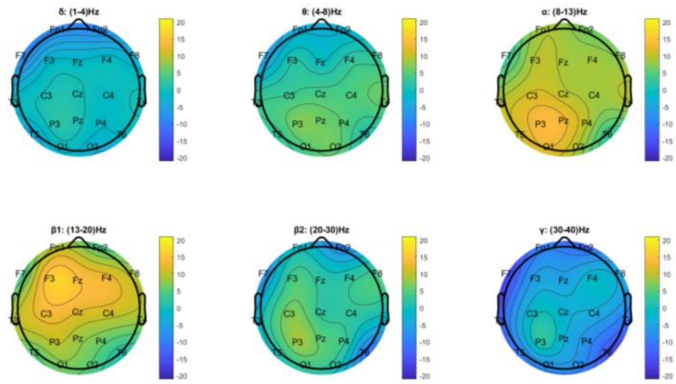

Figure III.1 Topographical maps per frequency band

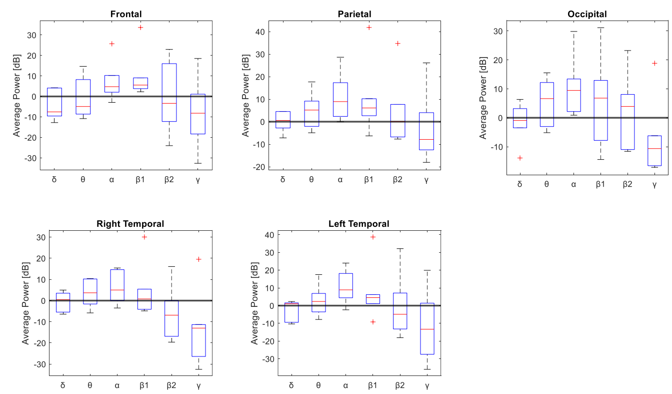

Figure III.2 Distribution of subject band power over lobes

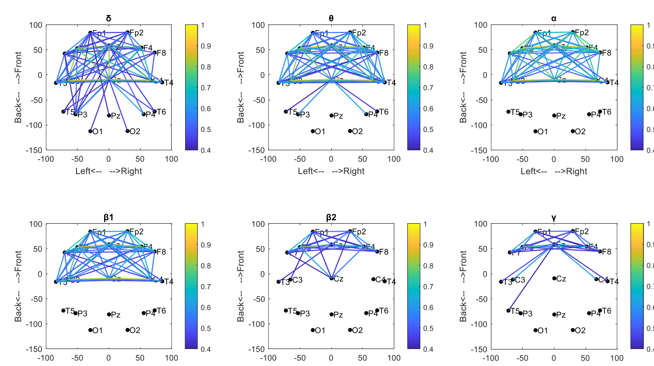

Figure III.3 Inter-channel strong coherence during work

References

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