EEG during mental task analysis

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*Abstract*— *In this study, we conducted electroencephalography analysis on subjects engaged in a repeated subtraction mental arithmetic task. Our analysis, utilizing power spectral density and coherence measures, revealed significant increases in average power within the theta, alpha, and beta wave bands during the task, particularly in the left frontal and left parieto-occipital regions. Furthermore, we found significant functional connectivity in the frontal region within these frequency bands.*

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

# Introduction

The human brain engages in complex neural processing during mental arithmetic tasks. Electroencephalography (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 coherence. The study investigates how different brain regions behave and interact with each other during the given mental task.

# Materials and Methods

## 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.

## Data Collection

The EEG recordings were obtained using a 23-channel system provided by XAI-MEDICA, Ukraine, 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.

## 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 example, by the transition between the stages of the experiment. Consequently, the total sample count was reduced to 22,500, constituting a 75% reduction for the resting state and a 25% reduction for the active cognitive engagement state. **Figure II.1** provides a concrete example of EEG signal preprocessing, illustrating the data before and after this step. Sample rate was kept as such because reference\*.



Figure . Example of time series preprocessing

## 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 [3]. 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.2** provides an illustration of our approach.



Figure . Example of normalization

## Frequency bands

To assess the specific contributions of distinct frequency bands to the overall power of cognitive brain activity compared to a resting baseline, 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 of these frequency bands was informed by foundational literature [1]. Moreover, the partitioning of the beta band was assessed in relation to relevant references [3], enhancing the resolution for the identification of pivotal brain activity.

## Lobe division

To analyze how cerebral activity varied by frequency bands among subjects we opted to compute the spatial average over the anatomical lobes of the brain: frontal, parietal, occipital, left/right temporal.

## Magnitude-Squared Coherence

A valid index to measure functional connectivity between regions of the brain is the Magnitude-Squared Coherence (MSC) evaluated between each pair of electrodes.

# Results and Discussion

The topographical maps depicted in **Figure III.1** were generated using baseline-normalized power spectral density averaged across subjects. Additionally, **Figure III.2**, displaying boxplots, provides a comprehensive view of patient differentiation and general behavioral trends. These visualizations allow us to draw the following conclusions:

## Frequency band activation

Alpha activation in parieto-occipital means\*. Beta activation in frontal means\*. From the topographical maps we can observe an increase in the average power density for the θ an α bands in the parieto-occipital region, for the β1 band in the frontal region and β2 in the central-parietal region. Equivalent observations arise from the region averaged boxplot distributions. Given that work is mental task and is supposed to cause stress given the difficulty on the task we can see that our observations align with literature. Such behavior follows the knowledge already settled in neuroscience: the arousal of neurons is task specific both in rhythm and location. In the frontal robe there are regions involved in mental tasks, attention and memory recalling while the parieto-occipital region with visual elaboration. Both θ and β bands are associated to attention and mental workload, the α band is associated with closed eyes relaxation and visual memory. It is interesting to notice how the right and left temporal lobes, even if far apart, behave almost in the same way.

## Hemispherical asymmetry in workload

It’s interesting to see how much more the left hemisphere appears to be involved in the cognitive effort behind mental tasks that require very specific procedures and resolution. Scientific literature widely acknowledges that the right hemisphere excels in general pattern recognition and high-resolution map generation, while the left hemisphere tends to activate when existing knowledge guides the task, demanding focused effort [2].

A group of circles with different colored circles

Description automatically generated

Figure . Topographical maps



Figure . Boxplot

## Coherence among channels

By empirical measures we came to the conslusion that a relevant threshold to identify inter-channel coherence was 0.4\*. Relatively to this level it is interesting to notice how the lobes \* specifically the electrodes \* appear to behave similarily. Since literature says \* we can say that our findings were ok.

##### References

1. J. Panksepp, “Affective Neuroscience: The Foundations of Human and Animal Emotions,” New York: Oxford University Press, 1998, pp. 85–90.
2. J. B. Peterson, “Maps of Meaning: The Architecture of Belief,” Routledge, March 1999, pp. 67-72.
3. I. Seleznov, I. Zyma, K. Kiyono, S. Tukaev, A. Popov, et al. “Detrended Fluctuation, Coherence,and Spectral Power Analysis of Activation Rearrangement in EEG Dynamics During Cognitive Workload,” August 2019.