EEG during Mental Arithmetic Task Performance

Andrea Scarpellini  
*Politecnico di Milano*  
Milan, Italy  
[andrea1.scarpellini@mail.polimi.it](mailto:andrea1.scarpellini@mail.polimi.it)  
  
Eleonora Sala  
 *Politecncio di Milano*Milan, Italy  
[eleonora1.sala@mail.polimi.it](mailto:eleonora1.sala@mail.polimi.it)  
  
Federico Tognoni  
*Politecnico di Milano*Milan, Italy  
[federico.tognoni@mail.polimi.it](mailto:federico.tognoni@mail.polimi.it)

*Abstract*—This project aims to analyze the EEG of 6 subjects during resting state and during arithmetical task, such as mental subtraction. In particular, three frequency ranges were analyzed: theta (4-8Hz), alpha (8-13 Hz) and beta (13-30 Hz). PSD (Power Spectral Density) maps have been applied in order have been applied in order to access the intensity of cortex activation and coherence index estimation to quantify the connections between different brain areas. Ultimately, it aims to enhance the difference features present in the aforementioned frequency bands.

Keywords—EEG, mental arithmetic, cognitive workload

# Introduction

The study of the EEG signal is of primary importance to understand the mechanisms of how the brain works. Many studies have been done on the matter, focusing on different aspects. Among other topics, the study of the brain dynamics during the cognition process has attracted a lot of attention from the researchers.

A traditionally used method of inducing the cognitive load is mental calculation, such as the serial calculation (subtraction, addition, multiplication, division) and the selection the correct sum on the screen. During mental calculation, the activation in the dorsolateral prefrontal cortex, or temporal cortex (rarely) was observed[1], while the dissociation in prefrontal and parietal cortex function happened during arithmetic processing. Other studies[2] have demonstrated that the areas of prefrontal cortex are responsible for the cognitive functions connected with mental arithmetic. In such prefrontal areas, θ rhythm generators of frontal midline are localized, so a significant increase in the power of the Frontal Midline θ is detected with the complexity, difficulty of the task.

At present time the β range is mainly associated with various aspects of the functioning of the brain, from simple sensory reactions (visual, auditory, somatosensory, etc.) to higher cognitive functions, such as sensory memory, mechanisms of regulation of visual attention, movements, the processes of identification and cognition, emotional states and the implementation of cognitive, creative tasks[3].

θ band (4-8Hz) and β band (13-30Hz) oscillations directly reflect such cognitive processes as retrieval and actualization of memory[4], emotional excitement[5] and other consciousness driven processes[6]. Also, it has been shown the increased activation of the processes underlying working memory, as well as in neurodynamics in altered states of consciousness.

Based on modern representations, α-activity (8–13Hz) is associated with resting state, passive wakefulness, relaxation, etc. When its power increases, there is a decrease in the activity of the cortical zones observed alongside with increased activity in the thalamic zones.

Traditionally, a significant part of electroencephalogram (EEG) studies uses Power Spectral Density (PSD) to find the key discriminative emotional features related to the arousal and valence in response to different stimulus and conditions, and the dynamics of activation of different brain areas during the cognitive tasks has been mainly studied by these methods. In fact, cognitive activation is a complex time-space process in the brain, for which PSD and coherence jointly reflect the strength of oscillations and similarity of the emergence of these oscillations in the brain.

In this work, PSD maps have been applied to access the intensity of cortex activation and coherence index estimation to quantify the connections between different brain areas, in θ, α and β bands.

# Materials and methods

## DataSet description

The given EEG signals[7] were recorded using the 10-20 international positioning system, with a monopolar 23 channel system, placing 19 electrodes on the scalp at symmetrical anterior frontal (Fp1, Fp2), frontal (F3, F4, Fz, F7, F8), central (C3, C4, Cz), parietal (P3, P4, Pz), occipital (O1, O2), and temporal (T3, T4, T5, T6) recording sites. All electrodes were referenced to the interconnected ear reference electrodes. The sample rate was 500Hz per channel and the signals was filtered with a band pass filter (0.5Hz-45Hz) and a notch filter at 50Hz to eliminate net noise. This project only refers to 6 of the 36 original subjects, taking into account they were all *good counters*, index of the capacity to calculate subtractions correctly. For each of the 6 subjects are provided a 180s EEG segment of the resting state and a 60s EEG segment of the mental task condition, in which the subjects were asked to perform simple subtraction.

## Data Processing

Each signal has been processed by using Matlab. First, every signal for each subject and for both segments (rest and task) have been filtered with a low pass and a high pass Butterworth filters of fourth order in order to isolate θ rhythm (4-8Hz), α rhythm (8-13Hz) and β rhythm (13-30Hz). After that, we calculated PSD for every EEG channel in every frequency range for every condition. PSD was calculated through the Welch method[8], which is preferred for finite and imperfect signals under analysis. In particular, PSD was obtained with the following parameters: window size = 2 s, window-type = Explicit Hamming, 1 s overlap, signal duration =the central 30 sec. This choice has been done to ensure having a reliable mental condition of every subject, avoiding adjustment periods such as the start of the acquisition recording, the passage between rest condition and arithmetic task condition and the end of acquisition recording.

After obtaining the PSD in the corresponding frequency range, it was normalized to the maximum value for task and rest, and then the PSD map was plotted over the head surface. Also, the spectrums have been distinguished by region of the brain and they have been mediated and plotted region by region (example in fig 2.). The plots obtained as a result represent two curves (one for the resting phase and the other for the task) that are the mean between the subject electrodes with a colored area representing the standard deviation. In addition, to evaluate at best the differences between the rest phase and the mathematical calculus phase, for each rhythm and brain region, boxplots have been calculated representing the max values distribution between subjects. Given the results, the subject number 5 has been considered as an outlier, therefore it was not taken into account for calculus.

To quantify the synchronicity of oscillations in two distinct area of the brain the coherence index of the EEG activity was calculated. For every frequency range, we took one of all possible pairs of different EEG channels and calculate the coherence[9] using the entire recordings. Subsequently, we took into consideration only the electrode pairs with coherence over the 0.8. Lastly, a validation process was not performed.

# Results and Discussion

Analysis in the subjects’ groups was aimed to describe spectral differences in the EEG signal during performing mental arithmetic task and mental resting state.

As shown in Fig. 1, the PSD of the subjects during rest condition compared with the task was characterized by a significant activation in the occipital lobe regions, primarily expressed in alpha-band. The same results have been observed in the boxplot analysis. This is consistent with the literature, where it is said that the alpha band activation in occipital and parietal lobe reflects the mental resting state.

Graphical user interface

Description automatically generatedGraphical user interface

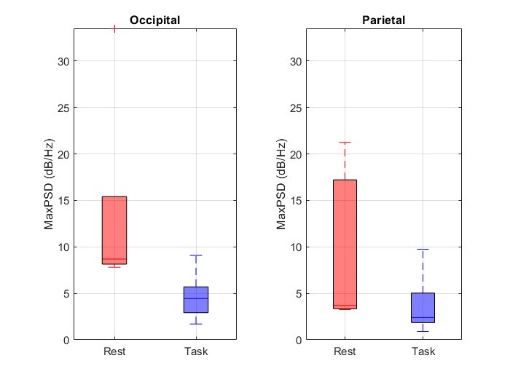
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Figure 1: Head-plot of PSD in alpha band [8-13 Hz]. Each row corresponds to each subject. The correspondent analysis of the maximum values of the PSD with boxplot is shown.

Chart, line chart

Description automatically generated

Figure 2:PSD error-bar of the frontal channels in theta band [4-8 Hz].

Regarding the beta band, an increase of the peak during the mathematical task was expected, however the results obtained from the error-bar plots and the topo-plots shows no evident differences between the rest and task conditions, also enhanced by the boxplots.

According to Fig. 2, higher PSD amplitude was recorded in the frontal lobe region during mental task than in the resting state. Such a result may seem unusual because typically the theta rhythm is associated with a sleeping condition, however recently it has been shown, that both cortical theta oscillations are critically involved in human episodic memory retrieval, being related to processes of recollection and conscious awareness, in addition, especially in the anterior-central regions, theta activity can be associated to cognitive functions [3].

The partial coherence analysis has shown elevated cortical synchronization in the frontal lobe in subjects 1, 3 and 5 during both conditions, and overall higher cortical connection numbers during arithmetic task. Although the results obtained cannot be seen as clear encephalographic manifestations, coherence analysis may be helpful in understanding various brain mechanism.

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EEG: Electroencephalogram, PSD: Power Spectral Density