THE IMPACT OF MEDITATION IN A VIDEO GAME BASED ON BCI

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Abstract: This study explores the impact of meditation-induced non-task related states on brain activity in a motor imagery paradigm for brain-computer interfaces (BCI). Using a wearable EEG device, the research analyzes theta (θ) and alpha (α) wave patterns during relaxation and meditation states. Three healthy subjects participated on an EEG recording session using the Emotiv Insight neural headset, maintaining a defocused eye gaze while viewing a static image of a BCI-controlled pool game. In this paper we developed an algorithm to preprocess EEG data that focus on frequency-specific signal extraction and peak-to peak amplitude computing for all channels in interest frequencies domain. The analysis aims to reveal distinct theta and alpha wave activity patterns across brain regions for each subject.

Key words: BCI, EEG, peek-to-peak, relaxation, MATLAB.

1. INTRODUCTION

The main worldwide problem that generates more than 23 million deaths per year is represented by mental stress. This is a health epidemic caused by cognitive disorders of the hippocampal region of the brain that affects memory and learning [1]. A possible solution to solve this major problem it represents by the practice of meditation, which is known to reduce the experience of anxiety, while improving both the level of consciousness and attention. Embracing this behavior can touch on key factors involving to driving the brain-computer interface, known as BCI, using the power of concentration as input to induce different states of consciousness [2], [16].
So, we investigate the effects of meditation induced by a non-task related state as part of motor imagery paradigm [3]. In this way, the user must maintain a totally mental state of relaxation based on the focus of not managing a task, freeing his mind, and keeping the eye gaze defocused, [17], [18], [20], [23], [25], [29].

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2. THE STUDY OF THE PROBLEM

Both relaxation and meditation state can be captured from brain signals using a wearable electroencephalogram (EEG) equipment with minimal contact with the subject's scalp area. As the specialized literature presents, the electrical signals of the brain have an amplitude related to the order of microvolts and a classification within frequency bands. Among these of interest are Theta waves (θ) predominant in meditation activities and Alpha waves (α) that dominate the resting and relaxing conditions [4], [19], [21], [24], [27], [31].

The θ waves are characterized by frequencies between: 4-8 Hz and amplitudes between: 100-150 µV. Some studies associate them with the installation of the state of relaxation, but also with the processes of working memory load [5], [6], [7]. The waveform of θ rhythm and brain areas localization are presented in Fig.1.

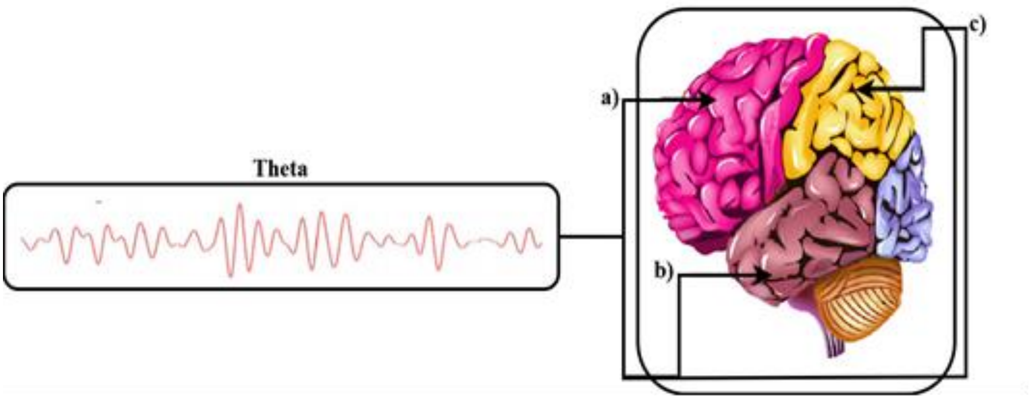

Fig.1. Theta rhythm waveform [5]

Theta rhythm appear on the frontal midline of the brain as presented in Fig.1 a) triggered by positive emotion evoked. The EEG signal from this brain region can be captured using a channel montage that is placed on proximal of the upper of forehead in left and right brain hemisphere on prefrontal cortex location [5], [8], [9], [22], [26].

The temporal and parietal lobes, presented in Fig.1 b), c), are linked to encoding and retrieval process in which theta rhythm present a higher activation and also an indicator of stress, anxiety and emotions regulation modulated by amygdala and hippocampus through temporo-parietal area [10], [11], [12], [28], [33], 35].

The α waves are characterized by frequencies between: 8-13 Hz and amplitudes between: 20-100 µV [5]. This rhythm presents a localization and a waveform as presented in Fig. 2.

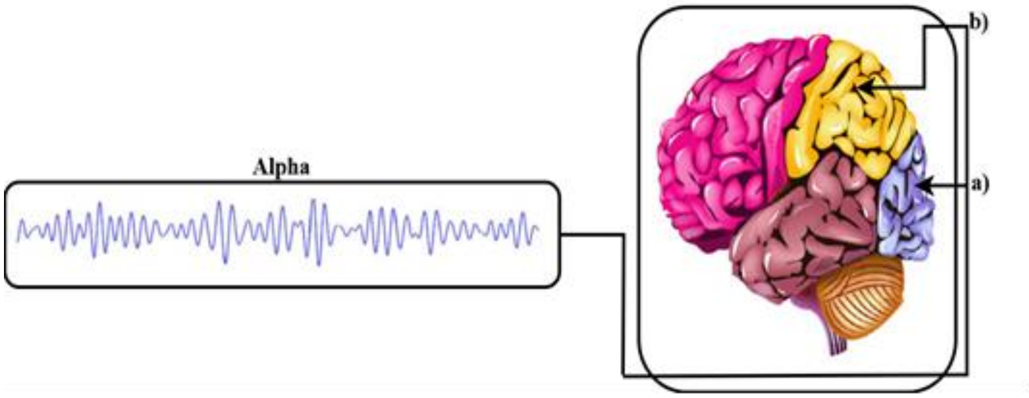

Fig.2. Alpha rhythm waveform [5]

Alpha rhythm occurs both on occipital lobe, as presented in Fig. 2 a), and on somatosensory cortex as part of parietal lobe, as presented in Fig. 2 b). The presence on occipital lobe is related to induce the mental relaxation process. Alpha rhythm prominence is higher on all brain regions, except the frontal lobe at rest condition [4], [5], [13], [30], [32], [36].

3. EXPERIMENT METHODOLOGY

For experiment study three healthy subject was chosen to participate to a brain EEG signal recording session. Each subject was trained to maintain a defocused eye gaze during the session and their brain activity was measured with same EEG device represented by Emotiv Insight neural headset with five EEG semidry electrodes. Each EEG session was record with Emotiv Xavier TestBench software in laboratory condition without external noise presence. This BCI solution was chosen for its capability to measure and visualize 3D brain activity using EEG electrodes placed according to the 10-20 International Standardized system, complemented by software for real-time analysis and offline data export [14], [34].

During one unique trial, each subject maintains a non-task related state based on how he was trained, during which he does not have to speak. Brain signal recording is performed based on a static image of each subject in a BCI-controlled pool game previously developed by us in Unity3D called ”Mental Pool Game” [15]. The BCI interface of this video game is presented in Fig. 3.

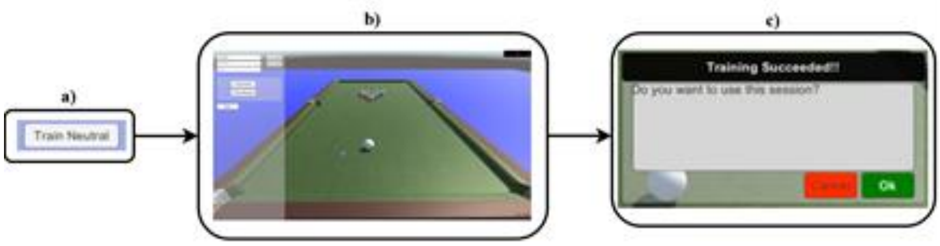

Fig.3. Mental Pool Game GUI [14]

The electrical potential activity of each subject's brain is recorded for a 9 second interval, once the BCI instructor presses the neutral state recording start button presented in Fig.3 a). During this interval the subject follows the established scenario, being presented a static image of the game interface, as presented in Fig.3 b), to induce a state of relaxation through meditation. Successful training of this state is signaled by a pop-up window, as presented in Fig.3 c).

4. EEG DATA RECORDED ANALYSIS

To study each recorded EEG session, we developed a three-step algorithm that prepare the data to be analyzed in-depth related the alpha and theta brainwave contributions for the specified time interval, which is to be integrated by code written in MATLAB programming language, as presented in Fig. 4.

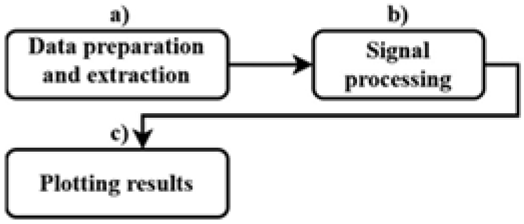

Fig.4. EEG data analyzation algorithm

The first step, presented in Fig.4. a), aim to load EEG data from CSV file exported by Emotiv software, obtained by extracting the specific EEG channels data for the 9 second interval, at a 128 Hz sampling rate, related to the data collection rate provided by the Emotiv Insight neural headset. Also, we implement instructions to eliminate the mean from each channel to eliminate DC offset, to center the signals around zero with the scope to enhance the signal-to-noise ratio for accurate frequency analysis.

The second step, presented in Fig.4 b), it focusses on frequency-specific signal extraction using a fourth-order Butterworth bandpass filter in order to isolate theta and alpha waves from the preprocessed EEG data. The filtfilt() MATLAB function as implemented to allow the zero-phase digital filtering to be applied so that the temporal properties of these frequency bands are preserved. A detailed time vector is created so that the time aligns with the extracted signals for further analysis and to prepare the results visualization.

The Third step, presented in Fig. 4 c), implement a way of visualization and interpretation of the analyzed EEG data by showing the results in terms of different plots. This represents the original plot of EEG data composed by raw EEG signals for the interest extracting time interval, as shown below, representative for subject S1, depicting the variation of amplitude with time for all channels, which helps in identifying general trends and potential artifacts, as presented in Fig. 5.

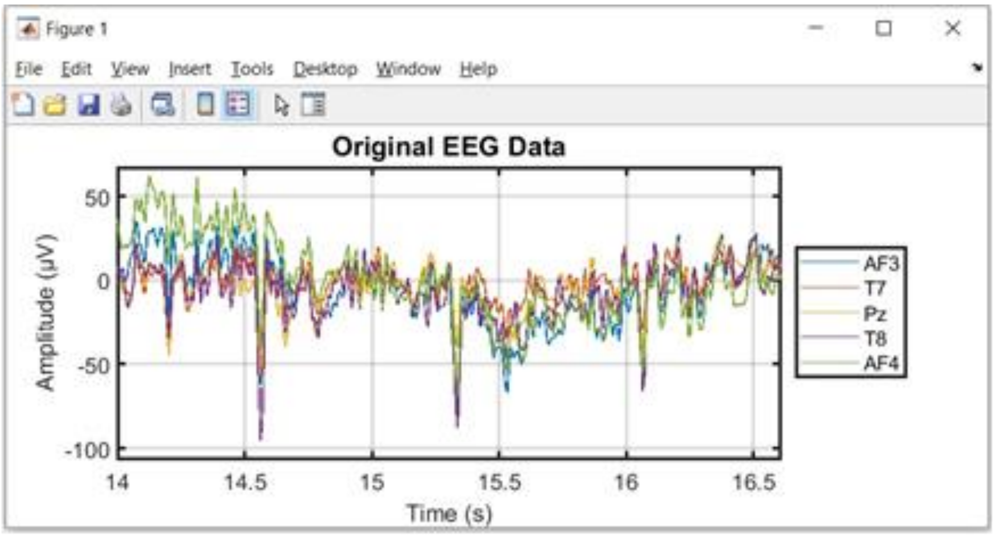

Fig.5. Sample of approximatively 2,5 second of raw EEG data from subject S1 recording

Next, the theta band activity is plotted with fixed spacing between the channels, which enables a clear representation of the filtered low-frequency brain activity associated with relaxation and cognitive states. The resulted plot for subject S1 is presented in Fig. 6.

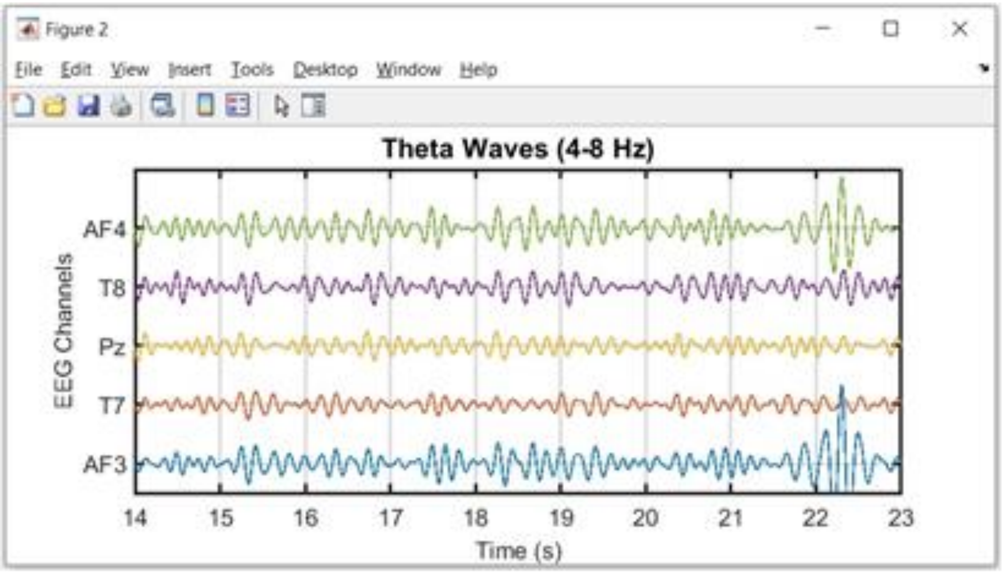

Fig.6. S1 Theta waves activity

Alpha band activity similarly shows mid-frequency oscillations linked to states of calmness and attentiveness as depicted from S1 resulted plot, presented in Fig. 7.

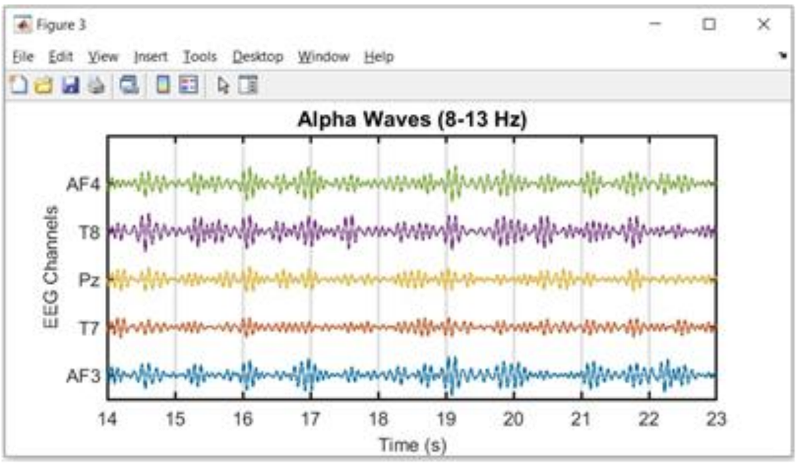

Fig.7. S1 alpha waves activity

Next, for each channel we calculate the maximum (max) and minimum (min) values for the filtered EEG data, separately for theta waves, then for alpha waves to compute the peak-to-peak amplitudes for all channels, based on the relation:

$$\textit{Peak to Peak Amplitude} = \max(signal) - \min(signal) \tag{1}$$

where:

signal - refers to electroencephalogram (EEG) data gathered for each of the frequency bands (theta and alpha) across all channels.

Next, based on the result obtained by calculus, we generate a comparative bar plot, to display each peak-to-peak amplitudes of theta and alpha waves across all channels, in order to understand the relative strengths of these frequency bands, as shown for subject S1 plot in Fig.8.

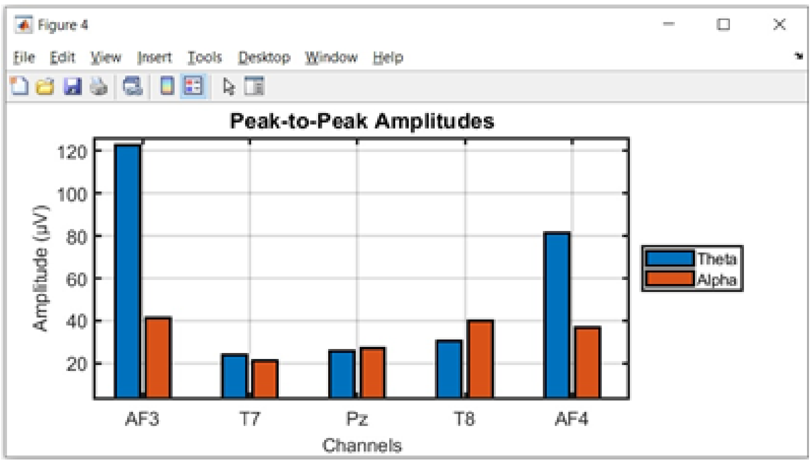

Fig.8. S1 Peak-to-peak amplitudes

Applying the same algorithm was obtained the comparative bar plot of peak-to-peak amplitudes of theta and alpha waves across all channels for the subject S2 EEG dataset, as presented in Fig. 9.

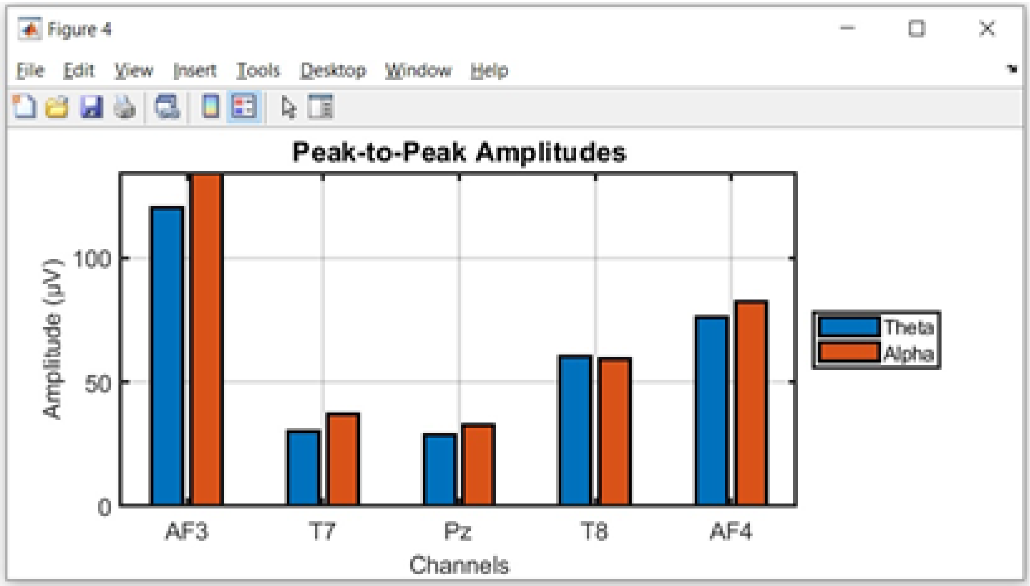

Fig.9. S2 Peak-to-peak amplitudes

Similar was obtained the peak-to-peak amplitudes plot for subject S3 dataset, as presented in Fig. 10.

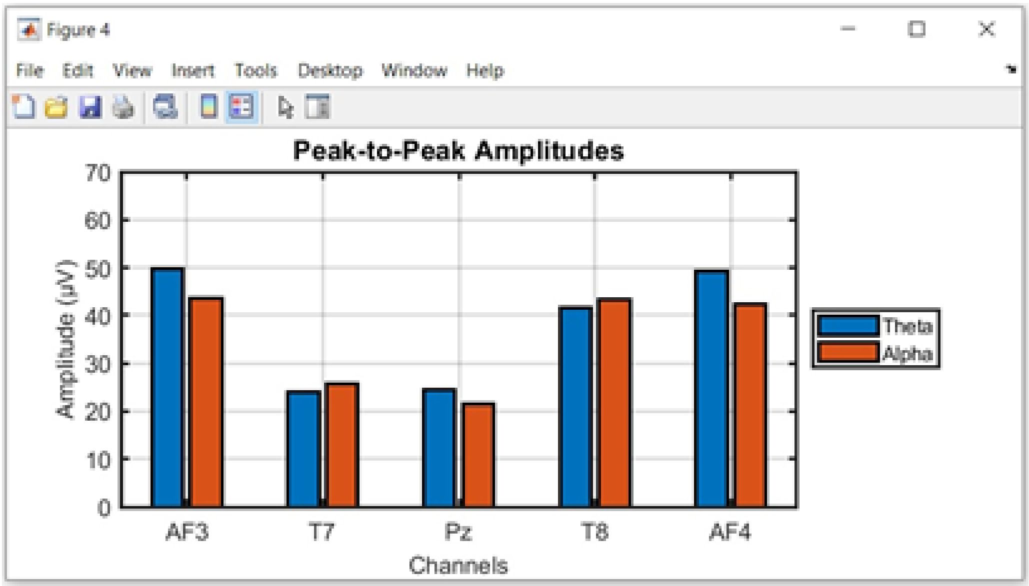

Fig.10. S3 Peak-to-peak amplitudes

5. COMPARATIVE RESULTS

The comparative analysis of theta and alpha wave patterns from each subject's dataset reveals some key findings:

- The frontal midline theta activity is most prominent on S1 and S2 dataset, indicating potentially stronger emotional processing and working memory engagement;
- The right temporal dominance across all subjects suggests consistent asymmetry in temporal lobe processing;
- The parietal activity shows lower than expected theta amplitudes, which might indicate reduced relaxation state during the open-eyes condition;
- The S2 dataset present high alpha activity in the frontal region, which differs from typical patterns where alpha should be less prominent in frontal areas.

6. CONCLUSIONS

The experimental setup using the Emotiv Insight neural headset succeeded in recording recognizable theta and alpha wave patterns. The defocused gaze protocol successfully elicited quantifiable alterations in markers associated with relaxation as well as cognitive processing. The defocused gaze protocol effectively induced measurable changes in both relaxation and cognitive processing markers.

The findings support the potential use of minimal-contact EEG devices for monitoring relaxation states. The clear differentiation between subjects suggests possible applications in personalized neurofeedback protocols.

Further study needs to be implemented to validate the result, as implementation of analysis of Signal-to-Noise Ratio (SNR), comparison across EEG channels, application of ICA decomposition to identify the neural sources and complete separate the artifactual component.

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