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Alpha-Theta Correlations during the Different States of the Brain for a Designed Cognitive Task

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ABSTRACT- Brain oscillations vary due to neurological activities that play an important role in designing a cognitive task. In the proposed study, 27 subjects experimented with different cognitive activities (rest, meditation, and arithmetic) and their alpha and theta bands of frequencies were analyzed. BIOPAC-MP-160 has performed the data acquisition and further processing of the acquired dataset was implemented in EEGLAB. The results illustrated that the cross-frequency correlation (alpha: theta: 1:2) between alpha and theta waves has been enhanced during effortful cognition (arithmetic state). The alpha-theta cross-frequencies were observed to be maximum in the arithmetic state, while it remains low in both the resting and meditation states. Maximum episodes of the cross-frequency correlations occurred when the alpha band of frequencies lies between 9-12 Hz. The study also reveals that maximum alpha-theta cross-frequency (40.74%) was found at the electrode positions Af3 and Af4. The comparisons based on event-related potentials (ERPs) and power spectral densities (PSDs) have shown that the meditation state is more sluggish than the arithmetic and rest states.

Keywords: Electroencephalography, alpha-theta correlation, cognitive task, independent component analysis, mindfulness meditation, OM chanting.

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1. INTRODUCTION

In today's fast-paced world, it has been observed that very few people have time to focus on mindfulness meditation [1]. Meditation is a process that consists of a specific practice, relaxing our muscles, and relaxation of logic by using self-focus skills [2]. It is a method to practice different religions, such as Buddhism, Hinduism and mindfulness from the non-religious context [3, 4]. Open monitoring and choice-less awareness are the main characteristics of mindfulness. Vipassana is the origin of mindfulness and is a non-selective awareness that concentrates on the breathing or mind [5]. The primary goal of meditation is to control our thoughts with a focus on a specific object, such as focusing on the expanse, counting the breath, guided meditation, etc. [6, 7]. Along with the dissolution of the ego, detachment and non-involvement with things have complimented meditation [8]. One of the goals of mindfulness meditation is to release one's brain from external interruptions, control one's thoughts, and lower the thought circle frequency to achieve a state of mental emptiness. Brain efficiency can be increased through meditation and a relaxed mind, enabling better coordination in our daily tasks and leading a happy and healthy life [9, 10].

The brain oscillations reflect the neural activities due to various actions or thoughts of the subject. In recent years, ubiquitous and pervasive healthcare devices have been widely used for low-computational human health prediction.

Electroencephalography (EEG) has been used to analyze brain oscillations in various mental states and detect human brain activity or neurological disorders. Different other techniques, *e.g.*, functional magnetic resonance imaging (fMRI), positron emission tomography (PET), magnetoencephalography (MEG), and optical imaging, are also available for data acquisition. EEG has been used more frequently than other known techniques due to its high temporal resolution, low cost, availability, and noninvasive nature. EEG frequencies played a crucial role in analyzing different cognitive states, e.g., arithmetic, meditation, and rest [11, 12]. Alpha (8-14Hz) and theta (4-8Hz) frequency bands have played a significant role and were often used to analyze and differentiate various mental states and cognitive activities [13-15]. Information storage and retrieval have been associated with the alpha band, while the theta band has been incorporated with information manipulation [16, 17]. While performing various mental tasks, the changes in alpha and theta band frequencies were observed by differentiating their peak amplitudes and powers [18].

The literature confirmed that the alpha-peak frequency was accelerated during effortful cognitive tasks [19], and alpha-theta peaks appeared around its harmonic, *i.e.*, alpha: theta: 2:1 [20]. Some results also reported that alpha and theta powers were enhanced during meditation compared to rest [21-24]. However, the results differ between experienced mediators and novice meditators [25]. The frequency variations also depended on different meditation techniques [26, 27]. The literature revealed that most of the studies used 19, 23, 36, and more number of electrodes covering the entire scalp surface during

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analysis [28]. Very few studies are available that focus on a particular area of the brain. Some research illustrates that theta waves have been increased during mindfulness meditation [29, 30].

In another study, the alpha rhythm increased in the starting phase of meditation, and the theta and delta rhythms increased when the subject entered in the more intensive state [31]. In various studies on meditation, the results illustrated that the theta waves had been increased usually. Various studies have used the theta-to-alpha ratio as neuro-feedback training [32]. Alpha and theta-based neurofeedback training has been used in relaxation therapy. Typically, the alpha-theta ratio has been found higher during this training. This neurofeedback training is used in the treatment of stress disorder and alcoholism etc. [33, 34].

In many cases, alpha-theta neurofeedback training has been attempted to induce a state where the theta rhythm is more dominant than the alpha rhythm in such a non-sleep pattern [35]. At the same time, the findings are different in some cases and illustrate the conflicting outcomes [36, 37]. However, a number of studies have different results between the meditative state and the state of control at different scalp positions, *i.e.*, frontal, occipital, and temporal [38-40]. Some other studies have also validated the difference between the control group and the experimental group during mindfulness meditation using alpha and theta waves in the occipital and temporal parts of the scalp [41, 42]. Several EEG studies illustrated a significant increase in the theta waves during the Vipassana mindfulness meditation technique [43, 44]. One of the other healing techniques, Juingong meditation, has several healing experiences. Kim et al. explained the effects of Juingong meditation on the temporal and frontal regions of the brain using the alpha-theta ratio [45]. Another study demonstrated the impact of 40 Hz binaural beats accelerated the training outcome for an attentional blink (AB) task [46].

The above literature shows that neural oscillations are the significant tools that synchronize neurophysiological actions inside and across scalp sections and stimulate the precise timing of the neuronal mechanisms controlling cognition, memory, perception, and behaviour. In the present work, experimental analysis has been performed with a pair of channels at six different positions associated with the frontal lobe (*i.e.*, Fp1, Fp2, Af3, Af4, Af7, and Af8). The main focus of this research is the study and analysis of changes in brain activation due to cognitive tasks such as rest, meditation, and arithmetic. This study demonstrated how the cross-frequency correlations in the brain's frontal region vary under different task conditions. A cognitive task has been designed to have three different mental states (rest, meditation, and arithmetic). Since meditation is non-quantitative, the subjects have been meditated by hearing the OM chant at a specific frequency (963 Hz). Human systems have seven chakras [47]. As shown in the *figure 1*, resonance frequencies for each chakra have been reported differently, starting from 436 Hz - 963 Hz [48]. Different colours are assigned to all chakras. The crown chakra is purple and vibrates at 963 Hz to the central part of the brain. The crown chakra is located at the top of the head (cerebral cortex) and is responsible for spiritual consciousness, enlightenment or spiritual connection. It stimulates brain functioning, such as focusing, memorizing and gaining intelligence. People experience mindfulness, divining growth and immeasurable wisdom when the crown chakra is awakened. They also achieve a sense of unity, power and self-knowledge by strengthening their connection to the soul or supreme power. Such healing therapy is responsible for relaxation, mindfulness, deep meditation, etc. [49]. The awakened crown chakra helps people better understand the physical things/world around them. It can provide a positive approach to life and help overcome the complications in their daily life. A detailed and excellent explanation of the chakras is given by vanessa eshaya in the article "List of solfeggio frequencies for the seven chakras". The OM chant at 963 Hz has been used to resonate the crown chakra to induce a powerful state of meditation in this study. Further, for the data processing and analysis of data, a study with test subjects and three different task conditions (rest, meditation, and arithmetic) has been created in EEGLAB.

Figure 1: Different chakras of the Human body

The paper organization is as follows: Section two consists of materials and methods in which the cognitive task has been explained, *i.e.*, the different task states (rest, meditation, arithmetic) and their preparation. The detailed demography of the participants, *i.e.*, their age detail, education status, gender etc., are also presented in this section. The data acquisition system, *i.e.*, BIOPAC MP 160 and the electrode placement protocols, and data processing have also been explained in this section. The following section three contains the results of the study, *i.e.*, the primary approach that defines the alpha-theta correlations during the task at different electrode positions, and the second approach, *i.e.*, ERP and PSD-based comparisons, have been explained in this section. While sections four and five consist of the discussion and conclusion, respectively.

2. MATERIALS AND METHODS

The specifics of the experiment design are well explained in this section, along with the data acquisition system and the processing techniques.

2.1 Task Design

The task design was a crucial step. The authors designed a specific cognitive task based on some textbooks and research articles [50-52]. Working Minds, a Practitioner's Guide to Cognitive Task Analysis by Robert R Hoffman [53] and a handbook on Cognitive Task Design: Human Factors and Ergonomics by Hendrik H. [54] helped us to design the cognitive task. All the factors, conditions, advantages, and disadvantages from the literature above were considered to design the task. The designed cognitive task consists of three states, *i.e.*, rest, meditation, and arithmetic as shown in *figure 2*. 20 minutes of data was collected for each condition. At rest, the test subjects were asked to close their eyes, feel free and de-attach themselves from the outside world interrupts and let go of thoughts. In the induced meditation state, subjects must listen to an OM chant at a specific frequency (963 Hz) for 20 min with closed eyes. During the arithmetic state, subjects were asked to subtract five from 100, and if they reached zero or lost track, they had to start again from 100. To make the length of the different states comparable, 5 minutes of data were analyzed for each state.

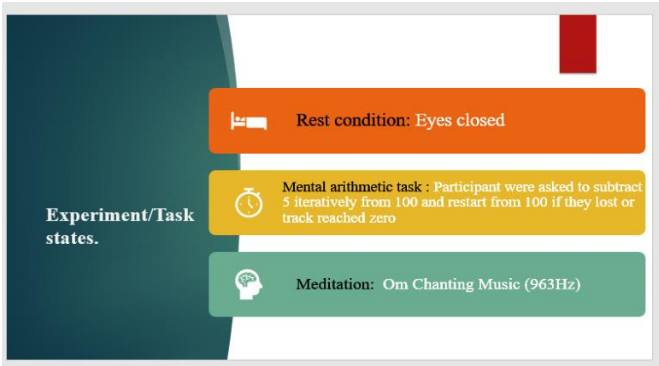

Figure 2: Different task states

2.2 Participants

For this study, authors approached to the university ethical committee, and after getting the recommendations from the appropriate authority, the data acquisition process was started. Thirty-six subjects volunteered and agreed to get the induced meditation training and then complete the study. All 36 participants were trained to meditate with the help of OM chant voice at 963 Hz. After two months of regular training, we started the cognitive task performance with the subjects. Out of 36 subjects, outliers were found in 9 subject data. For this reason, 27 subjects (N=27, S.D.=2.18, Mean=30.81, Variance=4.77) were found suitable for the data acquisition process. From 27 test persons, 18 men and nine women between the ages of 22-36 years. *Table 1* illustrates the demography of the subjects. The data was collected between November 2020 and January 2021 at SLIET University.

Table 1: Demography of Subjects

No. of Subjects	Gender/ Age	Education	State of Brain	Alcoholic	Physiological Issues	Any Medication
27	18M & 9F	UG, PG and PhD	Depressed/ normal	None	None	Diabetic (1)

2.3 Data Acquisition System & Electrode Placement

The data acquisition was completed using BIOPAC MP-160 for the designed task. Two channels of BIOPAC MP-160 were used for the EEG acquisition process. The electrodes were placed according to the international 10-20 system [55], as shown in *figure 3*. The size and shape of the test subject's heads were measured before attaching the electrodes. The scalp was measured individually by CADWELL tape, and electrodes were placed with the exact measurement of the dimensions of the individual scalp.

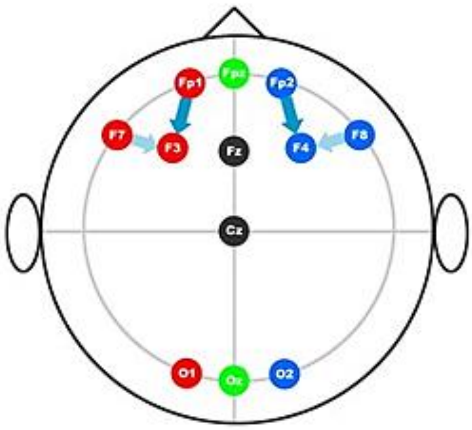

Figure 3: Electrode positions according to the international 10-20 system

First, the EEG electrodes were placed in Fp1 and Fp2 positions, and the task was carried out and the data recorded. The same pattern was repeated with Af3, Af4, and Af7, Af8 electrode positions. The surfaces were cleaned with a disinfectant to minimize the impedance between the electrode and the scalp. All participants were asked to come with a cleansed scalp with a branded hair shampoo to reduce excess oil and dirt from the scalp. In order to keep the noise and interruptions as low as possible, the data were collected in the laboratory when no other person was available except the subject. The appropriate time was the evening when the laboratory was empty, and the off days were chosen for the same reason. Some test subjects in *figure 4* carried out the task.

(a)

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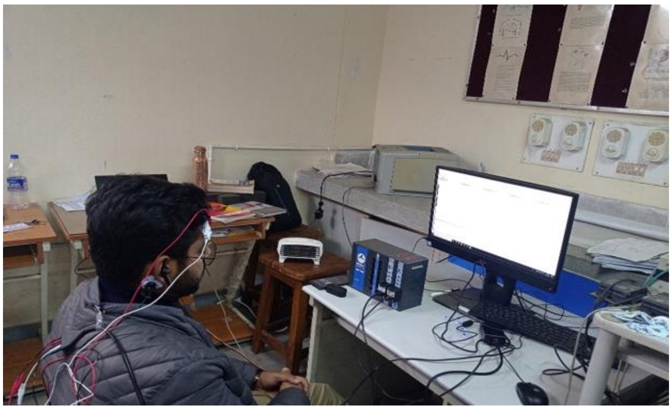

(b)

Figure 4. Different subjects *(a)* and *(b)* during data acquisition

2.4 Processing of Data

In this study, the features like ERP, PSD, and alpha-theta peaks were extracted and processed using EEGLAB. *Figure 5* shows the flow chart of the methodology. The three attained features have been compared in the three different states: rest, meditation, and arithmetic. The raw EEG data was loaded in EEGLAB, then re-sampled at 256 Hz, and basic filtering was applied from 0.5 to 40 Hz, then decomposed in different frequency bands to analyze the task in these frequency bands. Artifacts are a common occurrence while recording the data. Hence, they cannot be ignored. The typical artifacts in the case of EEG signals may be differentiated into three categories: physiological, habitual, and external. Whereas instructions were given to every subject to control physical activities during the task. Besides this, the power line interference was also considered the reason for the external artifacts.

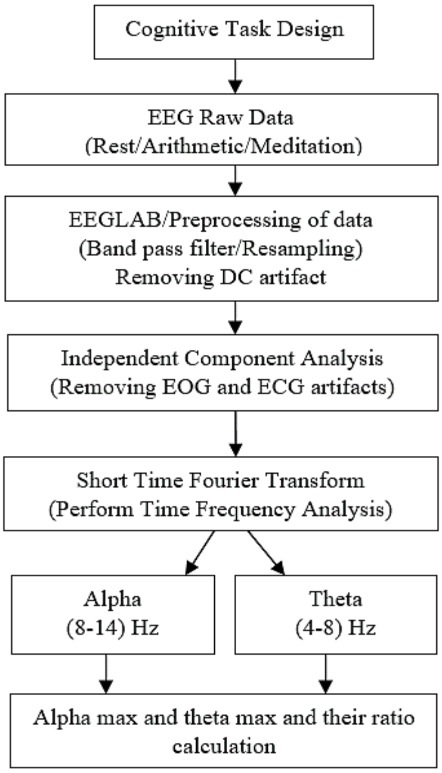

Figure 5. Flow chart of the methodology and signal processing

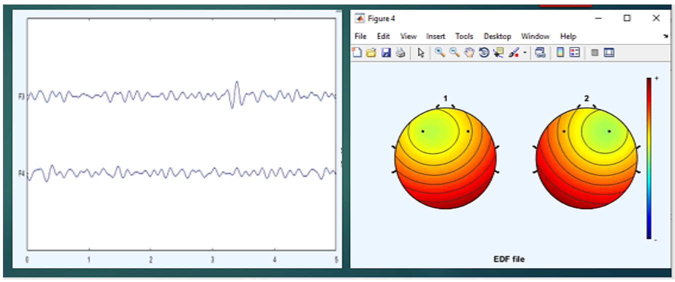

Figure 6. Preprocessed data of channel Af3 and Af4

To minimize the artifacts, the subjects followed the standard instructions (*i.e.*, not too much movement of eye or tongue, not talking and chewing, and not moving any body part during the task). Still, there were also interfering signals from alternating current power noise and fluorescent light. Such noises may result in erroneous brain wave measurement results or poor performance in brain-computer interfaces [56]. The eye-blinking artifacts, artifacts owing to heartbeats, and other noises have been removed by applying independent component analysis (ICA). Eye blinking signals primarily have a low frequency of less than 4 Hz, which affects the Fp1 and Fp2 channels, and they are the most interfering signal for EEG measurement because of their large amplitude. The frequency of EMG signals is typically considerably higher than that of brain waves, and these signals were mostly removed during EEG signal processing. Now the comparisons have been made based on the alpha and theta bands for the three different conditions of the cognitive task. After artifact rejection, short-time Fourier transform (STFT) was used to analyze the data in the frequency domain. *Figure 6* illustrates data and respective topo-plots of two channels after preprocessing. The instantaneous peak frequencies in the alpha (8-14Hz) and theta band (4-8 Hz) were detected for each 1-sec epoch of transformed data in MATLAB (version r2017b) using the local maxima functions, *i.e.*, find peaks [57], After finding the peak values of the ratio of alpha and theta peak frequencies have been calculated.

3. RESULT

This section discussed the alpha-theta correlations during the three different task conditions. Alpha-theta peak value-based comparisons and ERP, PSD-based analysis has been presented here.

3.1 Primarily Analysis (Alpha–Theta correlations during the task)

After preprocessing and decomposition of data into alpha (8-14Hz) and theta (4-8Hz) frequencies, the computation of their peaks have been carried out for the different task states. *Table 2* summarizes the approximate peak values of alpha and theta frequencies and their ratio at Fp1 and Fp2 electrode positions. For example, when subject S0 was instructed to relax, the resting position alpha and theta frequencies calculated were 11.2 Hz and 6.2 Hz, respectively. During meditation, the alpha frequencies significantly decreased from 11.22 Hz to 9.71 Hz, and the theta frequency reduced from 6.2 Hz to 4.6 Hz. During the arithmetic task, the alpha frequency suddenly rises from

11.2 Hz to 13.6 Hz, and the theta frequency varies from 6.2 Hz to 7.7 Hz. It signifies that during the meditation state, the brain frequency decreases, while in any arithmetic state, the frequency increases for the subject S0. All 27 subjects have been analyzed, and it has been observed that during rest, the alpha-theta cross frequency (alpha: thera: 2:1) occurs six times (i.e., for subjects S2, S3, and S10, S14, S18 and S26). In the meditation state, the alpha-theta cross-frequency occurrences have been found only twice (for subjects S6 and S23), and in the arithmetic state, it happens nine times (for subjects S3, S5, S6, S11, S15, S17, S22, S23 and S26).

From these findings, it is clear that:

% of alpha-theta cross-frequency occurrences during arithmetic state= 9*100/27=33.33

% of alpha-theta cross-frequency occurrences during meditation state=2*100/27=7.40

% of alpha-theta cross-frequency occurrences during rest state= 6*100/27= 22.22

The above calculations show that the alpha-theta cross-frequency percentage value during the arithmetic state (i.e., 33.33%) is far greater than the meditation state (i.e., 7.40%). Conversely, the alpha-theta cross-frequency percentage during the rest state (*i.e.*, 22.22%) is greater than the meditation State (i.e., 7.40%). The calculations made during the experiments comply with the cross-frequency occurrence pattern, i.e., arithmetic> rest>meditation. The box plot of the dataset is shown in *figure 7*. It can be observed that the mean values of meditation and rest state data were found less in comparison to the arithmetic state data. Whereas the width of the meditation box seems more than the remaining two boxes, which indicates the data range of the meditation state is more than the other two states. The outlier values have also been found in some states of the experiment. These outlier values may be caused due to some instantaneous distractions during the task or when the subject loses concentration and is again immersed in the same task state. We had tried our best that every subject emerged fully with the task states, but no one can control all his thoughts for a given task within a given time.

Table 2: Peak frequency values (Hz) values (approx.) of alpha, theta, and their ratios in three different task states, the electrodes were placed at Fp1 and Fp2 positions

Sub:	Rest			Meditation			Arithmetic		
	α(M)	**θ(M**	**α/θ(M)**	**α(M)**	**θ(M)**	**α(M)/θ(M)**	**α(M)**	**θ(M)**	**α(M)/θ(M)**
S0	11.2	6.2	1.8	9.7	4.6	2.1	13.6	7.7	1.7
S1	10.9	6.8	1.6	8.6	4.5	1.9	11.7	5.3	2.1
S2	9.3	4.6	2.0	7.3	4.5	1.6	12.1	6.3	1.9
S3	11.3	5.6	2.0	7.9	4.6	1.7	13.3	6.6	2.0
S4	10.7	6.5	1.6	8.3	5.2	1.6	12.3	5.9	2.1
S5	9.7	7.5	1.3	9.0	5.2	1.7	11.7	5.8	2.0
S6	13.1	7.3	1.8	9.8	4.9	2.0	12.1	6.0	2.0
S7	8.9	4.5	1.9	7.6	4.0	1.9	11.2	5.3	2.1
S8	9.3	4.9	1.9	11.2	6.2	1.8	11.0	6.1	1.7
S9	10.8	6.7	1.6	10.9	5.2	2.1	9.3	5.2	1.8
S10	9.7	4.8	2.0	10.2	7.8	1.3	12.5	6.5	1.9
S11	8.9	5.2	1.7	7.2	5.1	1.4	13.7	6.8	2.0
S12	9.3	6.6	1.4	11.3	6.6	1.7	11.7	7.3	1.6
S13	11.7	5.5	2.1	9.7	4.6	2.1	10.3	5.7	1.8
S14	12.9	6.4	2.0	12.6	6.6	1.9	9.7	5.1	1.9
S15	7.8	4.1	1.9	13.1	7.2	1.8	11.6	5.8	2.0
S16	9.4	6.2	1.5	8.9	5.9	1.5	12.6	7.4	1.7
S17	12.4	7.3	1.7	10.6	5.0	2.1	13.6	6.8	2.0
S18	11.8	5.9	2.0	11.3	5.9	1.9	10.9	6.8	1.6
S19	12.4	7.7	1.6	11.0	5.0	2.2	13.1	7.3	1.8
S20	13.4	7.0	1.9	12.2	6.4	1.9	11.2	5.1	2.2
S21	12.9	5.8	2.2	9.9	7.6	1.3	9.9	6.6	1.5
S22	11.6	6.4	1.8	8.9	4.9	1.8	11.7	5.8	2.0
S23	8.9	4.2	2.1	11.9	5.9	2.0	11.9	5.9	2.0
S24	10.9	7.3	1.5	9.7	6.0	1.6	9.9	5.8	1.7
S25	10.7	6.6	1.6	10.3	7.9	1.3	13.1	6.2	2.1
S26	11.7	5.8	2.0	12.5	5.6	2.2	12.1	6.0	2.0

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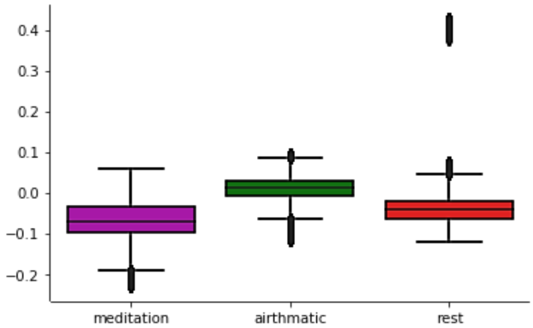

Figure 7: Box Plot of the data when the electrodes at Fp1 and Fp2 positions

Similarly, *table 3* summarizes the peak frequencies in alpha and theta bands and their ratios when the positions of electrodes were at Af3 and Af4. From the below findings, it is evident that the cross-frequency correlations (alpha: theta: 2.1) were maximum in the arithmetic state, i.e. 11 times (for subjects S0, S3, S7, S8, S9, S13, S15, S18, S19, S23 and S25) and minimum in the case of meditation, i.e. two times (for subjects S5 and S12) whereas, in the rest state, it has been found seven times (for subjects S3, S6, S10, S13, S19, S20 and S24).

From these findings, it is clear that:
% of alpha-theta cross-frequency occurrences during arithmetic state= 11*100/27=40.74
% of alpha-theta cross-frequency occurrences during meditation state= 2*100/27=7.40
% of alpha-theta cross-frequency occurrences during rest state= 7*100/27=25.92

From the above calculations, it was observed that the occurrence of the cross-frequency is maximum in the arithmetic state, i.e., 40.74, and minimum in the case of the meditation state, i.e.,7.40. In contrast, the rest state is found in between these two states, i.e., 25.92. Thus, the cross-frequency occurrence pattern has been found as *Arithmetic> Rest>meditation*. The box plot of the dataset is shown in *figure 8*. It can be observed that the mean values of the meditation and rest state data were found less than the arithmetic state data. Whereas the width of the meditation box and arithmetic box appear larger than the rest, suggesting that the data range of meditation and arithmetic was found more than the rest. The outlier values were also found in some states of the experiment

Table 3: Peak frequencies (in Hz) values (approx.) of alpha, theta bands, and their ratios in three different task conditions, the electrodes were placed at Af3 and Af4 positions

Sub:	Rest			Meditation			Arithmetic		
	α(M)	**θ(M)**	**α(M)/θ(M)**	**α(M)**	**θ(M)**	**α(M)/θ(M)**	**α(M)**	**θ(M)**	**α(M)/θ(M)**
S0	8.9	5.5	1.6	7.9	4.9	1.6	13.2	6.6	2.0
S1	11.2	5.8	1.9	9.2	4.8	1.9	12.3	6.8	1.8
S2	11.7	6.8	1.7	7.6	5.0	1.5	12.9	8.0	1.6
S3	9.3	4.6	2.0	8.9	5.5	1.6	11.9	5.9	2.0
S4	8.9	5.6	1.6	9.8	5.1	1.9	10.2	5.3	1.9
S5	11.2	6.5	1.7	10.1	5.0	2.0	10.6	6.6	1.6
S6	9.6	6.4	2.0	9.7	5.7	1.7	12.9	8.6	1.5
S7	10.3	5.7	1.8	10.9	7.2	1.5	11.8	5.9	2.0
S8	10.9	5.7	1.9	11.3	6.2	1.8	11.9	5.9	2.0
S9	11.3	6.6	1.7	12.1	7.5	1.6	12.3	6.1	2.0
S10	9.4	4.7	2.0	9.5	5.9	1.6	9.2	5.1	1.8
S11	10.7	5.6	1.9	7.2	4.0	1.8	8.1	4.2	1.9
S12	10.4	7.4	1.4	11.7	5.8	2.0	12.2	7.1	1.7
S13	11.1	5.5	2.0	12.2	6.4	1.9	11.5	5.7	2.0
S14	13.4	7.4	1.8	9.9	5.5	1.8	13.7	7.6	1.8
S15	7.9	5.6	1.4	10.5	5.0	2.1	11.2	5.6	2.0
S16	8.5	4.4	1.9	13.1	6.8	1.9	9.6	6.0	1.6
S17	9.7	6.9	1.4	8.9	6.8	1.3	8.7	6.0	1.4
S18	10.6	6.2	1.7	10.3	5.4	1.9	11.5	5.7	2.0
S19	12.5	6.2	2.0	7.6	4.7	1.6	11.8	5.9	2.0
S20	11.3	5.6	2.0	9.4	6.7	1.4	13.6	7.1	1.9
S21	9.0	5.6	1.6	10.9	6.4	1.7	9.8	5.7	1.7
S22	8.6	4.5	1.9	8.2	4.5	1.8	10.5	7.5	1.4
S23	7.6	5.8	1.3	11.9	7.0	1.7	11.6	5.8	2.0
S24	11.9	5.9	2.0	12.0	6.3	1.9	9.5	5.5	1.7
S25	12.3	6.8	1.8	9.5	5.5	1.7	10.8	5.5	2.0
S26	9.2	6.1	1.6	11.6	7.7	1.5	13.2	7.3	1.8

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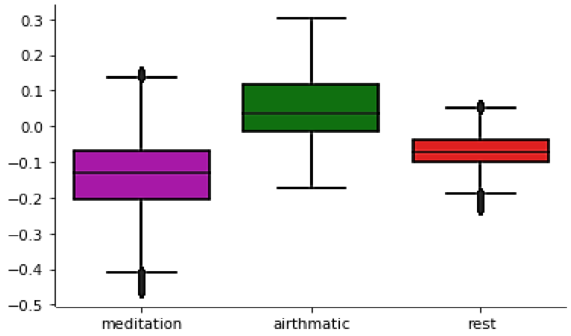

Figure 8: Box Plot of the data when the electrodes were at Af3 and Af4 positions

Similarly, *table 4* illustrates the alpha and theta band frequencies' peak values and their ratios at the electrode positions Af7 and Af8. The maximum occurrence of alpha-theta cross frequencies was found in the arithmetic state (nine times), while the resting and meditation states have seen the same number of cross-frequency occurrences (five times).

% of alpha-theta cross-frequency occurrences during arithmetic state= 9*100/27=33.33

% of alpha-theta cross-frequency occurrences during meditation state= 5*100/27=18.51
% of alpha-theta cross-frequency occurrences during rest state= 5*100/27=18.51

In this case, it was found that the maximum percentage of the cross-frequency is during the arithmetic condition (i.e. 33.33). At the same time, the meditation and resting states both have the same percentage of occurrence of cross-frequency, i.e., 18.51. Thus the cross-frequency occurrence pattern was found in *Arithmetic>rest=meditation*. The box plot of the dataset is also shown in *figure 9*. It can be observed that the mean values of the meditation and resting state data were found less than the arithmetic state data. While the width of the rest box seems more than the remaining two boxes, which indicates the data range of the rest state is more than the other two.

The findings reveal that at all three positions (i.e. Fp1, Fp2, Af3, Af4, Af7 and Af8), the maximum number of cross-frequency occurrences has been found in the case of the arithmetic state. The theta values are constantly lower in all three positions in the meditation state, while the alpha values are constantly high in the arithmetic state.

Table 4: Peak frequencies (approx.) of alpha-theta and their ratios in three different states (rest, meditation, and arithmetic), the electrodes were placed at Af7 and Af8 positions.

Sub:	Rest			Meditation			Arithmetic		
	α(M)	**θ(M)**	**α(M)/θ(M)**	**α(M)**	**θ(M)**	**α(M)/θ(M)**	**α(M)**	**θ(M)**	**α(M)/θ(M)**
S0	10.1	5.9	1.7	7.5	4.1	1.8	12.3	6.1	2.0
S1	11.0	6.8	1.6	8.3	4.1	2.0	13.2	6.2	2.1
S2	8.9	4.6	1.9	7.9	4.1	1.9	13.7	7.2	1.9
S3	9.2	4.6	2.0	9.1	5.6	1.6	11.8	7.3	1.6
S4	7.8	4.3	1.8	10.4	6.9	1.5	10.2	6.8	1.5
S5	7.4	4.1	1.8	9.9	5.5	1.8	9.9	5.5	1.8
S6	8.4	4.2	2.0	10.2	5.6	1.8	10.0	5.0	2.0
S7	8.2	5.4	1.5	10.3	6.4	1.6	11.7	6.1	1.9
S8	11.2	6.5	1.7	11.2	7.0	1.6	12.8	6.4	2.0
S9	12.0	6.3	1.9	7.5	4.6	1.6	11.7	7.3	1.6
S10	11.1	6.1	1.8	9.6	4.8	2.0	9.8	6.5	1.5
S11	8.8	5.5	1.6	11.2	6.5	1.7	10.5	6.1	1.7
S12	13.0	6.5	2.1	13.4	7.4	1.8	8.9	4.6	1.9
S13	11.8	6.2	1.9	9.2	5.7	1.6	11.2	5.6	2.0
S14	11.2	7.2	1.5	8.7	4.1	2.1	11.7	5.8	2.0
S15	10.4	5.5	1.8	12.4	6.2	2.0	13.6	6.4	2.1
S16	11.6	5.8	2.0	11.9	7.4	1.6	8.3	5.5	1.5
S17	9.1	4.8	1.8	13.2	6.6	2.0	12.6	7.0	1.8
S18	8.9	4.6	1.9	9.0	4.7	1.9	11.9	5.9	2.0
S19	13.5	7.9	1.7	9.7	5.7	1.7	8.9	4.6	1.9
S20	8.4	4	2.1	10.8	7.2	1.5	7.6	4.7	1.6
S21	7.3	4.8	1.5	10.1	5.0	2.0	11.1	5.5	2.0
S22	9.0	6.9	1.3	8.3	4.6	1.8	13.7	7.2	1.9
S23	10.7	6.2	1.7	13.4	7.0	1.9	9.0	6.4	1.4
S24	11.4	5.7	2.0	7.8	6.0	1.3	12.3	6.1	2.0
S25	10.6	5.3	2.0	8.6	5.0	1.7	7.9	4.6	1.7
S26	9.5	6.7	1.4	10.8	7.2	1.5	12.6	6.3	2.0

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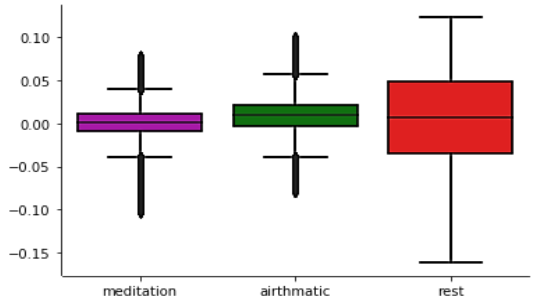


Figure 9: Box Plot of the dataset when the electrodes at Af7 and Af8 positions

3.2 Secondary Analysis

In the secondary approach**,** the authors simultaneously compared the ERPs and PSDs.

3.2.1 ERP-based comparisons

After a comparative study of peak alpha, theta, and cross-frequency correlations of the individual test subject, the study of all 27 subjects was created in EEGLAB. The comparisons were carried out about the ERPs and PSDs for all 27 subjects, and the comparison results are shown in the *figures 10-12*. The study creation option in EEGLAB provides us to analyze the group dataset simultaneously. An EEGLAB study contains a description and links to data contained in many epoched or continuous data sets, such as *A* set of the dataset from a group of subjects in one or more conditions of the same task or performing different tasks in the same or different sessions. A study may be created to manage and process the data recorded from multiple subjects, sessions, and conditions of an experimental study. The present study provided the toolbox of 27 test persons with three states (arithmetic, meditation, and rest). After uploading all the data in a SET file format, the options for comparing PSD and ERP concerning frequency and time are available. The analysis shows the differences among the three conditions, *i.e.*, rest, arithmetic, and meditation in the *figures 10, 11 and 12*.

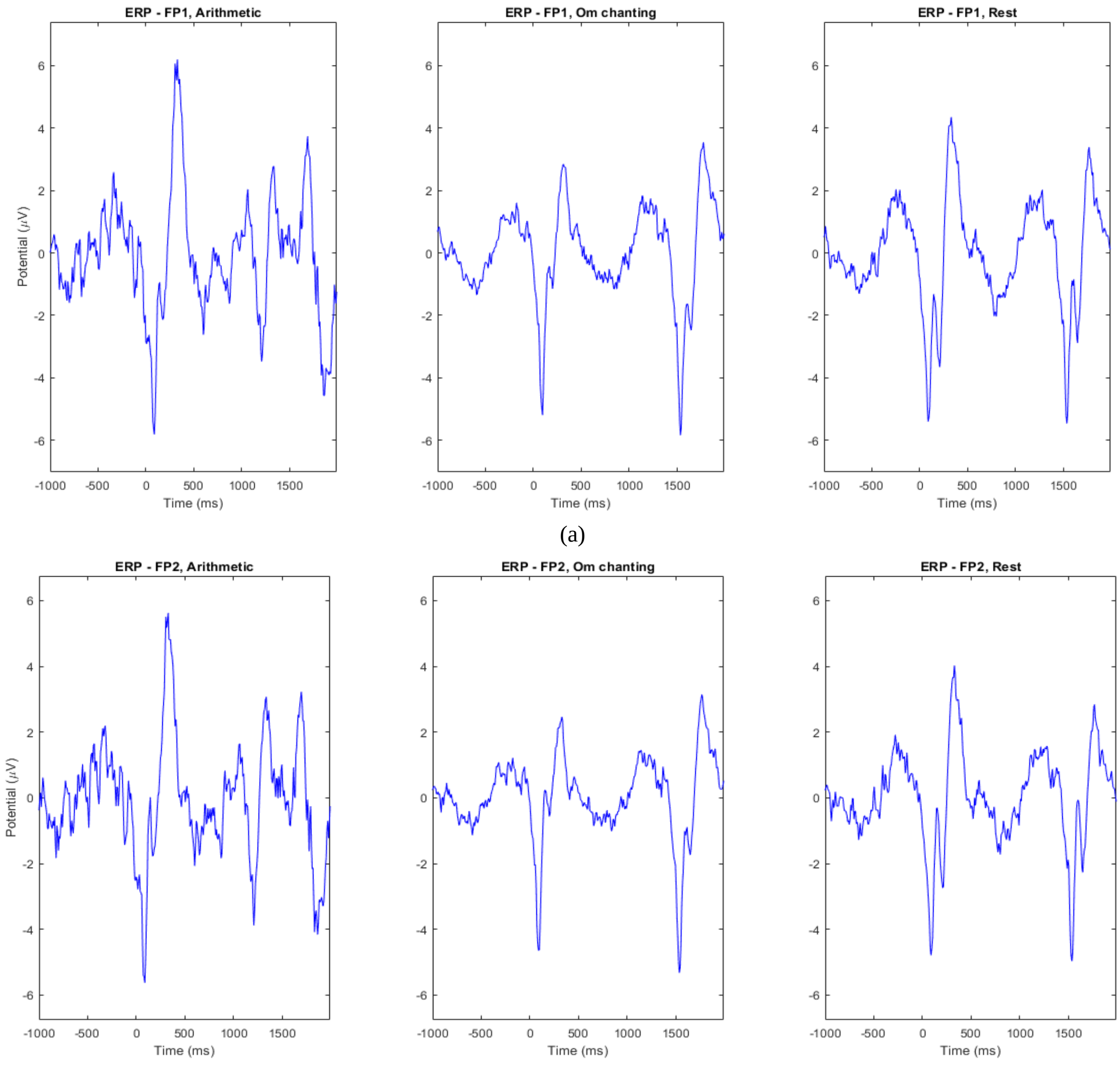
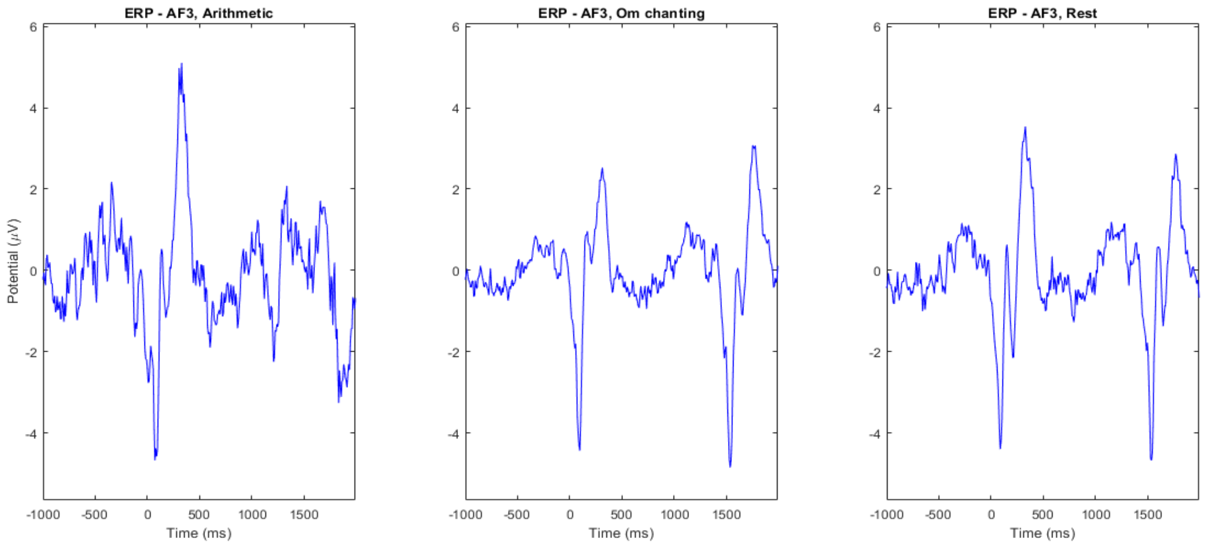
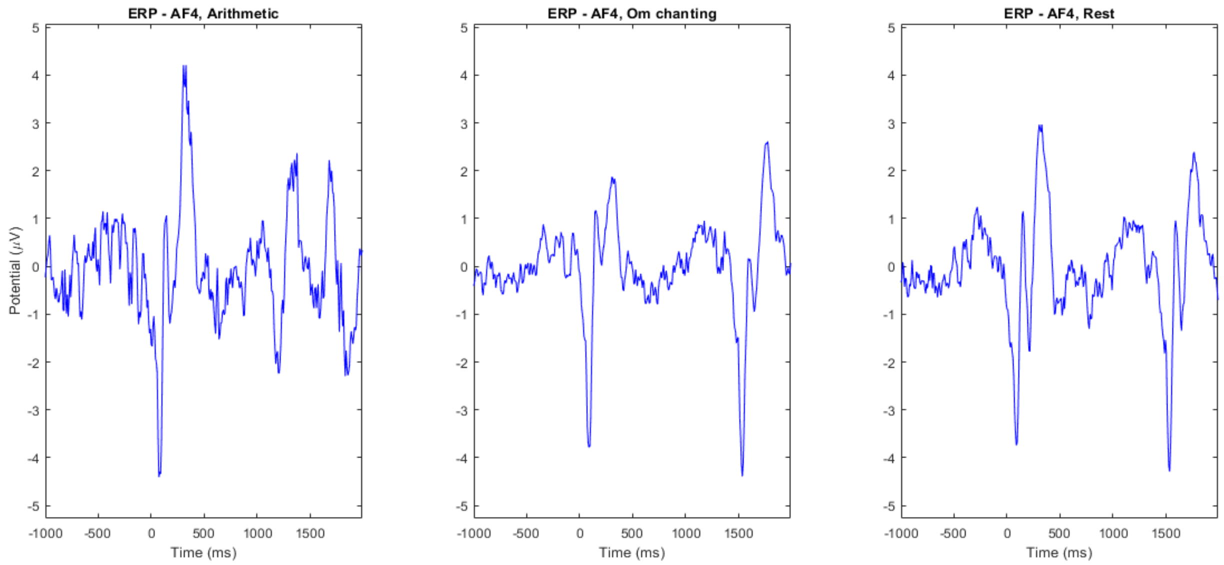


Figure 10- illustrates the ERP vs time variations in three different states (rest, meditation, arithmetic) (a) at Fp1 (b) at Fp2

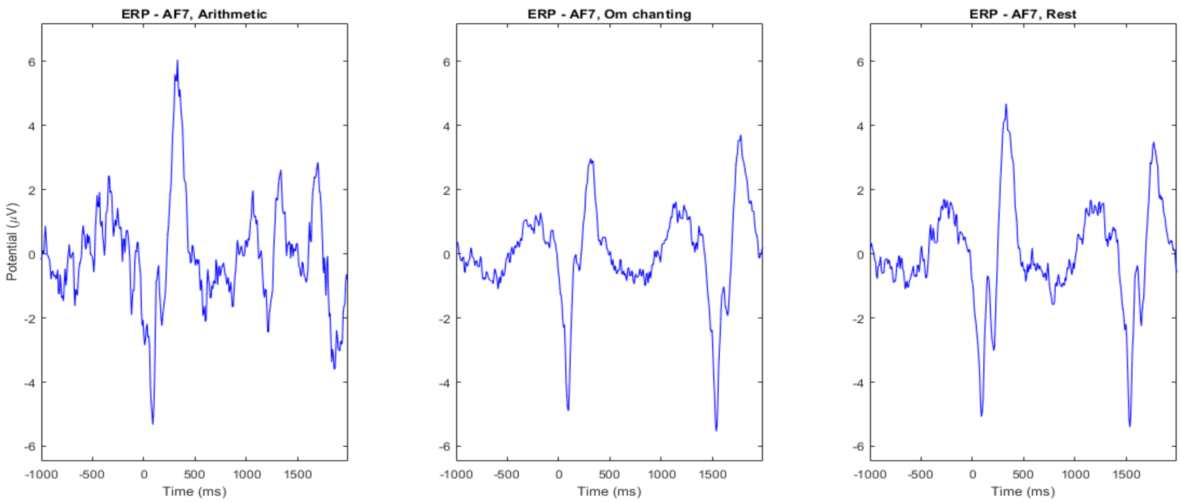


(a)



(b)

Figure 11: illustrates the ERP vs time variations in three different states (rest, meditation, arithmetic) (a) at Af3 (b) at Af4



(a)

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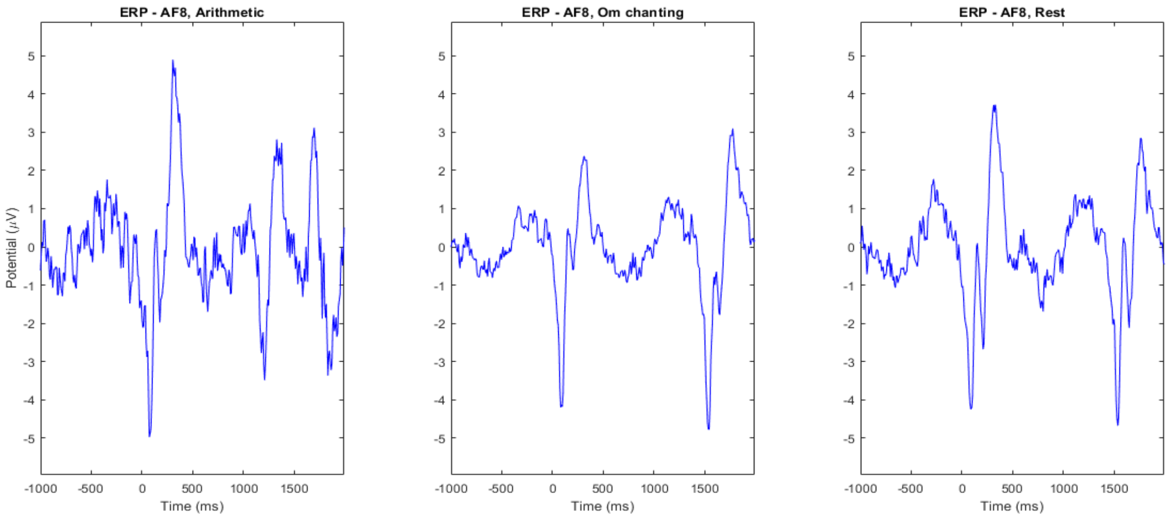


(b)

Figure 12: illustrates the ERP vs time variations in the three different states (rest, meditation, arithmetic) (a) at Af7 (b) at Af8

The ERP-based study analysis shows that the maximum values of ERPs were reported during an arithmetic operation. The ERP values are higher than the rest and meditation (at all the electrode positions).

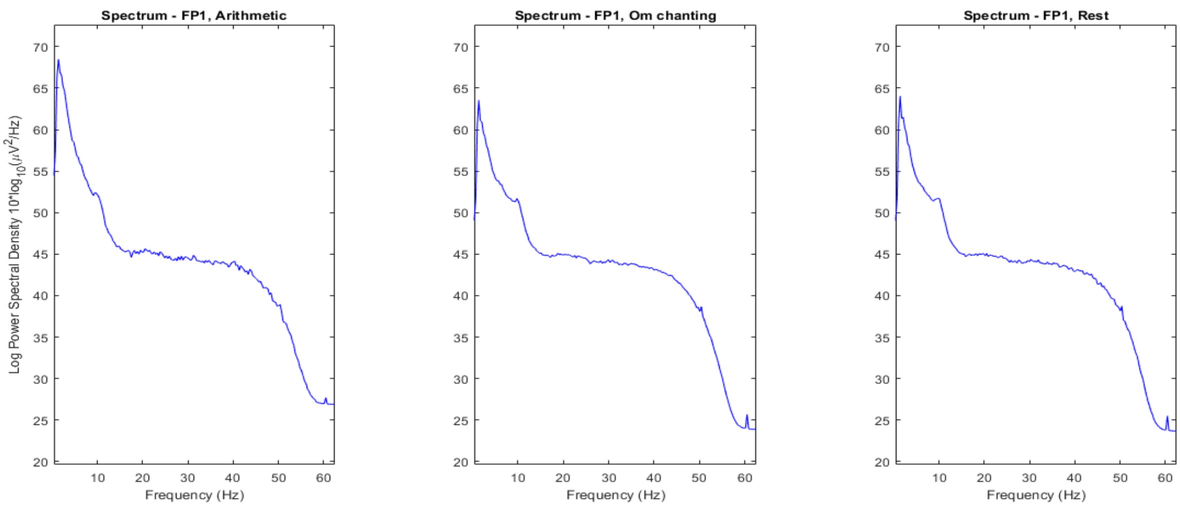
Table 5: Peak ERPs during different task conditions

Electrode positions	Task state	Peak (approx.) ERP values
Fp1, Fp2	Arithmetic	6.1, 5.9
	Rest	4.2, 4.0
	Meditation	3.7, 3.2
Af3,Af4	Arithmetic	4.9, 4.2
	Rest	3.4, 3
	Meditation	2.8, 2.7
Af7,Af8	Arithmetic	6.0, 5.0
	Rest	3.9, 4.9
	Meditation	3.9, 2.9

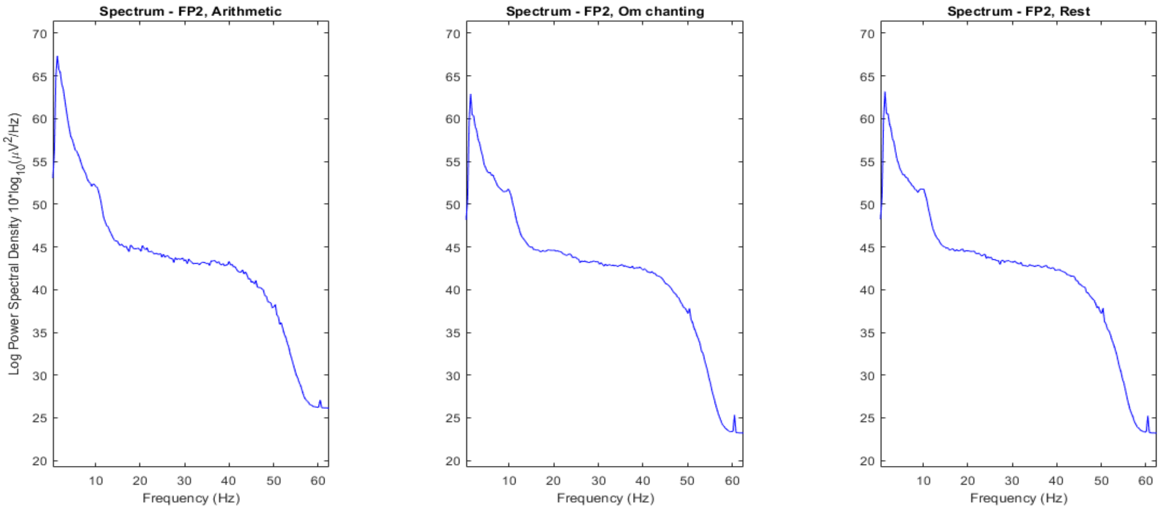
A comparison between the meditation state and rest has shown that the meditation state is more sluggish than the rest state. *Table 5* illustrates the maximum variations in ERPs in different electrode positions. The maximum variations have been seen in the arithmetic positions irrespective to all electrode positions. The ERPs in rest positions were found in between the arithmetic and meditation states. In the meditation state, the ERPs were found low in all the electrode positions. It clearly indicates that the meditation state is more sluggish than the rest and arithmetic states.

3.2.2 PSD-based comparisons

When analyzing the power spectral densities (PSDs) of the three different states, it has been found that the peak PSD values occurred during the arithmetic state. The arithmetic state PSD values were slightly higher in comparison to the other two states, i.e., rest and meditation, whereas in rest and meditation states, the results were approximately similar. In comparing PSD between meditation and rest state, it has been found that the human brain was more relaxed in the state of meditation, and this state was more sluggish than the other two.

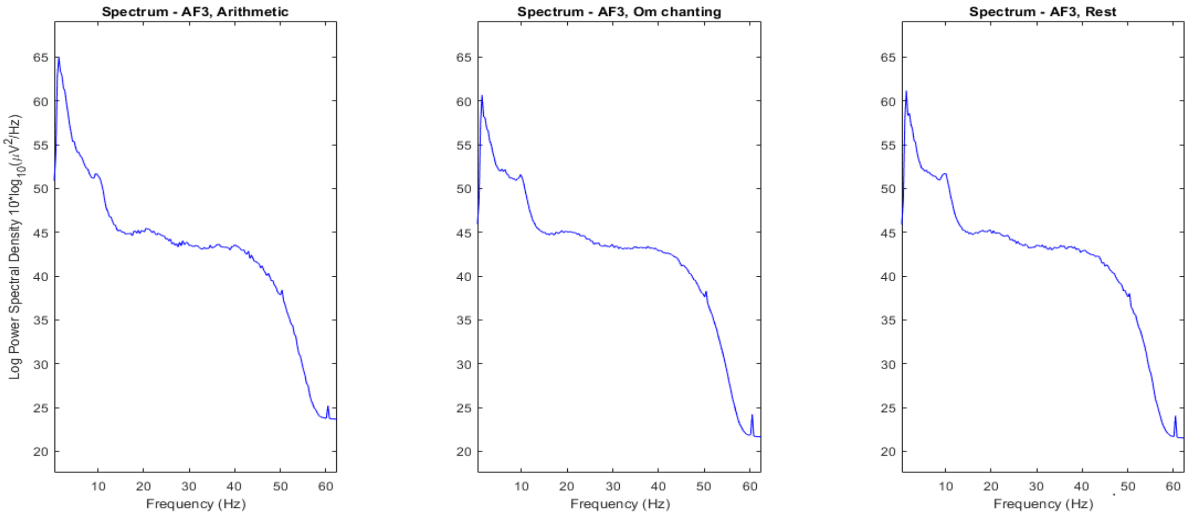


(a)

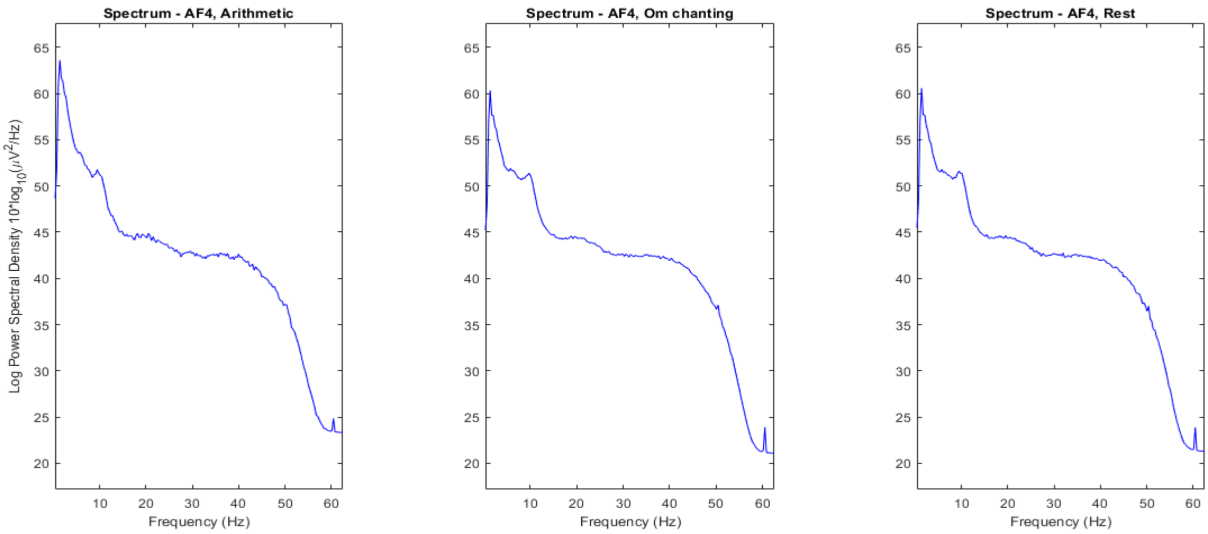


(b)

Figure 13-PSD vs frequency variations in the three different states (rest, meditation, arithmetic) (a) Fp1 (b) Fp2



(a)



(b)

Figure 14-PSD vs frequency variations in the three different states (rest, mediation, arithmetic) (a) Af3 (b) Af4

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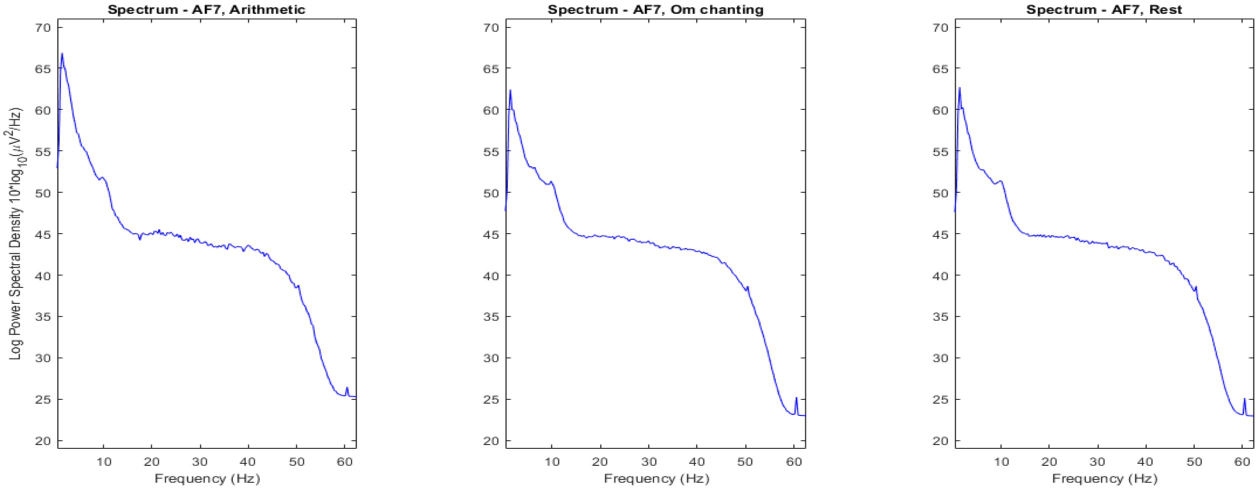
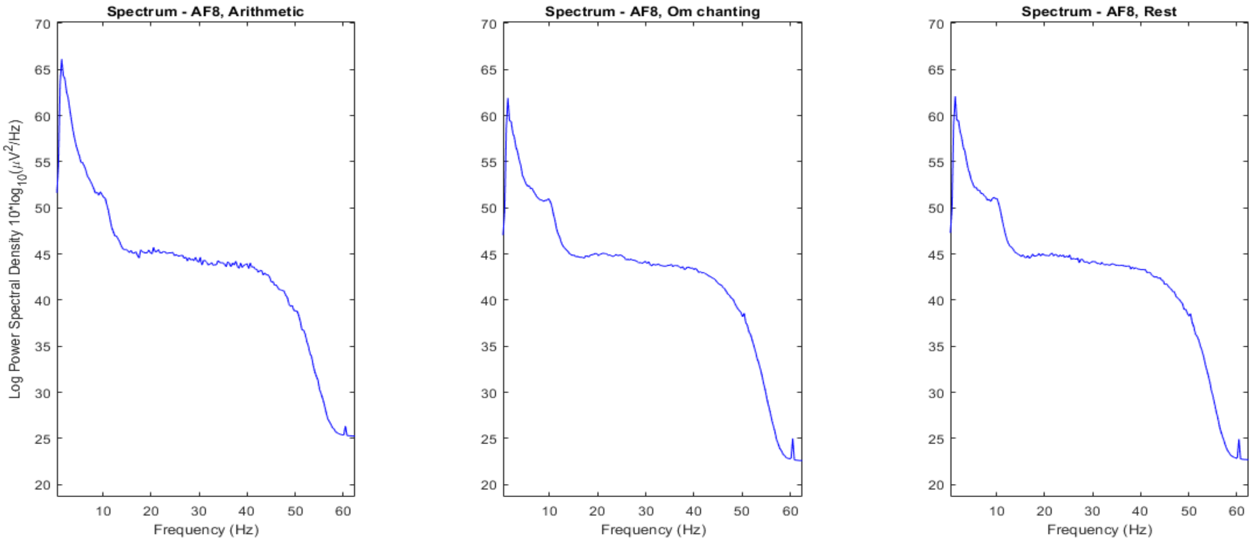


(a)



(b)

Figure 15-PSD vs frequency variations in the three different states (rest, meditation, arithmetic) (a) Af7 (b) Af8

In *figure 13*, at positions, Fp1, and Fp2, the PSD (peak values) of 68 and 67 were found in the arithmetic state, while these values lie between 60 and 65 in the resting and meditation states. Similarly, in *figure 14*, PSD peaks were 65 and 64 at positions Af3 and Af4 during the arithmetic task, while the rest and meditation-related PSD were slightly lower, *i.e.*, close to 60. In *figure 15*, similar patterns were found when the electrodes were placed at Af7 and Af8, *i.e.*, the maximum value of the PSD in the case of the arithmetic state and the resting and meditation states showing fewer PSD values. In most of these cases, a steep drop is seen after the frequency of 40 Hz

4. DISCUSSION

Previous studies [28,58] demonstrated the alpha-theta cross-frequency dynamics for the entire brain and they were not focused on the particular brain area that's why this study demonstrated the alpha-theta cross-frequency dynamics in the frontal region of the brain. Most of the mental activities are controlled and affected by the frontal lobe so that the effect of any cognitive task can be seen more in the frontal area of the brain. In our experiment, OM chanting sound (963Hz) has been used to achieve mental emptiness instead of meditation practice like in previous studies. Brain oscillations are non-stationary, so the condition of this transient relationship between alpha and theta peak values was instantaneous [59, 60]. Working memory and execution control has been related to the cognitive demand of the experiment [61-63]. Previous research demonstrated that the maximum manipulation and execution in the mind were during arithmetic operation [64-67] and during the meditation state, the same manipulation and execution has been found less because the brain was trying to be calm or mental emptiness [19, 68-70]. Our study suggested that the increase in cognitive demand significantly increases the occurrences of alpha-theta transient relationship for their peak frequencies.

It is possible that cognitively demanding tasks may require more sustained interactions between alpha and theta rhythms because information must be stored and manipulated for longer periods of time than during rest. As a result, a lower number of harmonic episodes was seen in the meditation condition compared to rest. Since meditators feel not only a decrease in the frequency of mind wandering but also a decrease in the semantic association to their concentrations while practising meditation. We predicted that meditation would result in less information retrieval, manipulation, and interaction between theta and alpha rhymes than rest. According to this hypothesis, we demonstrate that from arithmetic to meditation, the frequency configuration that allows alpha-theta interactions through cross-frequency synchronization occurs more frequently. The analysis results suggested that during arithmetic conditions, transient alpha-theta were found more frequently than the other two states (i.e., rest and meditation). Also, the peak values of alpha and theta appeared high during the arithmetic state.

Some studies suggest that the maximum occurrences of the alpha-theta cross-frequency relationship happen when the alpha range is 11-12 Hz and the theta range is 4-6 Hz [20, 71]. The authors claim comparable results with the six electrodes on the frontal lobe. Findings also indicated maximum episodes where the cross-frequency relationship occurred (in arithmetic conditions) with alpha values between 9-12 Hz. A previous work illustrated that effortful cognition increased the alpha peaks frequency [72], decreased theta peak frequency [20], and an increased in alpha-theta cross-frequency relationship [73]. The authors demonstrated maximum numbers of cross-frequency alpha-theta correlations in arithmetic conditions (at all electrode positions). Another insight reflected that maximum alpha-theta cross-frequency episodes were found when the electrodes were placed at Af3, and Af4 positions, indicating that Af3 and Af4 positions are maximally involved in the task process than the other two electrode positions. In the ERP and PSD comparisons, the maximum variations in arithmetic conditions and the maximum peak values of PSD in the arithmetic state also supported the previous studies. The result suggests that neural oscillations related to the arithmetic condition are higher than the other two (i.e., rest and meditation).

5. CONCLUSION

The experiment outcomes demonstrate how the cross-frequency correlations between alpha theta rhymes were enhanced during an effortful cognitive task, whereas it decreased during the state of meditation. This work analyzes and distinguishes the various states of mind for a designed cognitive task. The participants induced the meditation by listening to OM chanting of 963 Hz. The study concluded that alpha-theta cross-frequency occurrences were maximum during arithmetic operations, i.e., 33%, 40.74%, and 33.33%. The alpha-theta cross-frequency in the rest state is lower than the arithmetic task, *i.e.*, 22.22%, 25.92%, and 18.51%. Moreover, the Alpha theta cross-frequency in the meditation state is lower than the rest state, i.e., 7.40%, 7.40%, and 18.51%. It was found that alpha-theta cross-frequency occurrences are 40.74% (maximum) when electrodes are placed at Af3 and Af4. The comparisons based on ERPs and PSDs showed that the meditation state is more sluggish than the arithmetic and rest one.

Future scope and limitations of the study:

(1) In future studies, the sample size can be increased to 100 to increase the reliability of the research.
(2) Two different groups of novice and experienced meditators can be considered.
(3) This study examines alpha and theta band frequencies and would be interesting to investigate other frequency bands as well.
(4) Also, incorporating additional measures such as behavioural performances or self-reported measures of cognitive effort could help validate the findings of the study.
(5) Further different combinations of data acquisition systems can be utilized i.e. EEG and fMRI to extract more reliable features.
(6) The task may be redesigned with more different states of the brain

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