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# Investigating the impact of Mahā Mantra chanting on anxiety and depression : An EEG Rhythm Analysis Approach

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### ABSTRACT

Hare kṛṣṇa hare kṛṣṇa kṛṣṇa kṛṣṇa hare hare hare rāma hare rāma rāma hare hare is the Mahā Mantra (MM). The Mantra is believed to be the sacred mantra from the ancient times. In the current research, an attempt has been made to study the brain dynamics of oscillatory changes after MM chanting. The mantra chanting produces a state of mind that has a positive effect on the individual's brain. The electroencephalogram (EEG) signals are asynchronous in nature and record the brain's present state. In this study, forty individuals were assigned randomly into two (pre &post) groups,(n=20) with equal ratio of male and female and having mean age 25.5 yr. EEG signal was recorded in eyes closed condition both prior as well as after the MM chanting. The rhythms (Delta, theta, alpha, beta, and gamma) were extracted from the recorded EEG signals. To match the behavioural changes in the nature of the EEG, the power of the rhythm was computed and compared. According to the study, chanting MM leads to increase in alpha relative power in the central and parietal regions of the brain, which indicates that the brain has been refreshed and relieved. The study showed generous production of alpha, theta and delta waves which has been found in the study to be associated with the secretion of hormones or neurotransmitters causing dilation of blood vessels. As per literature it has been found that increase in relative alpha band power is associated with the secretion of hormones or neurotransmitters causing dilation of blood vessels which is further associated with the improvement in the mental well-being and feeling relaxed and releived, thus leading to decrease in anxiety and depression. The current research study proves the impact of the MM chanting leads to mental alleviation and mental well-being to a great extent.

#### 1. Introduction

*Mantras* are the inevitable, omnipresent and mystical occurrences within the various philosophical and ritualistic oral traditions of the Indian Knowledge Systems, existing as  $n\bar{a}da/dhvani$  or  $v\bar{a}c/\dot{s}abda$ , though difficult to comprehend as common language. The emergence of the *mantra* is ciphered in its origins as 'instrument' (*tra*) of thought (*man*). Thoughts when conveyed through words become instrumental.

From a psychophysiological perspective, a mantra can be understood as a powerful tool that combines elements of psychology and physiology to induce a state of focused attention and relaxation. Psychologically, the repetition of a mantra helps to quiet the mind by redirecting and narrowing the focus of attention. This process can promote a sense of mental clarity, reduce mental chatter, and create a state of mindfulness. By repeating a mantra, individuals can shift their awareness away from distracting thoughts and emotions, allowing them to cultivate a more present and centered state of mind. Physiologically, the practice of repeating a mantra can elicit a relaxation response in the body. The parasympathetic nerve system, which controls the body's rest and digest response, is activated when a mantra is chanted. This activation leads to a decrease in heart rate, blood pressure, and stress hormone levels, promoting a sense of calmness and well-being.

The Maha Mantra "Hare Rām Hare Rām, Rām Rām Hare Hare; Hare Krishna Hare Krishna, Krishna Krishna Hare Hare" was chosen for this study as a coping strategy among college students and staff in order to analyse the efficacy of this coping approach objectively.

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One of the facets of yoga, meditation is the deliberate and intentional control of one's own attention, whether for rest, self-discovery, or personal development. On focusing attention on a specific external, physical, or mental object while rejecting all irrelevant stimuli, or on an unchanging repetitive item, is consistently retained in concentration, such as mantra meditation [55]. Mantra meditation is said to be simple to perform [9]. Galvanic skin response-based OM meditation promotes psycho-physiological calmness [15]. A study using functional magnetic resonance imaging (fMRI) revealed that during OM meditation, limbic brain areas were significantly deactivated [31]. There were no band oscillations recorded after 30 minutes of OM chanting, although theta in the wide band of the EEG increased dramatically as a result of the meditation [38], reporting comparable theta EEG signals. Theta band variations are primarily related to one's level of expertise with meditation [32]. With novice meditators and only 30 minutes of OM mantra practise, the results are therefore quite encouraging.

The psychophysiological effects of a mantra can be further enhanced by focusing on the rhythmic and resonant qualities of the sound or words being repeated. The vibrations created by the vocalization of a mantra can have a soothing effect on the body and mind, promoting a sense of harmony and balance ([28,13]). Overall, from a psychophysiological perspective, the regular practice of a mantra can have numerous benefits, including stress reduction, improved focus and concentration, enhanced self-awareness, and a deeper sense of relaxation. By integrating both psychological and physiological mechanisms, a mantra serves as a powerful tool for promoting mental and physical well-being ([2]).

Evaluation of various interventions aimed at enhancing the prevention and treatment of mental symptoms and disorders, including meditation techniques, is crucial because mental health is a crucial aspect of people's quality of life and represents a central aspect of national and international action plans on health policies. Meditation is a type of cognitive training that aims to enhance focus and emotional control. The phrase "meditation techniques" refers to a vast and varied variety of exercises that are meant to improve focus and attention. These methods were taken from a number of ancient cultures and ideologies [70]. These strategies, in general, aim to improve self-awareness and deliberate control over mental processes. People can improve their psychological well-being and develop a better grasp of their own mental processes by using these strategies. The ultimate objective is to promote mental and emotional health and foster a deeper sense of self-awareness [70].

There are many different meditation techniques available right now, which makes it more difficult to categorise, separate, and logically define them [58]. The repeating recitation of a word, phrase, or group of syllables, with or without religious or spiritual implications, is the main component of mantra-based meditation (MBM). It is claimed that using a mantra during meditation is an effective way to block out the constant mental chatter, which for many people is the main source of conscious thought. MBM seeks to counteract unfavourable or intrusive automatic thoughts that cause distress and encourage a more calm and concentrated state of mind by directing attention to the mantra. A popular variety of mantra-based meditation (MBM) is Transcendental Meditation (TM). It entails reciting secular mantras with the intention of directing the mind to calmer levels of thought, which will finally result in a silent transcendental consciousness state. With the help of TM, people can learn to calm their minds and enter a profound level of inner quiet . A popular variety of mantra-based meditation (MBM) is Transcendental Meditation (TM). It entails reciting secular mantras with the intention of directing the mind to calmer levels of thought, which will finally result in a silent transcendental consciousness state. With the help of TM, people can learn to calm their minds and enter a profound level of inner quiet.

A mantra's power comes from the fundamental truth of the cosmic and human orders, known as "rta", and is expressed verbally. These facts are not merely made up; rather, they are profoundly ingrained in human consciousness and go beyond the scope of the mind. Mantras have the power to attain great wisdom and understanding in this space [65].

As a result, instead of directly bringing about human transformation, mantras serve as enlightened tools for the mind. Mantras raise awareness and clarity by harmonising with consciousness, revealing more profound insights, and fostering spiritual growth [64].

The electrical condition of the human brain in different psychological circumstances can be acquired by electroencephalogram (EEG). Any changed in the mindset is expected to be reflected in the EEG signal. EEG is of two types: non-invasive and invasive process [7]). In non- invasive EEG, electrode cap is implanted on the brain scalp. EEG is a useful technique used for widespread academic research in the diagnosis of epileptic seizure, sleep disorders, coma and other mental disorders which involve abundance or lack of neural activity in certain parts of the brain. Studies on meditation and other aspects of the human brain have used the techniques of electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). Bryant, Maria [8]. EEG recording process is considered as a cheaper process with good time resolution. EEG signals contain valuable information related to brain state, which help to understand physiology and psychology of an individual's human brain. The above mentioned reasons have justified the use of EEG in various research works [39,52,71,6].

It has been found in the studies that meditation can significantly contribute to improving physical and mental health in modern stressful life and any change in the mental well being is expected to reflected in the Electroencephalogram (EEG) signal [27,28]. The focus of our current research is on the impact of the *Mahā Mantra* (*Hare Kṛṣṇa Mantra*) on Electroencephalogram (EEG) Signal Rhythms and mental wellbeing.

#### 2. Related work

A lot of research has been done to analyze the impact of *mantra* chanting with meditation on individual human brain [10,11,12,14,23, 25,36,37,40,49,61]. The behavior of alpha EEG signals as well as galvanic skin response (GSR) are investigated as an after effect of *mantra* chanting with meditation. Research has showed a remarkable amplification in the behavioral pattern of alpha EEG and GSR leading to the increase in the level of calmness and potential fall in the stress levels in human mind [51]. The recitation of OM mantra along with meditation is also been studied for EEG spectral analysis [48].

The study of MBM's effectiveness has attracted more attention in recent years. Indeed, both physical and mental problems have been the subject of systematic reviews (SR) and meta-analyses (MA) [47,21]. According to these research, MBM is linked to lower systolic and diastolic blood pressure [21], reduces trait anxiety more effectively than standard treatment (Orme-Johnson, 2014), and can enhance psychological well-being and reduce depressive symptoms in non-clinical groups (Lynch, 2018).

Increased stress is a risk factor for the development of major depressive disorders, diabetes mellitus, hypertension, and other lifestyle problems. Therefore, it is crucial for the general populace to adapt to different coping mechanisms in order to manage stress and issues associated to stress as well as to support the maintenance of work-life balance. Numerous coping mechanisms, such as yoga, mind-body practises, meditation, individual belief systems, and stressmanagement programmes have been recorded. In these kind of stressful situations, reciting mantras may also be helpful. Chanting may have beneficial effects on one's body and mind, and using a mantra as a coping technique for stress relief and mental relaxation may be simple, simple to learn, and inexpensive [72]. Well-being, consciousness, Self-awareness, and health may all rise as a result of chanting. Anecdotal evidence suggests that adding Mah Mantra chanting as a coping strategy to encourage good conduct may be able to counteract the negative impacts of stress, but there hasn't been much research on this intervention. Some studies have suggested that reciting the "Hare Krishna" Maha Mantra, a mantra that is prominent in ancient Indian literature, can help people deal with stress, depression, and other mental health issues [54,

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#### 57].

According to a study done on nurses who were under moderate to extreme stress, chanting the Maha Mantra for 20 minutes each day for 45 days significantly decreased the levels of the stress hormones and improved metabolic indices. The results suggest that the straightforward method of chanting the Maha Mantra might benefit stress reduction, as seen by adjustments in stress biomarkers such lowered blood cortisol, raised DHEA, and lowered SAA. Additionally, the study showed that nursing workers under moderate to severe stress saw improvements in metabolic markers. These findings imply that reciting the Maha Mantra regularly can help those who are under a lot of stress reduce their tension and improve their general wellbeing [46].

Maha Mantra chanting may influence emotional, social, cognitive, and mood processes, promoting healing. The study of the brain functions supporting mental training appears to be made possible by neural synchronisation. Prior research has demonstrated the broad significance of neuronal synchronisation, particularly in the gamma-band frequencies (25–70 Hz), for mental functions including learning, working memory, attention, or conscious perception [20,45]. Such rhythmic neuronal discharge synchronisations are believed to be essential for the formation of transitory networks that combine dispersed brain processes into highly organised cognitive and affective activities [68] and may bring about synaptic alterations [29]. The result supports the notion that gamma-band EEG synchronisation may indicate flexible, trainable skills for attention and affective processes [41].

Since the last several decades, there have been significant changes in lifestyle, which have resulted in a greater risk of mental illnesses as sleep issues, depression, tension headaches, anxiety, etc. Studies have shown that starting in the mid-twenties, the volume and weight of the human brain gradually decreased [69]. With an ageing population, dementia and other forms of cognitive impairment have become more common in recent years. Numerous studies have concentrated on identifying the risk factors, but there have been very few attempts to promote effective methods for enhancing cerebral health. Numerous approaches of meditation fall under the general name "meditation". A select few of these include guided meditation, mantra meditation, mindfulness meditation, etc [28,3].

Alpha EEG activity, a sign of psychophysiological relaxation and a reduction in stress, significantly increased in Anand's study on the "Om" mantra meditation. The "Hare Krishna Mantra" (HKM) is recited aloud in a further popular mantra meditation practise. The phrase "Hare Krishna Hare Krishna, Krishna Krishna Hare Hare; Hare Rām Hare Rām, Rām Rām Hare Hare" make up HKM.

A study on "Om" mantra meditation performed by Anand reported significant increase in alpha EEG activity which is an indication of psychophysiological relaxation and decrease in stress level. Another well-known technique of mantra meditation in which "Hare Krishna Mantra" (HKM) is chanted loudly. HKM consists of the following words: "Hare Krishna Hare Krishna, Krishna Krishna Hare Hare; Hare Rām Hare Rām, Rām Rām Hare Hare".

The band power in various EEG bands based on FBSE was computed in a study. The alpha band power definitely has a propensity to rise, which can be a sign of someone feeling tranquil, calm, and relaxed. After meditation, beta band capabilities are slightly reduced. A rise in alpha band power activity was also observed during meditation, according to a prior study by [62].

Despite a wide range of participants, meditation methods, and EEG methodology, most attempts to characterise the neurophysiological foundation of meditation have produced a picture of EEG slowing and improved cortical synchrony [73]. A composite image of the progression of EEG changes during a meditation session, drawn from studies of zen, yoga and TM, appears to be, first, an increase in the abundance of alpha rhythm in the EEG, with well-organized alpha activity appearing in all leads, especially frontal and central; second, an increase in the amplitude of alpha potentials; third, a decrease in the modal frequency of alpha; progressing to, fourth, the appearance of rhythmical trains of

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theta waves (5–7 Hz) discovered a pattern of EEG slowing consisting of 50% alpha waves or a predominance of theta activity over a low-voltage mixed background in a study of another mantra practise, Ananda Marga Yoga [19].

The ability to accept negative emotions and cope with them productively may be enhanced by mindfulness training [16]. According to research, university students who participated in three weekly mindfulness training sessions saw significant reductions in their anxiety and stress symptoms [59].

Anxiety and depression is a widely prevalent phenomenon in modern society and has become a global health problem. Depression is event based, it may deprive quality of life, weak mental health, minimize work efficiency, deep suffering and negatively impacts whatever a person thinks, acts and does. In addition, due to anxiety and depression, there can be an increase in the risk factor for several massive heart attacks, hypertension, diabetes mellitus and other diseases [25,36].

It has been shown that normal, healthy people who practise yoga for a brief length of time without adhering to the strict yogic lifestyle see improvements in their lipid and glucose metabolism, cardio pulmonary function, and psychological function [56]. The autonomic nerve system and endocrine system interact to produce these effects of yoga, with melatonin release from the pineal gland perhaps playing a key role.

Research evidence suggest that, like Maha mantra, OM Mantra brings psycho-physiological relaxation on the basis of galvanic skin response [15]. A group of researchers found after experimental study on Om chanting on brain on the basis of spectral analysis of EEG signal before and after OM chanting implemented, and serving as an introduction to mediation that provides naïve meditators with the opportunity to experience the phenomenon of mediation[28].

#### 3. Research gap

The focal inspiration of current research is to study relaxation behavior of an individual's mind caused by the impending impact of *Mahā Mantra* chanting. This research work may help to clarify the benefits of meditation and encourage people to do it on a daily basis as a beneficial practice. *Mantra* chanting provides many benefits like better lungs functioning, reduction in stress and depression levels, increased level of mental peace and lastly environmental awareness and overall well-being. In hospitals, it is recommended to do *mantra* chanting for a patient's early recovery as it has much psychological usefulness like reduced heart rate, decreased adrenaline and cortical level and decreased level of tension as well as balanced rate of blood pressure. The vibration of *mantra* chanting with a constant deep inhalation process improves the efficiency of the spinal cord and boosts up the blood circulation to all body parts by supplying more oxygen to it [39,52].

### 4. Objective

Hypotheses: Maha Mantra significantly affects the relative alpha band power specifically central and parietal region of the brain.

Alpha signals are observed during the state when the mind is calm, apprehensive and not overwrought. Thus MM chanting leads to improved mental well-being

#### 5. Experimental design

#### 5.1. Participants

The study has been approved by the faculties of ICFAI Foundation for Higher Education University, Telangana, Hyderabad, India. The participants in the study were informed about the experimental set up and the study. At first for all the 40 individuals EEG signals were recorded. To make a comparison the participants were divided into two (pre & post) groups. The F test was used to compare the sociodemographic characteristics of individuals in the pre and post experiment groups. A

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univariate ANOVA revealed that the participants' age (range: 20–31 years), the number of years spent in school (range: 14–16 years), their employment experience (range: 0–3 years), the majority of them coming from nuclear families, and their per-capita family income (range: Rs. 80,000–Rs. 90,000) were all different from one another.

There were 40 individuals in total-20 men and 20 women, aged 18-30, who never did MM chanting, were asked to perform MM chanting. The participants of the study were the college students and staff members. Out of 40 subjects, two of them were left-handed. They were all non-smokers and none of them were habitual drinkers. Written consent has been taken from the participant whose data recording has been done. They did not have any history of neurological illness. EEG electrode cap was used for the study which had inbuilt metal disc electrodes, properly placed in fixed position based on the worldwide 10/ 20 EEG recording system for the purpose of capturing brainwaves in people. It measures voltage fluctuation of a group of neurons. It measures electrical activity of a group of neurons. The variations in the electrical potential recorded from the brain over time. EEG measures the electrical activity generated by the firing of neurons in the brain, and this activity is typically expressed in microvolts BIOPAC MP150 and EEG100C are used for data acquisition and amplification. To make proper connection between scalp and metal disc electrode, Electro-gel is used. It has good conductivity. Since it reduces the impedance between scalp and electrodes and we got better quality of signals [71]. Disposable sponge discs were used for forehead electrodes referencing. Disposable gloves were used to avoid cross-contamination between subject and research personnel. Fig. 1 shows different equipment and accessories used in the experiment.

EEG signals of 40 subjects with closed eyes before and after MM chanting were recorded. In next step pre-processing of recorded EEG signals was done. The EEG recording contained the artifacts (Electrocardiogram (ECG), eye-blink, body movement, power line interface etc). In the pre-processing stage, the artifacts were removed from the data recorded. After that, the FBSE approach was used to extract rhythms (alpha, theta, beta, delta and gamma) in the time and frequency domain from pre-processed EEG signals. Then a comparison is made for the power of each rhythm obtained before and after chanting. All the participants were instructed 15-20 min MM chanting before the EEG signals were reordered. There was a time gap of 2–5 min after MM chanting to the EEG recording of the participants. Each day 10 participants participated in the experiment; the total 4 days were spent for the completion of the experiment. Since each rhythm has its own significance, conclusion is drawn on that basis. Fig. 2 shows the block diagram of the experimental method.

EEG signal were recorded and further alpha, theta and delta waves band power was computed. It has been found in study in literature that more production of alpha to be associated in the increase in secretion of hormones or neurotransmitters causing dilation of blood vessels [24]. Alpha wave activity has been associated with the release of neurotransmitters like acetylcholine. Acetylcholine is known to induce



Fig. 1. The block diagram of experimental design.

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Fig. 2. Electrode placement based on the international 10-20 system.

vasodilation by stimulating the release of nitric oxide from endothelial cells, promoting relaxation of smooth muscle cells in blood vessel wall which is further associated with improvement in mental well-being [24].

Electroencephalogram signal were recorded and further alpha, theta and delta waves band power was computed. It has been found in the generous production of alpha, theta and delta waves which has been found in the study to be associated literature that increase in secretion of hormones or neurotransmitters causing dilation of blood vessels [17]. Alpha wave activity has been associated with the release of neurotransmitters like acetylcholine. Acetylcholine is known to induce vasodilation by stimulating the release of nitric oxide from endothelial cells, promoting relaxation of smooth muscle cells in blood vessel wall.

Additionally, alpha wave activity has been linked to the modulation of the autonomic nervous system, which can influence the release of hormones like adrenaline and noradrenaline [18],

#### 5.2. EEG data acquisition

The MM EEG database was created in the institute's Signal Analysis Research Lab. For acquisition of EEG signals BIOPAC MP150 (data acquisition unit) and EEG 100 C (EEG amplifier module) are used. A high-pass filter with a threshold frequency of 0.1 Hz is applied to the signal during recording, enabling frequencies above that frequency to pass while attenuating lower frequencies. In addition, a notch filter is used to target any interference or noise occurring at 50 Hz, such as electrical hum, by reducing the signal there by 50 dB. By eliminating undesirable frequencies and disruptions, these precision filtering techniques guarantee a clear and accurate recording of the required signal. Amplifier gain was 20,000 [71] with sampling frequency of 1000 Hz. Subjects were introduced by the research personnel about the whole experiment after which they were given a consent form to respond voluntarily. Experimental session was started only after signing the consent form.

#### 5.3. Electrode arrangement

EEG signals were recorded using 10 differential channels with 1000 Hz sampling frequency, electrode placement was according to

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10–20 international standard for electrode position (Gaurangpada, 2016). The bipolar arrangement of electrodes which has been used in the study is as follows: Ch1 (Fp1-Fp2), Ch2 (F3-F4), Ch3 (C3-C4), Ch4 (P3-P4), Ch5 (O1-O2), Ch6 (F7-F8), Ch7 (T3-T4), Ch8 (T5-T6), Ch9 (Fpz-Cz), Ch10 (Fz-Pz), GND (A1-A2). Fig. 2 shows the electrode placement based on the international 10–20 system.

The investigational arrangement for EEG signal documentation and verification is carried out with the given procedure:

At first, subjects were asked to lay down while relaxing with closed eyes and no voluntary muscle movement as far as possible. During this time EEG signals for 90 seconds were recorded. The recorded signals are called EEG signals before MM chanting. After this, subjects were asked to sit with spine straight, and were asked to chant one round (108 times) of MM. Subjects were also given Japa beads containing 108 beads. They had to touch each bead and chant MM. They were asked to chant MM loudly and concentrate on listening to the mantra. The subjects were then asked to lay down while relaxing with closed eyes and with minimal muscle movements, during which EEG signals for 90 seconds were again recorded. The recorded signals are called EEG signals after MM chanting. In this way, we got two signals from one subject. In Fig. 3 and Fig. 4, different steps of data acquisition are shown. The block diagram of experimental setup for recording EEG signal is shown in Fig. 4

### 5.4. Data pre-processing

EEG signals record the subject's mental state and often include false information gleaned from physical movements including eye blinking, heartbeats and hand motions. All such electrical activities corresponding to such unwanted phenomena are called artifacts and need to be removed since we were focused only on the information that is associated with *mantra* chanting. In the pre-processing stage, we removed the artifacts from the data recorded.

Artifacts due to eye blink and muscle was remove using Infomax algorithm of Independent Component Analysis (ICA). The software used were Matlab along with EEGLAB for the data analysis.

Apart from this, EEG signal of the first 60 seconds [30] was taken out from a total of 90 seconds for the analysis. The EEG signal was sampled from 1000 Hz to 250 Hz [71].

During the experimental investigation of scalp EEG it was observed that the majority of cerebral signals remain in the array of 0.1–100 Hz [71]. This array of frequency was further categorized into bands of alpha, theta, beta, gamma and delta band power. The significant values of rhythmic band in the brain are described below [71,6].

Delta: It is associated with the different mental states as profound, treadless hibernation, transfixion and paralytic situations. Its frequency range is between 0.1 and 4 Hz.

Theta: Theta waves appear for the mental states like instinctiveness, imaginativeness, remind dream, lethargic and recognizing. It lies between 4 and 8 Hz.

Alpha: Alpha signals are observed during the state when the mind is



Fig. 3. Images of Experimental setup for EEG recording.

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Fig. 4. Block diagram of experimental setup for recording EEG signal.

calm, apprehensive and not overwrought. The eyes are expected to be closed between 8 and 13 Hz in frequency.

Beta: Beta signal band power lies between 13 and 30 Hz. Such beat signals are observed because of state of preparedness, incorporation, centeredness, thoughtfulness, anxiety, attentiveness of surroundings.

Gamma: Gamma beat signals are found due to mental thinking, integrated thought or any complex activities being carried out. The frequency lies in between 30 and 100 Hz.

The alpha waves are typically associated with a relaxed and calm state of mind, while theta waves are associated with drowsiness, daydreaming, and meditative states. Delta waves are typically associated with deep sleep and are the slowest frequency band in the EEG spectrum. Alpha waves are associated with the release of the neurotransmitter acetylcholine, which plays a role in the regulation of blood vessel dilation and blood flow. Similarly, the production of theta and delta waves has been associated with the secretion of hormones such as melatonin and growth hormone, which can also affect blood vessel dilation and blood flow [53].

EEG signals were renovated into frequency domain using FBSE and the different frequency bands (rhythms) were separated. Alpha rhythm predominantly originated from the central sites (channels C3 and C4) at rest and the posterior region of the brain [34,63]. This study focused mostly on alpha rhythm in channels 3 and 4 since it is associated with relaxation as an outcome of mantra meditation [6,71].

#### 5.5. Rhythm separation by FBSE

The nature of EEG signals is non-stationary. Due to the inclusion of Bessel functions, FBSE is thought to be advantageous for the analysis of non-stationary signals. The foundation of FBSE is made up of Bessel operations, which have non-stationary possessions [1,35,50]. FBSE for x (n) is considered to be order of zero and can be expanded as

$$x(n) = \sum_{k=1}^{S} C_k J_0 \quad (\lambda_k \quad n/S) = 0, \quad 1, \quad 2, \quad 3, \dots, S-1$$
(1)

Where in the Eq. (1),  $C_k$  is the FBSE coefficients of x(n) and the value can be computed by

$$C_{k} = \frac{2 \sum_{n=0}^{S-1} nx(n)J_{0} (\lambda_{k} n/s)}{S^{2} [J_{1} (\lambda_{k})]^{2}}$$
(2)

In Eq. (2)  $JO(\cdot)$  and  $J1(\cdot)$  are of order zero and one Bessel functions, respectively. The positive roots  $\lambda_k$  for order zero and ascending Bessel function  $JO(\lambda)$  can be calculated with the respective frequency as in Eq. (3)

$$\lambda_k = \frac{2\pi f k^s}{f_s} \tag{3}$$

Where,  $f_s$  is the sampling frequency,  $\lambda_k \approx \lambda_{k-1} + \pi \approx k\pi$  and k=1, 2,.... S. consequently Eq. (3) can be reprinted as Eq. (4) [1].

$$k = \frac{2fk^S}{f_s} \tag{4}$$

The assessment values of k should be ranging from 1 to S (length of a discrete-time signal) in Eq. (4) so that it can wrap the frequency range of the signal in its entirety. In Eq. (2) the coefficient measures *Ck* of FBSE with respect to the range of frequency band for signal (delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma

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(30–100 Hz) of EEG signal can be calculated from the values of k. The coefficient measures being opted for different bands ( $\delta$ ,  $\theta$ ,  $\alpha$ ,  $\beta$ , and  $\gamma$ ) are employed in Eq. (5) for EEG signal. So Eq. (1) can be rewritten as:

$$\begin{aligned} \mathbf{x}(n) &= \sum_{k=\delta_1}^{\delta_2} C_k J_0\left(\frac{\lambda_k n}{S}\right) + \sum_{k=\theta_1}^{\theta_2} C_k J_0\left(\frac{\lambda_k n}{S}\right) \\ &+ \sum_{k=\alpha_1}^{\alpha_2} C_k J_0\left(\frac{\lambda_k n}{S}\right) + \sum_{k=\beta_1}^{\beta_2} C_k J_0\left(\frac{\lambda_k n}{S}\right) \\ &+ \sum_{k=\gamma_1}^{\gamma_2} C_k J_0\left(\frac{\lambda_k n}{S}\right) \end{aligned}$$
(5)

where,  $[\delta_1, \delta_2]$ ,  $[\theta_1, \theta_2]$ ,  $[\alpha_1, \alpha_2]$ ,  $[\beta_1, \beta_2]$ , and  $[\gamma_1, \gamma_2]$  stays in the frequency signal band power of 0.5–4 Hz, 4– 8 Hz, 8–13 Hz, 13–30 Hz, and 30–86.81 Hz respectively.

The relationship between FBSE and Fast Fourier Transform (FFT) lies in their shared objective of analyzing the frequency content of EEG data. Both techniques are used to examine the spectral characteristics of a signal but employ different methodologies to achieve this. The FFT is a widely used algorithm that efficiently computes the Discrete Fourier Transform (DFT) of a signal. It decomposes a time-domain signal into its constituent frequencies and provides information about the amplitudes and phases of different frequency components. The output of the FFT is a representation of the signal in the frequency domain. FBSE is an alternative approach that involves dividing the signal into multiple frequency bands using a set of bandpass filters. It then estimates the power or amplitude within each frequency band separately. FBSE essentially performs a spectral decomposition of the signal using a bank of filters, where each filter is responsible for a specific frequency range.

The FFT provides a global view of the entire frequency spectrum, offering fine-grained frequency resolution across the entire range. In contrast, FBSE allows for more focused analysis by providing individual frequency band estimates with higher resolution within specific frequency ranges. The FFT provides a continuous frequency spectrum representation, allowing analysis across the entire frequency range. FBSE, however, allows researchers to target specific frequency bands or ranges of interest, providing a more selective and localized analysis. The FFT is a fast implementation of the Fourier Transform and has become the standard method for frequency analysis due to its computational efficiency. FBSE, on the other hand, involves the use of multiple bandpass filters and requires more computational resources, making it relatively slower compared to the FFT [26].

A graphical contrive of these signal and their respective FBSE coefficient measures are demonstrated in Fig. 5 and Fig. 6 for EEG signal beat of a child prior to mantra recitation and after recitation.

#### 5.6. Rhythm power calculation and comparison

In this process, the power of all rhythms obtained before and after MM chanting is calculated. According to Parseval theorem the power representation of FBSE extension (Eq. 6) can be uttered as [50]

$$P = \sum_{k=0}^{s} n x^{2} \frac{n}{S} = \sum_{k=1}^{s} C_{k}^{2} \frac{s^{2}}{2} [J_{1} (\lambda_{k})]^{2} / S$$
(6)



Fig. 5. EEG signal recorded before MM Chanting.



Fig. 6. EEG Signal recorded after MM Chanting.

Table 1

Relative alpha power before and after MM meditation for all 40 subjects for channel 3 (Central -C3-C4).

Subject	Relative power in alpha rhythm before chanting	Relative power in alpha Rhythm after chanting	Subject	Relative power in alpha rhythm before chanting	Relative power in alpha rhythm after chanting
1	0.443	0.523	21	0.288	0.411
2	0.712	0.735	22	0.387	0.221
3	0.121	0.183	23	0.499	0.481
4	0.443	0.547	24	0.21	0.364
5	0.635	0.579	25	0.171	0.249
6	0.058	0.332	26	0.237	0.521
7	0.522	0.571	27	0.569	0.565
8	0.154	0.208	28	0.296	0.26
9	0.052	0.057	29	0.349	0.396
10	0.154	0.235	30	0.519	0.522
11	0.177	0.244	31	0.513	0.711
12	0.466	0.581	32	0.272	0.273
13	0.045	0.163	33	0.058	0.057
14	0.423	0.436	34	0.154	0.078
15	0.249	0.313	35	0.249	0.256
16	0.437	0.421	36	0.522	0.721
17	0.359	0.437	37	0.177	0.188
18	0.456	0.508	38	0.312	0.309
19	0.283	0.353	39	0.031	0.041
20	0.371	0.422	40	0.561	0.561

After that, relative alpha power comparison is done between rhythms obtained before and after MM chanting [30] for channel 3 and 4 (Table 1, Table 2) respectively. The comparative alpha power can be mathematically stated as (Eq. 7):

Relative alpha power = 
$$\frac{\sum_{k=\alpha_1}^{\alpha_2} C_k^2 \quad \frac{S^2}{2} [J_1 \quad (\lambda_k)]^2}{\sum_{k=1}^{s} C_k^2 \quad \frac{S^2}{2} [J_1 \quad (\lambda_k)]^2}$$
(7)

#### 6. Results and discussion

Fig. 7 is a channel 4 bar graph that demonstrates the assessment among comparative alpha power of EEG alpha signal band power acquired during pre and post manta recitation. From 40 female candidates 24 shows a significant amplification in comparative alpha power.

Statistical Analysis

From Table 1, it has been analysed using paired t-test that Relative alpha power before and after MM meditation for all 40 subjects for channel 3 (C3-C4) was found to be statistically significant at p<0.001. From Table 2, it has been analyzed using paired t-test that Relative alpha power before and after MM meditation for all 40 subjects for channel 4 (P3-P4) was found to be statistically significant at p<0.001. The result confirms the fact that MM meditation leads to mental alleviation, wellbeing and calmness and it's majorly reflected in the central and parietal

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#### Table 2

Relative alpha power before and after MM meditation for all 40 subjects for channel 4 (Parietal – P3-P4).

Subject	Relative power in alpha rhythm before chanting	Relative power in alpha rhythm after chanting	Subject	Relative power in alpha rhythm before chanting	Relative power in alpha rhythm after chanting
1	0.41	0.32	21	0.48	0.471
2	0.621	0.687	22	0.233	0.291
3	0.778	0.704	23	0.686	0.701
4	0.06	0.204	24	0.349	0.51
5	0.629	0.683	25	0.106	0.061
6	0.342	0.362	26	0.312	0.586
7	0.314	0.484	27	0.541	0.583
8	0.352	0.306	28	0.412	0.443
9	0.404	0.506	29	0.49	0.562
10	0.407	0.412	30	0.729	0.674
11	0.313	0.304	31	0.688	0.833
12	0.543	0.621	32	0.427	0.503
13	0.283	0.493	33	0.312	0.3
14	0.425	0.459	34	0.211	0.204
15	0.585	0.616	35	0.2	0.198
16	0.507	0.576	36	0.197	0.192
17	0.427	0.308	37	0.177	0.188
18	0.621	0.709	38	0.3	0.309
19	0.276	0.346	39	0.188	0.183
20	0.485	0.553	40	0.179	0.178

region of the brain.

In this study, Central and Parietal region is considered because it has been found in studies that Central region is related with motor functions and sensory functions and Parietal region is related to sensory function memory and perception of vision and space [66]. The study focuses on improvement of Mental Well Being. Mental well-being increases the focus of a individual with respect to sensory function memory and perception of vision and space [5,60].By fostering a positive emotional state and reducing stress levels, individuals can enhance their focus and cognitive abilities, leading to improved performance in various tasks requiring attention, memory, and perceptual skills. Alpha rhythm is associated with the attention and perceptual learning. So, in this study central and parietal region has been considered in context to alpha rhythm.

The bar graph in Fig. 8(a), (b) shows mean relative alpha power before and after MM chanting for all 40 subjects for channel 3 (Central -C3-C4) and (b) channel 4 (Parietal – P3-P4), respectively. So overall mean relative alpha power increases after MM chanting for central and parietal regions.

As shown in Fig. 8, Comparative alpha power of EEG alpha signal band power acquired during pre and post manta recitation and it as found that mean relative alpha power before and after MM chanting for all 40 subjects for channel 3 (Central -C3-C4) and (b) channel 4 (Parietal – P3-P4), respectively. So overall mean relative alpha power increases after MM chanting for central and parietal regions was observed in the statistical analysis. Statistical analysis shows that there is a significant

Table 3

Results of paired t-test for relative alpha power in central and parietal region (n=40).

		Paired Differences						
					95% Confidence Interval of the Difference			
Region	Difference in conditions	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Sig. (2-tailed)
Central (C3-C4) Parietal	Relative alpha power before and after MM meditation	05248	.08710	.01377	.08033	02462	-3.810	.000
(P3-P4)	Relative alpha power before and after MM meditation	04060	.08022	.01268	.06625	01495	-3.201	.003



Fig. 7. Demonstrates the assessment among comparative alpha power of EEG alpha band power acquired during pre and post manta recitation.



Fig. 8. (a)Mean Relative alpha Power before and after MM meditation for 40 subjects for channel 3 (Central -C3-C4) and (b) channel 4 (Parietal - P3-P4), respectively.

difference between mean relative alpha power in central and parietal region during pre and post manta recitation for all 40 subjects.

The study's findings suggest that the production of alpha, theta, and delta waves in the EEG signal may be a physiological response to the release of hormones or neurotransmitters that cause dilation of blood vessels. This could have important implications for understanding the relationship between cognitive processes, physiological states, and cardiovascular health. The study found that there was a generous production of alpha, theta, and delta waves in the EEG signal [67]. These waves are associated with specific frequency bands in the EEG spectrum and have been linked to different cognitive processes and physiological states. Study shows that the production of alpha, theta, and delta waves may be associated with the secretion of hormones or neurotransmitters that cause dilation of blood vessels. This means that the EEG signal could be reflecting changes in the body's physiological response to a particular stimulus. The alpha waves are typically associated with a relaxed and calm state of mind, while theta waves are associated with drowsiness, daydreaming, and meditative states. Delta waves are typically associated with deep sleep and are the slowest frequency band in the EEG spectrum. Alpha waves are associated with the release of the neurotransmitter acetylcholine, which plays a role in the regulation of blood vessel dilation and blood flow [4]. Similarly, the production of theta and delta waves has been associated with the secretion of hormones such as melatonin and growth hormone, which can also affect blood vessel dilation and blood flow [53]. Therefore, the study's findings suggest that the production of alpha, theta, and delta waves in the EEG signal may be a physiological response to the release of hormones or neurotransmitters that cause dilation of blood vessels vessels [22]. This could have important implications for understanding the relationship between cognitive processes, physiological states, and cardiovascular health.

In one of the study, the effect of "OM" mantra was studied where OM chanting was done for 30 min by 23 participants and theta power was analysed for different region of the brain [28]. It was found that "OM" mantra chanting leads to increase in theta amplitude which implies relaxation state. In our study also, MM chanting lead to increase in relative alpha rhythm in central and parietal region which indicates relaxed and peaceful state.

A lot related study has been to detect mental health issues like depression, schizophrenia, autism, etc [33,43,44,42]. Thus, the mental wellbeing of an individual is reflected in the EEG signal and MM has a positive impact on the mental wellbeing of an individual.

### 7. Limitation of the study and future scope

Sample size of this experimental study was small as it was an exploratory study, in next attempt with larger number of participants can help in reinforcing and influence of MM with effectiveness of EEG intervention. Secondly, the study was made only on female groups. Study needs to be extended to across all the age and group (male & female) for generalization of effects observed with MM chanting. The study has not been done in the relaxed state (normal rest state) taken as a control.

Further studies are required in the direction of the present study where a bigger data set can be used. Effect of meditation may be shown more prominently if more than one round of MM chanting is performed. Study can be further done to find the effect of regular chanting for a long time period. Since lesser sample study conducted, in the future study are need (i.e randomized controlled trials) by engaging a larger sample size. It may extend to further for examined with advanced techniques to evaluate its precise physiological effects and underlying mechanisms.

### 8. Conclusion

The study analyses the effect of MM on EEG band power before and after the chanting, The results shows that after MM chanting, the relative strength of the alpha rhythm increased, particularly in the central and parietal regions of the brain. It has been found in literature that increase in the presence of alpha brain waves is correlated with relaxed condition. Thus the study indicates that the increase in the relative alpha band power after meditation leading to increase in relaxed condition. Thus meditation leading to improved mental well-being and decrease in stress and depression.

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### CRediT authorship contribution statement

Sachi Nandan Mohanty: Methodology. Shalini Mahato: Validation. Suneeta Satpathy: Formal analysis. Richa Chopra: Conceptualization.

#### **Declaration of Competing Interest**

No conflict of Interest among the authors.

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### Authors' contributions

Sachi Nandan Mohanty contributed to design and implementation, Suneeta Satpathy contributed to data acquisition and analysis, Richa Chopra contributed to interpretation of data and Shalini Mahato contributed to analysis of the results and to the writing of the manuscript.

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