

## Exploration of Lower Frequency EEG Dynamics and Cortical Alpha Asymmetry in Long-term Rajyoga Meditators

### Abstract

**Background:** Rajyoga meditation is taught by *Prajapita Brahmakumaris* World Spiritual University (*Brahmakumaris*) and has been followed by more than one million followers across the globe. However, rare studies were conducted on physiological aspects of rajyoga meditation using electroencephalography (EEG). Band power and cortical asymmetry were not studied with Rajyoga meditators. **Aims:** This study aims to investigate the effect of regular meditation practice on EEG brain dynamics in low-frequency bands of long-term Rajyoga meditators. **Settings and Design:** Subjects were matched for age in both groups. Lower frequency EEG bands were analyzed in resting and during meditation. **Materials and Methods:** Twenty-one male long-term meditators (LTMs) and same number of controls were selected to participate in study as per inclusion criteria. Semi high-density EEG was recorded before and during meditation in LTM group and resting in control group. The main outcome of the study was spectral power of alpha and theta bands and cortical (hemispherical) asymmetry calculated using band power. **Statistical Analysis:** One-way ANOVA was performed to find the significant difference between EEG spectral properties of groups. Pearson's Chi-square test was used to find difference among demographics data. **Results:** Results reveal high-band power in alpha and theta spectra in meditators. Cortical asymmetry calculated through EEG power was also found to be high in frontal as well as parietal channels. However, no correlation was seen between the experience of meditation (years, hours) practice and EEG indices. **Conclusion:** Overall findings indicate contribution of smaller frequencies (alpha and theta) while maintaining meditative experience. This suggests a positive impact of meditation on frontal and parietal areas of brain, involved in the processes of regulation of selective and sustained attention as well as provide evidence about their involvement in emotion and cognitive processing.

**Keywords:** *Brahmakumaris Rajyoga meditation, electroencephalography, frontal alpha asymmetry, long-term meditator, spectral band power*

### Introduction

Meditation is presently accepted as a tool to achieve altered state of consciousness.<sup>[1]</sup> It has been studied extensively by philosophers to physiologists. Meditative practice brings significant changes in neurophysiological state<sup>[2]</sup> which drive toward enhanced cognition and cognitive processes. Extensive research has been performed worldwide to explore the physiological basis of different styles of meditation.<sup>[3]</sup> The brief practice of meditation has shown improvement in the cognitive ability,<sup>[4]</sup> psychological well-being, and sleep.<sup>[5-7]</sup> Slight improvements in cognitive abilities due to meditation<sup>[8]</sup> practice may lead to mental well-being and healthy day-to-day life.

Regulation of emotion and attention has been regimen of meditation practices.<sup>[9]</sup> Due

to the involvement of regulatory training of emotions, meditation positively affects the mental health of individuals<sup>[10]</sup> and efficacy to fight mental disorders.<sup>[11]</sup> Different types of meditation practice reported an increase in psychological functions with associated pattern of electroencephalography (EEG) in different frequency bands.<sup>[12,13]</sup> Particularly, low-frequency oscillations governs internalized attention and positive affect state. Alpha and theta band oscillations have been associated with the activity of multifunctional neuronal networks<sup>[14]</sup> and correspondingly related to the attention,<sup>[15]</sup> orientation,<sup>[16]</sup> memory,<sup>[17]</sup> and emotions.<sup>[18]</sup>

Rajyoga meditation is taught by *Prajapita Brahmakumaris* World Spiritual University (*Brahmakumaris*) and is different from the practice of Rajyoga described in ancient

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Hindu texts. It involves transcendence of individual from body-conscious to soul-conscious.<sup>[19]</sup> Sukhsohale and Phatak<sup>[20]</sup> evaluated physiological variables such as heart rate, respiratory rate, systolic, and diastolic blood pressure for the effects of short- and long-term (STM and LTM) Rajyoga meditation. They found that during resting period, there were no significant differences between the STM and LTM, but significant differences were reported when pre-post comparisons were made. The result suggested improvements in the basic cardio-respiratory functions due to the shifting of symphovagal balance toward parasympathetic nervous system. Another study carried out by Telles and Desiraju<sup>[21]</sup> explored respiratory and autonomic effects of Rajyoga meditation; however, concluded incompetence of a single model of sympathetic activation to describe the effects of meditation practice. Till date, we have not found any EEG study which can demonstrate effect of Rajyoga meditation on the brain dynamics of the LTMs and compared with the subjects who have no exposure to any meditation using high-density EEG system.

The present study examines the effect of meditation on multifunctional neural networks of the brain in the LTMs. Objective of the study is to explore changes in the neural activity for the low-frequency oscillation in the LTM and compared the same with the control subjects.

Calculated results include the band spectrum power and cortical asymmetry (why power in EEG is important to calculate). Alpha asymmetry has been a prominent marker for neurological conditions such as depression,<sup>[22]</sup> emotional disorders, and neurodevelopmental disorders, however, in meditation, it is relatively less explored. It was hypothesized that band power during meditation will increase significantly in distinct brain regions during meditation. A similar trend has been already established in the previous research in mindfulness practice<sup>[23]</sup> and nondirective meditation.<sup>[24]</sup>

## Materials and Methods

### Subjects

Twenty-one healthy right-handed male subjects: LTM who practiced Rajyoga meditation regularly for a period of more than 10 years (age 30–52 years, mean 43.9 (standard deviation [SD] = 3.96) years) were agreed to take part in this study. With excellent record of regular practice, these meditators had already spent 13–35 years in practicing this technique after learning it. Total number of hours spent in meditation ranged from 9000 to 31,000 h throughout their life (mean = 18,457 h) at the time of recording the EEG data. The same numbers of controls (aged 30–50 years, mean 41.23 [SD = 3.95] years) with no prior experience in meditation were also recruited. All subjects in both groups were free from cardiac, pulmonary, and other nervous system dysfunctions. No subjects were having artificial

pacemaker implanted. The experimental procedures were explained. Written information consent was obtained from each subject. Research protocol was approved by the Institutional Ethical Committee of INMAS-DRDO before the experimental recording. The status of nonconsumption of alcohol, cigarette, or any therapeutics by the subjects within last 6 months was confirmed. We approached to study homogenous groups matched with age.

### Physiological measurements

Sixty-one channel EEG activity was recorded using eego™ Software and 64 channel waveguard™ cap. Onestep cleargel (ANT Corp, The Netherlands) was applied in each electrode hole to make active connections between scalp and electrodes. Electrode placement in waveguard™ cap follows international 10–20 system. EEG signals of sampling frequency (1024 Hz), with an input impedance (>1 GΩ), were acquired for 61 active scalp sites and referenced to CPz electrode. Grounding was done with AFz electrode. Preparation of EEG cap was done carefully and a stabilization time of 5 min was given after filling gel into all locations. Impedance was kept below 5 kΩ throughout the experiment. EEG signals were digitally filtered at 0.5–75 Hz and amplified by eego™ sports ultramobile EEG and EMG recording amplifier (ANT Corp, The Netherlands) which includes a magnetic optical disk that simultaneously stores the data for offline analysis. Data were stored in the same disc for the further analysis.

### Electroencephalography data acquisition

EEG data were acquired during premeditation baseline for 5 min and during meditation for 10 min. After scalp preparation and before recording the EEG data, an audio file-based instructions was played for subjects to understand the protocol for baseline and meditation. This audio file was recorded as voiceover of a senior Rajyoga meditator. Uniformity of meditation experience was ensured with these instructions, and discourse was done with each LTM subject postmeditation. Control subjects were asked to sit in a relaxed wakefulness condition while their eyes were open.

### Rajyoga meditation

Rajyoga meditation is a method without rituals or mantras and can be practised anywhere at any time. It enables the mind to rule over the physical organs as a righteous king and to cease to act as a slave to sense gratification. Rajyoga is a way to self-realization and realization of supreme almighty. It helps an individual in divinization or self-purification.<sup>[19]</sup> Rajyoga meditation technique requires considerable commitment and involves concentrated thinking.<sup>[21]</sup> During the practice of meditation, subjects sit in a comfortable posture with eyes open and fix their gaze on a meaningful symbol (a light source). At the same time, they actively think positive thoughts about the universal force pervading all over as light and peace. Practicing with open eyes makes this method unique and versatile.

## Processing of electroencephalography signals

The EEG signals are nonstationary signals that pick up various noise components along with the relevant information while recording signals from the brain. Preprocessing steps become crucial to minimize these noise components. A 50 Hz notch filter was used to remove DC power line interference. A fourth-order Butterworth filter with cutoff frequency 0.5–75 Hz was used to select the frequency of interest. FASTICA algorithm in EEGLAB v1 (13.5.4b) was applied on data to identify independent components and components with artifacts were removed from the signal.<sup>[25]</sup> Independent component analysis attempts to reverse the superposition by separating the EEG into mutually independent scalp maps, or components.<sup>[26]</sup> Components with noise were removed manually. It proves to be an efficient tool for artifact identification and extraction from electroencephalographic data.<sup>[27]</sup> To extract various features during meditation, as well during the baseline the signals were segmented over time-based markers. Features such as power and frontal asymmetry were calculated for respective time frames of meditation and resting. EEG electrodes were topographically divided into the clusters provided in Table 1 for the analysis.

### Power

Spectral power was measured in  $\mu\text{V}^2/\text{Hz}$  for theta, alpha, and alpha subbands (alpha1 and alpha 2) in anterior frontal, medial frontal, lateral frontal, central, parietal, occipital, and temporal regions. The log power transformations were also calculated considering the absolute value of the signal. The spectral percentage power of theta, alpha 1, and 2 bands was computed in log values using the Welch's method<sup>[28]</sup> by computing the Fourier transform of the autocorrelation function of the signal. Mean power was computed across each region by taking the average of the respective band power from each of the measured scalp site.

### Frontal asymmetry

Lateralization of brain functions can be mapped with asymmetry index. Commonly, this index is calculated by subtracting the natural log of left hemisphere alpha

power from the natural log of right hemisphere alpha power ( $\ln [\text{right alpha}] - \ln [\text{left alpha}]$ ). In each lobe, major electrode pairs (F7/F8 for lateral frontal, FP1/FP2 for anterior frontal AF3/AF4 for medial frontal, P3/P4 for parietal, O1/O2 for occipital, T7/T8 for temporal, and C3/C4 for central) were considered for asymmetry index calculation. Higher values indicate a greater proportion of activity in the left cortical region,<sup>[29]</sup> which in case of frontal region, reveals a pattern associated with positive, approach-oriented emotional states. However, it provides no information regarding the particular contribution of each hemisphere.<sup>[30]</sup>

### Statistical analysis

To find significant difference between both groups and conditions of LTMs, one-way ANOVA was used. Data in charts were presented by mean  $\pm$  standard error of mean. Minimum significant level was fixed at  $P < 0.05$ . For the analysis of self-reported data which included years of regular practice of meditation and age, Pearson's Chi-square test was used. Compared groups for significant difference were pre meditation baseline, during meditation for LTM group, and resting in control group. *Post hoc* (Scheffe's) was applied for multiple comparisons between groups' scores.

### Results

Comparison between spectral properties including band power and cortical asymmetry was analyzed in premeditation resting and during meditation in LTMs as well as in resting of control subjects. No correlation was found between the total number of hours spent in meditation and any of the EEG band power variations. This result reflects that duration of practicing meditation among LTMs have no reported difference on EEG indices.

### Alpha 1 and 2

Due to the distinct functional characteristics of Alpha 1 (8–9 Hz) and Alpha 2 (10–13 Hz), they were separately calculated for spectral properties. There was a significant difference found in alpha 1 powers of groups during meditation compared with control subjects at resting [Figure 1]. At anterior frontal channels ( $F [1, 40] = 10.32$ ,  $P = 0.007$ ) and medial frontal channels ( $F [1, 40] = 7.917$ ,  $P < 0.001$ ) which reflects an increase in band powers during meditation. At lateral frontal channels, difference was not significant ( $F [1, 40] = 8.443$ ,  $P = 0.30$ ). At parietal channels, it was significantly higher in meditators ( $F [1, 40] = 5.221$ ,  $P < 0.001$ ). Alpha 2 band power was also seen to follow similar trend with significant higher power [Figure 2] at anterior frontal channels ( $F [1, 40] = 12.551$ ,  $P = 0.001$ ), medial frontal channels ( $F [1, 40] = 9.65$ ,  $P < 0.001$ ), and parietal channels ( $F [1, 40] = 5.52$ ,  $P = 0.002$ ). Lateral frontal channels were shown to follow the trend but did not reach up to statistically significant level ( $F [1, 40] = 10.982$ ,  $P = 0.07$ ).

**Table 1: Topographic distribution of electrodes according to specific region**

EEG clusters	Channels
Anterior frontal	FP1, FP2, AFz, FPz
Lateral frontal	AF7, F5, F7, F3, AF8, F6, F8, F4
Medial frontal	AF3, F1, Fz, F2, AF4
Occipital	POz, Oz, O1, O2
Parietal	P1, P2, P3, P4, P5, P6, P7, P8, Pz, PO3, PO4, PO7, PO8
Temporal	FT7, FT8, T7, TP7, TP9, T8, TP8, T10
Central	C1, C2, C3, C4, C5, C6, Cz, FC1, FC2, FC3, FC4, FC5, FC6, FCz, Cz, CPz

EEG = Electroencephalography

### Theta

For theta power calculated at anterior frontal channels  $F(1, 40) = 11.95, P = 0.000$ , meditators have highly significant theta power [Figure 3] during meditation compared with relaxed resting of control subjects. However, it was found to be high in lateral frontal ( $F(1, 40) = 10.74, P = 0.183$ ) and medial frontal channels ( $F(1, 40) = 11.54, P = 0.595$ ) at nonsignificant level.

### Cortical asymmetry

Mean values of asymmetry scores were calculated for alpha band (8–13 Hz). Mean and SD are summarized in Table 2. For frontal channels, it showed almost similar pattern. The mean medial frontal alpha asymmetry of meditators was higher than the controls [Figure 4] with  $t(21) = 1.8$  with  $P = 0.034$ , whereas the difference was not reached up to statistical significant in lateral frontal alpha asymmetry  $t(21) = 0.86$  with  $P = 0.058$ . At other EEG clusters, alpha asymmetry was not found to be significantly different [Figure 5].

### Discussion

The present study shows high concentration of low-frequency bands (alpha 1, alpha 2, and theta) in LTM

as compared to control. Powers of these low-frequency bands were significantly higher at anterior frontal, medial frontal, and parietal locations. Cortical asymmetry was significantly higher on positive side at medial frontal location. In addition, at lateral frontal and anterior frontal, it

**Table 2: Means and standard deviation of hemispherical asymmetry scores in premeditation baseline (n=21) and during meditation for long-term meditators group (n=21) and resting for control group**

EEG cluster	Mean (SD)		
	Baseline	Meditation	Control
Anterior frontal	0.012 (0.006)	0.145 (0.043)	0.003 (0.001)
Lateral frontal	1.153 (0.288)	1.478 (0.325)	1.072 (0.386)
Medial frontal	0.684 (0.137)	0.884 (0.221)	0.630 (0.756)
Central	0.066 (0.013)	0.068 (0.017)	0.287 (0.344)
Occipital	0.015 (0.004)	0.030 (0.007)	0.021 (0.025)
Parietal	0.008 (0.002)	0.010 (0.003)	0.167 (0.200)
Temporal	0.187 (0.047)	0.204 (0.051)	0.405 (0.487)

SD = Standard deviation, EEG = Electroencephalography

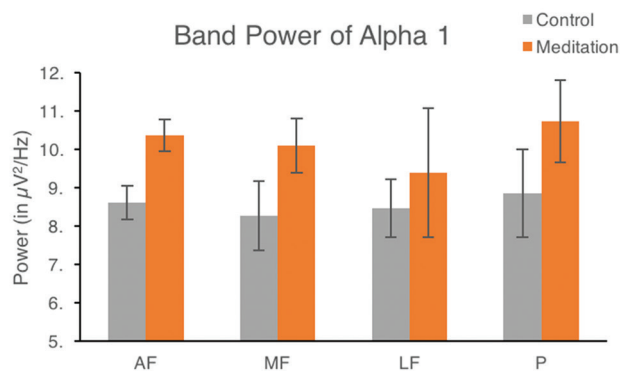


Figure 1: Band power of Alpha 1 (8–10 Hz) electroencephalography band measured in anterior frontal, medial frontal, lateral frontal, and parietal regions for resting and during meditation in control and meditators groups, respectively

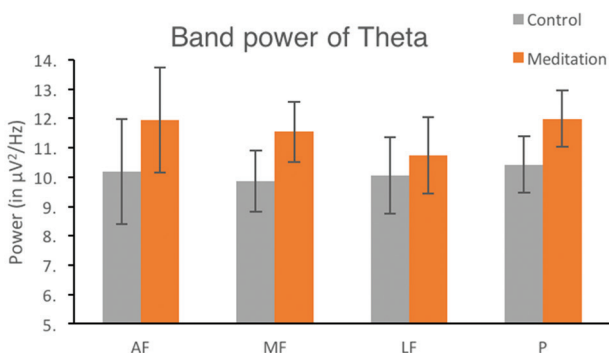


Figure 3: Band power of theta electroencephalography band (3–7 Hz) measured in anterior frontal, medial frontal, lateral frontal, and parietal electrode clusters for resting and during meditation in control and meditators groups, respectively

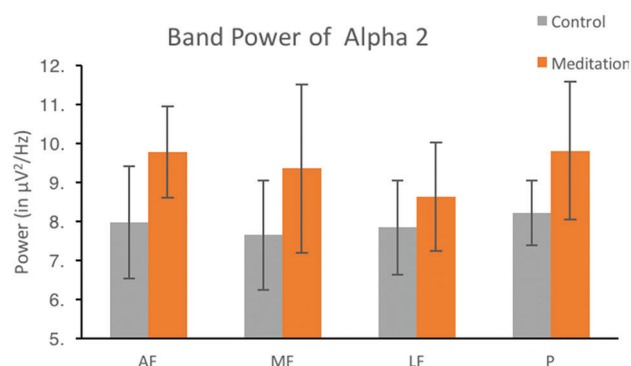


Figure 2: Band power of Alpha 2 electroencephalography band (11–13 Hz) measured in anterior frontal, medial frontal, lateral frontal, and parietal electrode clusters for resting and during meditation in control and meditators groups, respectively

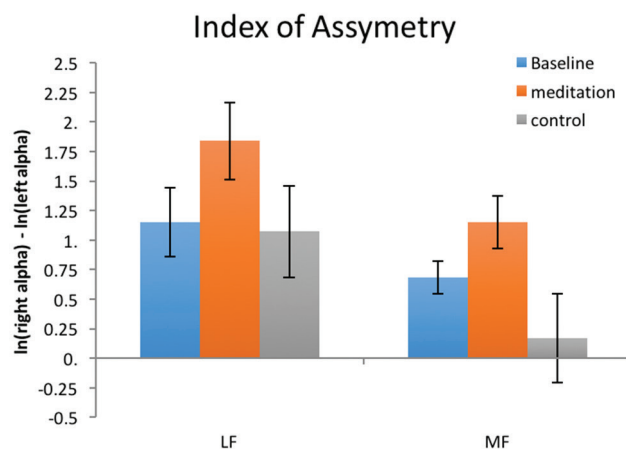
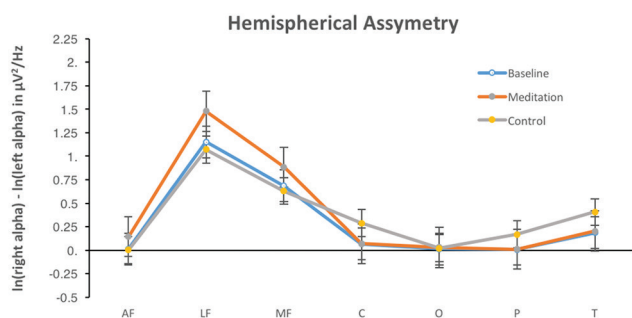


Figure 4: Index of alpha asymmetry measured from alpha band power at lateral frontal and medial frontal electrode clusters in premeditation baseline, during meditation for long-term meditator group, and resting in control group



**Figure 5: Index of hemispherical alpha band asymmetry measured at anterior frontal, medial frontal, lateral frontal, central, occipital, parietal and temporal electrode clusters in premeditation baseline, during meditation for long-term meditator group, and resting in control group**

was high on positive side yet not reached up to significant level.

High power in alpha bands is indicative of less engaged brain<sup>[29]</sup> which can be traced as more relaxed and an affirmative brain state to entertain meditation practice. Positive asymmetry scores reflect greater left-sided activity (i.e., greater alpha band power density on the right than on the left). Lower frequencies are most significant contributors for resting brain although spatial prominence of alpha in frontal regions has regulatory function related to emotional challenges and attentional engagements.

As, our research was focused on lower frequencies in frontal region, in a way it corroborates the previous research where increased alpha during mindfulness was identified in frontal regions.<sup>[31]</sup> Some network-related theories<sup>[32-34]</sup> have also assumed that small networks oscillate at faster frequencies (>40 Hz) while large networks oscillate at slower frequencies (<20 Hz); however, beta and other computation of faster brain waves are not collected in this research, it is assumed to have alpha as aftermath of coverage of large networks. It has to be kept indisputable that larger networks consist of more number of neurons and connection involved but not the Euclidian space. Lower alpha band (alpha 1) appears for vigilance and attention while upper alpha band (alpha 2) is thought to reflect task specific processes, i.e., perceptual and cognitive processes.<sup>[18]</sup> Upper band alpha (10–13 Hz) was higher in more creative individuals at frontal and parietal sites.<sup>[34]</sup>

Initially due to parietal prominence of alpha power was assumed to be reflected in cortical idling<sup>[35]</sup> and decrease in alpha power was thought to reflect increase in activation<sup>[36]</sup> which are no longer tenable. In recent advances, alpha synchronization considered as a marker of activation of functionally involved brain areas in higher functions<sup>[37]</sup> and regarded as a signature of meditative practices irrespective of the type of practice and degree.<sup>[2]</sup> However, it is indicative of increased processing in various attention modalities with respect to internally generated stimuli.<sup>[38]</sup> In different meditative practices also, alpha

power was prominently seen to be increased but decreased in idiosyncratic meditation.<sup>[39]</sup> More alpha power means greater mental silence, however, tasks requiring memory<sup>[40]</sup> and imagination<sup>[41]</sup> lead to increase in alpha power.

Theta power increase reflects the essential core of meditative experience whereas alpha power increase reflects internalized attention. The deactivation of cortical areas occurs in brain idling since it occurs during eyes closed wakefulness<sup>[42,43]</sup> may also synchronization of alpha frequency. Although decreased alpha power was also noted during mindfulness,<sup>[44]</sup> meditation generates greater cortical deactivation than during eye closed resting.<sup>[45]</sup> Thoughtless awareness and bliss are accounted by enhanced theta and alpha activities along with decreased EEG dimensional complexity.<sup>[13,46]</sup> Anterior cingulate cortex (ACC) elicits theta rhythm and stimulation of ACC seen to affect cognitive and affective processes during Zen meditation. Midline theta is seen to induce relaxed concentration and enhanced interaction between cognitive and affective processes.<sup>[47]</sup> In simultaneous EEG-functional magnetic resonance imaging experiments, theta was found to be negatively correlated with (Default Mode Network) DMN activity which suggest crucial role of theta during initial stages of meditation-related relaxation.<sup>[48]</sup> ERP experiment by Trujillo and Allen has defined role of theta band in error-related processing<sup>[49]</sup>

The amplitude of theta and Alpha was also found to be great during mindfulness.<sup>[3]</sup> Overall cortical synchronization, i.e., increased power in alpha and theta band indicate lower tonic arousal, a prerequisite for meditative state. In our observation, copresence of alpha and theta waves in frontal regions may reflect a state of relaxed alertness<sup>[50]</sup> by guarding against extremes of arousal toward high end and low end. Both alpha and theta can be interpreted as signifiers of increased attention with alpha specifically representing internalized attention as well as indexing states of relaxation.<sup>[45]</sup>

Frontal asymmetry in alpha band gets affected by many factors. It regulates emotions under challenging circumstances<sup>[3]</sup> is well defined by approach withdrawal model.<sup>[51]</sup> However, alpha asymmetry phenotype is attributable to trait characteristic, and it is defined by temporally stable and trans-situational consistent individual differences.<sup>[52]</sup> Relative left frontal trait activation is linked with approach and behavior activation motivation system. Sociability in children and adults was also seen with left cortical activation, which may be a suggestive of positive social behavior displayed by meditators. Individual differences in frontal EEG asymmetry are indeed more pronounced during emotional challenges than during resting tasks. Many factors, including experience of meditators, type of control task, and location of the EEG oscillations moderate the impact of meditation on neurophysiological markers. This led to a distinct phenomenology related

to meditation types, which was considered as one of the essential objective to work with a very less explored yet most followed meditation technique, i.e., *Brahmakumaris* Rajyoga meditation.

## Conclusion

Overall, this research has attempted to present how a meditation technique with different kind of practice strategy affects neurophysiological markers measured by EEG. However, in meditation researches role of frontal alpha asymmetry has not been well established which has formed the basis for experimental design of the present work. The experimental results clearly establish occurrence of high frontal alpha asymmetry in LTMs which links state of positive mind with positive scores of alpha asymmetries. High-band power of alpha subbands and theta contributes for meditative state experience. This outcome may suggest the interaction of positive emotion circuitry with attention and well-being. This study led a foundation on physiological research on *Brahmakumari's* Rajyoga meditation, which can prove to be one of the most effective meditation technique for performance enhancement. Although future studies can be proposed to find effects of short-term practice of this meditation techniques. There is also a need to formulate experimental paradigms for unique groups based on limited age so that this technique can be utilized at different population level.

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## Conflicts of interest

There are no conflicts of interest.

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