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RESEARCH REPORT

Theta activity and meditative states: spectral changes during concentrative meditation

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Abstract Brain oscillatory activity is associated with different cognitive processes and plays a critical role in meditation. In this study, we investigated the temporal dynamics of oscillatory changes during Sahaj Samadhi meditation (a concentrative form of meditation that is part of Sudarshan Kriya yoga). EEG was recorded during Sudarshan Kriya yoga meditation for meditators and relaxation for controls. Spectral and coherence analysis was performed for the whole duration as well as specific blocks extracted from the initial, middle, and end portions of Sahaj Samadhi meditation or relaxation. The generation of distinct meditative states of consciousness was marked by distinct changes in spectral powers especially enhanced theta band activity during deep meditation in the frontal areas. Meditators also exhibited increased theta coherence compared to controls. The emergence of the slow frequency waves in the attention-related frontal regions provides strong support to the existing claims of frontal theta in producing meditative states along with trait effects in attentional processing. Interestingly, increased frontal theta activity was accompanied reduced activity (deactivation) in parietal–occipital areas signifying reduction in processing associated with self, space and, time.

Keywords Meditation · EEG · Theta oscillations · Spectral analysis · Coherence

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Introduction

The role of oscillatory activity in cognition has been explored and is considered the building block of functional signaling in the brain. This view is supported by a diverse range of measurements from single-cell to cellular assemblies (Basar et al. 2001). Oscillations with different frequencies are associated with different cognitive processes (Klimesch 1999; Singer 1999). For example, alpha oscillations are generally associated with attention, alertness, and task load in general (Klimesch 1999), whereas gamma oscillations are associated with binding. The functional characteristics of the theta oscillations (generally 4–8 Hz) and its role in cognition have been studied extensively (Basar 1999; Jacobs et al. 2006; Klimesch 1999). The theta oscillations are involved with attentional processing (Basar-Eroglu et al. 1992; Deiber et al. 2007; Gomarus et al. 2006; Makeig et al. 2004; Pennekamp et al. 1994) and working memory operations (e.g., Gevins et al. 1997; Jacobs et al. 2006; Jensen and Tesche 2002; Krause et al. 2000; Onton et al. 2005). The interactions of frontal and parietal cortices with the limbic system (Basar 1999) and interregional coupling at theta frequency has been related to memory load (Weiss et al. 2000; Schack and Weiss 2005; Schack et al. 2005; Sauseng et al. 2007). In particular, the frontal theta activity had larger amplitudes when the task required focused attention such as detection task, 1-back, and 2-back tasks compared to passive viewing (Deiber et al. 2007). The transient rise in theta energy with respect to stimulus processing indicates its role in cognitive gating mechanism (Deiber et al. 2007; Krause et al. 2000) which turns on sharply during cognitive task and turns off between the trials (Raghavachari et al. 2001). Recently, Sauseng et al. (2007) showed that theta activity may be differentially involved in conditions of cognitive load and executive control. The local frontal midline theta activity localized in the anterior cingulated gyrus was associated with general level of cognitive demand, whereas stronger frontal–parietal theta connections were activated during greater memory based executive functions that require visuo-motor integration. This is consistent with the other views of oscillatory activity, which propose that these oscillations act as a universal operator of functional activity participating in multifold cognitive functions. Further understanding of cognitive processing mediated by theta oscillatory networks will depend on converging evidence from cognitive neuroscience.

The modulation of theta activity also has been shown to occur in a number of studies on meditation (Aftanas and Golocheikine 2001, 2002; Banquet 1973; Jacobs and Lubar 1989; Pagano and Warrenburg 1983; Hebert and Lehmann 1977; Pan et al. 1994). Meditation is considered a technique of training attentional networks of the brain. The evidence comes from the studies that show improvements in allocation of attention and executive control due to mental training (Brefczynski-Lewis et al. 2007; Jha et al. 2007; Slagter et al. 2007; Tang et al. 2007). This is consistent with the presumed association between theta activity and attentional processes (Basar-Eroglu et al. 1992; Deiber et al. 2007; Pennekamp et al. 1994; Makeig et al. 2004; Gomarus et al. 2006). Long-term training of meditation has resulted in positive changes in behavior and changes in brain activity (Aftanas and Golocheikine 2001, 2002; Srinivasan and Baijal 2007). These changes include increase in theta activity especially in the frontal areas (Aftanas and Golocheikine 2001, 2002; Banquet 1973; Hebert and Lehmann 1977). There have been attempts to relate frontal midline theta with concentrative aspect of the Qigong meditation (Pan et al. 1994). When practitioners of concentrative form of Qigong meditation were compared with practitioners of mindfulness form of Qigong meditation, the former were found to produce greater frontal midline theta even when the level of expertise between both the groups was matched. During Sahaj yoga meditation, the spectral power and coherence properties of the theta frequency band was found to be more sensitive to meditation compared to eyes closed rest of the meditators (Aftanas and Golocheikine 2002). Moreover, enhanced short and long distance coherence couplings, especially in the prefrontal cortex and reduced intra and inter-hemispheric coherence in the posterior cortex—all in the theta frequency band— characterized experienced meditators. However, the role of theta oscillations during meditation remains controversial due to the discrepancies observed. In sharp contrast with the findings of enhanced theta activity during meditation, some have found reduced theta power during meditation compared to relaxation across the entire cortex (Dunn et al. 1999). Moreover, other studies also show alterations in brain oscillatory activity in other frequency ranges such as alpha (Travis and Wallace 1999; Travis et al. 2002; Travis 2001). The role of theta oscillations in cognitive functions like working memory remains somewhat unclear when we consider the reduction in theta activity during visuo-spatial working memory tasks (Babiloni et al. 2004; Bastiaansen et al. 2002) conflicting with the more general finding of increased theta activity during similar tasks (Deiber et al. 2007; Krause et al. 2000).

A significant number of studies on meditation performed to explore its neural concomitants have largely employed protocols that ignore comparisons with the non-meditator control participants (Aftanas and Golocheikine 2002; Arambula et al. 2001; Hebert and Lehmann 1977; Kwon et al. 1996; Wallace 1970). Some studies have compared meditators with non-meditators during rest (Davidson et al. 2003; Travis et al. 2000, 2002; although see Travis et al. this volume). Trait effects occur due to long-term practice of meditation resulting in baseline differences between meditators and non-meditator controls (Cahn and Polich 2006). Therefore, comparison of brain activity between resting state and meditation of the meditators may not be optimal. Results from studies (Aftanas and Golocheikine 2001; Travis 1991; Deepak et al. 1994; Khare and Nigam 2000; Travis et al. 2002) that have compared neural activity during meditation with the resting state of meditators may be confounded by the trait changes in meditators.

The studies that compare oscillatory activity between meditators (during meditation) and non-meditators (during relaxation) have also ignored the tracking of *state* changes that occur when performing meditation (e.g., Banquet 1973; Davidson et al. 2003; Lehmann et al. 2001; Travis et al. 2002; Travis et al. under review). Due to the existing discrepancies and shortcomings in some of the studies done with different types of meditation, we performed the current study to estimate changes in brain activity across the major stages during meditation and compare the same with a group of age-matched non-meditators. We aimed to compare oscillatory changes in the standard frequency bands (delta, theta, alpha, and beta) during meditation (experienced meditators) and relaxation (non-meditator controls). We used the methodology followed by Aftanas and Golocheikine (2002) to compare temporal dynamics of oscillatory activity between three critical stages of meditation: (i) entering meditation or initial block, (ii) deep meditation or middle block, (iii) exiting meditation or end block. Aftanas and Golocheikine (2002) used this methodology to investigate mindfulness type of meditation. Here, we examine changes in oscillatory activity during Sahaj Samadhi meditation, which is a concentrative type of meditation that involves focusing of attention on breath and internal chanting (or *mantra*). It is a part of Sudarshan Kriya Yoga and is performed in conjunction with Mudra Pranayam that involves forming different finger postures and Sudarshan Kriya that is a breathing exercise. We were interested in investigating Sahaj Samadhi meditation in particular because to our knowledge, the neural activity underlying Sahaj Samadhi meditation has not been studied so far. Moreover, given the attentional benefits observed with concentrative meditation that includes less distractibility (Brefczynski-Lewis et al. 2007), it becomes increasingly important to investigate the neural activity underlying meditation.

Method

Participants

Twenty healthy participants participated in the study out of which ten (7 males and 3 females) were experienced meditators (mean age = 39 years, SD = 5) and ten (6 males and 4 females) were non-meditator controls (mean age = 35 years, SD = 5). The meditators were teachers of Sahaj Samadhi meditation at the Art of Living Foundation and had obtained rigorous mental training by practicing meditation daily for a period ranging from three to seven years. Control subjects had no Sudarshan Kriya or meditation training. All the participants voluntarily participated in the study by giving informed consent. They were informed that their brain activity will be recorded when they meditate or relax and also while performing other tasks (Srinivasan and Baijal 2007). All the subjects were right-handed and were blind to the experimental hypotheses. The participants had no history of neurological illness.

EEG recording and protocol

EEG data was recorded and analyzed with 64-channel Neuroscan system with a sampling frequency of 1000 Hz. The electrodes were fixed using a gel (silver chloride compound) and setup at appropriate impedance (2–15 kΩ) before beginning the recording. For the purpose of analysis, the raw EEG data were filtered with zero-phase shift, band pass filtering from 1 to 30 Hz at 12 dB/Octave. EEG segments with eye movement and muscular artifacts were manually removed from the data. The experiment was carried out in a soundproof, dimly lit room, conditions that were conducive for the participants to meditate.

Procedure

Baseline EEG was recorded before the experimental session with all the participants with their eyes closed and open, each for 1 min. The meditators performed a series of the daily practice of Mudra Pranayam, followed by Sudarshan Kriya and then the Sahaj Samadhi meditation with their eyes closed. The Sahaj Samadhi meditation lasted for 8–12 min. The control group on the other hand was instructed to relax by closing their eyes for 8 min. The participants were interviewed using a structured questionnaire format before and after the EEG recording. Subjective reports were obtained from the meditators about the quality of experiences during meditation and whether their experience in the laboratory was different from their everyday practice. The participants provided detailed descriptions of the experiences in written form.

Analysis

Since we were interested in investigating brain dynamics during meditation, we used the EEG data of the Sahaj Samadhi meditation (of meditator group) and eyes closed relaxation (of controls) along with baseline eyes closed and eyes open conditions. The EEG data were pre-processed by removing ocular and muscle artifacts by visual analysis. The artifact-free data was epoched using 1024 data points (1.024 s). The analysis was performed either on the complete meditation data (whole block Analysis) or on three blocks of 2 min each, which were extracted from the initial, middle, and end portions of the meditation/control's relaxation data (separate block Analysis). The separate block analysis was based on subjective reports obtained from the meditators who informed the experimenters about the three stages of Sahaj Samadhi meditation, i.e., entering meditation, deep meditation, and exiting meditation. All the three stages take approximately the same amount of time and are reported to be phenomenologically different. The spectral percentage power and absolute power values were computed in delta (0–3.91 Hz), theta (4.8–7.8 Hz), alpha (8.7–12.7 Hz), and beta (13.6–29.3 Hz) frequency bins that were obtained using Hanning Window (10% taper). The percentage power values were computed by dividing the power value for a frequency range by total power. For the purpose of statistical analysis, all the 62 electrodes (excluding the 2 reference electrodes) were divided into 16 cortical zones which are as follows: right posterior–occipital (O2, PO8, PO6, and PO4), left posterior–occipital (O1, PO7, PO5, and PO3), middle posterior–occipital (OZ, POZ, and PZ), right parietal (P8, P6, P4, and P2), left parietal (P7, P5, P3. and P1), right central–parietal (CP6, CP4, and CP2), left central–parietal (CP5, CP3, and CP1), right central (C6, C4, and C2), left central (C5, C3, and C1), right frontal–central (FC6, FC4, and FC2), left frontal–central (FC5, FC3, and FC1), right frontal–temporal (FT8, T8, and TP8), left frontal–temporal (FT7, T7, and TP7), right frontal (AF8, AF4, F8, F6, F4, F2, and FP2), left frontal (AF7, AF3, F7, F5, F3, F1, and FP1), and frontal–central (FCZ, FZ, CZ, CPZ, and FPZ). This procedure is based on that adopted by Aftanas and Golocheikine (2002). Under each cortical zone, power values of the constituent electrodes were averaged, and the procedure was repeated for all the frequency bins. The results are reported for absolute and relative/percentage power values calculated for delta, theta, alpha, and beta frequency bands.

Results

The subjective reports from the meditators revealed that they were able to successfully perform meditation in the laboratory that was no different from their daily practice. The one-way analysis of variance (ANOVA) was performed with the baseline eyes closed and eyes open conditions showed no significant difference between the two groups. Two-way ANOVA with group [2] and cortical zones [16] as factors was performed separately for power (both absolute and percentage power) values from the whole block for all the four types of oscillations (delta, theta, alpha, and beta) separately and greenhouse-geisser corrected values are reported.

The whole block analysis of percentage powers was done separately for all the four frequency bands by performing two-way ANOVA (Group [2] × Cortical zones [16]) separately for all the frequency bands. The analysis revealed differences in the theta percentage powers between the two groups in some cortical zones ($F(15, 270) = 2.821$, $P < 0.05$). Post-hoc comparisons revealed that the cortical zones showing increased percentage theta power for meditators compared to non-meditators were right frontal–central ($F(15, 270) = 3.865$, $P < 0.05$), left frontal–central ($F(15, 270) = 2.905$, $P < 0.05$), and right frontal ($F(15, 270) = 3.584$, $P < 0.05$). In addition, the difference between the percentage theta powers among meditators and controls in the left frontal zone was close to significance ($F(15, 270) = 2.688$, $P = 0.058$). Other cortical zones that showed decreased percentage theta power for meditators compared to non-meditators were left posterior–occipital ($F(15, 270) = 3.126$, $P < 0.05$), and left parietal ($F(15, 270) = 3.495$, $P < 0.05$) (see Fig. 1). The percentage power of delta and alpha frequency bins was found to be different for various cortical zones as shown by the main effect of cortical zones in the delta ($F(15, 270) = 5.704$, $P < 0.05$) and alpha ($F(15, 270) = 7.289$, $P < 0.05$) frequency bins. There was no difference in other frequency ranges between meditators and controls with percentage power analysis.

Similarly, the whole block analysis of absolute powers was done separately for all the four frequency bands by performing two-way ANOVA (Group [2] × Cortical zones [16]). The absolute power in the alpha frequency range was observed to be different between the meditator and non-meditator groups as indexed by the main effect of group ($F(15, 270) = 35.766$, $P < 0.05$). The meditators showed lower alpha power compared to the controls (see Table 1). No other significant interactions were observed in whole block analysis with absolute power values.

In order to understand the dynamics of brain processes during meditation, we decomposed the meditation and relaxation data into initial, middle, and end blocks. The earlier whole block analysis was used to identify the network of regions that showed significant interaction effect of Group × Cortical zones. Since this effect was mainly observed with the theta frequency band, we analyzed the relevant cortical zones in the whole block analysis for that band. As a result, eight cortical zones were selected which included the cortical zones that showed significant effects (increase or decrease in percentage power) in the whole block analysis and their corresponding opposite hemispheric cortical zones. These were left frontal, right frontal, left frontal–central, right frontal–central, left parietal, right parietal, left posterior–occipital and right posterior–occipital cortical zones. A two-way ANOVA (Group [2] × Conditions – initial, middle, and end periods of meditation/relaxation [3]) was performed separately for all the eight cortical zones using percentage and absolute power values in the theta band. Analysis with percentage theta powers showed significant Group × Conditions interaction in the right frontal–central ($F(2, 36) = 10.577$, $P < 0.05$), left frontal–central ($F(2, 36) = 5.219$, $P < 0.05$), right frontal ($F(2, 36) = 7.59$, $P < 0.05$), and left frontal

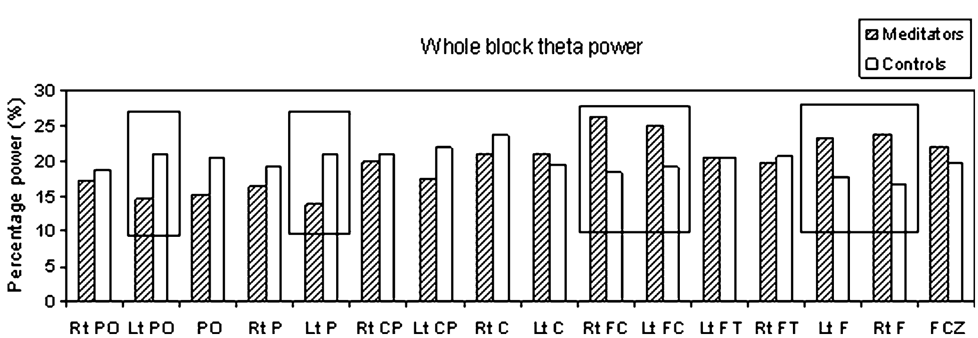

Fig. 1 Grand averaged percentage power values for both the groups are plotted for the whole bloc analysis of theta band

Table 1 Grand averaged spectral power values in the alpha band for meditators and controls and standard error of mean (parentheses)

Groups	Spectral power in alpha band (μV^2)
Meditators	0.042 (0.007)
Controls	0.127 (0.027)

($F(2, 36) = 4.434$, $P < 0.05$) cortical zones out of the eight selected zones. The main effect of conditions was also significant for right frontal–central ($F(2, 36) = 3.80$, $P < 0.05$), and right frontal ($F(2, 36) = 4.04$, $P < 0.05$). Post-hoc comparisons revealed that during meditation the theta power increased significantly in the middle block compared to the initial block ($F(2, 36) = 5.93$, $P < 0.05$) and then reduced significantly in the end block ($F(2, 36) = 5.70$, $P < 0.05$) in the right frontal cortical zone (see Fig. 2). This effect was also present in the left frontal, right frontal–central, and left frontal–central cortical zones showing increased theta percentage power in the middle block followed by reduction in the end block. Similarly the percentage theta power in the middle block was greater in left frontal ($F(2, 36) = 4.03$, $P < 0.05$), right frontal–central ($F(2, 36) = 5.40$, $P < 0.05$), and left frontal–central ($F(2, 36) = 4.83$, $P < 0.05$) compared to the initial block for the meditators. The percentage theta power in the end block was lesser than the middle block in left frontal ($F(2, 36) = 3.62$, $P < 0.05$), right frontal–central ($F(2, 36) = 6.96$, $P < 0.05$), and left frontal–central ($F(2, 36) = 4.30$, $P < 0.05$) compared to the initial block for the meditators. It is to be noted that changes in the theta percentage power was only observed for meditators, and there was no significant changes across the three blocks during relaxation for non-meditator controls. In addition, the theta power of the middle block was significantly higher for meditators compared to controls in the right frontal ($F(2, 36) = 7.08$, $P < 0.05$), left frontal ($F(2, 36) = 5.59$, $P < 0.05$), right frontal–central ($F(2, 36) = 6.89$, $P < 0.05$), and left frontal–central ($F(2, 36) = 5.54$, $P < 0.05$) cortical zones.

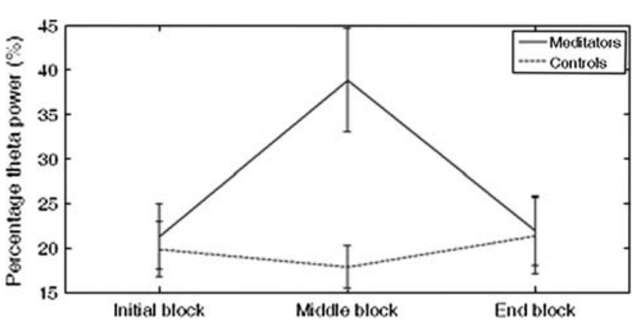

Fig. 2 Grand average of theta power values in the right frontal cortical zone are plotted for both the groups for separate block analysis

Similarly, a two-way ANOVA using absolute power in the theta range showed significant Group × Conditions interaction in the right frontal–central ($F(2, 36) = 6.09$, $P < 0.05$), left frontal–central ($F(2, 36) = 3.95$, $P < 0.05$), and right frontal ($F(2, 36) = 5.10$, $P < 0.05$). The main effect of conditions was significant in the right frontal cortical zone ($F(2, 36) = 3.89$, $P < 0.05$). As was observed with percentage powers, during meditation, the absolute power in theta band increased from initial block to the middle block ($F(2, 36) = 4.87$, $P < 0.05$) and then reduced from middle block to the end block ($F(2, 36) = 5.48$, $P < 0.05$) in the right frontal zone. Similar effects of increased theta power from the initial block to the middle block followed by a reduction in theta power from the middle block to the end block meditation data was also observed in the right frontal–central ($F(2, 36) = 4.16$, $P < 0.05$ and $F(2, 36) = 5.27$, $P < 0.05$, respectively) and left frontal–central cortical zones ($F(2, 36) = 4.133$, $P < 0.05$ and $F(2, 36) = 3.818$, $P < 0.05$, respectively). In sharp contrast to the changes in theta power observed with the meditators, the separate block analysis of relaxation data of the controls did not reveal any significant changes in theta power across all the three blocks. This supports the results observed with the separate block analysis using percentage power.

We further quantitatively investigated the characteristics of the concentrative form of meditation by computing coherence in the theta range for the initial, middle, and end blocks of the meditation/relaxation data. A two-way ANOVA was performed for a selected group of cortical zones as that was chosen for the separate block analysis. Within each cortical zone, coherence was calculated for all possible pairs of electrodes and then average coherence of all the pairs of electrodes within a zone was used for statistical analysis. The two-way ANOVA revealed significant Group × Conditions interaction in the right frontal cortical zone ($F(2, 36) = 3.13$, $P = 0.05$). Although coherence in the theta frequency band did not change across the three blocks either for meditators or for controls, meditators showed significantly higher coherence compared to controls in the initial block ($F(2, 36) = 17.39$, $P < 0.05$), middle block ($F(2, 36) = 12.33$, $P < 0.05$), and the end block ($F(2, 36) = 13.28$, $P < 0.05$) (Table 2). Moreover, the meditators showed significantly higher coherence compared to the controls in the left frontal cortical zone ($F(1, 18) = 4.87$, $P < 0.05$). This supports the claims of enhanced functional connectivity during meditation as indicated by the increase in the coherence values (Aftanas and Golocheikine 2001; Travis 2001; Travis et al. under review).

Table 2 Grand averages of theta coherence in right frontal zone that comprises of AF8, AF4, F8, F6, F4, F2, and FP2 electrodes and standard error of mean (parentheses)

	Meditators	Controls
Initial block	0.87 (0.017)	0.81 (0.07)
Middle block	0.86 (0.018)	0.82 (0.069)
End block	0.86 (0.014)	0.82 (0.071)

Discussion

We used EEG measures to probe the brain activity underlying concentrative (Sahaj Samadhi) meditation. The results are consistent with findings from other studies implicating theta oscillations in state changes during meditation (Aftanas and Golocheikine 2001, 2002; Banquet 1973; Jacobs and Lubar 1989; Pagano and Warrenburg 1983; Hebert and Lehmann 1977; Travis et al. under review). In addition to theta power, other studies on meditation have shown changes in other frequency bands. For example, Travis et al. (under review) have reported increases in power in alpha, beta, and gamma bands as well as increase in alpha and beta coherence during transcendental meditation. The increase in theta power in frontal and central midline areas accompanied by increased theta and alpha coherence have been found to underlie mystical experiences (Beauregard and Paquette 2008). The enhancement of theta activity during concentrative meditation provides strong support for the proposed link between theta oscillations and focused attention (Basar-Eroglu et al. 1992; Deiber et al. 2007; Pennekamp et al. 1994; Makeig et al. 2004; Gomarus et al. 2006). Specific observations include rise in theta power in bilateral frontal and frontal–midline areas with a corresponding decrease in theta power in the left occipital and left posterior–occipital areas. The neural generator for the frontal–midline theta lies in the anterior cingulate cortex (ACC) (Makeig et al. 2004; Sauseng et al. 2007). ACC has shown greater activation during mindfulness meditation (Vipassana) compared to conditions when controls performed a mental arithmetic task (Holzel et al. 2007). Our results are comparable to the imaging study that showed increased activation in ACC and bilateral prefrontal cortex and reduced activation mainly in the occipital areas in meditators during meditation compared to controls during the arithmetic task. An overall decrease in alpha power during meditation has been reported by a few studies (Jacobs and Lubar 1989; Pagano and Warrenburg 1983), and it can be linked to increasing demands of attention, alertness, and task load in general (Klimesch 1999).

Most importantly, by decomposing the meditation data into initial, middle, and end portions, we were able to track temporal dynamics of brain activity during concentrative meditation and its comparison with relaxation of non-meditators. We specifically observed enhanced theta activity during deep meditation phase compared to that observed when entering or exiting meditation. The meditators exhibited increased theta power only during the deep meditation phase compared to relaxation of the controls. This was also accompanied by coherence increases in the theta range for meditators compared to controls, which is consistent with other studies (Aftanas and Golocheikine 2001; Travis et al. under review). Another study, adopting a similar methodology as ours, found increased theta band power as well as coherence in the frontal areas and reduced theta coherence in the posterior brain areas during deep phase of mindfulness meditation. (Aftanas and Golocheikine 2001). However, our study enabled comparison with a control group, which was lacking in the study by Aftanas and Golocheikine (2001). Our results extend the findings from the previous studies that suggest the importance of theta oscillations during meditation (Aftanas and Golocheikine 2001, 2002; Banquet 1973; Jacobs and Lubar 1989; Pagano and Warrenburg 1983; Hebert and Lehmann 1977; Travis et al. under review). Expertise in the technique of meditation has also been associated with increases in theta power (Aftanas and Golocheikine 2001) and thus better attentional processing (Brefczynski-Lewis et al. 2007). Therefore, providing training based on meditative techniques to individuals with attentional disorders has been proposed to be an effective measure for their treatment (Arnold 2001).

An interesting finding in our study is the decrease in relative theta power in parietal areas. This was found in conjunction with the more typical increase in relative theta power in frontal areas. If increase in theta power is associated with enhancement of attentional and working memory processes during meditation, then these decreases in theta power potentially indicate that the reduction in processing performed by in the left posterior–occipital and left parietal cortical areas. Concentrative meditation is marked by a state of heightened awareness and focused attention on the object of concentration whose maintenance involves suppression of distracter information that the concentrative meditators are adept at (Brefczynski-Lewis et al. 2007). The transient spread of theta oscillations over frontal network especially during deep meditation mediate suppression of distracting effects of the environment (internal thoughts and external stimulation) as indicated by the shutting down of sensory and attentional processing in some of the parieto-occiptal and parietal areas. Prefrontal cortex is the important structure that provides us with the ability to segregate, differentiate, and analyze the environment. The characteristic frontal theta during deep meditation may underlie the altered state of consciousness due to meditation. Travis et al. (under review) have found increases in frontal theta power accompanied by increases in frontal alpha and beta power and coherence. Different types of meditation may show differences in frontal power and coherence in different frequency bands. The state of meditational awareness share a number of phenomenological characteristics with other altered state of consciousness such as those due to rigorous exercise (Dietrich 2003). These include experiences of timelessness, reduced awareness of one's surroundings, and peacefulness. The deactivation of the visual sensory and parietal areas are significant as they indicate shutting off the "when pathway" that is involved in temporal and spatial processing (Batelli et al. 2008). The reduced theta over posterior areas of the brain especially the left hemispheric sensory regions potentially linked to the increase in frontal theta activity may underlie some of the experiences associated with timelessness and reduced awareness of one's surroundings. Even abstruse feelings such as the unity with the self and/or nature during concentrative meditation might be more explicable with the differences in activity shown in frontal and parietal areas.

Conclusions

Frontal theta is critical for the production of meditative states. Given the association of theta and frontal regions with attentional processing, meditation is considered an effective way training attentional brain networks which has shown to benefit cognitive processing in humans. Further studies are needed to understand the role played by brain oscillatory activity in different stages of meditative practice as well as comparing oscillatory activity in different types of meditation and investigating their longitudinal effects.

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