High theta-low alpha modulation of brain-electric activity during eyes-open Brahma Kumaris Rajyoga meditation

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Abstract

Objective: The objective is to analyze EEG recorded during Brahmakumaris Rajyoga meditation (BKRYM) using eLORETA applied in the frequency domain for localizing sources during meditation vis-à-vis baseline condition. Unlike many other popular meditation practices, BKRYM is practiced with open eyes. To our knowledge, there has been no study of the changes in the brain's activity during the practice of BKRYM using source localization. Further, this seed-stage meditation goes through specific stages, and the corresponding changes in the brain activity, including the different brain networks are explored.

Method: EEG recorded during Brahmakumaris seed-stage meditation was studied in 52 long-term meditators. The meditation comprised three stages, namely focusing on peace, imagining being a soul and communion with the Supreme soul. Brain electric source localization in the frequency domain was used on multichannel EEG recordings to establish activation differences between meditation and open-eyed, task-free resting. Additional exploratory analyses were performed for the differences between initial rest, meditation and final rest.

Results: After 5000 randomized statistical tests of significance ($p<0.05$), meditation showed reduced activity in delta and increased activity in low alpha frequencies. The brain networks altered in their activation during meditation are the following: central executive network, mirroring network, task-positive, and task-negative networks.

Conclusions: The observed changes in activity reflect the main cognitive-affective and behavioral specifics of seed-stage meditation: attention modulation, self-related processing, visual imagery, extra corporeal experience. Future studies need to distinctly differentiate between the stages of the meditation.

Keywords Rajyoga meditation; EEG; source localization; eLORETA; frequency domain, central executive network; mirroring network; task-positive network; task-negative network; default mode network; soul-consciousness, non-dual awareness.

Brahma Kumaris (BK) Rajyoga is a modern revival of the Indian Rajyoga system. Unlike most other Rajyoga systems, BK Rajyoga (BKRY) is not based on Patanjali's yoga system and has little to do with it (Birch, 2013). Rajyoga as taught by the *Prajapita Brahma Kumaris World Spiritual University* is said to be a way for self-realization and the realization of the supreme almighty. It does not rely on rituals or mantras and can be practiced without rigorous training. The most common meditation practice within this tradition is *seed-stage meditation*. Practitioners believe that through this practice they seek the intellectual and loving communion of the soul with the Supreme Soul (Brahmakumaris, 1986). This meditation follows several steps and moves through different stages (Ramesh et al., 2013; Telles & Desiraju, 1993). Sitting with eyes open, in a comfortable posture, for example in an armchair, the practitioner gazes at a meaningful symbol (such as a picture depicting the Supreme Soul as a radiating point of light) or faces a neutral wall and visualizes the soul in between the two eyebrows.

The meditation itself goes through the following stages using appropriate autosuggestions (see supplementary material for some sample autosuggestions used) to keep the mind focused on the task and avoid it from wandering. Practice begins with sitting quietly and relaxed, followed by the stage of concentration, when the practitioner uses autosuggestions to settle into a feeling of peace. The practitioner may either create the feeling of peace in the moment or bring forth this feeling through recalling it from an autobiographical memory. This feeling of peace is the foundation for the next stage, namely soul consciousness. The practitioner reminds him-/herself that he/she is a soul, a sparkling light visualized between his/her eyes. The last stage is described by the practitioners as the connection (a conversation) of the soul with the Supreme Soul, a bodyless light source with peace. The practitioner imagines receiving these qualities from the Supreme Soul and letting them permeate her/his soul. When successful, this culminates in absorption. The practitioner's mind is totally calm and absorbed, and there is little to no active guiding of the intellect. Soul-consciousness is a progression away from everyday concerns, away from the body, towards the realization of being a soul and the connection of this soul with the Supreme Soul and ultimately the absorption within it.

Several ideas have been put forth in the literature to categorize meditation practices. The most common classification systems distinguish among focused attention, open monitoring, and automatic self-transcendence practices (Lutz et al., 2008; Raffone & Srinivasan, 2010; Travis & Shear, 2010). Josipovic (2010) proposed non-dual awareness as a defining characteristic of some practices. Nash and Newberg (2013) categorized practices into three classes: fostering enhanced (i) cognitive, (ii) affective, or (iii) non-cognitive/non-affective state. To allow for a better understanding of how the different practices might foster well-being, Dahl et al. (2015) proposed a classification distinguishing between attentional, constructive, and deconstructive families of practices, i.e., practices that cultivate meta-awareness, enhance cognitive and affective patterns which increase well-being or focus on self-inquiry, respectively.

Rajyoga meditation has strong elements of focused attention, since it needs focus to guide the mind through the different stages, focusing on the soul and the qualities of the Supreme Soul. This process of observing one's own soul as an entity distinct from the body can be categorized as self-monitoring. Following the classification of Nash and Newberg (2013), this self-monitoring belongs to the cognitive domain. It also has a strong affective component with the practitioner seeking the feeling of peace and other positive qualities such as purity, love, joy, bliss, and knowledge. Within the classification of Dahl et al. (2015), BK Rajyoga meditation (BKRYM) fits into the constructive family of practices, since it targets a change in perspective, a cognitive reappraisal of oneself as a soul that is pure in its qualities as are the souls of all human beings (see also Nair et al., 2017).

Let us briefly review the benefits of meditation in general, and BKYRM in particular. Regular practice of any meditation technique has many potential benefits (for a review, see Keng et al., 2011) such as increased subjective well-being, reduced psychological symptoms and emotional reactivity, and improved behavioral regulation. Meditation yields stronger effects than relaxation practices and other alternative treatment types provided (Sedlmeier et al., 2018). Pilot studies on meditation suggest downregulation of epigenetic pathways related to inflammation, cell aging and depression (Kaliman, 2019). Meditation intervention may possibly be utilized as an adjunct to guideline-directed cardiovascular risk reduction (Levine et al., 2017). The following are the specific benefits reported from the practice of BKRYM: improved basic cardio-respiratory functions (Sukhsohale & Phatak, 2012); higher self-satisfaction and happiness in life than the non-meditators (Ramesh et al., 2013); less neurotic symptoms and higher scores on hope and happiness (Misra et al., 2013); and significant increase of IQ in a group of 42 ADHD children after 3 months of practice (Naik et al., 2016). BK Rajyoga is thought to help generate resilience through the cultivation of meaning and self-transformation based on the respective spiritual guidelines (Ramsay & Manderson, 2011).

Few researchers have explored the brain electrical mechanisms sub-serving the different states of the practice of BKRYM. In a study, a popular 1-minute meditation was explored in long-term BK Rajyoga practitioners, short term practitioners and meditation naïve subjects. This study reported increased theta and alpha band-power in the EEG for long-term and short-term practitioners, respectively, during meditation compared to resting (Nair et al., 2017). Also, long-term meditators reliably shifted between resting and meditation states, short-term meditators less reliably and controls were unable to do so. Another study exploring a 10-minute practice of meditation found changes in theta and lower alpha band and higher alpha-asymmetry in meditators during meditation compared to controls during resting (Sharma et al., 2018a). The activity of the default mode network during BKRYM and resting compared to resting in control subjects was studied by Panda et al. (2016) using simultaneous EEG-fMRI recordings. Increased occurrence and duration of the EEG microstates corresponding to default mode network activation was reported as well as an increase in EEG spectral power in the alpha, theta and beta bands (Panda et al., 2016). Increase in grey matter volume of reward processing centers was found in long term meditators practicing Rajyoga as well as strong positive correlation found between practice years and the grey matter volume (Babu et al., 2020). An enhancement of white matter microstructural properties was reported in all the regions of corpus callosum fibers as investigated by diffusion tensor imaging (Sharma et al., 2018b).

To prepare the ground for future investigations on how physiological and psychological health benefits might be associated with the brain electrical activity of the BKRYM practice, we investigated the brain electrical underpinnings of this meditation practice compared to task-free resting within a large group of experienced practitioners. Based on the above description of the cognitive and affective particulars of this practice, we expected brain areas involved in attention modulation as well as emotion and memory processing to show alterations in electrical activity. Consequently, we expected the central executive network (CEN) and the task-positive network to show increased activation and the task negative or default mode network to show decreased activation.

To study the above, we need to know the electrical activity of the brain at the subcortical level. Since the EEG data we have recorded corresponds mainly to the cortical activity, we need to use the mathematical technique of source localization to inverse map from the scalp EEG data to the electrical activity at each voxel *(three-dimensional pixel)* in the entire volume of the brain. In our work, we first convert the EEG data of each channel into frequency domain by taking the discrete Fourier transform of the data. Then we perform source localization in the frequency domain to obtain the activity of each voxel of the brain at different frequencies starting from 0.5 Hz and going up to 64 Hz. The resulting data is used to detect intracortical electrical activity changes during meditation occurring at different frequencies.

Method

Participants

Fifty-two meditators (mean age: 42.0 ± 10.1 years, range: 25-59; mean meditation experience: 17.5 ± 10.8 years, range: 4-43; 14 females) were recruited and recorded during a winter season when followers from across the world visited the headquarters of Brahma Kumaris. Meditation experience was calculated based on the year of learning the first course of BKRYM and practiced regularly.

Procedure

EEG recordings

The EEG recordings took place at the International Centre for Higher Learning, Brahma Kumaris, Gyan Sarovar, Mount Abu, India (1722 m above sea level). The recordings were performed in a small, normally lit room with the participants sitting upright either cross-legged on a couch or on the couch border with their feet on the ground. They faced a neutral, coffee-coloured tapestry on the wall. The experimenter controlled the recording from a small adjacent room containing the recording computer and allowing easy view of the participant through a clear glass window. Based on the 10-10 electrode placement system (Nuwer et al., 1998), EEG was recorded at the following 61 locations: Fp1, Fpz, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, POz, O1, O2, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FC3, FCz, FC4, C5, C1, C2, C6, CP3, CP4, P5, P1, P2, P6, PO5, PO3, PO4, PO6, FT7, FT8, TP7, TP8, PO7, PO8, and Oz. All the channels were referenced to CPz, and AFz was used as ground. Since the EEG cap has only left EOG electrode, it was placed on the corner of the left eye to record horizontal eye movements. The recordings were performed using a 64-channel ANT neuro mylab system. EEG was recorded at 500 Hz sampling rate. Impedance for all the EEG and EOG channels was kept below 10 K ohms to ensure good data quality. The EEG amplifier and the acquisition system (laptop) were running on battery and were not connected to the mains during the data recording. Band pass filter was applied from 0.3 to 75 Hz in the recording software as was a 50 Hz notch filter.

Recording conditions

The recordings adhered to the following protocol: (1) Initial rest with eyes open (EO1): 3 min (instruction: “sit quietly without meditating”). (2) Initial rest with eyes closed: 3 min (instruction: “close your eyes and sit quietly without meditating”). (3) Rajyoga seed-stage meditation with eyes open (Med): 30 min (shifting the awareness from the visible world to *the soul and its peaceful nature* and then connecting to the *Supreme Soul*). (4) Final rest with eyes open (EO2): 3 min (instruction: “sit quietly without meditating”). (5) Final rest with eyes closed: 3 min (instruction: “close your eyes and sit quietly without meditating”).

Since this meditation is practiced with open eyes, we felt that it was appropriate to compare the brain activity during meditation with the activity during a baseline with eyes open. However, since it is standard practice in most EEG studies on meditation to use an eyes-closed baseline, we chose to record a second baseline with eyes closed as an abundant precaution in case it would be required later. This data can be used later in a comparative analysis of resting state networks with different meditation types. However, we did not use the eyes-closed baseline recordings in this study. The whole protocol was timed using a digital stopwatch to ensure proper durations of the different data segments. To ensure that the participants align with the practice variables, on days before the recording, they listened to recorded audio instructions from a senior meditator and followed the same steps during the actual session. During the meditation, the participants were presented an acoustic tone 4 to 5 times at random intervals to check if the meditators could later remember the total number of prompts given during the experiment. However, these data were not used for the current study.

This report compares the meditation (Med) state to the initial eyes-open (EO1) rest state. Additional analyses were performed to look for possible changes over time during the meditation. Also, meditation as well as initial rest (eyes open) were compared to final rest (EO2: eyes open).

Measures

The data was preprocessed using BrainVision Analyzer version 2.1.2 (www.brainproducts.com). The EEG data was first downsampled to 128 Hz using spline interpolation. The eye movement artifacts were corrected using independent component analysis where necessary, and then the remaining eye, muscle, sweat, and other artifacts were marked through visual inspection. To remove the distraction that possibly occurred due to the acoustic prompts, 30 sec. data before and after each prompt was removed from the final analysis. The EEG was segmented into 2-s epochs and all artifact-free epochs were exported for further analysis. The meditation session was divided into three parts to study the effect of time elapsed since the meditation began (hereinafter referred to as the first, middle and the last tertiles). To account for the difference in the recording durations of meditation and rest sessions, a random selection of 50 artifact-free epochs were collected from the initial and final rest data as well as from the first, middle and the last tertiles of the meditation data. This resulted in a total of 150 epochs for the complete meditation session.

Data analyses

The preprocessed, artifact-free 2-s epochs (50 for each rest condition and 150 for the three meditation segments) underwent source localization analysis using exact, low-resolution brain electromagnetic tomography (eLORETA, Pascual-Marqui et al., 2011), available at http://www.uzh.ch/keyinst/loreta.htm. eLORETA is a solution to the inverse problem that gives reliable localization even in the presence of measurement and structured biological noise (Pascual-Marqui et al., 2011). The analysis procedure follows the LORETA functional tomography analysis approach (Pascual-Marqui et al., 1999; Pascual-Marqui et al., 1994). Applying the procedure delineated in Frei et al. (2001), power spectra (128 discrete frequencies, from 0.5-64.0 Hz, at 0.5 Hz frequency resolution) were computed for all the available epochs and averaged per condition and participant and then transformed into eLORETA images (with 6239 cortical voxels at a spatial resolution of 5 mm^3). For all comparisons between and within conditions, paired t-statistics were computed on the log-transformed current density values at each voxel. Corrections for multiple testing were applied over all the 6239 voxels and 128 frequencies using nonparametric randomization (Nichols & Holmes, 2002). The Brodmann areas (BAs) corresponding to the voxels with significant changes are identified based on their coordinates in MNI space (Evans & Collins, 1993). Combined meditation data (of all three tertiles) was compared with the initial and final rest data separately (Tables 1 and 2). Meditation tertiles of 50 epochs each were separately compared (Table 3) to one another.

Results

Meditation vs initial rest

Table 1 lists the number of voxels in each Brodmann area with significant differences in the brain activity between the meditation, initial and final rest states in pairwise comparison of conditions. Data from only those specific frequencies or frequency ranges with at least 15 significant voxels are included in the Table. The counts of significant voxels are given in terms of their location in the left or right hemisphere, or along the midline. Increased activity in any frequency / frequency range with respect to an earlier condition is shown in italics. On the other hand, decreased activity is shown using numbers in normal font.

Significant differences were found between meditation (averaged across all the tertiles) and initial rest in several clusters with a total of at least 15 voxels in two frequency ranges: the delta range between 0.5 and 4.0 Hz and the range between 7.0 and 9.5 Hz, which we consider as "high theta-low alpha". The number of voxels significantly differing between meditation and initial rest in these two frequency bands are given in the left-most columns of Table 1 as per the Brodmann areas they belong to.

Table 2 lists the number of voxels in each anatomical structure of the brain with activity significantly differing between meditation (averaged over the complete meditation data) and initial rest in two frequency ranges (delta: 0.5-4.0 Hz and high theta-low alpha: 7.0-9.5 Hz). Table 2 clearly shows that the activity in the delta band decreases during meditation compared to the initial rest condition, whereas it increases during meditation in the other frequency band.). Figure 1 illustrates these findings with cortical slices through difference maxima between the two conditions per frequency in the same two frequency bands with a resolution of 0.5 Hz. The largest cluster of significant voxels was found at 1.5 Hz within the delta range and at 9.0 Hz within the low-alpha range.

Compared to the initial resting state, meditation data showed decreased delta activity in a large cluster encompassing bilateral prefrontal (BAs 9, 10, 46), orbitofrontal (left BAs 11, 47) and dorsolateral areas (BA 46), the frontal eye fields (BA 8), Broca's area (BAs 45, 44), and extending to the premotor (BA 6), primary motor (BA 4), and the somatosensory (BAs 1, 2, 3) cortices, the precuneus (BA 7) and parietal (left BAs 5, 40) areas, as well as the temporal areas (BAs 20, 21, 22, 41, 42 and 43).

In the high theta-low alpha range, meditation data revealed increased activity compared to the initial rest state. These increases were found bilaterally in the cingulate cortex (BAs 23, 24, 29, 30, 31), the parahippocampal and fusiform gyrus (BAs 27, 28, 36, 37), the superior and inferior temporal gyrus (BAs 22, 20), Wernicke's area (BAs 39, 40), the auditory cortex (BAs 41, 42 right), the insula (BA 13), the associative and secondary visual cortices (BA 18, 19), and precuneus (BA 7). No significant differences were present between meditation and initial rest in other frequency ranges, namely the low theta, upper alpha, beta, and gamma bands.

EEG changes across the tertiles within the duration of meditation

EEG activity did not differ significantly between successive tertiles (one-third segments) of meditation i.e. the first from the middle, and the middle from the last tertile. However, compared to the first tertile, there were significant changes in the activity in the last tertile. Table 3 gives the counts of voxels in each Brodmann area, where the activity significantly differs between the first and the last tertiles (one-third segments) of meditation period for frequencies / frequency ranges showing at least 15 significant voxels in each associated frequency. The counts of significant voxels are given in terms of their location in the left or right hemisphere, or along the midline. Increased activity in any frequency / frequency range with respect to an earlier condition is shown in italics, and decreased activity is shown using numbers in normal font. Decrease was found in low frequencies (1.5-4.5 Hz) in the motor (BAs 4, 6) and somatosensory (BAs 1, 2, 3, 5) cortices as well as parietal areas (BA 40). However, a significant increase was observed at 26 Hz, in the posterior and anterior left cingulate cortex (BAs 23, 24, 31; Table 3).

Final resting state compared to the meditation and initial resting states

The final rest state showed decreased brain activity compared to meditation (complete data – averaged over the tertiles) in two frequency ranges (1.5-7 Hz and 11-14.5 Hz) in large areas, and also decreased activity compared to initial rest in the frequency ranges of 1.5-7 Hz and 26 Hz (Table 1). For visualizing the relative number of voxels with significant changes, Figure 2 shows bar graphs of the top five Brodmann areas contributing to the largest differences in activity between the initial rest, meditation and the final rest conditions in pairwise comparisons.

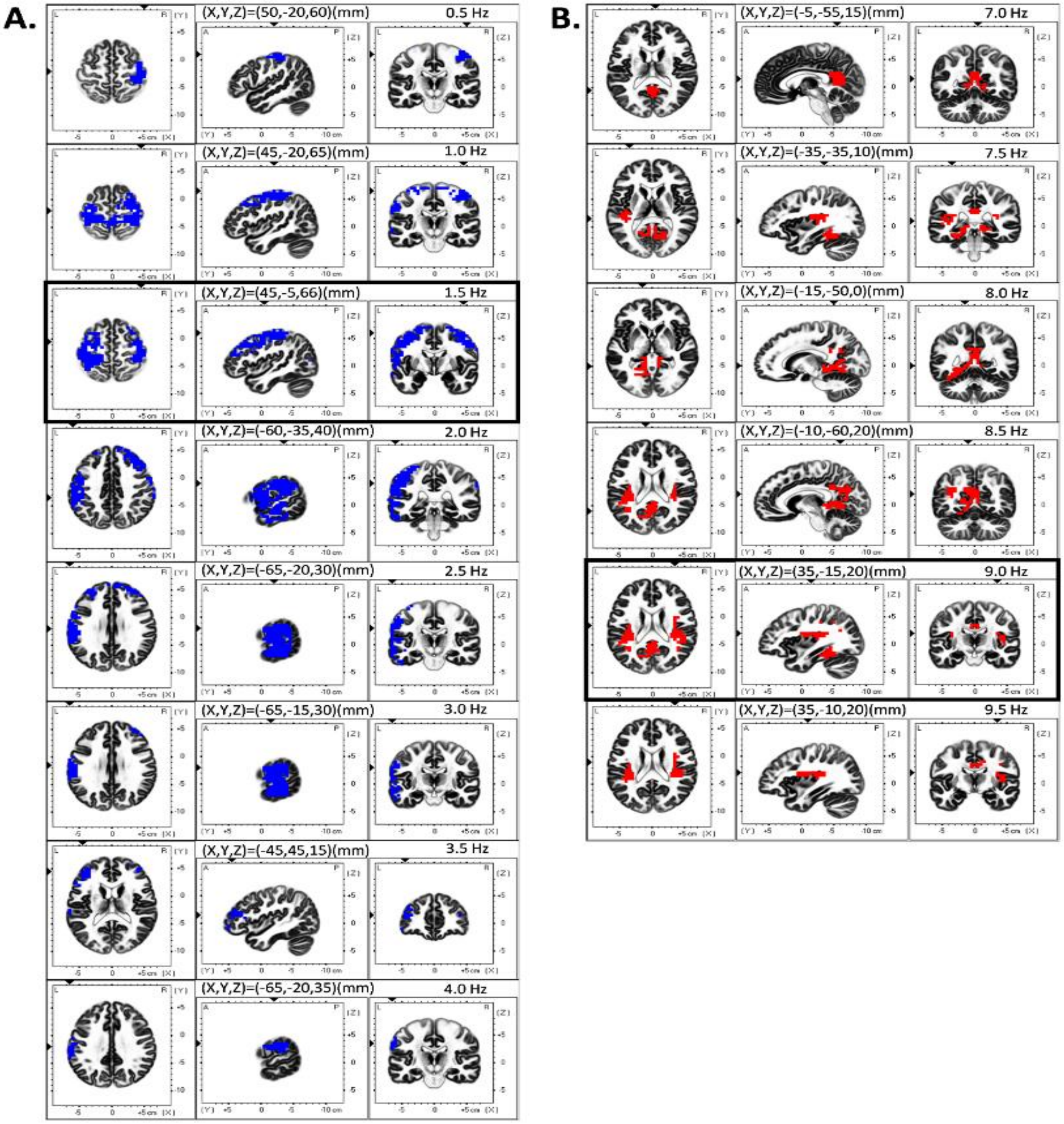

Fig. 1. Frequencies showing significant differences between meditation and initial rest. Decreases (blue) during meditation were seen in delta frequencies (panel A on the LHS.) Increases (red) during meditation were seen in low alpha frequencies (panel B on the RHS.). Shown are slices (transverse, sagittal and coronal from left to right) through the voxel of maximal difference (indicated by black triangles on the axes) between meditation and initial rest per frequency. The MNI coordinates of the voxel of maximal difference are indicated on top of each sagittal slice, and the frequency on top of the coronal slice. Slices with bold borders indicate the frequency in each frequency range with the highest number of significant voxels.

Table 1. Number of voxels per Brodmann area significantly differing among meditation, initial and final rest states in specific frequency / frequency ranges showing at least 15 significant voxels in each associated frequency range. (LH: left hemisphere, RH: right hemisphere, M: midline voxels. Numbers in italics indicate increased activity in the respective frequency / frequency range and condition. Normal font numbers indicate decreased activity.)

	Meditation vs initial rest						**Final rest vs meditation**						**Final rest vs initial rest**					
	δ: 0.5 – 4.0 Hz			**7.0 – 9.5 Hz**			**1.5 – 7.0 Hz**			**11.0 – 14.5 Hz**			**1.5 – 7.0 Hz**			**26 Hz**		
	Decreases during Meditation			*Increases* in Meditation			Decreases in final rest			Decreases in final rest			Decreases in final rest			Decreases in final rest		
BA	**LH**	**M**	**RH**	**LH**	**M**	**RH**	**LH**	**M**	**RH**	**LH**	**M**	**RH**	**LH**	**M**	**RH**	**LH**	**M**	**RH**
1	9	-	9	-	-	-	7	-	9	4	-	2	9	-	8	1	-	-
2	40	-	27	-	-	*3*	42	-	46	18	-	13	43	-	42	6	-	-
3	66	-	41	-	-	-	67	-	56	49	-	31	72	-	54	17	-	-
4	63	1	56	-	-	-	59	1	66	40	1	42	69	1	70	8	-	-
5	20	1	8	-	-	-	40	9	41	40	9	41	40	9	41	14	-	9
6	173	1	153	-	-	*2*	185	12	122	163	13	150	261	13	275	15	-	-
7	9	-	-	*13*	*4*	*2*	186	25	189	98	10	85	186	25	198	15	-	78
8	9	-	63	-	-	-	23	8	36	10	7	9	74	9	91	-	-	-
9	34	-	93	-	-	-	38	3	9	-	-	2	124	9	134	-	-	-
10	30	-	46	-	-	-	-	-	-	-	-	-	56	-	51	-	-	-
11	4	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-
13	11	-	2	*30*	-	*66*	12	-	4	-	-	-	37	-	36	-	-	-
17	-	-	-	-	-	-	36	2	21	-	-	-	36	2	36	-	-	-
18	-	-	-	*8*	-	*9*	145	28	80	-	-	-	141	28	142	-	-	-
19	-	-	1	*41*	-	*26*	180	2	78	-	-	-	179	2	170	-	-	-
20	31	-	-	*8*	-	*11*	-	-	-	-	-	-	11	-	74	-	-	-
21	63	-	-	-	-	-	-	-	-	-	-	-	12	-	101	-	-	-
22	60	-	10	*3*	-	*8*	6	-	4	-	-	-	37	-	85	-	-	-
23	-	-	-	*12*	*15*	*19*	15	15	22	10	8	11	3	-	3	-	-	-
24	-	-	-	*4*	*5*	*15*	39	13	46	44	13	58	43	9	37	-	-	-
27	-	-	-	*7*	-	*9*	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	*3*	-	*1*	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	*5*	-	*4*	5	-	4	-	-	-	-	-	-	-	-	-
30	-	-	-	*30*	*3*	*35*	32	3	19	-	-	-	13	-	13	-	-	-
31	-	-	-	*56*	*16*	*53*	80	29	59	42	19	37	49	10	35	-	-	-
32	-	-	-	-	-	-	17	4	26	22	4	28	39	5	39	-	-	-
35	-	-	-	*5*	-	*1*	-	-	-	-	-	-	-	-	-	-	-	-
36	-	-	-	*10*	-	*10*	-	-	-	-	-	-	1	-	15	-	-	-
37	2	-	-	*28*	-	*15*	23	-	-	-	-	-	83	-	88	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-
39	3	-	8	*18*	-	*3*	70	-	29	-	-	-	77	-	60	-	-	-
40	164	-	101	*3*	-	*8*	174	-	147	59	-	43	189	-	180	4	-	6
41	11	-	-	*17*	-	*21*	-	-	-	-	-	-	13	-	27	-	-	-
42	19	-	4	-	-	*1*	2	-	2	-	-	-	11	-	20	-	-	-
43	10	-	1	-	-	-	-	-	-	-	-	-	12	-	11	-	-	-
44	22	-	8	-	-	-	-	-	-	-	-	-	22	-	15	-	-	-
45	25	-	15	-	-	-	-	-	-	-	-	-	14	-	27	-	-	-
46	20	-	21	-	-	-	-	-	6	-	-	-	18	-	26	-	-	-
47	14	-	1	-	-	-	-	-	-	-	-	-	1	-	28	-	-	-

Table 2: Number of voxels per anatomical structure significantly differing between meditation (averaged over the complete meditation data) and initial rest in two frequency ranges (0.5-4.0 Hz: decreases and 7.0-9.5 Hz: increases during meditation).

	Meditation vs initial rest					
	0.5 – 4.0 Hz			**7.0 – 9.5 Hz**		
	Decreases during meditation			*Increases* during meditation		
Anatomical structure	**LH**	**M**	**RH**	**LH**	**M**	**RH**
Inferior Frontal Gyrus	76	-	40	-	-	-
Medial Frontal Gyrus	9	-	20	-	-	-
Middle Frontal Gyrus	108	-	164	-	-	-
Superior Frontal Gyrus	50	-	107	-	-	-
Precentral Gyrus	149	-	115	-	-	*2*
Postcentral Gyrus	160	-	103	-	-	*5*
Paracentral Lobule	6	3	8	-	-	-
Anterior Cingulate	-	-	-	*6*	*6*	*22*
Posterior Cingulate	-	-	-	*241*	*116*	*236*
Parahippocampal Gyrus	-	-	-	*204*	-	*93*
Transverse Temporal Gyrus	12	-	-	*20*	-	*10*
Inferior Temporal Gyrus	27	-	-	*1*	-	-
Middle Temporal Gyrus	64	-	6	*8*	-	*2*
Superior Temporal Gyrus	77	-	18	*58*	-	*40*
Insula	8	-	1	*125*	-	*129*
Fusiform Gyrus	9	-	-	*80*	-	*22*
Lingual Gyrus	-	-	-	*70*	-	*37*
Precuneus	1	-	-	*92*	*30*	*38*
Cuneus	-	-	-	*19*	-	*14*
Inferior Parietal Lobule	146	-	86	*2*	-	*8*
Superior Parietal Lobule	10	-	-	*7*	-	-

LH: left hemisphere, RH: right hemisphere, M: midline voxels. Numbers in italics indicate activity increases in the respective frequency range and condition. Normal font numbers indicate activity decreases.

Table 3. Number of voxels per Brodmann area significantly differing in activity between the first and the last tertiles (one-third time segments) of meditation period for frequencies / frequency ranges showing at least 15 significant voxels in each associated frequency.

	Meditation data last tertile vs first tertile					
	1.5 – 4.5 Hz			**26 Hz**		
	Decreases in last tertile			*increases* in last tertile		
BA	**LH**	**M**	**RH**	**LH**	**M**	**RH**
1	6	-	-	-	-	-
2	24	-	6	-	-	-
3	17	-	5	*1*	-	-
4	11	-	7	*1*	-	-
5	-	-	6	-	-	-
6	2	-	1	*7*	-	-
7	-	-	1	-	-	-
23	-	-	-	*5*	-	-
24	-	-	-	*18*	-	-
31	-	-	-	*13*	-	-
40	25	-	18	-	-	-

LH: left hemisphere, RH: right hemisphere, M: midline voxels. Numbers in italics indicate activity increases in the respective frequency / frequency range and condition. Normal font numbers indicate activity decreases.

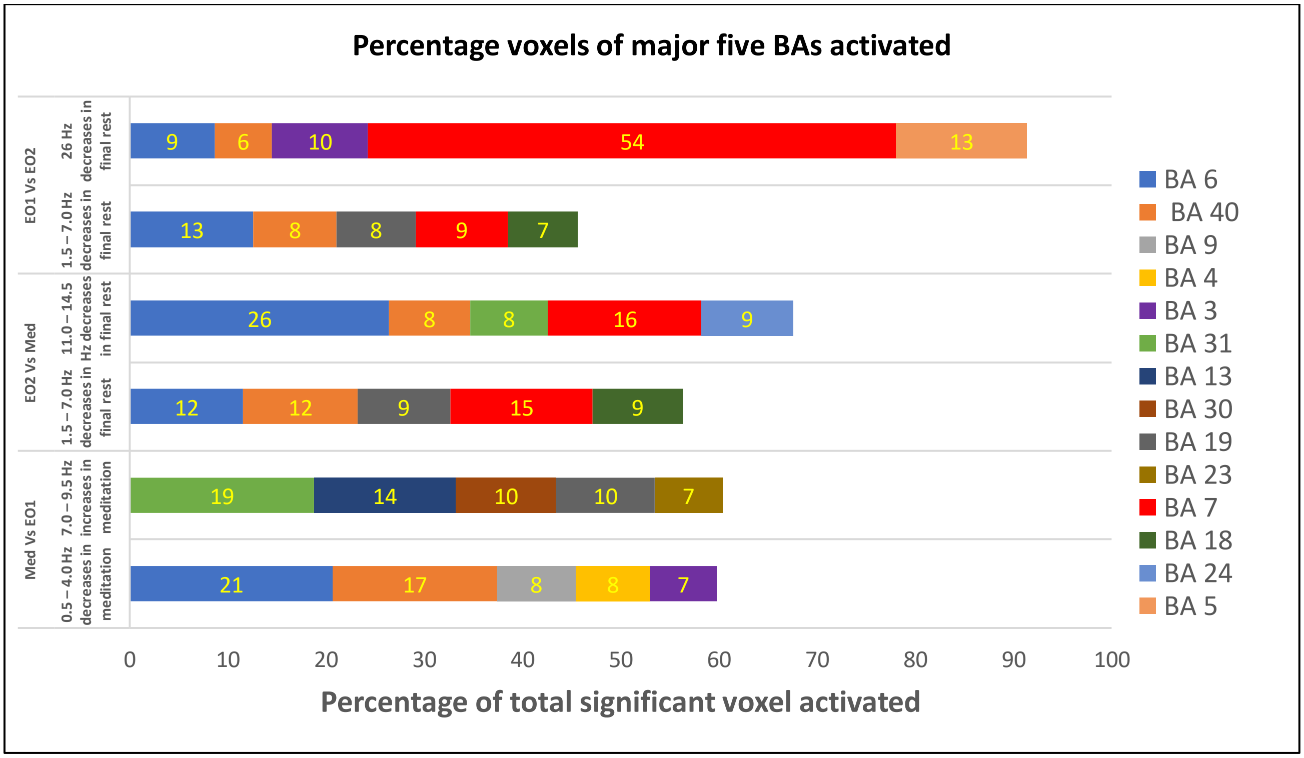

Fig. 2: Percentage of total voxels activated for the top five BAs contributing the largest activation or above fifty percent activation. Y-axis represents different comparisons between initial resting (EO1), meditation (Med) and final resting (EO2).

A summarized account of the number of voxels in BAs having prominent change in activity is given in Fig. 2. For each BA, the number of activated voxels is calculated as a percentage of the total voxels of that anatomical region in each protocol comparison. Only five BAs with maximum activation for each comparison (Med vs EO1, EO2 vs Med, EO1 vs EO2) have been plotted in the graph.

Discussion

The main goal of the present study was to examine the changes in EEG sources (i.e., activity in specific brain areas) during BKRY meditation compared to the resting state. It is possible that the initial resting state before meditation (EO1) is closer to everyday resting than the final rest (EO2) immediately following the meditation session. This is because we expect that the brain of a long-term meditator may take some time to settle down to its normal activity after the practitioner stops meditating. Therefore, our focus was on the comparison of meditation with the initial rest. In an exploratory analysis, the final resting state was included to evaluate possible lingering effect of the meditation session. Further, the meditation session data was partitioned into three segments of equal duration (tertiles), which were pairwise compared to find possible differences of arousal with increasing time into the meditation. First, we discuss the results of the comparison between meditation and initial rest.

Reduced inhibition

During BKRY seed-stage meditation, the inhibitory delta band activity (Niedermeyer & Lopes da Silva, 1993) decreased in a large bilateral frontal and central cluster that extended into left-hemispheric temporal and parietal areas (Figure 1, Table 1 (left) and Table 2). Thus we see reduced functional inhibition, which likely implies increased activation (processing) in the above areas during meditation as compared to task-free rest. These areas sub-serve functions such as empathy (bilateral (pre) frontal: Seitz et al., 2006), behavioural inhibition / executive control (dorsolateral prefrontal cortex: Kübler et al., 2006; Van Oort et al., 2017), visuo-spatial cognition and spatial information processing (middle frontal, BAs 9/46: Leung et al., 2002), somatosensory processing (homunculus) (BAs 3,1,2) and semantic language processing (BAs 20,21,22,44,45,6: Bookheimer, 2002). As hypothesized, we see an activation of the central executive network with decreased delta activity in the dorsolateral prefrontal cortex (BAs 9,10, 46), the frontal eye fields (BA 8) and the posterior parietal cortex (BA 7). Sustaining attention during meditation has been reported to keep the dorsolateral prefrontal cortex (as part of the CEN) activated (Hasenkamp et al., 2012). Task positive networks have been categorized into two: central executive network and the salience network. CEN is a dominant control network involved in higher cognition and information processing. Anatomically, frontoparietal regions are part of CEN. Anterior cingulate cortex, the inferior parietal lobe, and the posterior-most portions of the middle and inferior temporal gyri connect functionally to regulate emotions, cognitive traits and behaviour. It also acts in self-control mechanisms and suppressing the unpleasant thoughts. Individuals with high connectivity in CEN are found to be resilient and not manifesting cardiometabolic risk under high-violence conditions (Miller et al., 2018).

Our results fit well with the subjective experience involved in seed-stage meditation. The increased behavioural inhibition is expected since the meditators sit still and relaxed while having higher wakefulness (Cahn et al., 2010) during meditation. Increased semantic language processing could be the result of the auto-suggestive nature of the meditation process, since the meditators internally verbalize the steps involved in achieving each stage of the meditation. Activation of the left-side language areas (BAs 44/45 and 21/22) possibly reflects the logical reasoning involved in following the sequence of autosuggestive sentences (Bookheimer, 2002; Caplan & Dapretto, 2001).

We found increased activation in the somatosensory cortex (homunculus, BAs 3,2,1) during the first tertile of meditation, which decreased during the last tertile. One explanation for this finding is that during resting, the practitioners were actively inhibiting (higher delta activity) the somatosensory cortex, as they were instructed to sit quietly and not move during the experiment. Overall, during meditation, there was no longer any special focus on relaxation or on maintaining body posture and thus the activity in the somatosensory cortex went back to more normal levels, i.e. resulting in reduced delta activity as compared to resting. On the other hand, the 20% of voxels showing the highest t-values for reduced delta activity were located in a small cluster with average MNI coordinates (44, 1, 51 mm) in the right hemisphere and (-60, -28, 32 mm) in the left hemisphere, corresponding to the face areas on the homunculus (Roux et al., 2018). This might be the result of focusing the attention between the eyes as an important step during the meditation. The increased visuo-spatial cognition and spatial information storage might result from having the eyes open during the meditation. This allows the meditator to keep an image of himself/herself in relation to the tapestry on the wall that he/she gazes at. It is even conceivable that the nature of the meditation itself fosters spatial processing. Indeed, the meditator is reported to become aware of himself/herself as a soul, a point of light between the eyes that becomes increasingly distanced to the material world. Also, the Supreme Soul is envisioned as separate from the soul before letting the qualities of the Supreme Soul permeate the soul, which implies a direction. This latter part of sensing the qualities of the Supreme Soul and attempting to let them permeate the self, might explain the apparently enhanced empathic processing during meditation.

Increased facilitation

Power in the high theta-low alpha frequencies (7.0 to 9.5 Hz) increased during meditation in a cluster of voxels with the largest cluster being at 9.0 Hz (Figure 1). While upper alpha frequencies have been considered inhibitory and suppress potentially distracting sensory information, lower alpha is facilitatory and is involved during phasic alertness (Bowman et al., 2017; Bazanova & Vernon, 2014; Klimesch et al., 1998, 1999). This cluster encompassed the bilateral posterior (and to a lesser degree the right anterior) cingulate, extended bilaterally to the parahippocampal gyrus and the superior temporal gyrus, the bilateral insula, the fusiform gyrus, the inferior parietal lobule, bilateral lingual gyrus, and occipitally and bilaterally to the cuneus and precuneus. The BA 19 bilaterally and left BA 37 have been implicated in mental imagery (D'Esposito et al., 1997), as were BAs 40, 7 (Knauff et al., 2000) and 18 (De Volder et al., 2001). Seed-stage meditation has a strong focus on mental imagery since the practitioner imagines himself/herself as a point of light between the eyes, as distant from his/her body and the world and witnessing the light of the Supreme being. The involvement of the insula (BA 13) might result from feeling peaceful, since cortically the insula processes the states of feeling (Damasio et al., 2012). The perirhinal cortex (BA 36) processes semantic memory (Davies et al., 2004) as do other parts of the temporal lobe (BAs 20, 21 and 22) (Bookheimer, 2002) and their activation could reflect the meditators' focus on peace and related memories. One of these areas was activated by decreased delta (BA 21), another by increased low alpha (BA 36) and others by both frequency ranges (BAs 13, 20, 22).

Combined activations

Across delta and low alpha, several networks were activated. The mirroring or experience-sharing network was activated in its classical regions (ventral premotor cortex, inferior frontal gyrus, inferior parietal lobule) and also in regions associated especially with mirroring emotional expression (insula and cingulate cortex) (Molenberghs et al., 2012). An important part of BKRY-seed-stage meditation is the practitioner mirroring the peace perceived in the Supreme Soul and let it permeate his/her own soul. This could explain the activation of the mirroring network.

Thirty-five percent of all significant voxels across delta and low alpha belonged to the task-positive network (BAs 6, 19, 37, 40, 46) and 25% to the task-negative network (BAs 8, 10, 20, 21, 30, 31, 39) (Fox et al., 2005). Task-negative network, mostly referred to as default mode network, includes precuneus/posterior cingulate cortex, the medial prefrontal cortex, and medial, lateral, and inferior parietal cortex. While the activation of the task-positive network confirms our hypothesis, the activation of the task-negative network was unexpected. These two networks are typically mutually exclusive (Fox et al., 2005; Fukunaga et al., 2006), except for states of non-dual awareness during deep meditation as proposed by Josipovic (2014). The task-negative network (Raichle et al., 2001) has been related to mind wandering (Mason et al., 2007), episodic memory processing (Buckner et al, 2008; Greicius et al., 2004) and conceptual processing (Binder et al., 1999). Clearly these processes are all important for maintaining the sense of self (Gusnard et al, 2001; Lou et al., 2004). Many meditation practices tend to weaken the sense of self and are accompanied by a deactivation of the default mode network (e.g. Brewer et al., 2011; Garrison et al., 2015). However, soul consciousness has a strong focus on the self, since it relates the self to the everyday world, its own body, the point between the eyes and the Supreme being during its different stages. Self-related processing is known to activate the default mode network (Buckner et al., 2008; Raichle et al., 2001).

The areas belonging to the task-positive network have been associated with different aspects of attention (Corbetta et al., 2008; Posner & Petersen, 1990). Shifting the attention back to the focus of meditation after noticing mind wandering as well as sustaining the attention on the focus of meditation have been associated with activation in the task-positive network (Hasenkamp et al., 2012). It is interesting that the two networks are both activated during BKRY seed-stage meditation. It is not clear whether this indicates that the subjects experience a state of non-dual awareness during some stage of the meditation; alternately, the two networks may be active at different times during the meditation, and the appearance of simultaneous activation may be due to the averaging over the different stages of meditation. This needs to be disentangled in future studies by delineating the different stages of meditation. Across all the states, BKRY seed-stage meditation seems to involve the task-negative network with its strong focus on self-referential processing and the task-positive network with its need to shift attention to and sustain it on the task of going through the different stages of meditation.

It is unclear why certain brain areas were activated by reduced delta activity and others by increased high theta-low alpha activity. A few regions showed activations in both frequency ranges (Table 1). Possibly, studying separately the different states of BKRY seed stage meditation may shed some light on this issue.

It has been proposed that associative learning processes through imagination help promote mental well-being through reduced neural threat expression (Reddan et al., 2018). Therapies based on associative learning are usually applied to reduce symptoms of anxiety, phobias (Pittig et al., 2018) and addiction (Bevins & Palmatier, 2004). In the case of meditation, practicing imagination of pleasant stimulus or scene may mimic the process of associated learning and follow Hebb’s rule (Hebb, 1949) to establish and strengthen new synapses. However, no direct measure of mental health was used in this study, and it requires a new study to explore the above possibility.

Probing for time effects

To probe for the effects (e.g., changes in arousal) of passing time over the 30-min meditation session, the meditation data was partitioned into three consecutive segments, each covering 10 min. The differences of the middle tertile from the first or last tertile were not significant. However, there were significant changes from the first to the last tertile of meditation. These changes were decreases in delta (1.5 – 4.5 Hz) activity in somatosensory, premotor, and motor cortices (BAs 1-6) as well as the inferior parietal lobule (BA 40) and increases at 26 Hz in the cingulate cortex (BAs 23, 24, 31) and the premotor and supplementary motor areas (BA 6). All these changes also show up when comparing the complete meditation session to the initial resting state. These changes thus slightly increase with the progression of time into the 30-min meditation session. However, when the activities of successive time segments (during meditation) are compared to each other, only a few voxels show significant differences. Subject variability and varying temporal progression across subjects during meditation might explain this.

Comparisons with the final rest state

Meditation shows different changes in comparison with the final resting state than it does to the initial resting state. Most noteworthy is the decrease of upper alpha (11.0-14.5 Hz) frequencies in the final rest, but also decrease of activity in the delta and theta (1.5-7.0 Hz) frequencies in many areas. Thus, it is apparent that coming out of meditation is different from the state before going into meditation. This has already been described in a study of EEG and eLORETA-based functional connectivity on meditators from 5 different meditation traditions (Lehmann et al., 2012). On a side note, the differential involvement of low alpha during meditation in comparison with initial rest and high alpha during final rest in comparison with meditation seems to imply that low and high alpha reflect different processes and caution should be applied when analyzing a single broad alpha band.

Activation in a single frequency bin of 26 Hz is increased in anterior and posterior cingulate cortices (BAs 24 and 23). The anterior cingulate area is active during the detection of conflicts and maintains attention by alerting the top-down systems involved in resolving the conflicts (Van Veen & Carter, 2002). Our findings contradict those of Faber et al. (2015) mentioning the posterior cingulate area deactivation in expert zazen meditators as resulting from the detachment from perceptions during the meditative state. Zazen is considered as open mindfulness and reduced conceptual processing and self-referential. However, the seed stage of BKRY is a more involved practice with positive thoughts and requires self-related processing and visualizing the soul as distinct from the body. BK Rajyoga practice involves imagining oneself as a point of light, detached from one’s physical body. This may give them an extracorporeal experience during meditation. The self-reported phenomenon of detachment of the soul from the body by most meditators of BKRY tradition can be supported by our findings of activation/deactivation in BA 6 (supplementary motor area) and BA 40 (supramarginal gyrus, inferior parietal lobe) (Fig. 2) in different frequency bands (Bünning & Blanke, 2005), also seen earlier in fMRI studies (Smith & Messier., 2014).

Similarly, the deactivations in the last tertile of meditation indicate decreasing requirement of networks involved in conflict monitoring and different sensory perceptions running during the beginning of meditation in order to initiate and maintain the meditative state. It seems reasonable that large parts of the brain show changes during this transition back to a normal state. To study in detail the changes in returning to rest after meditation, future studies should record EEG for a longer period after meditation or at periodic intervals for a couple of hours after meditation. This would help elucidate how the brain returns to its normal, everyday state of mind after an extended meditation session. The final resting data differs largely from the initial resting data in almost all the brain areas, thus possibly showing a lingering effect of the meditation session combined with a reorganization of brain activity in order to return to normal processing. Looking only at the first 3 min after the meditation practice without knowing when the return to the normal state is complete, seems insufficient to draw any useful conclusions.

Conclusion

The current study attempted to find common brain networks activated in eyes open meditation. To the knowledge of the authors, these have not been explored so far. The major areas of involvement of default mode network are common between seed-stage meditation and other meditation traditions. In a non-dual practice, where self-regulation is involved, no activation in frontoparietal network was found (Schoenberg et al., 2018), suggesting that this network plays no role in meditation. The anterior cingulate cortex, posterior cingulate cortex, precuneus, insula, and middle frontal gyrus are a few involved areas common to meditation practices in the current study and previous ones (Deolindo et al., 2020).

In summary, the BKRY seed-stage meditation with open eyes showed activations in brain areas sub-serving the subjective experience of the practitioners during the different stages of meditation. The modulated areas were part of the CEN, the task-positive and task-negative networks. They inhibit movement, foster and modulate attention to stay on the task of moving through the different stages of the meditation, reducing the requirement of distraction-inhibiting networks to maintain the meditative state and enable self-related processing for experiencing the soul as a point of light between the eyes, and endowing it with the properties (i.e., peace) of the Supreme Soul (as taught in the Prajapita Brahma Kumaris World Spiritual University while learning meditation).

Limitations and Directions for Future Research

The eLORETA tool for source localization of EEG data provides brain activations with low spatial resolution. Our findings can be interpreted based on the previous literature of neuroimaging methods with high spatial resolution, where the subjects performed tasks based on defined instructions while the data was being recorded. However, since meditation is an activity with few known attributes while being practiced, is challenging to fit in a prepared instructional order. A more robust study can be planned with subjective ratings or questionnaire-based scoring of cognitive traits to correlate with the EEG indices. The participants in the current study were all adept Brahma Kumaris meditators. As such, they practice a certain lifestyle that could very well have an influence on their general state of mind, irrespective of the seed-stage meditation studied here. This lifestyle includes maintaining celibacy, consuming vegetarian diet and a rigorous daily routine (e.g., getting up early for morning meditation). Mount Abu is situated at 1,722 m above sea level and the altitude could have influenced the EEG patterns. Also, the recordings were performed during a winter retreat. All the participants had at least three days of acclimatization before the recording. The intense meditation schedule during the retreat might also have reflected in the findings. However, these effects should all be mitigated by our intra-subject comparisons.

The recording protocol did not control the durations of the different stages of meditation and hence, each meditator might have followed his/her normal characteristic timing to advance from one stage of meditation to the next. Because of this, it is difficult to mark the timings of the various cognitive and emotional states of the subjects. To delineate the brain's electrical characteristics during the different sub-stages of meditation, these may need to be triggered by the experimenter in a controlled fashion in future studies. Further, specific cognitive/psychological tests can be carried out to cross-validate the functional activation of brain regions relevant to our study. This information can then be used to better explain the changes to the activity occurring in each of those brain regions during meditation. A psychophysiological study is suggested to provide an idea of the effect of meditation practice on cognitive functions with evidenced source activation. To study how the brain activity returns to normal after an extended meditation session, future studies should record rest after meditation over a prolonged period.

The high theta-low alpha (7-9.5 Hz frequency range) could be a new range to explore when experiments are designed for meditation involving multiple phenomenological components such as self-realization, positive thought inculcation, and out-of-body experiences.

Ethical approval

The study was approved by the Institutional human ethics committee of Indian Institute of Science. All the procedures performed in this study were in accordance with the ethical standards of the Institutional human ethics committee of Indian Institute of Science and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to participate

Individual informed consent was obtained from all the study participants.

Funding

The first author would like to acknowledge the support received as post-doctoral fellowship under the DST-Cognitive science research initiative (DST-CSRI-87/2018). Members and decision makers of the grant had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Data Availability

We are not in a position to make our EEG data public at this time since some of the other research work we have carried out on this data are yet to be published.

Disclosure

The authors declare that they have no conflict of interest.

Acknowledgements

The authors would like to acknowledge the team members Ms. Priya and Ms. Manju Mohan, who supported in experimental data recording.

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