Original Article

Influence of High-frequency Yoga Breathing *(Kapalabhati)* on States Changes in Gamma Oscillation

Rana Bal Budhi, Deepeshwar Singh[1], Jeetu Goswami, N. K. Manjunath, Suhas Vinchurkar[2]

Division of Yoga and Life Sciences, Swami Vivekananda Yoga Anusandhana Samsthana (Deemed to be University), Bengaluru, Karnataka, [1]Department of Yoga, School of Yoga Naturopathy and Cognitive Studies, Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow, Uttar Pradesh, India, [2]Director of Technical Sales, Magstim, Electrical Geodesics, Inc., USA

Abstract

Background: Yoga breathing has been shown to enhance neurocognitive function and positive emotions by increasing electrical power in several frequency bands and synchronizing interhemispheric brain waves. The current study examined the immediate impact of practicing *Kapalabhati* (KBH) on the electrical activity of the brain. **Methods:** Thirty-six individuals who met the inclusion and exclusion criteria and ranged in age from 18 to 25 were randomly assigned, 1:1, to the KBH (n = 18) and breath awareness (BAW) (n = 18) groups. Before data collection, both groups received their respective practices for 10 min each day for a total of 15 days. The brain's electrical activities were assessed using 128-channel EEG recording. The electrodes were placed on their scalps according to the international 10-10 system, ensuring optimal coverage of different brain regions. The EEG signals were amplified, digitized, and stored for offline analysis. **Results:** The EEG data showed that the practice of KBH significantly increased alpha waves in the frontal and temporal regions. Moreover, gamma waves increased significantly in the frontal, temporal, and occipital regions after the practice of KBH when compared with BAW. **Conclusion:** The results suggest the involvement of frontal and temporal regions, which highlights the importance of KBH in enhancing higher-order cognitive processes. These results provide valuable insights and support for the use of KBH as a potential intervention for individuals seeking to enhance their cognitive abilities.

Keywords: *Brain waves, cognition, electroencephalogram, Kapalbhati*

Introduction

Natural breathing synchronizes the electrical activities of the brain that support stimulus processing and behavioral cognitive functions.[1] Further, changes in its rhythm modulate cortical neuronal oscillation that regulates sensory, motor, emotional, and cognitive processes.[2] Similarly, Herrero *et al*. revealed that iEEG-breath coherence increases in a frontotemporal-insular network during volitionally paced breathing, and coherence increases in the anterior cingulate, premotor, insular, and hippocampal cortices during attention to breathing.[3]

The practice of yogic breathing with conscious and controlled variation in frequency, nostril dominance, resistance, and pauses has demonstrated increased electrical power in multifrequency bands and synchronization in interhemispheric brain waves, which subsequently enhances neurocognitive abilities and positive emotional states.[4-6]

Breathwork is a crucial component of the Hatha yoga practice; it is regulated by changing the rate, depth, and other above-mentioned aspects of breathing.[7] *Kapalabhati* (KBH) is a fast or high-frequency (approximately 1–2 Hz) yoga breathing practice that involves forceful exhalations followed by effortless inhalations. Studies have reported that it improves cognitive, respiratory, mental, cardiovascular, and physical health[8-12] on different parameters.

An earlier electroencephalography (EEG) study conducted on KBH[13] in 11 advanced yoga practitioners reported that the α and β-1 activity increased during the first 5 min of the 15-min practice of the KBH session. β-1 activity continued to be high in the next 5 min; however, there was increased θ activity in a later stage of practice. Further, increased θ activity persisted after the practice session of 15 min, which suggested a relative increase in slower EEG frequencies and subjective relaxation. Other

Address for correspondence:
Dr. Deepeshwar Singh, Department of Yoga, Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh, India. E-mail: deepeshwar.singh@gmail.com

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studies on KBH assessed with p300 have shown a reduction in peak latency[8] and increased peak amplitude,[14] which suggests faster attentional-immediate memory processing and an increase in neural resources availability for task execution.

Recent EEG studies have revealed that neocortical oscillations in the gamma (30–100 Hz) frequency range have been closely linked to cognitive and affective brain processes such as language processing,[15] decision-making,[16,17] memory formation,[18] problem-solving,[19] sensory perception,[20] and attention.[21]

Similarly, beneficial effects of KBH have been reported in attention, sensory perception, and other parameters aforementioned. A recent study found that following KBH pranayama, there was an increase in gamma and beta waves and a decrease in delta, theta, and alpha waves, but the difference was not statistically significant.[22] Studies examining the KBH effect on a neocortical oscillation in the gamma frequency region using high-dense array EEG are lacking. Hence, the current study explores and investigates state changes in neuronal oscillations in multiple frequency bands during the practice of KBH.

Methods

Participants

Thirty-six participants were recruited in the study and randomized into two groups by an online randomizer (https://www.randomlists.com/list-randomizer)[23] Eighteen participants with an age of 21.3 ± 2.7 years practiced KBH, and an equal number of participants with an age of 20.5 ± 2.2 years practiced breath awareness (BAW). The Edinburgh handedness inventory was used to determine the right-hand dominance of each participant.[24] After data EEG collection, three participants were excluded from the final analysis due to the high signal noise and artifacts. The consort flow diagram is shown in Figure 1. The demographic data are displayed in Table 1. The study was conducted at the Cognitive Neuroscience Laboratory of South India. Potential participants were healthy male individuals recruited from yoga institutions. Participants' recruitment was based on advertisements.

The participants recruited were willing to participate in the study and adhere to the study's protocols. Females were excluded from the study because some studies have found that their cognitive functions[25] and autonomic and respiratory variables can modulate with the menstrual cycle's phases.[26]

Those participants were excluded from the study if they (1) were on any medication that influenced cognitive and attention functions, (2) were involved in any other ongoing research activities, (3) had self-reported tobacco or illicit substance use or use of other medicine, (4) had undergone any surgery, such as gastrointestinal surgery, in the 6 months before the study, (5) used stimulants, antipsychotics, or anxiolytics, (6) had attention or cognitive impairment, or (7) had neurological and physiological abnormalities that could affect electrophysiological functions.

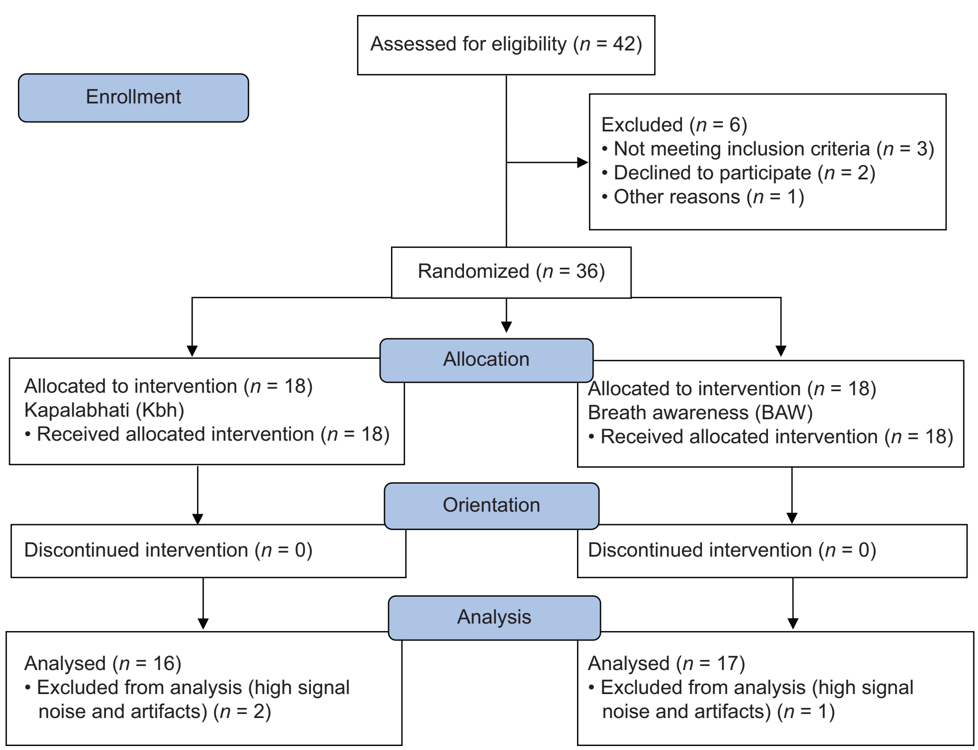

Figure 1: CONSORT Flow diagram of the study participants

Table 1: The demographic characteristics of the yoga and control groups at baseline

Variables	Mean±SD	
	KBH group	BAW group
Age	21.23±2.72	20.5±2.16
Weight	66±11.31	61.25±8.33
Height (m^2)	1.72±0.05	1.72±0.04
BMI	22.18±3.04	20.6±2.89
Education level	14.63±0.96	14.71±0.99

Education level (major of the participants was graduate and few master) it's shown in number of years. BMI: Body mass index, SD: Standard deviation, KBH: Kapalabhati, BAW: Breath awareness

Signed informed consent form was obtained from all participants in the study. All the study protocols were approved by the Institutional Ethics Committee (IEC) of the University (RES/IEC-SVYASA/110/2017) on December 2, 2017. The trial was registered at the Clinical Trial Registry of India (CTRI/2018/01/011209), and the study was performed in line with the principles of the Declaration of Helsinki.

Procedure of electroencephalogram data acquisition

All participants were asked to report by 7:00 A. M. in the cognitive neuroscience laboratory.

The EEG was recorded using a 128-channel EGI system of Net Amps 300 amplifiers (Electrical Geodesics, Inc., Eugene, OR, USA). Hydrocel Geodesic Sensor Net (GSN128) was put on the participant's scalp as per the stipulated instructions in the EGI manual. The reference channel was placed on the vertex sensor (Cz), and a notch filter was applied at 50 Hz. The impedance of each electrode was kept below 50 kΩ. The EEG signals were sampled at 250 Hz.[27] Data were acquired in NetStation™ software (version 4.5.8) which is the available component of EGI's Geodesic EEG System products. Continuous data were acquired for 18 min, i.e. baseline (bs), during 1 (d1), and during 2 (d2) 5 min each, with a minute's break in between each session.

Testing environment

For the assessments, participants sat in a dimly lit cabin with sound attenuated at 26 dB, and they were monitored through a glass window in the wall behind a participant to detect if he moved during a session. The instructions were given through a slight opening in the door so that participants could remain undisturbed during a session. The recording room temperature was maintained at 24.0°C ± 1.0°C. The average humidity was 56% on the days the team conducted the experiments.

EEG data preprocessing

The EEG data were imported into the open source MATLAB toolbox EEGLAB v13.4.4b[28] (Delorme and Makeig, 2004) using the Philips "mff" import plugin and preprocessed.

The data were screened visually to remove mechanical and motion artifacts. Three epochs of 5 min were extracted from 18 min of data (5 min each), i.e., baseline (bs), during 1 (d1), and during 2 (d2). The finite impulse response filter was applied for the low-pass filter at 75 Hz and the high-pass filter at 0.1 Hz to the data, followed by the CleanLine[29] method for removing 50 Hz of line noise. Bad channel removal was done using spectrum criteria with a standard deviation of 3 for the outlier threshold. The infomax independent component analysis, i.e., runica was conducted for artifact (muscle, eye blinks, or eye movements) removal. The spherical function of EEGLAB was used to interpolate the removed channels. Finally, the average reference was applied to the dataset.

Power spectral density was computed, and the results of the topographical distribution for the delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (13–30 Hz), and gamma were further divided into three different ranges based on a previous study,[30] i.e., (i) low-gamma (31–40 Hz), (ii) medium gamma (41–60 Hz), and (iii) high gamma (61–75 Hz) were used for statistical analyses.

Statistical analysis

A 2 × 3 design (i.e., 2 groups × 3 conditions or states) using the EEGLAB study design was used to explore the EEG data in both the KBH and BAW groups. For two groups (KBH and BAW) and three conditions (a-baseline [bs], b-during 1 [d1], c-during 2 [d2]), differences related to power spectra were examined for each of the channel measures. The different bands of interest were delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (13–30 Hz), low-gamma (30–40 Hz), medium gamma (41–60 Hz), and high gamma (61–75 Hz).

Statistical significance for the above EEG measures was set at alpha <0.05 and tested using a two-way analysis of variance (ANOVA) with 2000 permutations and a false discovery rate correction for multiple comparisons.[31] The study had two independent groups (between factors) and three conditions or states (within factors). Therefore, a two-way or mixed ANOVA was used for analysis.

Intervention

The KBH-experimental group was given orientation for 15 days, i.e., 10 min. practice of KBH at 1 Hz (60 strokes per min or 1 strokes/s), divided into 2 sessions of 5 min each with a minute break in between.

To promote uniformity in the breathing exercise, the participants of the KBH group were provided with this orientation. The BAW-passive control group was provided with orientation on the same days as the KBH group.

Results

The following power spectrum topographic maps were compared in the EEGLAB study:

(i) Alpha (8–12 Hz), (ii) beta (13–30 Hz), (iii) theta (4–8 Hz), (iv) delta (1–4 Hz), (v) low gamma (30–40 Hz), (vi) medium gamma (41–60 Hz), and high gamma (61–75 Hz). Major changes occurred in the frontal and temporal regions of the brain. Therefore, frontal and temporal results have been reported in this study. For convenience, topographic maps of the frontal region of the brain have been reported in the current study.

Frontal region of the brain

The KBH group had significant differences within the group (different states) comparison, the scalp location for different frequency bands (power spectrums) were as follows:

1. Alpha in both hemispheres, i.e., left (E34, E33 or F7, E27, E28, E24 or F3) at $P < 0.05$ and right (E116, E123, E122 or F8) at $P < 0.01$, it is shown in Figure 2. There was no between and interaction effect
2. Low gamma in both the left hemisphere (E34, E33 or F7, E26, E27, E28, E24 or F3, E23) at $P < 0.05$ and in the right hemisphere (E116, E123, E122 or F8, E2) at $P < 0.01$ is shown in Figure 3. There was no between and interaction effect
3. Medium gamma in the left hemisphere (E33 or F7, E34, E26, E27, E28, E24 or F3, E23) at $P < 0.05$ and in the right hemisphere (E116, E123, E122 or F8, E2) at $P < 0.01$ is displayed in Figure 4. There was no between and interaction effect
4. High gamma in the left hemisphere (E33 or F7, E34, E26, E27, E28, E24 or F3, E23) at $P < 0.05$ and in the right hemisphere (E123, E122 or F8, E2) at $P < 0.01$ is shown in Figure 5. There was no between and interaction effect.

While there were no significant changes in BAW in the above-mentioned power spectrum except in the alpha band in a few channels, i.e., (E117, E123, and E124) at a less significant level, i.e., $P < 0.05$. Similarly, there were no significant changes in KBH in the delta frequency band; however, there were significant changes in the BAW group in a few channels, i.e., (E27, E28, E33, and E34 in the left and E116, E117, and E123 in the right hemispheres) at $P < 0.05$, as shown in Figure 6.

In the beta and theta frequency bands, there were significant differences in the within-group comparison in both the groups, where the BAW group had a higher magnitude of significance difference as compared to KBH at $P < 0.01$, which is displayed in Figures 7 and 8, respectively. There was no between and interaction effect.

Temporal region of the brain

The KBH group had significant differences in within-group (different states) comparison, but there were no between-group or interaction effects. The scalp location for different frequency bands (power spectrums) was as follows:

1. Alpha in (E39, E40, E44) at $P < 0.05$
2. Low gamma in both hemispheres right (E39, E40, E44, E45, E46, E49, E50, E56, E57) and left (E100, E101, 102, E107, E108, E113, E114, E115), at $P < 0.01$
3. Medium in hemispheres left (E39, E40, E44, E45, E46, E50, E57) and right (E100, E101, E107, E108, E113, E114, E115), both at $P < 0.05$
4. High gamma in hemispheres left (E39, E40, E44, E45, E46, E50, E57) and right (E100, E101, E107, E108, E113, E114, E115), both at $P < 0.05$.

In the temporal region of the brain, as well as the above-mentioned power spectrum or frequency band, there were no significant differences in the states of the BAW group. While in the beta, theta, and delta frequency bands, there were significant differences in the states of both groups, where KBH had a higher magnitude of significant changes in more channels and BAW had a lesser magnitude of significant changes in fewer channels.

Similarly, in the occipital region, KBH had significant changes in all three rhythms of the gamma frequency band of higher magnitude than BAW.

Discussion

The spectral analysis of the present study results reveals that during the practice of KBH, there was a significant increase in alpha waves in the frontal region, with higher magnitude and lesser magnitude in the temporal region. Further, the gamma band was categorized into three rhythms based on a previous study.[30] The three gamma rhythms assessed in this study were (i) low gamma (31–40), (ii) medium gamma (41–60), and (iii) high gamma (61–75). In the low gamma rhythm or power spectrum, KBH showed significant differences in the frontal, temporal, and occipital regions. Similarly, medium gamma and high gamma rhythms also revealed significant differences in the frontal, temporal, and occipital regions of the brain. BAW showed a very less significant change when compared with the baseline data. To the best of our knowledge, this is the first study to report the KBH influence on gamma oscillation using high-density array electroencephalography.

The findings of the increase in alpha waves are consistent with the previous studies.[32,33] Alpha power inhibits irrelevant sensory inputs.[34] This hypothesis was supported by the increase of alpha power when subjects were asked to imagine a stimulus or perform tasks that required the redirection of attention toward internal objects. In addition, alpha rhythm modulation has been shown to play a part in selective attention processes by regulating thalamocortical sensory transmission[35] and thus contributing to functional inhibition.[36,37] The increase in alpha power spectrum in the frontal region of the brain during KBH might be the result of suppressing irrelevant sensory input in a top-down fashion,[38] as the participants have to actively focus on active exhalation rather than inactive exhalation (normal breathing).

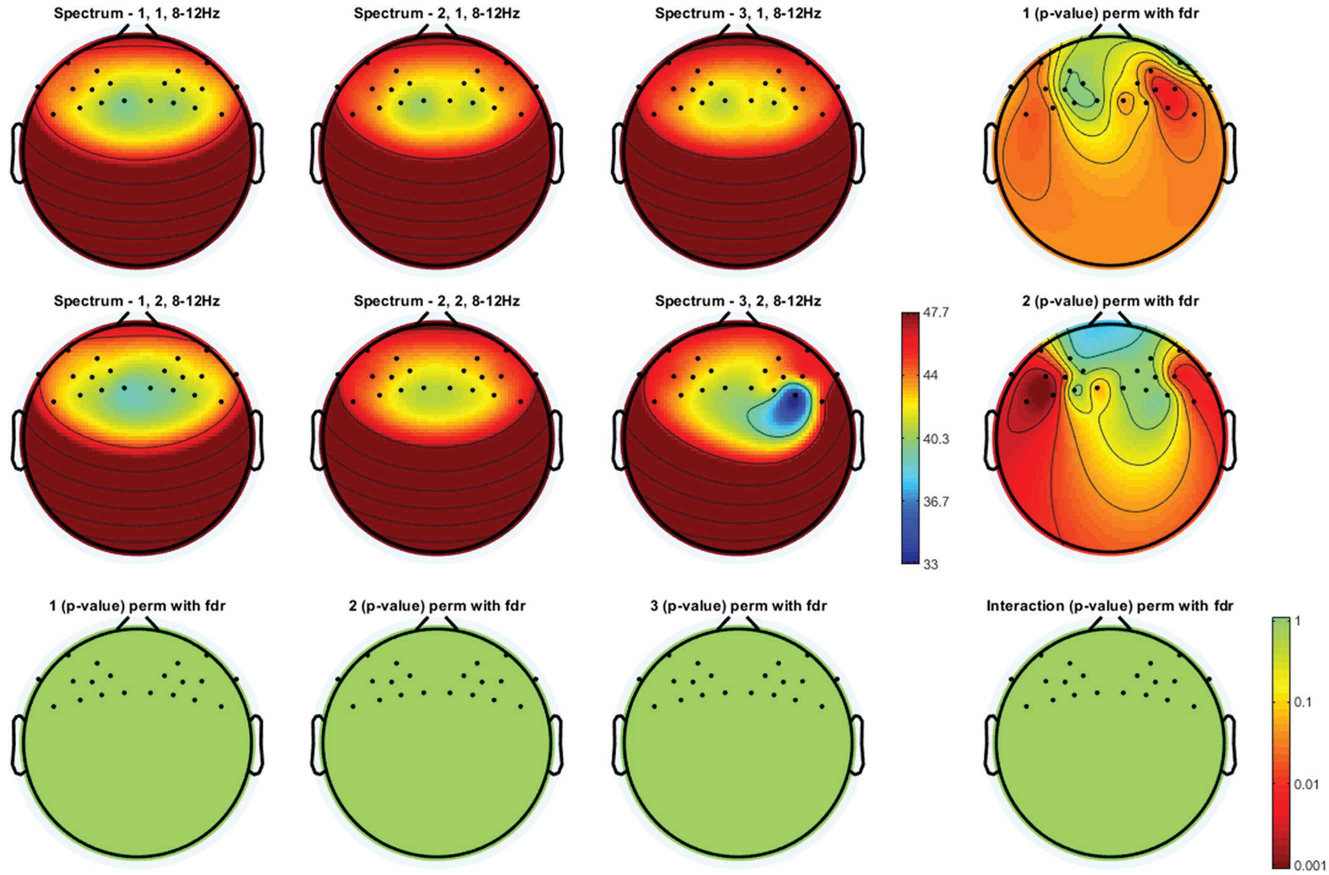

Figure 2: Alpha power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

Gamma brainwaves, the fastest brain waves (high frequency, like a flute), are associated with the simultaneous processing of data from several brain regions.[33] Further, these waves are linked to varied cognitive functions such as attention, memory, visual perception, and long-range neuronal communications.[39,40] Researchers have discovered that it was highly active in the states of altruism, universal love, and the higher virtues.[41] Further, it has been speculated that gamma rhythms modulate consciousness and perception, and its higher magnitude has been associated with spiritual emergence and expanded consciousness.[30] One of the recent studies reported decreased delta, theta, and alpha waves and increased gamma and beta waves after KBH pranayama. However, there were no statistically significant spectrum changes in EEG waves before, during, and after KBH practice.[22] The authors speculated that 5 min. Short-duration KBH practice could have been an insufficient maneuver to bring about statistically significant changes. The details of the EEG equipment used in the aforementioned study are also not available. In the present study, KBH was practiced for 10 min with a break of 1 minute in-between, and the result demonstrates that there was enhanced gamma power in the KBH group in during-1 and during-2 when compared with baseline in all the three categories of gamma rhythms. Studies investigated earlier had established significant increases in parieto-occipital gamma power in long-term practitioners of mindfulness[42] and Vipassana meditation.[43] In addition, studies on yogic breathing have depicted a significant increase in fronto-central-occipital after *Bhramari pranayama*,[44] *Sudarshan kriya* Yoga,[45] and long-term practice of pranayama.[46] Similarly, the findings of the current study show an increase in the power of gamma oscillation in the fronto-temporal-occipital region of the brain.

A recent study on mice testified that breathing causes respiration-locked oscillations that synchronize neocortex large areas and impose global brain rhythm.[47] Zelano *et al*.[1] further demonstrated that nasal airflow is the major force for synchronized neuronal activity in both olfactory and nonolfactory brain areas, including the amygdala and hippocampus. It is well known that the olfactory and limbic systems are linked closely; nasal breathing rhythms propagate the limbic system and correspondingly generate effects on cognitive functions such as emotional processing and memory formation. Heck *et al*.[2] also experimentally revealed that respiration through multisensory pathways produces a subtle continuous rhythmic modulation of neuronal activity in the cortex that alters sensory, motor, cognitive, and emotional processes. Similarly, during

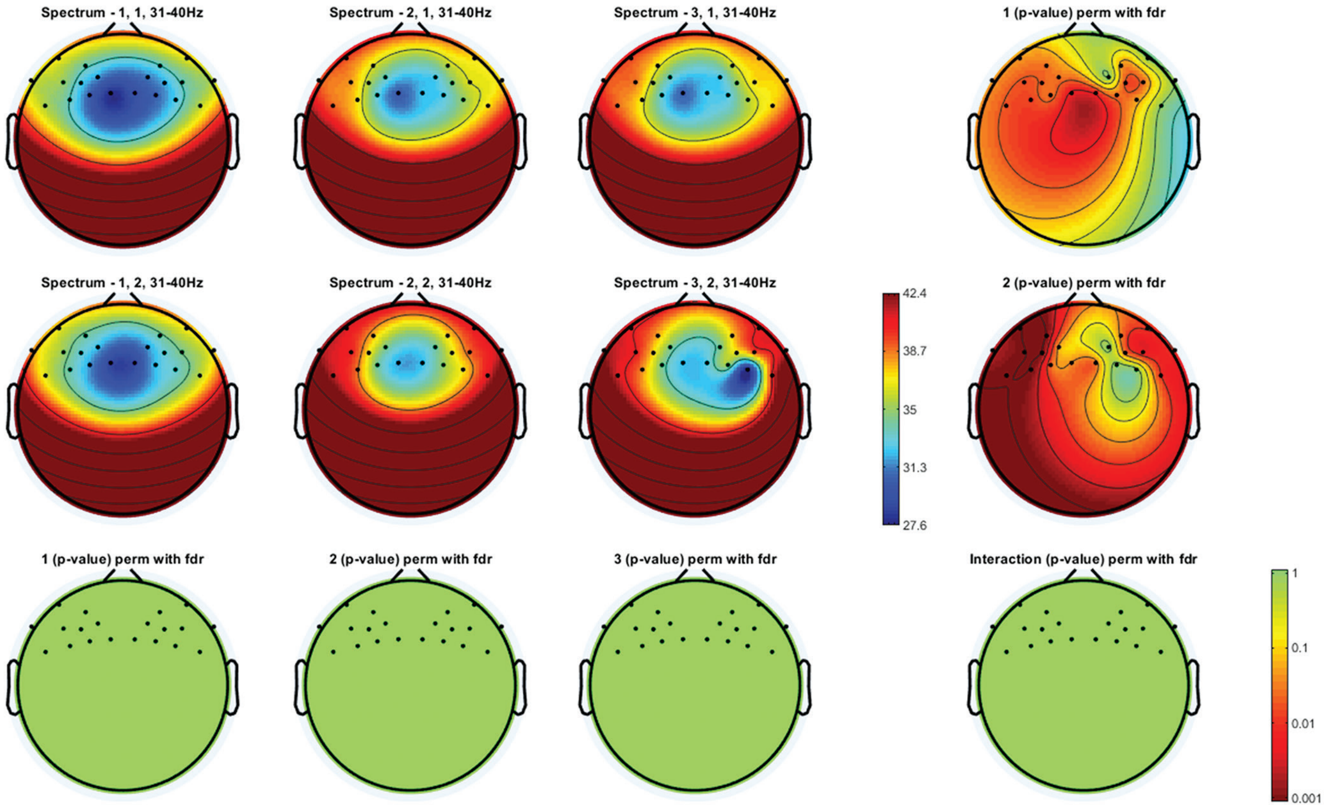

Figure 3: Low Gamma power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

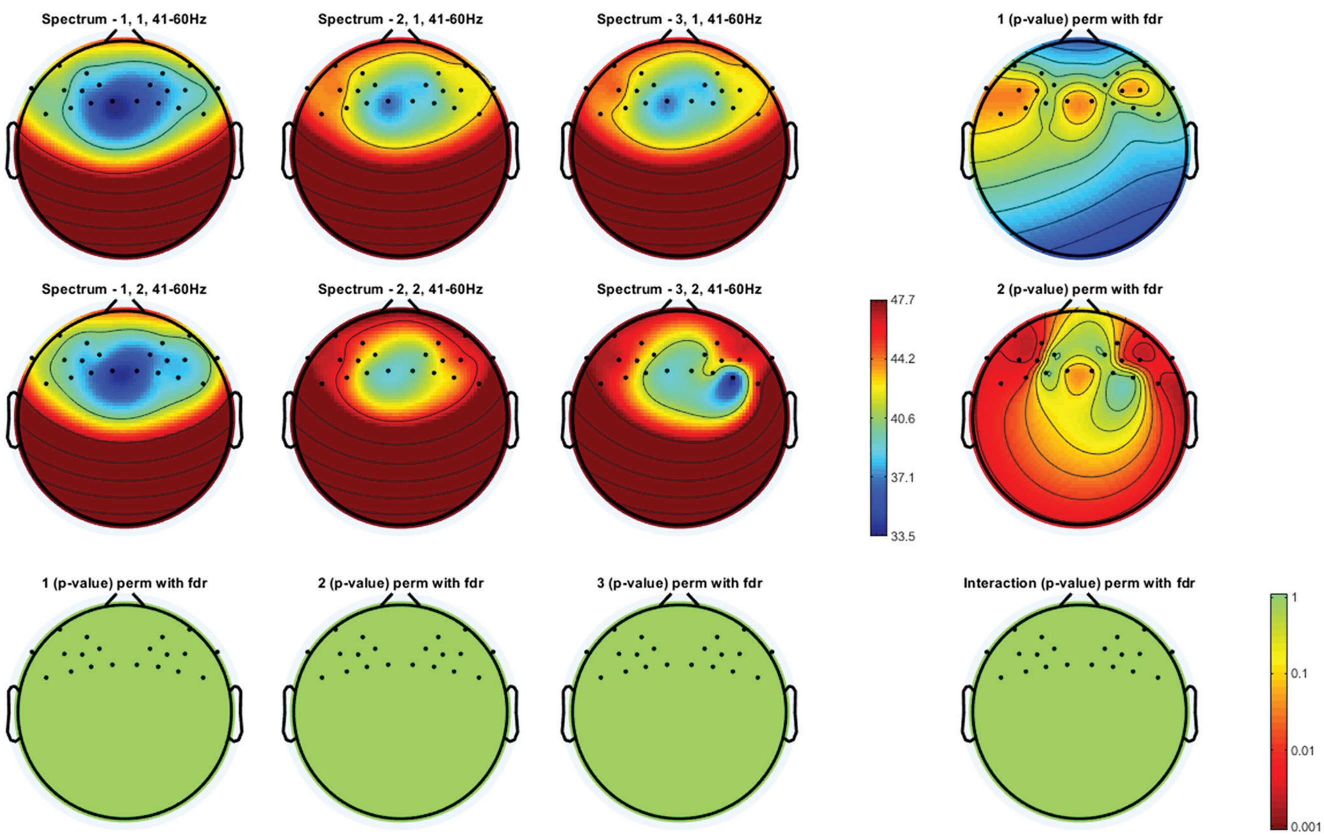

Figure 4: Medium Gamma power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

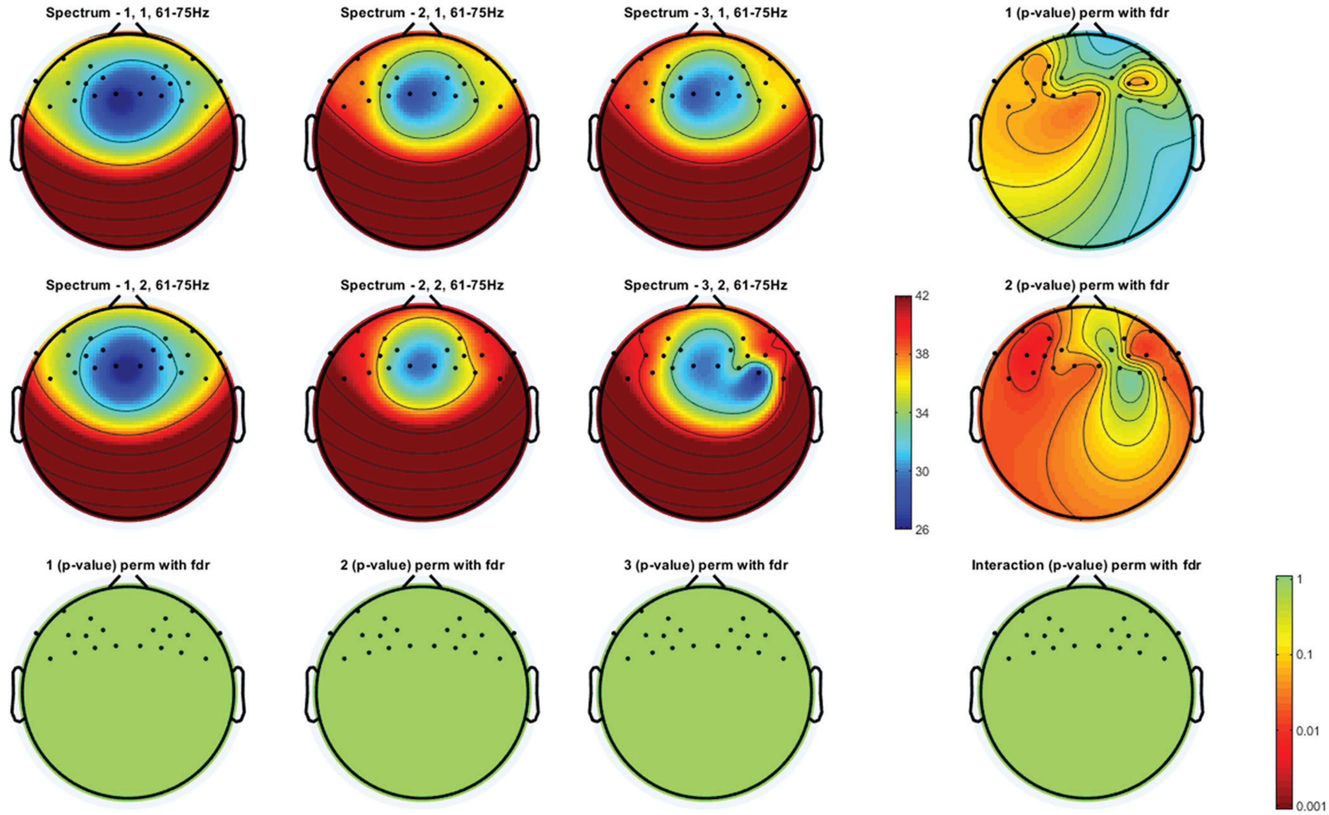

Figure 5: High Gamma power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

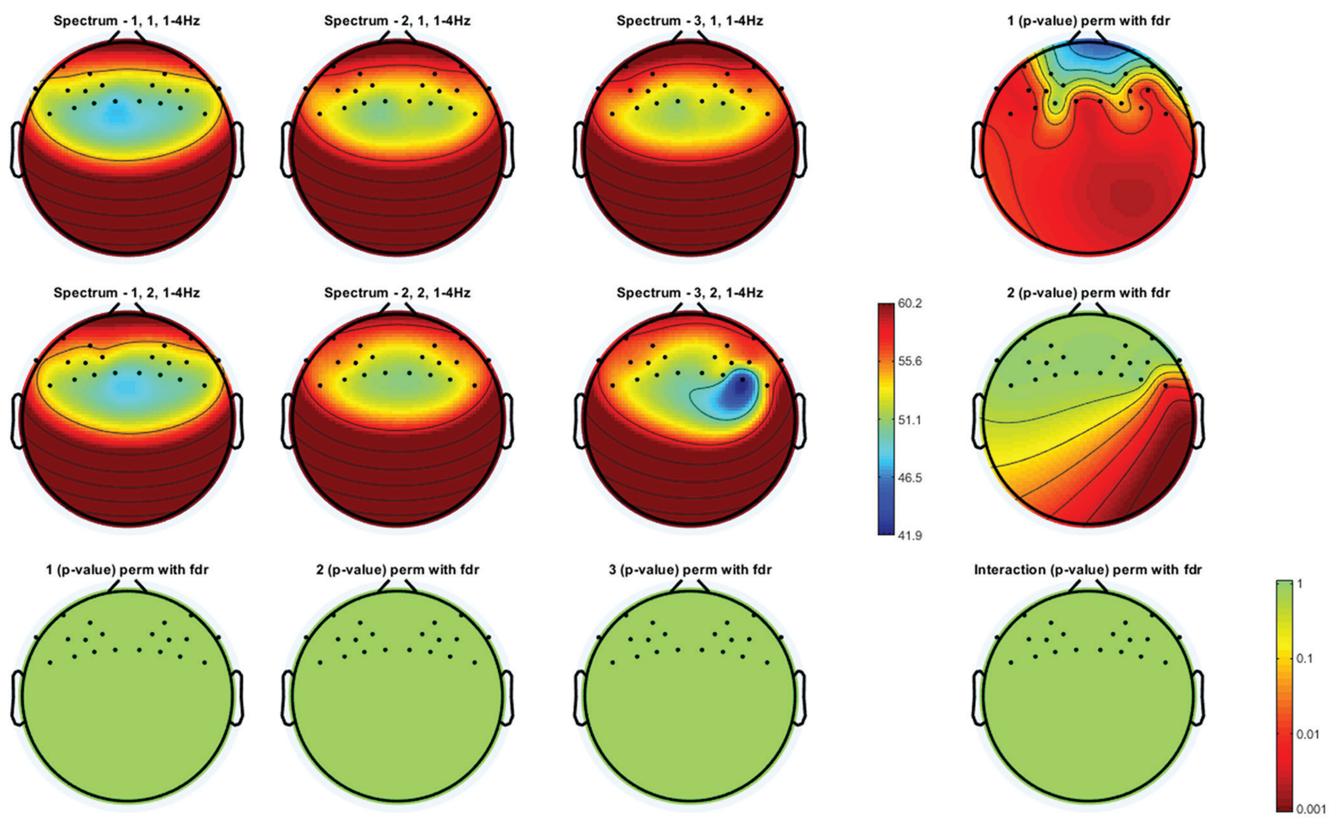

Figure 6: Delta power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

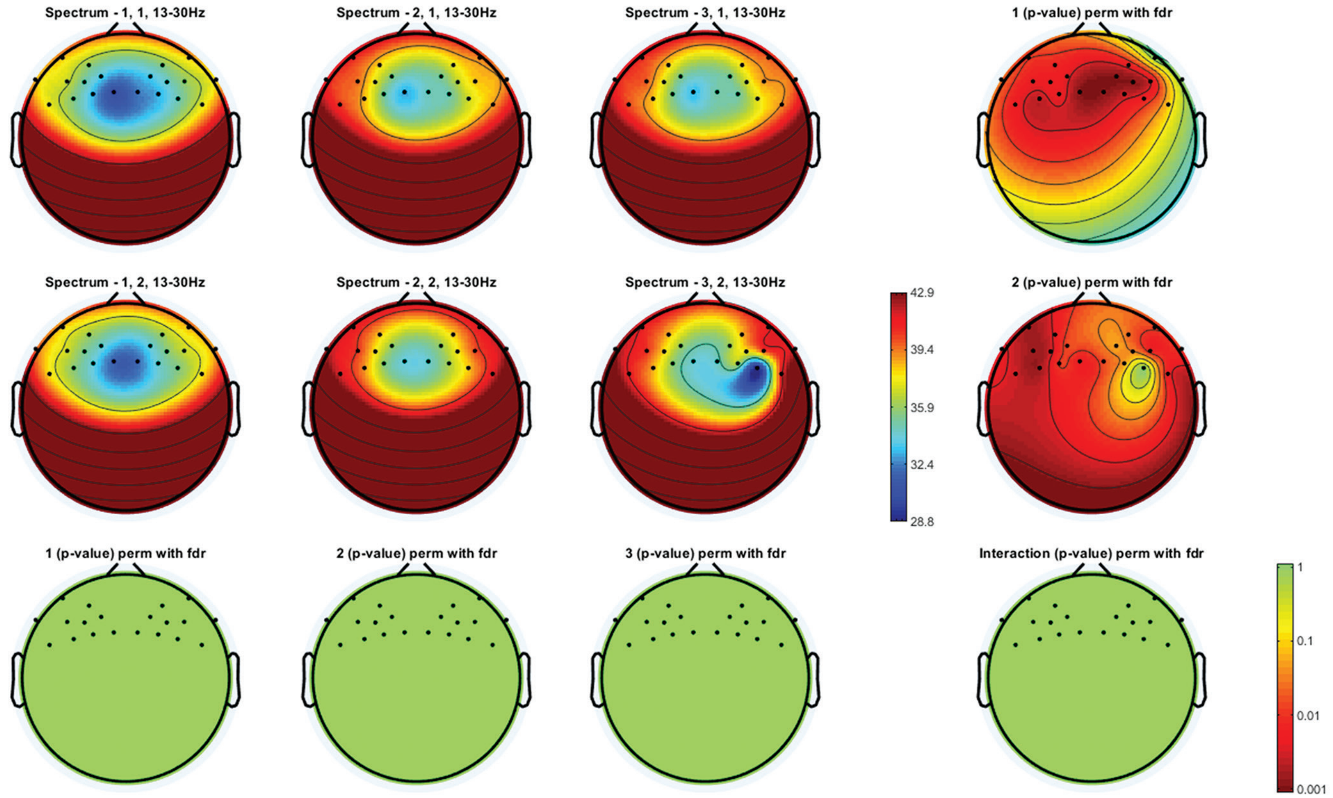

Figure 7: Beta power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

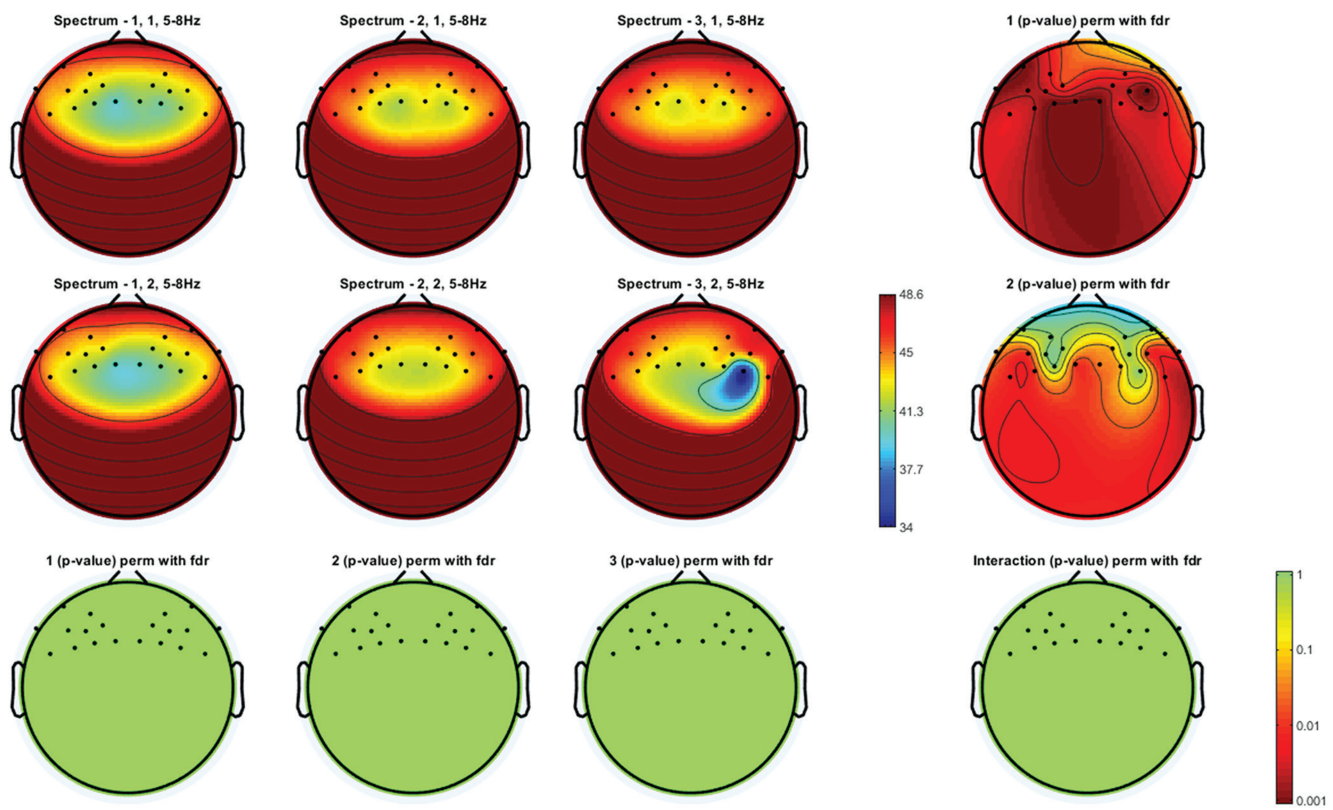

Figure 8: Theta power topography of the brain during *Kapalabhati* and breath awareness practice. Note: 1,1 means baseline (bs) of breath awareness; 2,1 means during-1; 3,1 means during-2, and 1,2 means bs of *Kapalabhati*, 2,2 means during-1, and 3,2 means during-2 of *Kapalabhati*

KBH practice, a medium pace with abdominal movement may produce multisensory pathways to cortical areas.[48] These sensory inputs may then generate a brain rhythm with high-frequency cerebral activation, thereby resulting in increased power in the gamma brain rhythm or power spectrum in a topographic map. In addition, a continuous focus on forceful active exhalation rather than normal breathing might have increased top–down control, resulting in increased gamma power, as reported in other previous studies.[49,50]

The inclusion of only healthy male participants restricts the generalizability of the current study's findings. A future study with a larger sample size for both males and females is required to scientifically validate the findings of the present study. In addition, the current study had only during sessions of intervention for comparison with the baseline (pre). Hence, the future study can be designed with a postsession of equal duration and simultaneous recording of respiration with EEG before, during, and after KBH to authenticate the findings of the present study. In addition, studies using positron emission tomography and functional magnetic resonance imaging can be investigated for the same.

Conclusion

The findings demonstrate that the practice of KBH increases the alpha power spectrum prominently in the frontal region and increases power in different ranges of gamma oscillation in the fronto-temporal-occipital region of the brain. As aforementioned, these findings indicate that KBH increases the cortical activities that may help in better attention, emotional control, memory, and a higher cognitive state. So far, this is the first study that has investigated the effect of KBH on the brain with a high-dense array of EEG in the multifrequency band.

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Conflicts of interest

There are no conflicts of interest.

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