Original Article

High-Frequency Cerebral Activation and Interhemispheric Synchronization Following Sudarshan Kriya Yoga as Global Brain Rhythms: The State Effects

Abstract

Context: Respiration is known to modulate neuronal oscillations in the brain and is measured by electroencephalogram (EEG). Sudarshan Kriya Yoga (SKY) is a popular breathing process and is established for its significant effects on the various aspects of physiology and psychology. **Aims:** This study aimed to observe neuronal oscillations in multifrequency bands and interhemispheric synchronization following SKY. **Settings and Design:** This study employed before- and after-study design. **Subjects and Methods:** Forty healthy volunteers (average age 25.45 ± 5.75, 23 males and 17 females) participated in the study. Nineteen-channel EEG was recorded and analyzed for 5 min each: before and after SKY. Spectral power for delta, theta, alpha, beta, and gamma frequency band was calculated using Multi-taper Fast Fourier Transform (Chronux toolbox). The Asymmetry Index was calculated by subtracting the natural log of powers of left (L) hemisphere from the right® to show interhemispheric synchronization. **Statistical Analysis:** Paired *t*-test was used for statistical analysis. **Results:** Spectral power increased significantly in all frequency bands bilaterally in frontal, central, parietal, temporal, and occipital regions of the brain after long SKY. Electrical activity shifted from lower to higher frequency range with a significant rise in the gamma and beta powers following SKY. Asymmetry Index values tended toward 0 following SKY. **Conclusions:** A single session of SKY generates global brain rhythm dominantly with high-frequency cerebral activation and initiates appropriate interhemispheric synchronization in brain rhythms as state effects. This suggests that SKY leads to better attention, memory, and emotional and autonomic control along with enhanced cognitive functions, which finally improves physical and mental well-being.

Keywords: *Brain rhythms, cerebral activation, electroencephalogram, interhemispheric synchronization, Sudarshan Kriya Yoga*

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Introduction

Respiration entrains the electrical activity of the brain. Respiratory rhythms modulate neural oscillatory patterns throughout the brain and organize neuronal activity. The link between breathing cycle and brain activity was revealed by Adrian in hedgehog in 1942.[1] This link is further established by recent studies in animals[2,3] as well as in humans.[4-6]

Yogic practices with conscious and controlled variation in breathing frequency, resistance, pauses, and nostril dominance are found to increase electrical power in multifrequency bands and are known to enhance interhemispheric brain wave synchronization, which subsequently improves neurocognitive abilities and emotional states in a positive way.[7-10]

Sudarshan Kriya, a rhythmic breathing technique, is a form of yoga (hereby mentioned as Sudarshan Kriya Yoga [SKY]) and is introduced through workshops conducted by the Art of Living (AOL) foundation. Physiological and psychological studies have indicated that SKY reduces anxiety and stress;[11] leads to decline in blood lactate and increase in antioxidant levels and natural killer cells;[12,13] improves autonomic balance;[14-16] reduces posttraumatic stress disorder symptoms; and leads to better sleep and increased enthusiasm,[17] in addition to providing antidepressive efficacy.[18] At molecular level, SKY has rapid effects on gene expression profile in circulating immune cells[19] and may exert effects on immunity, aging, cell death, and stress regulation through transcriptional regulation.[20]

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Effect of SKY on brain rhythms has not been studied adequately so far. Earlier electroencephalogram (EEG) studies have shown that SKY induces a state of wakeful alertness,[21] and SKY followed by *Sahaj Samadhi* meditation exhibits larger mismatch negativity amplitudes suggestive of enhanced preattentive perceptual process, enabling better change detection in auditory sensory memory;[22] and enhanced theta band activity; as well as increased theta coherence during deep meditation.[23]

Previous electrophysiological studies on SKY till date have been performed on the shorter version (short Sudarshan Kriya) which is recommended as a daily practice instead of the long Sudarshan Kriya which is advised to be done once a week. The present study investigates and explores state changes in neuronal oscillations in multiple frequency bands immediately after the conclusion of long SKY practice.

Subjects and Methods

Forty individuals (average age 25.45 ± 5.75, 23 males and 17 females) participated in the study. Individuals with a history of epilepsy, any psychological disorder, or prolonged medication were excluded from the study. The study participants were randomly selected from AOL Centre, Bengaluru, Karnataka, India. The Department of Human resources advertised about the research study and interested volunteers participated in the study. All participants had attended Happiness program organized by the AOL Foundation and had learned the process of doing SKY by a trained AOL teacher. They were regular practitioners of SKY having experience of doing SKY for <1 year to >7 years; maximum years of practice were 18 years and 15 persons had more than 6 years of experience.

Ethics, consent, and permission

The experimental protocol was explained to the participants. The informed consent and permission were obtained from all individual participants. Ethical clearance was obtained from the Ethical Committee of Ved Vignan Maha Vidya Peeth.

Recording conditions

Superspec 24 (Recorders and Medicare Systems Pvt. Ltd., Chandigarh, India), a 24-channel EEG system, was used to acquire EEG signals. Electrodes were placed according to the international 10–20 system. EEG was acquired from the frontal (FP1, FP2, F3, F4, F7, and F8), centro-temporal (T3, T4, C3, C4, FZ, CZ, PZ, T5, and T6), parietal (P3 and P4), and occipital (O1 and O2) regions. All electrodes were referenced to the linked earlobe with the ground at the forehead. The signal was acquired with the band-pass filter of 0.1–75 Hz at the sampling frequency of 256 Hz. The room was dimly lit, and the room temperature was controlled to 25°C. Impedance levels were kept below 5 kΩ.

Protocol

The participants rested for 15 min and the electrodes were placed. EEG was recorded in supine eyes closed condition before and after long SKY. Five minutes' data each, before, and after Sudarshan Kriya were acquired and analyzed. The participants practiced long SKY in synchronization with the guided audio instructions, and consistency in breathing frequency was maintained for each participant.

Procedure for long Sudarshan Kriya

Long SKY is a cyclic breathing and is performed in sitting posture, with the spine erect preceded by three-stage pranayama in controlled *Ujjaayi* breathing (9 min), *Bhastrika* pranayama (9 min), and Om chanting (2 min). During SKY, three different rhythms of breath (slow, medium, and fast) are followed cyclically for 7–8 consecutive rounds (20 min) followed by 20 min rest in supine position (*Yog-nidra*). It is practiced under the guidance of a trained teacher once in a week. Long SKY has been described in detail in earlier publication.[16]

Analysis

Electroencephalogram analysis

Data were screened visually to remove mechanical and motion artifacts, and nonoverlapping 40 epochs of 4 s each were selected from 5-min EEG each, before, and after SKY. MATLAB 2016b (The Mathworks Inc., Natick, MA, USA, 2016) was used for analysis along with freely available toolboxes. Epochs for each section were appended. We extracted delta (1–4 Hz), theta (4.5–7.5 Hz), alpha (8–13 Hz), beta (13–25 Hz), and gamma (35–45 Hz) bands for analysis. Mono-polar montage of channels was utilized followed by re-referencing using the average of all channels. The artifact-free signal was used to calculate spectral power (uV2) using Multi-taper Fast Fourier Transform (Chronux toolbox)[24] band passed at 1 and 60 Hz. Log of the spectral power was taken to normalize the spectral power. The data for each given band were averaged across the range. CZ has been omitted due to high noise in the signal. In total, we had the spectral power of five frequency bands at the 18 locations, before and after SKY. These 18 locations were further averaged across different regions: left frontal (FP1, F7, F3, and FZ), right frontal (FP2, F8, F4, and FZ), left temporal (T3 and T5), right temporal (T4 and T6), occipital (O1 and O2), parietal (P3, P4, and PZ), and central (C3 and C4) regions.

Statistical analysis

Paired *t*-test was applied for statistical analysis to compare results before and after SKY for five frequency bands at seven different regions and Asymmetry Index. Statistical test was considered significant at ≤0.05.

Results

Spectral power of EEG, before and after SKY, was calculated in all the five frequency bands (delta, theta, alpha, beta, and gamma) at frontal, central, parietal, temporal, and occipital regions. The total average power across all locations in different frequency bands (from delta to gamma) is plotted in Figure 1.

After SKY, a significant increase in average spectral power was observed in all frequency bands from delta to gamma. The spectral power values before and after SKY at the seven cortical regions in five frequency bands are shown in Table 1.

The percentage change was calculated to compare the actual changes in spectral power and is shown in Figure 2. A statistically significant increase was observed in the spectral power of delta, theta, alpha, beta, and gamma bands after SKY as compared to baseline and is presented in terms of percentage change. Spectral power in gamma and beta relatively increased more (10%-15%) than delta, theta and alpha (4%-8%).

Asymmetry Index

To observe an expression of balance between right® and left (L) cerebral hemispheres, Asymmetry Index[25] was calculated by subtracting the natural log of left hemisphere power from the natural log of right hemisphere power (ln[right power] − ln[left power]), for all the five frequency bands [Figure 3]. This approach results in an unidimensional scale representing the relative activity of the right and left hemispheres. Zero value or middle point of the scale of Asymmetry Index represents symmetrical activity, coherence, and connectivity between the right and left hemispheres. It has been observed that Asymmetry Index values which were higher than 0 at baseline decreased after SKY and values lower than 0 at baseline increased after SKY significantly and tended toward 0. The balancing state effect of SKY was observed from the Asymmetry Index. SKY showed the pattern of balancing the activity between the right and left cerebral hemispheres in all the five frequency bands. It is clearly observed from Figure 3 that after SKY, coherence between the right and left hemispheres increased.

Discussion

The primary findings of the study are:

1. Increased overall brain activation after long SKY. Neuronal oscillations increased significantly in all frequency bands bilaterally in frontal, central, parietal, temporal, and occipital regions of the brain
2. Percentage change in spectral power before and after SKY reveals that immediately after SKY, power shifts from lower to higher frequency range with statistically significant rise in the gamma and beta powers when compared with delta, theta, and alpha powers
3. Asymmetry Index showed the interhemispheric synchronization after SKY, which indicates increased connectivity, complexities, and symmetry between the right and left cerebral hemispheres.

The above findings suggest that SKY generates a global brain rhythm dominantly in high-frequency range and increases synchrony between the left and right cerebral hemispheres.

Some of the recent studies conducted in rodents and humans acquired respiration and intracranial encephalograph (iEEG) simultaneously throughout the brain and found strong coherence in breathing and neuronal oscillations.[2-6]

Sudarshan Kriya Yoga generates global brain rhythm

Increase in the multifrequency oscillations in all brain regions and generation of global brain rhythm following SKY is consistent with the earlier findings that respiration

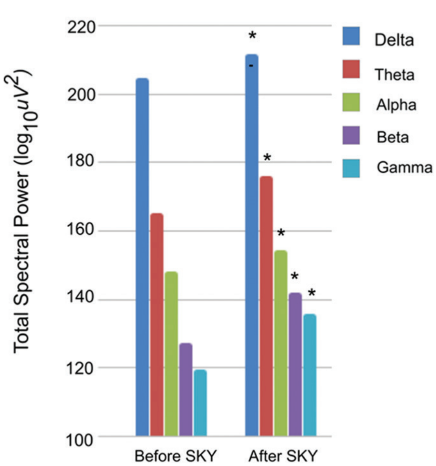

Figure 1: Total average spectral power. Total average spectral power (log10 uV2) of delta, theta, alpha, beta, and gamma brain waves (represented by blue, red, green, purple, and teal colors, respectively), before and after Sudarshan Kriya Yoga: Significant increase in spectral power in all the five frequency bands after Sudarshan Kriya Yoga. *marks the significant differences between before and after values (*P* ≤ 0.05)

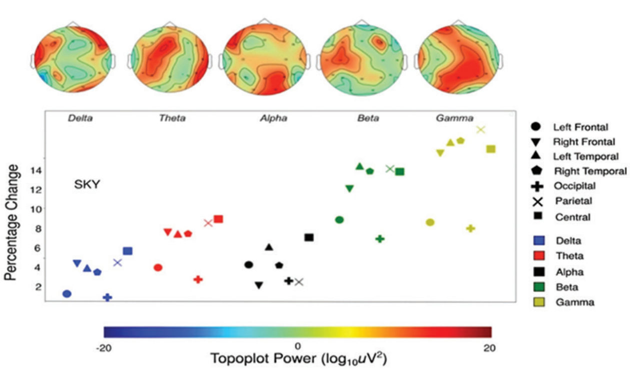

Figure 2: Percentage change in spectral power. Percentage change in spectral power before and after Sudarshan Kriya Yoga (delta, theta, alpha, beta, and gamma: represented by blue, red, black, dark green, and light green colors, respectively) in all the five frequency bands across seven regions (left frontal, right frontal, left temporal, right temporal, occipital, parietal and central). Percentage change is showing higher increase in gamma and beta power after Sudarshan Kriya Yoga as compared to delta, theta, and alpha. Topoplots are showing increase in delta, theta, alpha, beta, and gamma power after Sudarshan Kriya Yoga

Table 1: Mean spectral power before and after Sudarshan Kriya Yoga: Showing mean spectral power (log10 uV2) before and after Sudarshan Kriya Yoga in five frequency bands (delta, theta, alpha, beta, and gamma) at 7 cortical regions (left frontal, right frontal, left temporal, right temporal, occipital, parietal, and central)

Brain waves	Event	Brain regions						
		Left frontal	Right frontal	Left temporal	Right temporal	Occipital	Parietal	Central
		Mean spectral power (log10 uV2)						
Delta	Before SKY	32.64	27.53	27.65	27.12	34.51	27.39	27.85
	After SKY	33.11* (3.54, 0.132)	28.76* (6.56, 0.187)	28.77* (5.99, 0.185)	28.09* (6.15, 0.158)	34.87 (1.31, 0.281)	28.64* (7.07, 0.177)	29.44** (7.7, 0.206)
Theta	Before SKY	25.46	22.14	22.27	21.63	29.26	22.06	22.42
	After SKY	26.49* (8.7, 0.119)	23.82** (11.13, 0.15)	23.93** (11.07, 0.149)	23.24** (11.14, 0.144)	30.1* (3.87, 0.218)	23.94** (12.52, 0.149)	24.42** (11.48, 0.174)
Alpha	Before SKY	22.07	20.51	20	19.97	24.93	20.96	19.92
	After SKY	23.03* (5.38, 0.177)	20.98 (1.92, 0.243)	21.23** (5.48, 0.224)	20.82* (3.27, 0.261)	25.61* (2.85, 0.237)	21.51* (2.09, 0.262)	21.33** (7.03, 0.20)
Beta	Before SKY	18.89	17.17	17.23	17.18	22.11	17.32	17.34
	After SKY	20.56** (8.41, 0.198)	19.21** (12.87, 0.159)	19.69** (12.95, 0.189)	19.53** (13.94, 0.168)	23.64** (6.59, 0.233)	19.73** (13.13, 0.184)	19.71** (13.08, 0.181)
Gamma	Before SKY	17.17	15.89	16.24	16.34	21.49	16.1	16.16
	After SKY	18.64** (6.42, 0.229)	18.35** (13.63, 0.18)	18.94** (13.93, 0.193)	19.08** (15.01, 0.182)	23.21** (7.04, 0.243)	18.97** (15.55, 0.184)	18.73** (12.9, 0.199)

*Marks the significant difference ($P \leq 0.05$), **Marks highly significant difference ($P \leq 0.005$). First value in the parentheses is the *t*-statistic value followed by the standard error

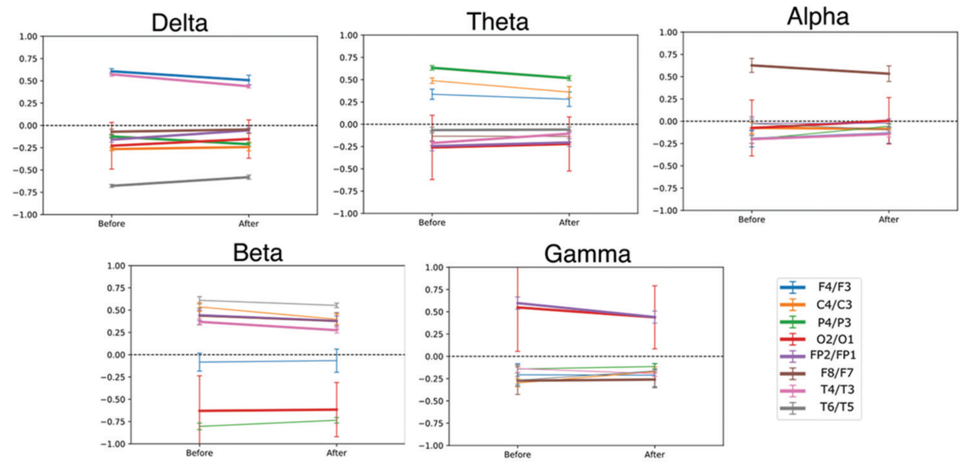

Figure 3: Asymmetry Index. Asymmetry Index for all the five frequency bands (delta, theta, alpha, beta, and gamma) at a given electrode pair (F4/F3, C4/C3, P4/P3, O2/O1, FP2/FP1, F8/F7, T4/T3, T6/T5). Asymmetry Index values which were higher than 0 at baseline decreased after Sudarshan Kriya Yoga and values lower than 0 at baseline increased after Sudarshan Kriya Yoga significantly and tended toward 0. Thick lines are showing significant differences before and after Sudarshan Kriya Yoga

causes respiration-locked oscillations that are synchronized across large areas of neocortex[5,4] and imposing global brain rhythm.[3] Zelano *et al*.[4] further established that nasal airflow is the main driving force to synchronize the activity of neurons in both olfactory and nonolfactory brain regions including hippocampus and amygdala. Knowing the fact that olfactory and limbic systems are closely linked; rhythms of nasal breathing propagate to limbic system also and generate corresponding effect on cognitive functions such as memory formation and emotional processing. Heck *et al*.[5] also experimentally revealed that respiration-locked activity propagates from primary sensory areas to other parts of the cortex that do not receive direct respiration-related sensory input. Respiration via multisensory pathways generates continuous, subtle, and rhythmic modulation of cortical neuronal activity that alters sensory, motor, emotional, and cognitive processes. Similarly, during SKY, *Ujjaayi* breathing with increased resistance and breath holding; *Bhastrika* pranayama in fast pace with chest and abdominal muscle movement; and normal breathing in cyclic slow, medium, and fast pace may generate multisensory pathways to cortical regions.[26] These sensory inputs may then generate a global brain rhythms with high-frequency cerebral activation and may subsequently influence cortical activity underlying sensory, motor, emotional, and cognitive functions, which support the commonly encountered psychological and physiological benefits of SKY.[13,14,16,17]

Conscious and controlled breathing with awareness are the intrinsic part of yogic practices since ages and are known for their therapeutic effects. SKY is a combination of different rhythms of breath (slow during *Ujjaayi* pranayama, fast during Bhastrika pranayama, and variable breathing frequencies during Sudarshan Kriya). Moreover, breathing in SKY is done with full awareness toward the process of breathing. Herrero *et al*.[6] emphasized that volitional and conscious breathing involves more complex higher brain circuits, unlike natural automatic breathing which is driven by the medulla oblongata in the brain stem. Herrero *et al*.[6] further suggested that fronto-temporal-insular cortices are involved during volitional fast pace breathing along with the increase in iEEG-breath coherence in the same cortices network, and conscious breathing modulates anterior cingulate, premotor, insular, and hippocampal cortices, thereby increasing the coherence among the same regions. During SKY, similarly, it is likely that iEEG-breath coherence increases in nonolfactory regions of the brain and thereby causes changes in cognitive and emotional states often observed among those practicing SKY.

Effect on interhemispheric synchronization

According to bio-hemispheric autonomic model,[27] the hemispheric lateralization plays a role in the management of the autonomic nervous system. Asymmetrical activation of bilateral homologous brain regions is responsible for autonomic management and is associated with different forms of physiological arousal and behaviors. Right asymmetries are associated with sympathetic high arousal and left hemispheric asymmetries are related with parasympathetic freeze tendencies, and return to relative symmetry is associated with improved autonomic regulation. In the present study, Asymmetry Index across all bands and cortical regions has improved, suggesting that SKY initiates appropriate balance in interhemispheric synchronization and subsequently may improve in the autonomic balance. This finding complements earlier studies correlating SKY and heart rate variability (HRV). Studies evidenced that after SKY, parasympathetic tone and HRV increase, sympathetic tone decreases, and autonomic balance improves.[14-16]

Effect of Sudarshan Kriya Yoga on neurophysiological and psychological states

Extraction of different frequency components from the EEG signals establishes an association between brain states and function. Different levels of cerebral integration mediated by spatial and temporal oscillatory activity in multiple frequency bands are linked to precepts, memories, emotions, thoughts, cognition, and actions, indicating that different frequency oscillations are associated with different processes.[28]

Delta power significantly increased bilaterally in frontal, temporal, parietal, and central areas except occipital after long SKY. Delta oscillations appear to be involved in the synchronization of brain activity with homeostatic processes, autonomic functions, basic biological motivational processes, higher emotional involvement, and in cognitive processes related to attention and the detection of motivationally salient stimuli in the environment.[29-31]

Increased theta for both state and trait effects in meditation is associated with reported decreases in anxiety level, and correlation analysis reveals positive correlation of theta power with enhanced feelings of peace or blissful state and low-thought content.[32] Some studies of yogic meditation practices found increases in theta to be associated with proficiency in meditation technique and also, investigation with Zen meditation indicates theta increase to be characteristic of only the more advanced practitioners.[33] In the present study, however, we observed significantly increased theta power across all regions after SKY even among those practitioners who were relatively new to the practice of SKY.

Alpha-band oscillations can play a key role in uniting brain activity in different frequencies.[34] Greater levels of alpha activity have generally been found correlated with lower levels of anxiety and feelings of calm and positive effect. A review on Zen meditation found increased alpha and theta activities in many brain regions, including the frontal cortex, and was found to be relaxing with reduced stress and blood pressure.[35] Alpha power significantly increased across all regions after SKY.

Experienced Zen meditators also have shown increased beta power at occipital region during deep state of meditation.[36] One of the earlier studies had shown increased beta activity among practitioners of SKY, indicative of alertness of the practitioners.[21] Highly significant increase of beta power in the present study suggests behavioral conditioning and cortical activation without any external stimulus.

High-frequency gamma waves are linked to varied cognitive functions, visual perception, attention, memory, and long-range neuronal communications by binding of distributed brain activities.[37,38] Earlier studies established significantly increased parieto-occipital gamma power in long-term practitioners of Vipassana and mindfulness meditation,[39,40] also after bhramari pranayama,[41] and with increased practice of pranayama.[9] Experienced meditation practitioners showed higher gamma-band activity pre, during, and post meditation than the controls over most of the areas. The postmeditation higher values suggest that temporal integrative mechanisms induce short-term and long-term neural changes.[42]

In the present study of SKY, gamma activity was found increased in almost all regions of the brain even among those who were relatively new to the practice of SKY.

Conclusions

A single session of SKY can produce high-frequency cerebral activation and interhemispheric synchronization in brain rhythms as state effect. These findings suggest that SKY increases complexity in neural correlates, which may lead to better attention, memory, emotional control, and higher cognitive state. In addition, SKY initiates appropriate balance in interhemispheric synchronization, improves autonomic control and state of restful alertness, and improves physical and mental well-being.

Future scope of the study

Simultaneous recording of respiration and EEG before, during, and after SKY can further establish the findings of the present study. Comparison with appropriate control group will also evidently verify the effectiveness of long SKY. Further studies need to find out as to which areas of the brain get activated or deactivated when one practices SKY on a regular basis. Studies using functional magnetic resonance imaging and positron emission tomography can be explored for the same. Longitudinal studies can facilitate to understand the trait effects of SKY on neuronal plasticity and cognitive flexibility. Cross frequency coupling can also be a useful, informative, and valuable approach to study the neural processes and to relate specific cortical areas and specific stages of information processing following SKY.

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Conflicts of interest

There are no conflicts of interest.

References

1. Adrian ED. Olfactory reactions in the brain of the hedgehog. J Physiol 1942;100:459-73.
2. Ito J, Roy S, Liu Y, Cao Y, Fletcher M, Lu L, *et al*. Whisker barrel cortex delta oscillations and gamma power in the awake mouse are linked to respiration. Nat Commun 2014;5:3572.
3. Tort ABL, Ponsel S, Jessberger J, Yanovsky Y, Brankačk J, Draguhn A. Parallel detection of theta and respiration-coupled oscillations throughout the mouse brain. Sci Rep 2018;8:6432.
4. Zelano C, Jiang H, Zhou G, Arora N, Schuele S, Rosenow J, *et al*. Nasal respiration entrains human limbic oscillations and

modulates cognitive function. J Neurosci 2016;36:12448-67.

5. Heck DH, McAfee SS, Liu Y, Babajani-Feremi A, Rezaie R, Freeman WJ, *et al*. Breathing as a fundamental rhythm of brain function. Front Neural Circuits 2016;10:115.
6. Herrero JL, Khuvis S, Yeagle E, Cerf M, Mehta AD. Breathing above the brain stem: Volitional control and attentional modulation in humans. J Neurophysiol 2018;119:145-59.
7. Busek P, Kemlink D. The influence of the respiratory cycle on the EEG. Physiol Res 2005;54:327-33.
8. Gaurav S, Meenakshi S, Jayshri G, Ramanjan S. Effect of alterations in breathing patterns on EEG activity in normal human subjects. Int J Curr Res Med Sci 2016;2:38-45.
9. Gandhi T, Kapoor A, Kharya C, Aalok VV, Santhosh J, Anand S. Enhancement of inter-hemispheric brain waves synchronisation after pranayama practice. Int J Biomed Eng Technol 2011;7:1-17.
10. Saoji AA, Raghavendra BR, Manjunath NK. Effects of yogic breath regulation: A narrative review of scientific evidence. J Ayurveda Integr Med 2019;10:50-8.
11. Kjellgren A, Bood SA, Axelsson K, Norlander T, Saatcioglu F. Wellness through a comprehensive yogic breathing program – A controlled pilot trial. BMC Complement Altern Med 2007;7:43.
12. Sharma H, Sen S, Singh A, Bhardwaj NK, Kochupillai V, Singh N. Sudarshan Kriya practitioners exhibit better antioxidant status and lower blood lactate levels. Biol Psychol 2003;63:281-91.
13. Kochupillai V, Kumar P, Singh D, Aggarwal D, Bhardwaj N, Bhutani M, *et al*. Effect of rhythmic breathing (Sudarshan Kriya and Pranayam) on immune functions and tobacco addiction. Ann N Y Acad Sci 2005;1056:242-52.
14. Kharya C, Gupta V, Deepak KK, Sagar R, Upadhyav A, Kochupillai V, *et al*. Effect of controlled breathing exercises on the psychological status and the cardiac autonomic tone: Sudarshan Kriya and Prana-Yoga. Indian J Physiol Pharmacol 2014;58:211-21.
15. Jyotsna VP, Ambekar S, Singla R, Joshi A, Dhawan A, Kumar N, *et al*. Cardiac autonomic function in patients with diabetes improves with practice of comprehensive yogic breathing program. Indian J Endocrinol Metab 2013;17:480-5.
16. Bhaskar L, Kharya C, Deepak KK, Kochupillai V. Assessment of cardiac autonomic tone following long Sudarshan Kriya yoga in art of living practitioners. J Altern Complement Med 2017;23:705-12.
17. Zope SA, Zope RA. Sudarshan kriya yoga: Breathing for health. Int J Yoga 2013;6:4-10.
18. Sharma A, Barrett MS, Cucchiara AJ, Gooneratne NS, Thase ME. A Breathing-based Meditation intervention for patients with major depressive disorder following inadequate response to antidepressants: A randomized pilot study HHS public access. J Clin Psychiatry 2017;78:59-63.9
19. Qu S, Olafsrud SM, Meza-Zepeda LA, Saatcioglu F. Rapid gene expression changes in peripheral blood lymphocytes upon practice of a comprehensive yoga program. PLoS One 2013;8:e61910.
20. Sharma H, Datta P, Singh A, Sen S, Bhardwaj NK, Kochupillai V, *et al*. Gene expression profiling in practitioners of Sudarshan Kriya. J Psychosom Res 2008;64:213-8.
21. Bhatia M, Kumar A, Kumar N, Pandey RM, Kochupillai V, EEG study, *et al*. Electrophysiologic evaluation of Sudarshan Kriya: An EEG, BAER, P300 study. Indian J Physiol Pharmacol 2003;47:157-63.
22. Srinivasan N, Baijal S. Concentrative meditation enhances preattentive processing: A mismatch negativity study. Neuroreport 2007;18:1709-12.
23. Baijal S, Srinivasan N. Theta activity and meditative states: Spectral changes during concentrative meditation. Cogn Process 2010;11:31-8.
24. Bokil H, Andrews P, Kulkarni JE, Mehta S, Mitra PP. Chronux: A platform for analyzing neural signals. J Neurosci Methods 2010;192:146-51.
25. Coan JA, Allen JJ. Frontal EEG asymmetry as a moderator and mediator of emotion. Biol Psychol 2004;67:7-49.
26. Brown RP, Gerbarg PL. Sudarshan Kriya yogic breathing in the treatment of stress, anxiety, and depression: part I-neurophysiologic model. J Altern Complement Med 2005;11:189-201.
27. Lee SW, Gerdes L, Tegeler CL, Shaltout HA, Tegeler CH. A bihemispheric autonomic model for traumatic stress effects on health and behavior. Front Psychol 2014;5:843.
28. Knyazev GG. Motivation, emotion, and their inhibitory control mirrored in brain oscillations. Neurosci Biobehav Rev 2007;31:377-95.
29. Harmony T. The functional significance of delta oscillations in cognitive processing. Front Integr Neurosci 2013;7:83.
30. Knyazev GG. EEG delta oscillations as a correlate of basic homeostatic and motivational processes. Neurosci Biobehav Rev 2012;36:677-95.
31. Ako M, Kawara T, Uchida S, Miyazaki S, Nishihara K, Mukai J, *et al*. Correlation between electroencephalography and heart rate variability during sleep. Psychiatry Clin Neurosci 2003;57:59-65.
32. Aftanas LI, Golocheikine SA. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: High-resolution EEG investigation of meditation. Neurosci Lett 2001;310:57-60.
33. Kasamatsu A, Hirai T. An electroencephalographic study on the zen meditation (Zazen). Folia Psychiatr Neurol Jpn 1966;20:315-36.
34. Klimesch W. α-band oscillations, attention, and controlled access to stored information. Trends Cogn Sci 2012;16:606-17.
35. Chiesa A. Zen meditation: an integration of current evidence. J Altern Complement Med 2009;15:585-92.
36. Huang HY, Lo PC. EEG dynamics of experienced Zen meditation practitioners probed by complexity index and spectral measure. J Med Eng Technol 2009;33:314-21.
37. Lee KH, Williams LM, Breakspear M, Gordon E. Synchronous gamma activity: A review and contribution to an integrative neuroscience model of schizophrenia. Brain Res Brain Res Rev 2003;41:57-78.
38. Kaiser J, Lutzenberger W. Human gamma-band activity: A window to cognitive processing. Neuroreport 2005;16:207-11.
39. Cahn BR, Delorme A, Polich J. Occipital gamma activation during Vipassana meditation. Cogn Process 2010;11:39-56.
40. Ferrarelli F, Smith R, Dentico D, Riedner BA, Zennig C, Benca RM, *et al*. Experienced mindfulness meditators exhibit higher parietal-occipital EEG gamma activity during NREM sleep. PLoS One 2013;8:e73417.
41. Vialatte FB, Bakardjian H, Prasad R, Cichocki A. EEG paroxysmal gamma waves during Bhramari Pranayama: A yoga breathing technique. Conscious Cogn 2009;18:977-88.
42. Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RJ. Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. Proc Natl Acad Sci U S A 2004;101:16369-73.