Review Article

Reducing Stress with Yoga: A Systematic Review Based on Multimodal Biosignals

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Abstract

Stress is an enormous concern in our culture because it is the root cause of many health issues. Yoga asanas and mindfulness-based practices are becoming increasingly popular for stress management; nevertheless, the biological effect of these practices on stress reactivity is still a research domain. The purpose of this review is to emphasize various biosignals that reflect stress reduction through various yoga-based practices. A comprehensive synthesis of numerous prior investigations in the existing literature was conducted. These investigations undertook a thorough examination of numerous biosignals. Various features are extracted from these signals, which are further explored to reflect the effectiveness of yoga practice in stress reduction. The multifaceted character of stress and the extensive research undertaken in this field indicate that the proposed approach would rely on multiple modalities. The notable growth of the body of literature pertaining to prospective yoga processes is deserving of attention; nonetheless, there exists a scarcity of research undertaken on these mechanisms. Hence, it is recommended that future studies adopt more stringent yoga methods and ensure the incorporation of suitable participant cohorts.

Keywords: *ECG, EEG, electromyogram, functional magnetic resonance imaging, galvanic skin response, meditation, stress, yoga*

Introduction

Any form of change that creates emotional, psychological, or physical strain is referred to as stress. It is a commonly occurring reaction that occurs when people feel challenged or intimidated.[1] Humphrey[2] defines stress as a factor that makes people feel like it is difficult to adapt to and maintain homeostasis with their surroundings, both internally and externally. Every person encounters stress in life, and it affects both the brain and body. Fear, concern, difficulty in relaxing, rapid heartbeat, breathing difficulty, disturbed sleep patterns, altered food habits, and increased drug usage are all symptoms of stress.[3] Mind–body interventions can help with stress-related mental and physical problems. Yoga promotes both physical and mental relaxation, which lowers anxiety and stress.[4] It includes the practice of meditation, precise postures (asana), and controlled breathing exercises (Pranayama). The purpose of meditation-based practice is to consciously calm the mind by separating thoughts from each other and/or focusing on one's breathing. Physical postures encourage flexibility, ease stress, and lessen discomfort. Moreover, the third sort of Yoga practice, Pranayama is a breathing-based technique that entails deliberate inhalations and exhalations at a set speed and intensity. The aforementioned three types of yoga can be practiced separately or combined into a single session. Asana, meditation, and breathing-based techniques all have different and distinct benefits on cognitive and neurological functioning. Previous qualitative research has found that yoga can help with depression and anxiety.[5,6] With yoga, there is a significant decrease in perceived stress and backache.[7] Understanding what causes changes in the brain and body that lead to increased cognition and reduced stress levels with yoga might help in the creation of cognitive therapies in both healthy and clinical populations.

Stress is difficult to diagnose and monitor because everyone experiences stress

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differently. Stress can be measured by assessing the concentrations of several stress biomarkers found in physiological fluids of the body. Medical professionals can analyze anomalies occurring inside the body using biomarkers, which provide quantifiable indicators of biological processes, without undertaking any surgical procedures.[8] Endocrine system hormones and nervous system neurotransmitters are the two major systems in the body that categorize biomarkers. Hormones, namely adrenaline and norepinephrine, present in the bloodstream play a crucial role in initiating and regulating the fight-or-flight response.[9] Alpha-amylase, an enzyme present in saliva, exhibits a concentration range of 0.6–2.6 mg/mL. Recent investigations have established a correlation between elevated levels of salivary alpha-amylase and the presence of chronic stress.[9-11] The central nervous system regulates the release of cortisol, a glucocorticoid hormone. To counteract actual or expected stressors noticed during the stress reaction, energy must be redistributed, and glucocorticoids are responsible for this.[12] The field of stress monitoring systems has witnessed noteworthy advancements, wherein many biosensor technologies that offer precise, dependable, and feasible assessments of physiological conditions have emerged. Various biological signals, including heart rate variability (HRV) and electrocardiogram (ECG),[13] electroencephalogram (EEG),[14] Functional magnetic resonance imaging (fMRI),[15] and respiratory signals,[16] can be utilized to assess and detect stress. While biosignals do not serve as the primary catalyst for stress response, they represent the physiological manifestation of stress biomarkers produced within the body. Therefore, sensing various biosignals provides a more precise method of stress detection and will be the main emphasis of this publication.

Review objectives

The following are the objectives of the review:

1. To focus on various biosignals measurement technologies that are used for stress detection
2. To emphasize the use of these technologies to measure the effects of yoga on reducing stress.

Methodology

Literature selection: Inclusion and exclusion criteria

The criteria for inclusion and exclusion in this study are mostly determined by the key objectives outlined in the aforementioned review. The investigations exclusively pertain to the incorporation of biosignals to detect stress levels during the practice of Yoga. Furthermore, this evaluation specifically omitted research that incorporated medication trials and therapy. The selected data from each article encompasses several aspects such as the year of publication, the authors involved, the type of biosignals examined, the protocols employed for doing yoga exercises, the qualities of the subjects, and the methods used for measuring stress levels. The typical stress-related biosignals that have been studied in the literature are shown in Figure 1.

Search strategy

The reviewed research publications encompass a range of scholarly sources, including IEEE Xplore, Ei-Compendex, PubMed, Web of Science, and ACM Digital Library. The search queries encompass specific terminology pertaining to biosignals, EEG, fMRI, ECG, EMG, wearable technologies, stress, breathing exercises, meditation, and yoga. The search fields are connected using the logical operator "AND" to guarantee that the results contain at least one of the specified terms. The terms within each search field are linked using the logical operator "OR." The search was restricted to studies on humans. Subsequently, the cumulative number of hits acquired from querying the aforementioned databases was consolidated, and any instances of duplication were eliminated. Following that, the studies underwent a screening process in which the titles, abstracts, and complete texts of the publications were read. At this step, studies that did not meet the inclusion criteria were excluded. To get supplementary data, a manual search was conducted by examining the reference

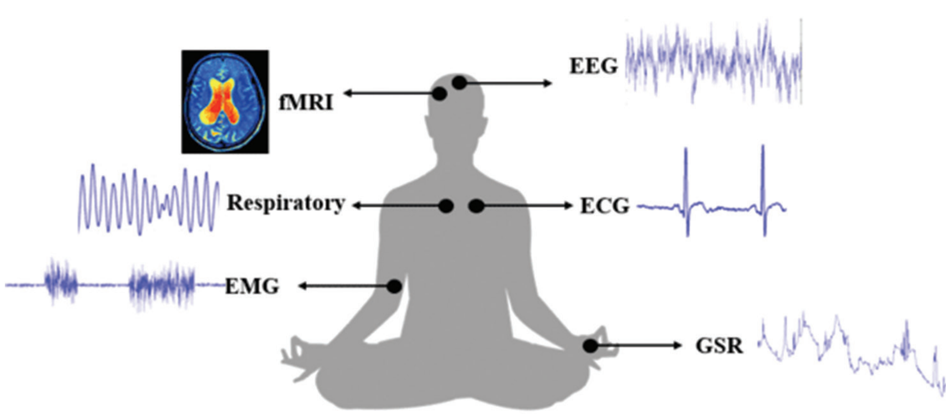

Figure 1: Common bio-signal measures related to stress investigated during different forms of yoga. EEG: Electroencephalogram, ECG: Electrocardiogram, EMG: Electromyogram, fMRI: Functional magnetic resonance imaging, GSR: Galvanic skin response

lists of the publications that were chosen in the final round. The selection of the final set of articles to be incorporated into the review was established by an iterative consensus procedure among the reviewers. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis method is applied for this investigation, as depicted in Figure 2.

Risk of bias assessment

The evaluation of the risk of bias in individual studies, as well as across many studies, was conducted using the Robvis visualization tool (Rob 2 tool). Robvis is a web app designed for visualizing risk-of-bias assessments performed as part of a systematic review. The framework comprises five components, namely: Randomization process, deviation from intended interventions, missing outcome data, measurement of outcome, and selection of reported results. Based on the aforementioned items, the study can be categorized as either high risk, low risk, or exhibiting an indeterminate level of risk. The risk of bias graph and summary is represented in Figure 3.

Results and Discussion

Electroencephalogram

The electroencephalogram (EEG) is a diagnostic procedure utilized to assess the electrical patterns and activity within the brain utilizing electrodes affixed to the head. It has been used as a noninvasive and reliable tool to measure physiological and psychological changes in response to stress. The EEG frequency band's power serves as an indicator of its degree of activity. Different EEG frequency bands have varying powers that can be used to measure brain activity and identify neurological conditions. EEG signals can be categorized into five primary frequency bands, nam ly Delta (0.1–4 Hz), Theta (4–8 Hz), Alpha (8–13 Hz), Beta (13–30 Hz), and Gamma (30–50 Hz). The exact boundaries of these bands can vary depending on the source. The objective of power spectral density (PSD) analysis is to determine the distribution of power in the time-domain electroencephalogram (EEG) signal across a variety of frequencies. This analysis yields valuable insights about brain activation. The utilization of PSD is valuable in characterizing the stochastic behavior of a signal and assessing its properties based on limited data sets.[17] Various techniques are employed for estimating the PSD, including the fast Fourier transform (FFT), Welch method, Burg method, Yule–Walker method, Welch's method, and periodogram.[18,19] Multiple studies have provided evidence supporting the efficacy of employing PSD as a means of estimating stress levels. The delta band is associated with deep sleep. Theta waves are associated with relaxed wakefulness and daydreaming. Alpha waves are associated with focused attention and relaxed wakefulness. Beta waves are associated with active attention and problem-solving. Gamma waves are associated with high-level cognitive functions such as learning and memory. Several previous studies have shown that EEG activity can be altered by mental stress.

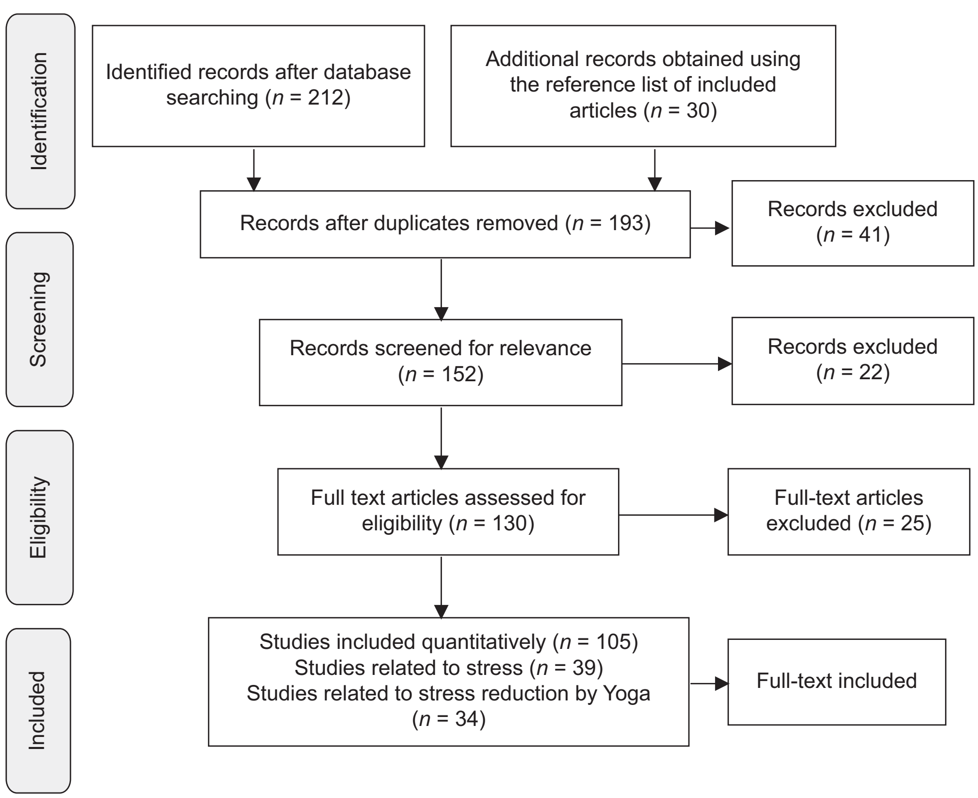

Figure 2: Summarised Search strategy. Preferred reporting items for systematic reviews and meta-analysis flow diagram for the review

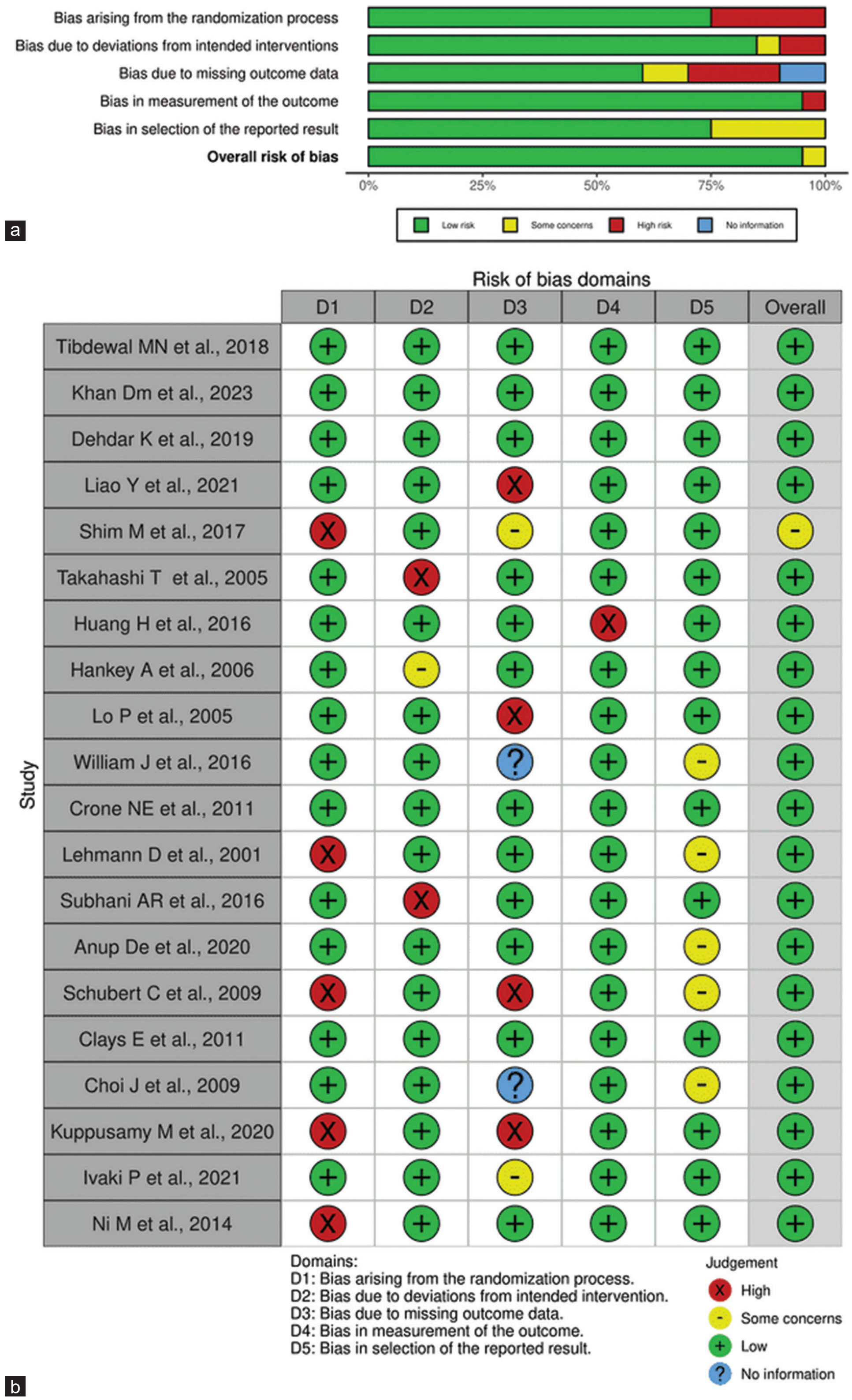

Figure 3: Risk of bias assessment: (a) Summary plot; (b) Traffic light plot

Delta waveband

The delta frequency band is the slowest of the brain's EEG frequency bands. It is associated with deep sleep, unconscious processing, and memory consolidation. Multiple studies have demonstrated a correlation between heightened delta power in the prefrontal cortex (PFC) and worse cognitive functioning under conditions of stress. This suggests that increased delta activity may be a marker of cognitive overload or dysfunction. A previous study found that increased delta activity in the amygdala was associated with increased fear responses.[20] It is also very crucial to note that individual differences exist, and the effects of delta frequency band activity on cognitive stress can vary from person to person. It was believed that increased delta activity in the PFC may reflect a decrease in the efficiency of neural processing, which can lead to impaired cognitive performance.[21] It was proved that decreased delta activity in the PFC might reflect an increase in the activity of the amygdala, which is a brain region involved in processing emotions.[22] As a supplemental therapy for many diseases, meditation and yoga-based techniques are being used more frequently by psychologists and other medical professionals to assist their patients in reducing stress. Delta wave modulations have been observed in the literature during various types of yoga and meditation. When Cahn *et al*.[23] examined Vipassana's meditation impact on the frontal areas, they found that the delta was reduced. This finding demonstrated that it served as an indicator of a heightened level of awareness and was suggestive of enhanced neural activity linked to the amalgamation of sensory information from both internal and external sources.

Theta waveband

Several factors can influence the level of theta band activity observed in response to mental stress. These factors encompass the nature of the stressor, the coping technique employed by the individual, and the intensity of the stress experienced. The increased theta band activity in mental stress has several implications for stress measurement and management. This theta band activity can be used to identify people who are at risk of developing stress-related health problems and to develop interventions to manage stress. Moreover, the presence of focused theta activity in aware states suggests the occurrence of focal brain impairment. The calculation of absolute power (AP) within a specific frequency band involves the division of the absolute value of the FFT of the electroencephalogram (EEG) signal by the length of the signal.[24] In previous research conducted by authors,[25,26] the relative power (RP) metric was employed to assess the rhythmic characteristics of EEG signals. This involved calculating the ratio between the power of individual frequency bands and the overall power across all bands. The research conducted by Subhani *et al*.[27] and Arsalan *et al*.[17] revealed notable findings in the application of AP on stress/nonstress detection. Specifically, they observed a substantial distinction in the theta band compared to other frequency bands. In addition, their investigations into RP indicated a decrease in RP as stress levels escalated. The presence of theta waves during stress could be a sign of cognitive effort or mental engagement, but it does not necessarily mean that stress is always associated with theta wave activity. Yoga practices, encompassing deep breathing, meditation, and physical postures, have the potential to elicit activation of the parasympathetic (PNS) nervous system while concurrently attenuating the activity of the sympathetic nervous system (SNS). Consequently, these practices may provide a discernible decrease in stress levels. Pranayama using alternate nostril breathing demonstrated a decrease in theta band power, which was associated with greater calmness in the brain.[28] This was also associated with a better ability to perform certain cognitive tasks. A significant increase in EEG theta activity was shown pre- to post-Tai Chi/Yoga session, which suggested increased relaxation and decreased anxiety.[29]

Alpha waveband

Alpha waves in the occipital region are observed in EEG recordings during the typical state of wakefulness. Prior studies have indicated that the deceleration of environmental alpha waves is indicative of cerebral problems and mental stress.[30] The alpha rhythm is most effectively visualized when individuals engage in a state of rest with their eyes closed, and its amplitude is diminished on eye-opening and engagement in cognitive processes. Individuals diagnosed with stress disorder exhibit a lack of simple alpha activity. The phenomenon referred to as "alpha coma" is characterized by a lack of responsiveness to both internal and exterior stimuli. Decreased alpha power band activity has been observed in people who are experiencing mental stress. This is thought to be due to the increased cognitive demands that are placed on the brain during stressful situations. When people are relaxed, their alpha band activity increases. This is because the brain is not as active when it is relaxed. The decreased alpha band activity in mental stress can be used to develop new interventions to manage stress. As an illustration, a prior study[31] found that mental stress was associated with a reduction in the PSD of the EEG in the alpha frequency band. Similarly, the research conducted by the authors in reference[32] revealed a notable reduction in the alpha rhythm as the stress level escalated from level 1 to level 2, which was achieved by augmenting the complexity or difficulty of the mathematical work. Furthermore, the stress level continued to rise as it progressed from levels 2 to level 3. The level of complexity for the math problem was enhanced by increasing the integer numbers and operands utilized in the mathematical operation, progressing from level 1 to level 3. In accordance with the findings presented in reference,[32] it has been established that the right PFC plays a prominent role in the detection of stress. The EEG-based biofeedback can be used to train people to control their alpha band activity. This can help people to reduce their stress levels and improve their mental health. Studies have shown that certain yoga practices can have a positive effect on stress and can modulate the EEG alpha dynamics. This modulation can lead to changes in brainwave patterns, including increased alpha and theta waves, which are associated with relaxation and reduced stress.[33] The practice of Pranakarshan pranayama is one of the practices that control the mind by conserving pranic energy from the cosmos. By performing Pranakarshan pranayama and yoga nidra, EEG alpha rhythm significantly changes its mean value, which is characterized by mental relaxation.[34] Sudarshan Kriya is a potent and uncomplicated breathing technique that integrates distinct natural patterns of respiration, fostering a state of balance among the physical, mental, and emotional aspects of an individual. It has been observed that long-term practitioners of Sudarshan kriya showed improved energy in the EEG components in comparison to short-term practitioners.[35] Improved energy values in alpha wave show the extreme relaxation state. A decrease in frontal brain alpha band power was also seen as the mental stress increased. However, after practicing Sudarshan kriya yoga, there was a change in cognitive function and a corresponding rise in alpha band power.[36] This suggests that Sudarshan kriya exposure leads to a rise in stress tolerance. Another type of yogic technique, Bhramari pranayama, is a breathing technique that promotes a state of relaxation and has instant effects on stress relaxation. The PSD of trained Bhramari meditators shows a significant increase in overall theta and alpha power.[37] The cross-spectral density exhibits a notable rise after the execution of the Bhramari pranayama, as compared to its pre-pranayama state, specifically within the alpha frequency band.[37] This shows a relaxed state of mind with feelings of happiness and well-being. Daily meditation (OM chanting) for 20 min each day for 1 month shows a significant increase in the alpha power of the practitioners, indicating relaxation and stress reduction.[38]

Beta waveband

Beta waves are the predominant oscillatory patterns commonly recognized in both adult and pediatric populations. The observation of this phenomenon is readily apparent in the frontal and central regions of the head. The beta wave exhibits an amplitude range of 10–20 μV and demonstrates a consistent increase during periods of drowsiness. Prior research has established a positive association between mental stress and beta power rhythms. The beta frequency band is associated with alertness, attention, and cognitive processing. Several studies have shown that increased beta-band activity has been observed in people who are experiencing mental stress.[39] This is thought to be due to the increased cognitive demands that are placed on the brain during stressful situations. A previous study found that people with anxiety disorders showed increased beta-band activity in the frontal cortex, which is associated with attention and cognitive processing.[40] Another study observes that people with posttraumatic stress disorder showed increased beta-band activity in the amygdala, which is associated with fear and anxiety.[41] The rapid beta band exhibits a statistically significant positive interaction, suggesting a more pronounced increase in stress levels during the respective stages. Moreover, the cortical regions that have the greatest impact from delayed beta activity are the central and parieto-temporal areas. One type of Buddhist meditation, known as Zen meditation, is distinguished by a modest increase in alpha wave power and a rapid theta wave power reflecting more mindfulness in the frontal region.[42] Long-term meditators of Zen showed a beta rise over the occipital areas.[43] Huang and Lo[43] proved that the EEG is dominated by alpha at the beginning of meditation, indicating a calm, awake state of awareness. However, as the meditation continued, the occipital areas occasionally experienced a beta rhythm. In other words, meditation caused an arousal state, which caused the EEG to change to a higher frequency. In another study, the amplitude of the beta waveband was lowered over the right occipital region after alternate nostril yoga breathing.[28] This shows that, in line with descriptions of yoga breathing as soothing, there is a decrease in alertness following alternate nostril yoga breathing. Previous research also suggested that the deeper meditation states, such as samadhi or "transcendence," were associated with the beta activity displayed by experienced meditators.[44,45] According to Dunn *et al*.,[46] meditation increased the mean amplitude of beta activity at the central and posterior areas because of an increase in concentration levels.

Gamma waveband

Gamma waves are a type of high-frequency brainwave pattern that typically ranges from 25 to 100 Hz. They are associated with various cognitive processes, including attention, memory formation, and problem-solving. Gamma waves are often observed when the brain is actively engaged in complex tasks or during states of heightened focus and concentration. Previous research on epilepsy[47,48] has indicated that epileptic foci generate episodes of high-frequency activity. When it comes to mental stress, the relationship with gamma waves is somewhat different compared to theta waves. In instances characterized by acute or transient stress, there is typically an observed augmentation in gamma wave activity. The observed increase in gamma wave activity is hypothesized to be associated with the brain's adaptive response to a circumstance that is seen as demanding or challenging. During stressful events, the brain needs to quickly process information, make decisions, and mobilize resources to deal with the perceived threat. Gamma waves are thought to facilitate the coordination of neural networks involved in these processes, allowing for efficient information processing and integration.[49] However, chronic or long-term stress has different effects on gamma wave activity. Prolonged exposure to stressors can lead to dysregulation of brainwave patterns, including a decrease in gamma wave activity. This disruption in gamma oscillations may contribute to cognitive impairments, attention difficulties, and reduced mental flexibility often associated with chronic stress. The gamma activity exhibited a diverse range of responses, while it was usually noted that gamma activity tends to decrease in stressful situations.[50] Research has demonstrated that the practice of Bhramari Pranayama can induce the production of gamma waves characterized by their high frequency.[51] The study employed complex Morlet wavelets and Fourier analysis to extract features that exhibited high frequencies in the beta range (15–35 Hz) and gamma range (>35 Hz). This was shown to represent a nonepileptic hypersynchrony that induces a subjective feeling of "bliss" among the practitioners. Deep meditation causes similar gamma-band bursts of high frequency.[52] In addition, Lehmann *et al*.[53] investigated where in the brain gamma-range rapid EEG activity comes from when people are meditating. Lutz *et al*.[54] have reported that individuals who engage in meditation exhibit a greater proportion of gamma-band activity (25–42 Hz) relative to slow oscillatory activity (4–13 Hz), even during periods of rest, compared to individuals who do not practice meditation. The potential efficacy of incorporating meditation and yoga practices to create fast oscillations in the EEG may offer benefits in managing anxiety and stress-related factors.

Coherence

EEG coherence also plays a vital role in identifying the mental stress in an individual. It reflects the degree of synchronization between brain regions, providing information about how different areas of the brain communicate and work together. Mental stress triggers a complex cascade of physiological and psychological responses, leading to alterations in brain activity. During mental stress, the brain undergoes dynamic changes in coherence patterns.[55] The hypothalamic–pituitary–adrenal axis, which governs the physiological stress response, engages in intricate interactions with several brain regions engaged in cognitive and emotional processing.[56] These interactions can be observed through EEG coherence measurements, revealing the impact of stress on brain network dynamics. Changes in coherence during mental stress, as observed through EEG, provide valuable information about alterations in brain connectivity. Heightened coherence in specific regions suggests increased coordination and information exchange, while reduced coherence may indicate disrupted integration between brain regions. Previous studies have consistently shown that increased mental stress levels are associated with enhanced coherence within specific frequency bands, reflecting heightened synchronization between brain regions.[57] These findings suggest that stress promotes greater coordination and communication between areas involved in processing stress-related information. In addition, elevated coherence is often observed in regions responsible for emotional regulation, such as the PFC and amygdala, indicating the brain's concerted effort to manage stress-induced emotions. However, stress-induced changes in coherence are not uniform across all brain regions. Some studies report reduced coherence in certain regions, suggesting a disruption in normal information flow.[58,59] These decreases in coherence may reflect impaired integration between cognitive and emotional processing centers, potentially leading to cognitive deficits and emotional dysregulation under stress. By unraveling the intricate relationship between coherence and stress, we can better comprehend the impact of stress on brain functioning and ultimately improve the well-being of individuals facing challenging circumstances.

Overall, EEG-based evidence suggests that changes in brain activity can provide a reliable and sensitive measure of stress. Brain wave coherence has been used extensively in the literature to study the effects of yoga on stress and anxiety. Following a period of engaging in yoga, a study conducted by researchers revealed a reduction of 1.67% in beta wave activity, accompanied by notable increases of 19.31% in delta wave activity, 5.04% in theta wave activity, 15.40% in alpha wave activity, and 18.68% in gamma wave coherence.[60] This has been linked to higher levels of consciousness and has been demonstrated to impact wakefulness and vigilance, according to experts. Meditation practice results in an increase in frontal electrical coherence, which represents gains in frontal integration, flexibility in cognition, intelligence, and emotional stability.[61,62] A systematic review of brain functional improvement with yoga using brain wave coherence is presented elaborately in the literature.[63]

Electrocardiogram and heart rate variability

The electrocardiogram (ECG) refers to the graphical representation of the electrical impulses produced by the heart.[64] The signal under consideration is frequently utilized in stress detection studies due to its direct reflection of cardiac activity, which is known to be influenced by variations in the autonomic nervous system (ANS). Placing some electrodes on particular body parts and determining the potential difference makes it simple to measure an ECG. The most common and relevant ECG characteristics are probably those linked to HRV. The heart rate refers to the number of times the heart beats per minute, commonly abbreviated as bpm. HRV refers to the slight fluctuations observed in the duration between successive heartbeats. Acetylcholine and norepinephrine, which correlate to the PNS and SNSs, respectively, are two neuromodulatory receptors that regulate heart action. Stress activates the SNS, which causes an increase in heart rate and contraction force. To combat the stressor, the body's blood volume increases and circulates more quickly throughout the body, supplying the organs and skeletal muscles with more oxygen. The ST segment on an electrocardiogram (ECG) signifies the duration between the completion of ventricular depolarization and the initiation of ventricular repolarization. During periods of stress, it is possible for alterations to develop in the ST segment. An illustration of ST-segment depression (ST depression) may be observed, suggesting myocardial ischemia or a reduction in blood supply to the cardiac muscle. ST-segment elevation (ST elevation) can also occur in rare cases and may indicate myocardial infarction (heart attack). Stress can also trigger arrhythmias or abnormal heart rhythms. Examples of cardiac arrhythmias that can occur include premature ventricular contractions, supraventricular tachycardia, or atrial fibrillation. These arrhythmias may be observed as irregularities on the ECG tracing. Numerous research studies have been published in the literature that show how stress considerably raises heart rate.[65-68] The study conducted by Melillo *et al*.[68] investigated the influence of stress on HRV parameters in real-life scenarios. The researchers selected two significant timeframes, specifically during an oral examination and immediately following the holiday period, to assess the students' electrocardiograms (ECGs). The classification of stressed and un-stressed circumstances using 13 nonlinear HRV features and linear discriminant analysis resulted in an accuracy of 90%. This finding highlights the potential of these signals for the identification of stress in real-world settings. Okada *et al*.[69] developed a stress monitoring system for office workers that utilized ECG recordings and incorporated an accelerometer for activity recognition and movement artifact reduction. According to Hjortskov *et al*.,[70] HRV has been identified as a highly responsive indicator of psychological stress experienced in workplace environments. It was determined that during periods of stress, there was an observed rise in the ratio of low-frequency to high-frequency HRV. An alternative method for identifying mentally stressful events using HRV is the application of a nonlinear system identification methodology called principle dynamic modes (PDM).[71] Zhong *et al*.[72] employed the PDM technique to predict the activation of autonomic branches only based on heart rate readings. According to their findings,[71] this approach successfully discriminates stressful episodes within subjects with an 83% success rate when PDM and spectral information were combined. It is important to note that while stress can cause temporary ECG changes, persistent or severe ECG abnormalities should be evaluated by a healthcare professional to rule out underlying cardiac conditions.

Practicing yoga and meditation has been associated with numerous health benefits and coping with stress and anxiety. Engaging in yoga, particularly practices that emphasize slow, controlled movements and deep breathing, can lead to a decrease in heart rate. ECG recordings can demonstrate a reduction in heart rate during and following the practice of yoga, indicating a decline in SNS functioning (which is linked to the stress response) and a concurrent rise in PNS activity (which is connected with relaxation). A study was conducted to examine the impact of mindfulness meditation on attention enhancement, specifically focusing on HRV signals. The findings of the study demonstrated that the R-R interval value, which serves as an indicator of HRV, generally decreased in the majority of participants following the meditation session.[73] This finding demonstrates that individuals have increased relaxation and improved stress management abilities following engagement in mindfulness meditation. To assess the effects of yoga breathing practice, i.e., Bhramari Pranayama, on cardiac autonomic function using HRV parameters, a significant improvement was shown in the PNS domain.[74] This study found that healthy adolescents who practiced yoga breathing for 6 months experienced a beneficial shift in their cardiac autonomic regulation toward PNS predominance. Another study used HRV data to analyze how a yoga and mindfulness-based approach affected the ANS in elementary school students.[75] However, after 16 weeks of training, there were no significant variations between the groups in the HRV measures. On the other hand, exploratory *post-hoc* studies reveal intriguing patterns in the cardiac autonomic control of PNS activity. It is imperative to acknowledge that there can be variations in individual reactions to yoga, and the impact on electrocardiogram (ECG) parameters can be influenced by several factors, such as the duration and intensity of the yoga practice, the baseline cardiovascular health of the individual, and other lifestyle factors. Certain yoga practices, such as pranayama (breathing exercises) and meditation, can lead to coherence between breathing patterns and heart rate patterns. This synchronization is associated with reduced stress and improved emotional well-being. ECG can demonstrate increased heart coherence during and after these practices.[76] In summary, ECG can provide insights into stress reduction with yoga practice by measuring changes in heart rate, HRV, and coherence. Yoga's emphasis on slow movements, controlled breathing, and relaxation techniques can lead to a reduction in heart rate and improved HRV, indicating a shift toward a more relaxed physiological state.

Electromyogram

The electromyogram (EMG) is a diagnostic tool utilized to evaluate the condition of skeletal muscles. The electrical activity of muscles is quantified by the utilization of electrodes positioned on the specific muscle being studied. Given the well-acknowledged relationship between stress and muscle tone, a considerable body of research has been dedicated to investigating the possibility of electromyogram (EMG) as a means of assessing stress levels. Stress has been shown to cause uncontrollable reflexes in the muscles of the face and trapezius.[77] It was established in the Wijsman *et al*. study[78] that mental stress results in a notable increase in Trapezius muscle activation. The observed elevation in Trapezius muscle activity is reflected by an increase in EMG amplitude and a decrease in gaps, which represent short periods of rest. In addition, a strong positive association between EMG activity at work and negative stress evaluations has been documented[79] without a corresponding link with positive responses. This suggests a specificity of muscle action on adverse stress that has to be researched. Muscle tremor is also regarded as a stress indication. The frequency range of a normal physiological tremor is 6.5–11 Hz. Tremors within the uppermost frequency range, around 11 Hz, are attributed to the presence of anxiety or stress.[80] The efficacy of electromyography (EMG) signals in detecting stress is supported by a study conducted by Wei,[81] which achieved a discrimination accuracy of 97.8% in distinguishing between states of relaxation and stress.

Different forms of yoga have been reported to increase muscle strength and reduce anxiety and stress.[82] Engaging in yoga often involves gentle stretching, holding poses, and controlled movements. These actions can lead to muscle relaxation and decreased muscle tension, which are associated with stress reduction. EMG readings can show a decrease in muscle activity and tension, indicating relaxation. EMG signals have been employed as a means of quantifying the level of abdominal muscle activation during abdominal yoga movements.[83] The results of the study revealed that the muscle activity levels were comparable between abdominal crunches and the yoga breathing exercise. However, the extended length of the breathing exercises resulted in a significant increase in the overall workload on the abdominal muscles, up to five times greater. A separate investigation examines the patterns of muscular activation in 14 muscles on the dominant side of the body during various yoga positions.[84] Each of the 11 Surya namaskar positions was done individually for 15 s, during which the EMG signals were captured. The findings show that different poses might cause particular muscle activation patterns, which may vary depending on the proficiency of practitioners. A further study demonstrated the impact of several standing yoga poses on the musculoskeletal system through the utilization of EMG data.[85] The efficacy of standing yoga positions, such as Vrksasana (tree position) and Natarajasana (dancer position), in enhancing mental and physical attention, stability, and balance has been demonstrated. The muscle synergies were derived from the EMG signals recorded during the execution of standing yoga poses.[86] The study shows that individuals who practice yoga employ a reduced number of muscle synergies, which exhibits a positive correlation with their center of pressure trajectory. This finding indicates a decrease in control complexity among yoga practitioners. Yoga poses have also been found to engage the scapular stabilizer muscles to varied degrees.[87] The muscle activity exhibited a range of values, spanning from 3% to 57% of the maximum voluntary isometric contraction, across different yoga postures. This knowledge helps create treatment plans that incorporate yoga poses to relieve stress and activate the scapular muscles. Another strategy that uses medical yoga therapy to treat chronic back pain and stress showed that by the end of the training, practitioners' nociceptive flexion reflex threshold from their EMG had significantly increased.[88] Researchers can conduct studies comparing EMG readings before and after yoga practice with control conditions (such as resting without yoga). Significant reductions in muscle tension, as indicated by EMG, can suggest that the specific yoga practice has led to stress reduction. Different individuals may respond differently to yoga practice. Some people might exhibit more pronounced muscle relaxation and reduced tension in response to yoga, while others may take more time to achieve similar effects. In summary, EMG can provide insights into stress reduction with yoga practice by measuring changes in muscle activity and tension. Yoga's focus on muscle relaxation, controlled breathing, mindfulness, and progressive relaxation techniques can lead to reduced muscle tension, which is associated with a relaxation response and stress reduction.

Functional magnetic resonance imaging

fMRI is a commonly employed neuroimaging modality that quantifies alterations in cerebral blood oxygenation and flow, hence providing insights into fluctuations in neural activity. When there is an increase in neuronal activity in a certain brain region, there is a corresponding rise in oxygen consumption, leading to an augmented blood flow to that particular location to satisfy the heightened metabolic demand. The amygdala, hippocampus, superior frontal gyrus, inferior parietal gyrus, superior parietal gyrus, inferior frontal gyrus, and superior temporal gyrus are commonly implicated in the examination of stress response inside the brain. In their study, Hayashi[89] employed fMRI to investigate the presence of stress-related alterations in brain activity, specifically those linked with emotional and cognitive processing. This was achieved by exposing both stressed and nonstressed participants to audio-visual stimuli. The results indicated that there were no discernible disparities in the brain regions implicated in emotional processing. However, individuals experiencing high levels of stress demonstrated reduced neural activity in brain regions associated with cognitive processing. Furthermore, it was shown that individuals who were not undergoing stress exhibited much higher sensitivity to both positive and negative stimuli than those who were, suggesting that deficits in attention may manifest in the initial stages of stress.

The effects of yoga on reducing stress have provided insights into the neural mechanisms underlying stress reduction through yoga practice. The amygdala is a brain region associated with the processing of emotions, including stress and fear. Some fMRI studies have shown that regular yoga practice, particularly mindfulness-based practices, can lead to decreased amygdala activation in response to stress-inducing stimuli.[90,91] This suggests that yoga helps dampen the brain's stress response. The practice of yoga has been linked to heightened levels of neural activity within the PFC, a brain region that plays a crucial role in cognitive control and the regulation of emotions. Greater PFC activation is thought to contribute to better regulation of emotional responses and stress.[92] Yoga practitioners may develop improved abilities to manage and mitigate stress through enhanced PFC function. The Default Mode Network (DMN) is a network of brain regions associated with self-referential thinking and mind-wandering. Mindfulness-based practices in yoga have been shown to influence DMN activity.[93] Enhanced connectivity within the DMN and reduced mind-wandering during yoga may contribute to a shift away from rumination and worrying, thereby reducing stress. Comparing mantra meditation to neutral word pronouncing (the control condition), Engström[94] discovered distinct areas of the brain were activated. The activation of the bilateral hippocampus/parahippocampal structure was found to be particularly pronounced during the meditation task, and this activation was found to be associated with a notable decrease in stress levels. Furthermore, the study investigated the hemodynamic associations of "OM" chanting and identified changes in the functioning of the hippocampal formation.[95] The limbic brain regions, anterior cingulate cortex, orbitofrontal cortex, and thalami were included in the *a priori* ROIs because it was anticipated that the vagal effect of chanting "OM" would cause these brain regions to become inactive. As a result, "OM" chanting has been proven as a cue to relaxation. After practicing Bhastrika pranayama for 1 month, there was a noticeable reduction in anxiety that was linked to modifications in the connectivity of a few brain regions that are involved in processing emotions.[96] This implies that when compared to a control sample, anxiety-prone people exhibit considerably higher bilateral amygdala and insula activity. Resting-state fMRI indicated significantly diminished functional connectivity, especially in the anterior insula and lateral PFC, which are involved in awareness and attention. In an additional investigation, the study observed variations in the volume of grey matter within the hippocampus, thalamus, and caudate nucleus, as well as the patterns of brain activation during the execution of the Sternberg working memory task.[97] Compared to controls, yoga practitioners' dorsolateral PFC showed reduced activity throughout the Sternberg task's encoding phase. This observation suggests a potential association between regular and prolonged engagement in yoga and alterations in the composition and operation of specific regions of the brain that are implicated in executive function, specifically working memory. Research has indicated that working memory can be enhanced by yoga exercises, resulting in a reduction in stress levels. In summary, fMRI can provide insights into stress reduction with yoga practice by measuring changes in brain activity patterns associated with emotion regulation, mindfulness, and stress response. Yoga's emphasis on mindfulness, body awareness, and relaxation techniques can lead to shifts in brain activation that indicate reduced stress and improved emotional well-being.

Galvanic skin response

Galvanic skin response (GSR), alternatively referred to as electrodermal activity (EDA), is characterized as the alteration in the electrical characteristics of the skin.[98] It is frequently employed as a measure of SNS activation, which is linked to the physiological response known as the "fight or flight" response. Sweating rises with increased mental or physical exertion or emotional stimulation, altering the characteristics of the skin by causing it to become more conductive and less resistant. GSR detection can be achieved by placing two electrodes nearby on the surface of the skin and applying a low-intensity electrical current across them. In a study conducted by Healey and Picard,[99] an investigation was carried out on stress levels by analyzing a real-life driving task using hand and foot GSR. The findings demonstrated that GSR exhibited the highest correlation with real-time stress, with an accuracy rate of 97.4%, specifically for high-stress levels. Commonly, statistical measures such as the mean amplitude, standard deviation of the amplitude, minimum and maximum values, and the root mean square are employed to extract relevant information from a GSR signal.[100-102] To depict the standard EDA in response to a stressful stimulus, additional parameters have been selected, including the number of peaks,[103] increasing time, maximum/minimum position, zero crossings, and discrepancies between the initial and maximum value. With the aid of GSR, heart rate, and a fuzzy logic algorithm, De Santos Sierra *et al*.[100] devised personalized stress templates for a sample of 80 individuals. The classification problem involving two classes was successfully addressed, achieving a high accuracy rate of 99.5%. This outcome suggests that both signals possess the capability to effectively and promptly detect levels of stress.

A multitude of scholarly inquiries have been conducted to examine the impact of yoga on the reduction of stress, with a substantial number of these investigations yielding affirmative results as indicated by GSR measurements. Previous studies have indicated that the adoption of yoga practices is associated with a reduction in the activity of the SNS and an elevation in the activity of the PNS nervous system. This shift is often associated with a relaxation response, leading to reduced stress levels. The stress reduction could indeed be reflected in a decrease in GSR, indicating a more relaxed physiological state.[104] GSR values are significantly increased during meditation (OM chanting), which reflects participants' feelings of relaxation and reduced stress.[38] A further study has demonstrated the efficacy of using yoga and music as a means of reducing stress levels among students.[105] They found that when individuals engaged in deep yogic breathing exercises, listened to religious hymns, and played the flute, their mean value of the GSR decreased. Deep breathing yoga (DBY) is an effective method that has been demonstrated to lower stress levels, as evidenced by the cognitive evaluation of skin conductivity measurements using GSR biofeedback.[106] Following the implementation of the DBY intervention, the experimental group, which was subjected to stress, had a notably higher average value in comparison to the control group. It is important to consider that individuals may respond differently to various yoga practices. Some people might experience greater stress reduction with specific styles of yoga due to personal preferences or physiological differences. Monitoring GSR in response to different practices can help tailor recommendations to individual needs. In brief, a substantial body of research indicates that the practice of yoga can mitigate stress levels and may be linked to a drop in GSR, which serves as an indicator of diminished activity in the SNS. Ultimately, the goal of using GSR in the context of yoga research is to provide objective evidence that aligns with the reported benefits of stress reduction and relaxation associated with regular yoga practice.

Study characteristics and quality

A comprehensive depiction of the characteristics of each study is presented in Table 1.

Table 1: An overview of the numerous bio-signal markers that demonstrate stress reduction by yoga

Literature cited	Target	Yoga form	Bio-signal	Feature select	Implication
[18]	Stress	Pranakarshan pranayama and Yoga nidra	EEG and GSR	RP and change in impedance of skin	Reduction in stress
[19]	Stress	Sudharshana Kriya	EEG	Energy	Reduction in stress
[20]	Mental stress	Sudarshan Kriya	EEG and ECG	PSD and HRV	Decrement in mental stress
[21]	Stress and anxiety	Alternate nostril yoga breathing	EEG	RP	Reduction in stress and anxiety
[22]		Bhramari pranayama	EEG	PSD	Alpha band functional network structure integrates better during and after yoga
[41]	ANS	Integrated yoga-based intervention	ECG	HRV	Increased PNS activity
[42]	Anxiety	Tai chi	EKG and EEG	PSD	Decreased anxiety and increased EEG theta activity
[43]	Stress	Vipassana	EEG	PSD	Increased occipital gamma power
[44]		Zen meditation	EEG and ECG	AP and low frequency/high-frequency ratio	Internalized attention
[45]		Zen meditation	EEG	Spectral powers	Zen meditation increased the state of consciousness
[47]		Transcendental meditation	EEG	Coherence	Stabilization attentional awareness
[50]		Bhramari Pranayama	EEG	Gamma wave	Generate controlled high-frequency gamma waves
[53]		Nonreferential compassion meditation	EEG	RP	
[56]	Stress	Shambhavi Maha Mudra	EEG	Spectral analysis	Higher level of mental consciousness
[63]	The spinally mediated reflex response	Medical yoga therapy	EMG	Nociceptive flexion reflex	Reduce stress
[66]	State of consciousness	"OM" chanting	EEG and GSR	RP and change in impedance of the skin	Alleviating stress
[67]	Stress	Abdominal breathing	GSR	Skin resistance	Reducing the stress level
[70]	Stress	Mindfulness meditation	fMRI	Resting-state functional connectivity	Stress reduction effects
[71]	Depression	Hatha yoga	fMRI	Functional connectivity	Reduce depressive symptomatology
[72]	Cognitive aging	Hatha yoga	fMRI	Functional connectivity	Influences healthier cognitive aging process
[74]	Depression and epilepsy	"OM" chanting	fMRI	Neuro-hemodynamic	Potential role of this "OM" chanting in clinical practice
[75]	Anxiety	Bhastrika Pranayama	fMRI	Functional connectivity	Significantly reduce the levels of anxiety
[84]	Autonomic reactivity	Mukh Bhastrika	ECG	HRV	Increase in PNS activity

PNS: Parasympathetic, ANS: Autonomic nervous system, RP: Relative power, AP: Absolute power, PSD: Power spectral density, HRV: Heart rate variability, ECG: Electrocardiogram, fMRI: Functional magnetic resonance imaging, GSR: Galvanic skin response, EEG: Electroencephalogram, EMG: Electromyogram, EKG: Electrocardiogram

Conclusion

The practice of yoga offers a promising avenue for reducing stress and promoting overall well-being. Through a variety of physiological and psychological mechanisms, yoga has demonstrated its potential to alleviate the burdens of modern-day stressors. From the measurable changes in GSR and electromyography (EMG) indicating muscle relaxation and reduced SNS activity to the shifts in ECG, showcasing lowered heart rate and enhanced HRV, and the insights gained from fMRI and EEG revealing alterations in brain activity patterns associated with emotion regulation and mindfulness–yoga presents a comprehensive approach to stress reduction.

The incorporation of deliberate, measured movements, conscious breathing, and mindfulness strategies in yoga exercises facilitates the stimulation of the PNS nervous system, resulting in a state of relaxation. With consistent engagement, yoga has the potential to reshape habitual stress responses, cultivating resilience and emotional balance over time. However, it is crucial to recognize the individuality of responses to yoga and the multifaceted nature of stress reduction. Factors such as the type and intensity of yoga practice, individual predispositions, and external influences all contribute to the observed outcomes. Therefore, a holistic approach to stress reduction should consider the diverse range of physiological, psychological, and subjective measures to truly appreciate the transformative potential of yoga. As modern life continues to present challenges to our well-being, the ancient wisdom of yoga offers a timeless remedy. Whether it is the calming effects observed in GSR, the muscle relaxation highlighted by EMG, the heart-centered changes reflected in ECG, brainwave variations detected in EEG, or the profound shifts in brain activity detected through fMRI–yoga stands as a beacon of hope, guiding individuals toward a state of inner harmony and tranquillity in the face of life's pressures. Through its holistic and integrative approach, yoga beckons us to explore not only the physical postures but also the profound journey toward stress reduction, emotional well-being, and a more balanced existence.

Futures Aspects

Looking ahead, the exploration of reducing stress with yoga is poised to uncover even greater insights and applications. As scientific research and technology continue to advance, future aspects in this field hold the promise of deepening our understanding and expanding the impact of yoga on stress reduction. Here are some exciting future directions for consideration:

Personalized approaches

With the advent of precision medicine and individualized health care, future studies may delve into tailoring yoga practices to individuals based on their physiological responses, genetic factors, and stress profiles. This could lead to optimized stress reduction strategies that are uniquely suited to each person.

Neuroplasticity and brain resilience

Ongoing research into the effects of yoga on brain plasticity and resilience may reveal how consistent practice can remodel neural pathways, enhancing our ability to cope with stress and emotional challenges. Understanding the mechanisms through which yoga shapes the brain could pave the way for innovative interventions.

Virtual reality and immersive experiences

The utilization of virtual reality (VR) and augmented reality technologies has the potential to provide immersive yoga experiences that effectively engage several senses and amplify the state of relaxation. Future studies might explore the impact of VR-enhanced yoga sessions on stress reduction and emotional well-being.

Combination therapies

Integrating yoga with other therapeutic modalities, such as cognitive-behavioral therapy, biofeedback, or mindfulness-based stress reduction holds promise for more comprehensive and synergistic approaches to stress management.

Biometric wearables

Advances in wearable technology could enable real-time monitoring of physiological parameters during yoga practice. The utilization of real-time data has the potential to yield significant insights into the immediate effects of various yoga approaches on the reduction of stress.

Neuroscientific discoveries

As neuroscience techniques evolve, including more advanced neuroimaging methods and neurochemical assays, we can anticipate more detailed insights into how yoga influences brain function, neurotransmitter balance, and stress-related biomarkers.

Public health integration

Collaborations between yoga practitioners, researchers, and healthcare professionals may lead to the integration of yoga-based interventions into mainstream healthcare systems, offering accessible and evidence-based stress reduction strategies to a broader population.

In embracing these future aspects, the exploration of reducing stress with yoga is primed to not only deepen its scientific foundation but also to impact individuals' lives on a global scale. As we journey forward, the ancient wisdom of yoga continues to intertwine with modern science, offering a path toward enhanced well-being and resilience in the face of life's challenges.

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Conflicts of interest

There are no conflicts of interest.

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