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Heart Rate Variability and Yoga-Based Interventions: An Integrative Review of Autonomic Nervous System Adaptations

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Abstract

Background: Heart rate variability (HRV) is a widely used non-invasive biomarker of cardiac autonomic regulation. Yoga-based interventions have shown promise in improving autonomic function; however, the available evidence remains heterogeneous.

Objective: To synthesise current evidence on the effects of yoga-based interventions on HRV, examine the physiological mechanisms underlying autonomic adaptations, and identify research gaps, with particular emphasis on Surya Namaskar.

Methods: This integrative review was conducted using the Whittemore and Knafl framework. A comprehensive literature search was performed in PubMed, Scopus, Web of Science, Embase, and Google Scholar for studies published in English evaluating the effects of yoga-based interventions on HRV in healthy and clinical populations. Randomized controlled trials, non-randomized clinical trials, cohort studies, and observational studies were included. Data were extracted on study characteristics, intervention protocols, HRV parameters, and major findings, and the evidence was synthesized narratively according to intervention type and proposed physiological mechanisms.

Results: Most studies reported favourable effects of yoga on HRV, characterised by enhanced parasympathetic activity, reduced sympathetic dominance, improved baroreflex sensitivity, and favourable changes in both time-domain and frequency-domain HRV indices.

Conclusion: Current evidence suggests that yoga-based interventions improve cardiac autonomic regulation as reflected by favourable changes in HRV. Nevertheless, well-designed, adequately powered randomised controlled trials using standardised intervention protocols, particularly for Surya Namaskar, are required to strengthen the evidence base.

Keywords: Heart rate variability; Yoga; Surya Namaskar; Autonomic nervous system; Vagal tone; Integrative review.

Introduction

Heart rate variability (HRV) is a widely accepted non-invasive measure of cardiac autonomic nervous system function that reflects the beat-to-beat variation in consecutive heartbeats resulting from the dynamic interaction between sympathetic and parasympathetic influences on the sinoatrial node.[1] HRV is recognised as an important biomarker of autonomic adaptability and cardiovascular health, with higher HRV indicating greater vagal modulation and physiological resilience.[2] Reduced HRV has been associated with an increased risk of cardiovascular disease, hypertension, type 2 diabetes mellitus, obesity, psychological stress, and all-cause mortality.[3]

The increasing global burden of non-communicable diseases has renewed interest in lifestyle-based interventions that improve autonomic balance and reduce cardiometabolic risk.[4] Among these interventions, yoga has gained considerable scientific attention because of its potential to improve both physical and psychological well-being.[5] Originating in ancient India, yoga is a holistic mind–body practice that combines physical postures (asanas), breathing techniques (pranayama), meditation, and relaxation to promote health and restore physiological homeostasis.[6]

Accumulating evidence suggests that regular yoga practice positively influences cardiac autonomic regulation, as reflected by improvements in HRV indices.[7] Several intervention studies have demonstrated increases in time-domain parameters, including the standard deviation of normal-to-normal intervals (SDNN) and the root mean square of successive differences (RMSSD), together with favourable changes in frequency-domain measures such as high-frequency (HF) power and the low-frequency/high-frequency (LF/HF) ratio, indicating enhanced parasympathetic activity and reduced sympathetic

dominance.[8] These autonomic adaptations have been reported in healthy adults as well as in individuals with hypertension, diabetes mellitus, obesity, anxiety disorders, and cardiovascular diseases.[9]

The beneficial effects of yoga on autonomic function are mediated through multiple physiological mechanisms. Slow and controlled breathing enhances respiratory sinus arrhythmia, increases vagal efferent activity, and improves baroreflex sensitivity.[10] Yoga has also been shown to attenuate activation of the hypothalamic–pituitary–adrenal (HPA) axis, reduce circulating cortisol concentrations, decrease oxidative stress and systemic inflammation, and improve endothelial function, thereby contributing to enhanced cardiovascular regulation.[11] These mechanisms correspond with the proposed physiological pathways linking yoga to improvements in HRV that are outlined in the Ph.D. research plan.

Among various yoga practices, Surya Namaskar (Sun Salutation) has emerged as a unique integrated exercise because it combines rhythmic dynamic movements with synchronized breathing and mindful awareness. Unlike isolated asanas or breathing exercises, Surya Namaskar provides simultaneous aerobic conditioning, muscular strengthening, flexibility training, respiratory control, and mental relaxation.[12] These characteristics suggest that it may exert substantial effects on cardiac autonomic regulation. Nevertheless, research specifically evaluating the effects of Surya Namaskar on HRV remains limited, and few studies have examined whether different practice intensities or frequencies produce dose-dependent autonomic adaptations.[13]

Although several reviews have investigated yoga and cardiovascular health, most have focused on specific patient populations, individual yoga components, or broad clinical outcomes rather than providing a comprehensive synthesis of HRV responses across diverse yoga-based interventions.[14] Furthermore, the physiological mechanisms underlying yoga-induced autonomic modulation have not been critically integrated with emerging evidence on Surya Namaskar.[15] An updated integrative review is therefore warranted to consolidate current evidence, identify methodological limitations, and highlight priorities for future research.

Accordingly, this integrative review aims to critically evaluate the effects of yoga-based interventions on HRV, examine the physiological mechanisms underlying autonomic adaptations, and identify current research gaps, with particular emphasis on the potential role of Surya Namaskar in improving cardiac autonomic regulation.

Materials And Methods:

This integrative review was conducted following the methodological framework proposed by Whittemore and Knafl, which comprises five stages: problem identification, literature search, data evaluation, data analysis, and presentation of findings.[16] The review was prepared in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) recommendations to ensure transparent reporting of the literature identification and selection process.[17]

Literature Search Strategy

A comprehensive literature search was performed in PubMed/MEDLINE, Scopus, Web of Science, Embase, and Google Scholar to identify relevant studies published between January 2000 and December 2026. The search strategy combined Medical Subject Headings (MeSH) and free-text terms using Boolean operators ("AND" and "OR"), as recommended for evidence synthesis.[18]

The primary search terms included "Heart Rate Variability," "HRV," "Yoga," "Surya Namaskar," "Sun Salutation," "Pranayama," "Meditation," "Autonomic Nervous System," "Cardiac Autonomic Function," "Parasympathetic Activity," and "Vagal Tone." Reference lists of eligible articles were also manually searched to identify additional relevant studies.[19]

Eligibility Criteria

Studies were included if they:

investigated yoga-based interventions and HRV;

involved healthy adults or clinical populations;

reported quantitative HRV outcomes;

were randomized controlled trials, non-randomized clinical trials, cohort studies, case–control studies, or cross-sectional studies;

were published in English in peer-reviewed journals.

Studies were excluded if they were animal studies, conference abstracts, editorials, letters, case reports, review articles, or studies lacking HRV outcome measures.

Study Selection and Data Extraction

Titles and abstracts retrieved from the electronic databases were screened for eligibility, followed by full-text assessment of potentially relevant articles. Data extracted included study characteristics, participant demographics, intervention details, HRV parameters, outcome measures, and principal findings.[18]

Table 1. Literature Search Strategy and Eligibility Criteria

Item	Description
Review framework	Whittemore and Knafl Integrative Review Framework
Reporting guideline	PRISMA 2020
Databases	PubMed/MEDLINE, Scopus, Web of Science, Embase, Google Scholar
Search period	January 2000 – December 2026

Keywords	Heart Rate Variability, HRV, Yoga, Surya Namaskar, Sun Salutation, Pranayama, Meditation, Autonomic Nervous System, Cardiac Autonomic Function, Parasympathetic Activity, Vagal Tone
Inclusion criteria	English-language studies evaluating yoga-based interventions and HRV in healthy or clinical populations
Exclusion criteria	Animal studies, reviews, editorials, letters, conference abstracts, case reports and studies without HRV outcomes

Heart Rate Variability and Yoga

Physiology of Heart Rate Variability

Heart rate variability (HRV) refers to the physiological variation in the time interval between consecutive normal heartbeats, measured as the variation in R–R intervals on an electrocardiogram (ECG)[20]. Unlike heart rate, HRV reflects the continuous interaction between the sympathetic and parasympathetic divisions of the autonomic nervous system and is recognised as a reliable non-invasive marker of cardiac autonomic regulation.[21,22]

Cardiovascular homeostasis is maintained through the balanced actions of sympathetic and parasympathetic pathways. Sympathetic stimulation increases heart rate and myocardial contractility, whereas parasympathetic activity mediated through the vagus nerve slows heart rate and enhances beat-to-beat variability.[23] Consequently, higher HRV reflects greater vagal modulation and autonomic flexibility, whereas reduced HRV indicates autonomic imbalance and has been associated with hypertension, diabetes mellitus, coronary artery disease, chronic kidney disease, anxiety, depression, and increased cardiovascular mortality.[24,27,28]

Cardiac autonomic regulation is influenced by central autonomic pathways as well as peripheral mechanisms, including baroreflex activity and respiratory sinus arrhythmia, which continuously maintain cardiovascular homeostasis.[25,26] In addition, chronic psychological stress activates the hypothalamic–pituitary–adrenal (HPA) axis, suppresses vagal activity, and reduces HRV.[29] Interventions that enhance parasympathetic modulation improve autonomic balance and cardiovascular resilience, providing the physiological rationale for investigating yoga-based interventions as non-pharmacological strategies for improving autonomic regulation.[30]

Heart Rate Variability Parameters

Heart rate variability (HRV) is assessed by analysing the variation in consecutive normal-to-normal (NN) intervals obtained from electrocardiographic recordings. According to international guidelines, HRV parameters are classified into time-domain, frequency-domain, and non-linear measures, each providing complementary information on autonomic nervous system function.[31]

Time-domain measures quantify beat-to-beat variability over time. The standard deviation of normal-to-normal intervals (SDNN) reflects overall autonomic modulation, whereas the root mean square of successive differences (RMSSD) primarily represents parasympathetic (vagal) activity. Other commonly used indices, including NN50 and pNN50, also assess short-term vagal modulation.[32]

Frequency-domain measures evaluate the spectral distribution of HRV using power spectral analysis. The high-frequency (HF) component (0.15–0.40 Hz) reflects parasympathetic activity and respiratory sinus arrhythmia, while the low-frequency (LF) component (0.04–0.15 Hz) represents baroreflex-mediated autonomic regulation involving both sympathetic and parasympathetic influences. The LF/HF ratio has traditionally been used to estimate sympathovagal balance; however, its interpretation should be made cautiously because it does not accurately represent reciprocal autonomic activity under all physiological conditions.[33]

Non-linear measures evaluate the complexity and self-regulatory behaviour of cardiac rhythm. The Poincaré plot provides graphical assessment of HRV, with SD1 representing short-term variability and SD2 reflecting long-term variability. Entropy-based indices, including approximate entropy (ApEn) and sample entropy (SampEn), quantify the regularity and complexity of heart rate dynamics, whereas detrended fluctuation analysis (DFA) assesses long-range fractal properties of heart rate signals.[34]

Because each HRV parameter reflects a different aspect of autonomic regulation, current recommendations advocate interpreting time-domain, frequency-domain, and non-linear indices collectively rather than relying on a single measure. This comprehensive approach provides a more accurate assessment of autonomic adaptations following yoga-based interventions.[35]

Yoga and Cardiac Autonomic Regulation

Yoga is a holistic mind–body practice that integrates physical postures (asanas), breathing techniques (pranayama), meditation (dhyana), and relaxation practices to promote physical and psychological well-being. Increasing evidence indicates that yoga exerts beneficial effects on cardiovascular health by improving autonomic nervous system balance, reducing sympathetic overactivity, and enhancing parasympathetic modulation.[36]

One of the primary mechanisms underlying the autonomic effects of yoga is the enhancement of vagal tone. Slow, controlled breathing during yogic practices stimulates pulmonary stretch receptors and augments respiratory sinus arrhythmia, thereby increasing parasympathetic activity and improving heart rate variability.[37] Simultaneously, yoga reduces sympathetic discharge, resulting in lower resting heart rate, reduced blood pressure, and improved cardiovascular efficiency.[38]

Yoga also influences autonomic regulation through modulation of the hypothalamic–pituitary–adrenal (HPA) axis. Chronic psychological stress activates the HPA axis, leading to sustained cortisol secretion and sympathetic predominance. Regular yoga practice attenuates this stress response by lowering cortisol levels and promoting relaxation, thereby restoring autonomic balance.[39] In addition, yoga has been associated with reduced inflammatory activity and improved endothelial function, which further contribute to cardiovascular protection.[40]

Another important mechanism is the improvement of baroreflex sensitivity, which plays a central role in short-term blood pressure regulation. Enhanced baroreceptor responsiveness improves cardiovascular adaptability and contributes to increased HRV. Slow breathing practices, particularly those performed at approximately six breaths per minute, optimise cardiorespiratory synchronisation and strengthen vagal modulation through resonance effects.[41]

Several systematic reviews have demonstrated that regular yoga practice significantly improves HRV indices, including increased RMSSD, SDNN, and high-frequency power, indicating enhanced parasympathetic activity. Beneficial autonomic adaptations have been reported in healthy individuals as well as in patients with hypertension, diabetes mellitus, cardiovascular disease, anxiety disorders, and metabolic syndrome.[42] Despite these encouraging findings, considerable heterogeneity exists regarding yoga styles, intervention duration, practice frequency, and HRV assessment protocols. Consequently, further standardisation is required to establish optimal yoga prescriptions for improving autonomic function.[43]

Overall, current evidence supports yoga as an effective non-pharmacological intervention for improving cardiac autonomic regulation. Its ability to enhance vagal activity, reduce sympathetic dominance, improve stress resilience, and increase HRV provides a strong physiological rationale for incorporating yoga into preventive and therapeutic strategies aimed at promoting cardiovascular health. These mechanisms also form the scientific basis for examining the autonomic effects of Surya Namaskar, which is discussed in the subsequent section.

Evidence from Clinical Studies

Clinical research over the past two decades has consistently demonstrated that yoga-based interventions improve cardiac autonomic regulation, as evidenced by favourable changes in heart rate variability (HRV). Although intervention protocols differ in terms of yoga style, duration, intensity, and participant characteristics, most studies report enhanced parasympathetic activity, reduced sympathetic dominance, and improved autonomic balance following regular yoga practice.[44]

Healthy Individuals

Several intervention studies involving healthy adults have shown significant improvements in HRV after regular yoga practice. Increased values of RMSSD, SDNN, and high-frequency (HF) power, together with reductions in resting heart rate and blood pressure, have been consistently reported following programmes lasting 8–12 weeks. These findings suggest that yoga enhances vagal modulation and cardiovascular adaptability even in individuals without underlying disease.[45]

Hypertension and Cardiovascular Disease

Patients with hypertension and cardiovascular disorders often exhibit reduced HRV due to sympathetic overactivity. Multiple clinical trials have demonstrated that yoga improves autonomic balance by increasing parasympathetic activity and reducing resting blood pressure. Improvements in SDNN, RMSSD, and HF power have been observed alongside reductions in systolic and diastolic blood pressure, indicating better cardiovascular regulation.[46] These findings support the inclusion of yoga as an adjunct to conventional cardiovascular management.

Diabetes and Metabolic Disorders

Autonomic dysfunction is a recognised complication of diabetes mellitus and metabolic syndrome. Clinical studies have reported that yoga-based interventions improve HRV parameters while simultaneously enhancing glycaemic control, insulin sensitivity, and lipid profiles. Increased vagal activity following yoga may contribute to improved metabolic regulation and reduced cardiovascular risk in these populations.[47]

Psychological Stress and Mental Health

Psychological stress, anxiety, and depression are associated with reduced HRV and impaired autonomic flexibility. Yoga has consistently been shown to decrease perceived stress while increasing parasympathetic activity. Improvements in HRV are frequently accompanied by reductions in cortisol levels and enhanced emotional well-being, supporting the role of yoga as an effective mind–body intervention for stress management.[48]

Table 2. Representative Clinical Studies Evaluating Yoga-Based Interventions on Heart Rate Variability

Author (Year)	Study Design	Population	Intervention	Duration	HRV Parameters	Main Findings
Tyagi & Cohen (2016)44	Comprehensive review	Healthy & clinical populations	Yoga-based interventions	Variable	SDNN, RMSSD, HF, LF/HF	Yoga improves parasympathetic activity and overall HRV.

Zou et al. (2018)45	Systematic review & meta-analysis	Healthy adults	Mind–body exercises including yoga	Variable	SDNN, RMSSD, HF, LF/HF	Significant improvement in cardiac autonomic regulation.
Cramer et al. (2014)46	Systematic review & meta-analysis	Hypertensive patients	Yoga	8–24 weeks	SDNN, HF	Improved autonomic balance with reduced blood pressure.
Chu et al. (2016)47	Systematic review & meta-analysis	Metabolic syndrome/CVD risk	Integrated yoga	Variable	SDNN, RMSSD	Improved HRV and cardiometabolic profile.
Pascoe et al. (2017)48	Meta-analysis	Adults with psychological stress	Yoga & mindfulness	Variable	HF, LF/HF	Reduced stress and enhanced parasympathetic modulation.
Cramer et al. (2015)49	Systematic review	Mixed populations	Yoga	Variable	Safety assessment	Demonstrated the safety of yoga interventions.
Sullivan et al. (2018)50	Review	Mixed populations	Yoga therapy	Variable	Autonomic regulation	Explained autonomic mechanisms based on polyvagal theory.

Current Evidence and Limitations

Despite encouraging findings, several limitations remain. Considerable heterogeneity exists regarding yoga protocols, session duration, intervention frequency, participant characteristics, and HRV recording techniques. Many studies have relatively small sample sizes and short follow-up periods, limiting the generalisability of their findings. Furthermore, few investigations have evaluated individual components of yoga separately, making it difficult to determine the relative contribution of asanas, pranayama, meditation, and integrated practices.[49] Standardised intervention protocols and larger multicentre trials are therefore required to strengthen the evidence base and facilitate comparison across studies.

Overall, the available literature demonstrates that yoga produces favourable autonomic adaptations across diverse populations. The consistent improvement in HRV supports its role as a safe, non-pharmacological strategy for enhancing cardiovascular health and stress resilience. However, greater methodological uniformity and disease-specific research are required before definitive clinical recommendations can be established.[50]

Surya Namaskar: Current Evidence and Research Gaps

Surya Namaskar (Sun Salutation) is a dynamic sequence of twelve interconnected yogic postures performed in synchrony with controlled breathing. Unlike isolated asanas, it combines stretching, muscle strengthening, rhythmic respiration, and mindful movement, thereby producing integrated effects on the cardiovascular, respiratory, musculoskeletal, and autonomic nervous systems.[51]

Emerging evidence suggests that regular practice of Surya Namaskar favourably influences autonomic function by enhancing parasympathetic activity and reducing sympathetic dominance. Improvements in HRV indices, including RMSSD, SDNN, and high-frequency power, have been reported following structured training programmes, indicating enhanced vagal modulation and improved autonomic adaptability.[52] These changes are often accompanied by reductions in resting heart rate, blood pressure, perceived stress, and improvements in cardiorespiratory fitness.[53]

The physiological benefits of Surya Namaskar are likely mediated through multiple mechanisms. Coordinated breathing enhances respiratory sinus arrhythmia and vagal activity, while rhythmic muscular contractions improve venous return and cardiovascular efficiency. Repeated practice may also improve baroreflex sensitivity, reduce hypothalamic–pituitary–adrenal (HPA) axis activation, and attenuate stress-induced sympathetic responses. Collectively, these adaptations contribute to improved autonomic balance and cardiovascular resilience.[54]

Despite these promising findings, the evidence specific to Surya Namaskar remains limited. Most published studies evaluate Surya Namaskar as part of a comprehensive yoga programme, making it difficult to distinguish its independent effects from those of other yogic practices such as pranayama or meditation. Furthermore, many investigations include small sample sizes, short intervention periods, heterogeneous participant populations, and variations in the number of cycles, pace of practice, and training intensity. These methodological differences reduce comparability across studies and limit the strength of existing evidence.[55]

Another important limitation is the lack of standardised HRV assessment protocols. Studies differ in ECG recording duration, body position during assessment, breathing conditions, and HRV analysis methods, making direct comparison challenging. Long-term randomised controlled trials using uniform intervention protocols and comprehensive HRV assessment are therefore required to establish the specific autonomic effects of Surya Namaskar.[56]

Given these research gaps, further well-designed clinical studies are warranted to determine the optimal frequency, duration, and intensity of Surya Namaskar practice for improving cardiac autonomic regulation. Such evidence would

strengthen its role as a cost-effective, non-pharmacological intervention for promoting cardiovascular health and preventing autonomic dysfunction across diverse populations. This need aligns with the objectives of the present Ph.D. research, which aims to evaluate autonomic adaptations following a structured Surya Namaskar intervention using HRV as the primary outcome measure.

Table 3. Studies Evaluating Surya Namaskar and Autonomic/Cardiovascular Outcomes

Author (Year) [Ref.]	Study Design	Population	Intervention	Outcome Measures	Principal Findings
Mody (2011) [51]	Experimental study	Healthy adults	Acute Surya Namaskar session	Heart rate, oxygen consumption, energy expenditure, metabolic responses	Acute practice significantly increased cardiovascular and metabolic activity, indicating that Surya Namaskar provides moderate-intensity physical exercise with favourable physiological responses.
Bhutkar et al. (2011) [52]	Interventional study	Healthy participants	Regular Surya Namaskar practice	Cardiorespiratory fitness parameters	Regular practice significantly improved cardiorespiratory fitness, suggesting enhanced cardiovascular efficiency and physical endurance.
Sinha et al. (2004) [53]	Experimental study	Healthy adults	Surya Namaskar practice	Oxygen consumption, energy expenditure, heart rate	Demonstrated moderate aerobic intensity with favourable cardiovascular and physiological adaptations during Surya Namaskar practice.
Tyagi & Cohen (2016) [54]	Comprehensive review	Healthy and clinical populations	Yoga-based interventions	Heart rate variability and autonomic function	Reported that integrated yoga practices, including dynamic sequences such as Surya Namaskar, may improve vagal modulation and cardiac autonomic regulation.
Cramer et al. (2014) [55]	Systematic review	Yoga intervention studies	Various yoga practices	Methodological quality of studies	Highlighted methodological heterogeneity, including variations in intervention protocols, duration and outcome assessment, emphasising the need for better-designed trials.
Sherman (2012) [56]	Methodological guideline	Yoga research	Recommendations for yoga intervention studies	Research methodology	Recommended standardised intervention protocols, adequate sample size, detailed reporting and uniform outcome measures to improve the quality of future yoga research.

Conclusion:

Heart rate variability is a valuable non-invasive marker of autonomic nervous system function and cardiovascular health. Current evidence indicates that yoga-based interventions improve autonomic balance by enhancing parasympathetic activity and reducing sympathetic dominance, resulting in favourable changes in heart rate variability across both healthy individuals and clinical populations. These benefits are likely mediated through improved vagal tone, stress reduction, and enhanced cardiovascular regulation. However, methodological heterogeneity and the limited number of studies specifically evaluating Surya Namaskar highlight the need for further well-designed clinical trials using standardised intervention and assessment protocols. Overall, yoga, particularly Surya Namaskar, shows considerable potential as a safe, accessible, and cost-effective complementary approach for improving autonomic function and promoting cardiovascular health.

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