Review Article

Yoga and heart rate variability: A comprehensive review of the literature

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ABSTRACT

Heart rate variability (HRV) has been used as a proxy for health and fitness and indicator of autonomic regulation and therefore, appears well placed to assess the changes occurring with mind-body practices that facilitate autonomic balance. While many studies suggest that yoga influences HRV, such studies have not been systematically reviewed. We aimed to systematically review all published papers that report on yoga practices and HRV. A comprehensive search of multiple databases was conducted and all studies that reported a measure of HRV associated with any yoga practice were included. Studies were categorized by the study design and type of yoga practice. A total of 59 studies were reviewed involving a total of 2358 participants. Most studies were performed in India on relatively small numbers of healthy male yoga practitioners during a single laboratory session. Of the reviewed studies, 15 were randomized controlled trials with 6 having a Jadad score of 3. The reviewed studies suggest that yoga can affect cardiac autonomic regulation with increased HRV and vagal dominance during yoga practices. Regular yoga practitioners were also found to have increased vagal tone at rest compared to non-yoga practitioners. It is premature to draw any firm conclusions about yoga and HRV as most studies were of poor quality, with small sample sizes and insufficient reporting of study design and statistical methods. Rigorous studies with detailed reporting of yoga practices and any corresponding changes in respiration are required to determine the effect of yoga on HRV.

Key words: Cardio-autonomic; meditation/relaxation; pranayama; vagal tone; yogic.

INTRODUCTION

Heart rate variability: A measure of cardiac autonomic control

There is growing evidence that physiological and psychological stress disrupts autonomic balance and prolonged autonomic imbalance is associated with a wide range of somatic and mental diseases.[1] Such autonomic imbalance is reflected in measures of heart rate variability (HRV), which have been positively associated with aerobic fitness,[2] resilience to stress,[3] and psychological and physiological flexibility[4] and negatively associated with cardiovascular disease,[1] stress,[1,5,6] neuronal atrophy,[7] negative affective states,[8] and maladaptive stress responses.[1]

Heart Rate (HR) in healthy humans is influenced by physical, emotional, and cognitive activities,[7] and physiological oscillations that lead to variable beat-to-beat fluctuations in HR is known as HRV. HR and HRV are perhaps the most sensitive and easily accessible indicators of autonomic regulation and vagal activity. A high resting HR is a risk factor for cardiac disease[9,10] while HRV reflects the dynamic balance arising from the coactivation, coinhibition, or reciprocal activation

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or inhibition of the sympathetic and parasympathetic nervous systems[11] and provides a proxy for the health, adaptability, flexibility, and neural regulation of the cardiovascular system.[1,7,12]

Quantification of heart rate variability

HRV is measured using the R-R interval (QRS peak) on an electrocardiogram with the beat-to-beat variation reflecting the chaotic properties of the heart. There are a variety of different algorithmic approaches for operationalizing HRV that have been reported elsewhere.[11,13,14] This section outlays a brief description of time and frequency domain analysis.

It is generally accepted that under resting conditions, HRV in the time domain mainly reflects parasympathetic outflow and there are many time domain measures such as standard deviation of all normal-to-normal "N-N" intervals, root mean square of successive differences of interval (RMSSD), pair of successive normal-to-normal intervals that differ by more than 50 ms (NN50), proportion of NN50 (pNN50) etc. Frequency domain analysis reflects overall autonomic balance[13,15] and is the most widely used tool to investigate HRV and involves decomposition of sequential R-R intervals into sinusoidal components of different amplitude and frequency.[13,14] Power spectrum analysis is most commonly performed using the fast Fourier transformation which allows the classification of HRV into three frequency bands; very low frequency (VLF < 0.04), low frequency (LF - 0.04–0.15 Hz), and high frequency (HF - 0.15–0.4 Hz).[13,14] The spectral components such as VLF, LF, and HF may be expressed in absolute values of power (ms^2)[13] while Pagani *et al.* suggest the use of relative values in the form of normalized units (n.u.) for LF and HF components such as HFn.u. and LFn.u.[15] The total frequency or variance reflects the net effect of all physiological oscillations contributing to HRV while HR oscillations in the HF band are respiratory-dependent and reflect respiratory sinus arrhythmia (RSA). As RSA is vagally modulated, HF-HRV is often considered an index of parasympathetic activity during spontaneous breathing. However, while RSA and vagal tone are inversely related to respiration rate and directly related to tidal volume under rest conditions,[11] the assumption that respiration is limited to the HF band has been questioned.[16]

Just as HF-HRV is related to parasympathetic activity, LF-HRV is often related to sympathetic activity, yet the interpretation and clinical significance of HRV in the LF band have aroused intense controversy.[16,17] The relationship between the LF band and sympathetic activity has been disputed because LF-HRV has been shown to be partly under parasympathetic control.[16] Further, it has been argued that respiratory modulation is frequency-dependent and the impact of respiration on HRV is exacerbated when the respiration rate is between 3 and 9 breaths/min, which is within the LF range.[12,17] In this case, RSA affects primarily LF-HRV by producing large amplitude HR oscillations in the LF range.

The enormous intra- and inter-individual differences observed in respiratory patterns[17] under many different conditions[18] suggest that differences in respiratory patterns may influence the HRV spectra independent of autonomic output.[17] Large-amplitude HR oscillations occurring in the LF range resulting from breathing at an optimal frequency may reflect resonance, also known as "coherence" occurring due to entrainment between HR, blood pressure (BP), and the relaxation response (RR)[19] rather than sympathetic tone. While such entrainment of heart rhythm coherence may lead to improved BP control and gas exchange via efficient ventilation/perfusion matching,[12,19] it obscures the interpretation of LF or LF/HF as measures of sympathetic tone or autonomic balance.

Interpretation of the "VLF" band (Hz) is even less clear than that of the LF band. While it is accepted that the VLF band is related to thermoregulation and is sympathetically mediated,[11] standardized guidelines on HRV measurement suggest that VLF band measures cannot be accurately assessed from short-term recordings. The VLF band is, therefore, rarely reported in HRV studies.[11,13]

Yoga and autonomic influence

Yoga involves a diverse range of mind-body practices such as meditation/relaxation techniques (*dhyana*), breathpractices (pranayama), and physical postures (asana) that aim to integrate the mind and body and bestow the practitioner with physical, mental, intellectual, and spiritual development. Several studies report associations between yoga and markers of autonomic activity such as HR,[20] baroreflex sensitivity,[21] galvanic skin resistance,[22] evoked potentials,[23] attention,[24] cognitive ability, emotional regulation,[25] and mental resilience.[26] Further studies report that regular yoga practice improves a wide range of clinical conditions associated with autonomic dysfunction, such as hypertension,[27,28] diabetes,[20] anxiety,[29] depression,[30] and pain.[31] Furthermore, two systematic reviews report that yoga practices have profound effects on autonomic and metabolic activities[20,32] and reduce cardiovascular risk.[20] In contrast, a recently published systematic review and meta-analysis that included 14 randomized clinical trials suggests there is no convincing evidence that yoga modulates HRV.[33]

Despite the known, strong relationship between autonomic function and HRV, and multiple reports of changes in HRV with yoga practice, the literature on yoga and HRV has not yet been subjected to a comprehensive review. This current paper aims to review the existing literature and document the long- and short-term effects of different yoga practices on HRV.

METHODOLOGY

For this systematic review, a comprehensive search of multiple databases including Scopus, PubMed, PsycINFO, CINAHL, Cochrane, and Science Direct Database was conducted, and a separate search was performed in Indian medical journals through IndMed, which indexes more than 100 prominent Indian scientific journals. The bibliographies of identified papers were also searched for relevant articles. The search was performed for articles published up to July 2015 and was not otherwise restricted by date or study population. The primary search terms included yoga, yogic, asana/posture, pranayama/breathing, yoga nidra/relaxation, and meditation that included Transcendental, *Brahma Kumaris*, *AUM*, *mantra* and *Kundalini*, *Kriya* Yoga, *Ananda* Yoga, and *Sudarshan* Kriya with keywords HRV, RSA, autonomic, sympathetic, parasympathetic, and vagal. All studies that reported quantification of HRV in power spectrum frequency band, standard deviation values of beat-to-beat intervals or heart rhythm coherence with any yoga practice including yoga asanas (postures), pranayama (breathing), meditation, and yogic relaxation/nidra practices used either alone or as an integrated practice were included. Studies that included meditative practices directly associated with yoga such as transcendental meditation (TM) were also included in the review.

Studies were excluded if they were not in English, unobtainable, or only involved meditation and relaxation practices that are not directly associated with yoga such as Zazen/Zen, Buddhist, Vipassana or concentrative meditation, g-Tummo yoga, Qigong, RR, progressive muscle relaxation, and autogenic relaxation.

Selected studies were categorized according to the type of intervention: Relaxation/meditation, breathing, and postures/integrated yoga; the quality of the randomized controlled trials (RCT) was assessed using a Jadad score, which is a score from 0 to 5 that provides a measure of methodological rigor based on randomization, masking, and accountability (dropout and withdrawals).[34]

RESULTS

This review included 59 studies involving 2358 experimental subjects with study durations ranging from a single session to 6 months. A total of 16 RCTs were located with all of them having a Jadad score of 3 or less. A flowchart of the study search including the numbers of papers identified is shown in Figure 1. Studies, categorized according to the type of intervention (relaxation/meditation, pranayama practice, and integrated yoga/asana practice), are presented in Tables 1-5.

Heart rate variability and yogic relaxation or meditation

Table 1 summarizes the 12 studies investigating HRV during yoga relaxation and/or meditation. Seven of these studies are laboratory-based studies, of which six studies involved regular yoga/meditation practitioners while one involves non-yoga practitioners including hypertensive patients. Studies are longitudinal studies that include one cohort, one non-RCT (NRCT), and three RCTs that range from 6-week to over 6-month. These studies, which include 581 participants, reported varied outcomes with 8 studies reporting increases in HRV during yoga relaxation and/or meditation and 4 studies reporting no change.

Five of the laboratory-based studies compared HRV at baseline with HRV during or after a single laboratory session of yoga relaxation or meditation practice in regular yoga practitioners while a further study compared HRV during different stages of meditation. A further laboratory study compared HRV between different interventions after a single laboratory session study involving normotensive and hypertensive subjects. Of these studies, four reported reduced LFn.u. and increased HFn.u.[22,35,36,40] while two different studies of TM in advanced meditators reported increased HF power during periods of meditation compared to baseline eyes closed[37] and during periods of transcendental experience compared to other experiences

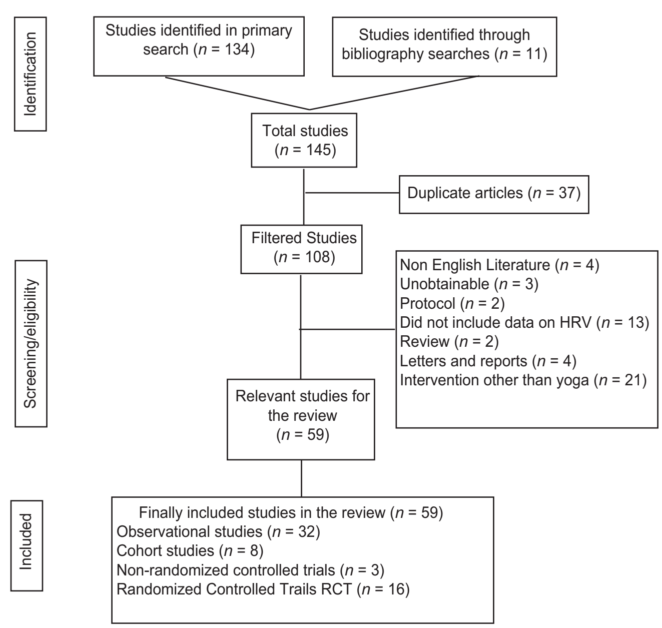

Figure 1: Flowchart of study search and included studies

Table 1: Heart rate variability with yoga relaxation and meditation

Study authors and year	Population	Study design	Intervention	Length of intervention	Comparators	HRV* (only statistically significant changes are reported with ↓ decrease and ↑ increase)	Other outcomes	Jadad scale score for RCT¶
Vempati and Telles 2002[35]	Regular yoga practitioner (*n*=35)	Multiple practices in multiple session	Yoga beaded relaxation; Supine rest	10 min each session	Baseline versus postintervention	Frequency domain ↓ LFn.u.‡, ↑ HFn.u.§, ↓ in LF/HF after yoga relaxation No significant change after supine rest	↓ ‖HR and ↓ skin conductance after relaxation ↓ HR after supine rest	-
Markil *et al*. 2012[36]	Regular Yoga practitioners with experience of >2 months; (*n*=20)	Multiple practices in multiple session	Hatha Yoga and relaxation (HY&R); yoga relaxation (YR)	90 min each session	Baseline versus postintervention	Frequency domain ↓ LFn.u., ↑ HFn.u. after both the sessions Time domain ↑ in pNN50** after both the sessions	↓ HR after both HY&R and YR	-
Telles *et al*. 2013[22]	Regular male Yoga practitioners with >6 months experience (*n*=30)	Multiple practices in multiple session study	Effortless meditation "*dhyana;*" mediative focusing "*dharana;*" nonmeditative thinking "*ekagrata;*" Random thinking "*cancal*"	20 min each session	Baseline versus during intervention	Frequency domain ↓ LFn.u., ↑ HFn.u. during *dhyana* ↑ LFn.u., ↓ HFn.u. During *ekagarata* and *cancalta* interventions Time domain ↑ NN50††, ↑ pNN50 during *dhyana*	↓ HR, BR‡‡ and ↑ in skin resistance and during *dhyana*	-
Travis and Wallace 1999[37]	Regular advanced meditators (*n*=20)	Single session	TM§§	10 min	Baseline eyes closed versus meditation	Frequency domain ↑ HF amplitude during meditation compared to baseline	↓ BR and skin conductance during meditation	-
Travis 2001[38]	Regular advanced meditators (*n*=30)	Single session	TM	15 min	Two different stages of meditation (transcending versus other inner experience)	Frequency domain ↑ HF amplitude during transcending stage compared to other inner experience No change in LF/HF	Higher ‖‖EEG alpha amplitude during transcending stages	-
Vempati and Telles 1999[39]	Regular Yoga practitioner (*n*=40)	Multiple practices in multiple sessions	Yoga-based relaxation; supine rest	10 min each session	Baseline versus postintervention	Frequency domain No change	↓ oxygen consumption	-
Santaella *et al*. 2014[40]	Hypertensive patients (*n*=16) and Normotensive population (*n*=14)	Multiple practices in multiple sessions	Yoga bases relaxation; supine rest	20 min each session	Comparison between intervention	Frequency domain ↓ LFn.u., ↑ HFn.u., ↓ LH/HF during relaxation compared to supine rest in both population group	No change in vasomotor tone	
Yunati *et al*. 2014[41]	Healthy nonmeditators >40 years (*n*=30)	Cohort Study	Sahaja Yoga meditation	12 weeks	Preintervention versus postintervention	Frequency domain ↑ TPms^2***, ↓ LFms^2†††, ↑ HFms^2‡‡‡, ↓ LF/HF Time domain ↑ SDNN§§§, ↑ pNN50	↓ in HR	
Madanmohan 2004[42]	Healthy adolescents (*n*=43)	NRCT‖‖‖	Yoga relaxation group (*n*=26) no intervention control (*n*=17)	6 weeks	Preintervention versus postintervention	Frequency domain No change	↓ HR following yoga training	-
Monika *et al*. 2012[43]	Females with menstrual irregularities (*n*=150)	RCT	Yoga Nidra (*n*=75) No intervention control (*n*=75)	6 months	Preintervention versus postintervention	Frequency domain No change in either group	↓ HR and ↓ in SBP****/DBP†††† in yoga group	2

Contd...

Table 1: Contd...

Study authors and year	Population	Study design	Intervention	Length of intervention	Comparators	HRV (only statistically significant changes are reported)	Other outcomes	Jadad scale score for RCT*
Travis *et al*. 2009[44]	Nonmeditators (*n*=50)	Crossover RCT	TM-Immediate start meditation group (*n*=25) Waitlist control: Delayed start meditation group (*n*=25)	10 weeks intervention (after 14 weeks gap waitlist control began meditation for 10 weeks)	Comparison between groups	Frequency domain No significant different between group after first postsession and second postsession in HRV	High frontal coherence in the immediate start group after first postsession	3
Paul-Labrador *et al*. 2006[45]	CHD patients (*n*=103)	Single-blinded RCT	TM group (52) Control-health education group (*n*=51)	16 week	Preintervention versus postintervention and comparison between groups	Frequency domain ↑ HFms² in meditation group from baseline, no significant change in control No significant postintervention difference between groups	↓ SBP in meditation group ↓ in insulin resistance compared to control	3

*HRV = Heart rate variability, ᵗRCT = Randomized controlled trial, ‡LFn.u. = Low frequency normalized unit, §HFn.u. = High frequency normalized unit, |HR = Heart rate, **pNN50 = Proportion of NN50, ᵗᵗNN50 = Pair of successive NN's that differ by more than 50 ms, ‡‡BR = Breath rate, §§TM = Transcendental meditation, ||EEG = Electroencephalogram, ***TP = Total power in absolute value, ᵗᵗᵗLFms² = Low frequency in absolute value, ‡‡‡HFms² = High frequency in absolute value, §§§SDNN = Standard deviation of NN interval, |||NRCT = Nonrandomized controlled trial, ****SBP = Systolic blood pressure, ᵗᵗᵗᵗDBP = Diastolic blood pressure

during meditation.[38] The one study examining HRV during meditation (*dhyana*), focused thinking (*dharana*), nonmeditative thinking (*ekagrata*), and random thinking (*cancatla*) reported reduced LFn.u. and increase HFn.u. during meditation (*dhyana*) and an increased LFn.u. and reduced HFn.u. during nonmeditative thinking and random thinking.[22] Whereas the study examining HRV in normotensive and hypertensive subjects reported decreased LFn.u. and increased HFn.u. after yoga relaxation compared to supine rest.[40] Furthermore, one study that compared HRV at baseline with HRV after yoga relaxation reported no change in HRV.[39]

A recent 12-week cohort study reported increases in both frequency and time domains[41] whereas of the three randomized studies, one study of coronary heart disease patients (with Jadad score 3) reported a marginal increase in absolute power of HF-HRV (HFms²) after 16-weeks of TM compared to a control group that received heath education.[45] Of the two RCTs reporting no change in HRV, one (with Jadad score 3) reported no change after 10-weeks of TM[44] while another (with Jadad score 2) reported no change in HRV after 6-months of regular yoga relaxation practice.[43] Similarly, a NRCT of adolescents reported no change in HRV after 6-weeks of yoga relaxation practice.[42]

Heart rate variability and yoga breathing

Table 2 summarizes 5 studies that involved rapid breathing practices. Two studies that measured HRV during rapid *Kapalbhati* breathing reported decreases in LFms² and HFms²[46,47] while two studies that compared HRV before and after *Kapalbhati* breathing reported increased LFn.u. and reduced HFn.u.,[48] or no change in LFn.u. and HFn.u. and a reduction in pNN50 after the practice.[49] The only longitudinal study was an RCT (with Jadad Score of 2) of elderly people regularly performing *Bhastrika* (rapid shallow breathing) that compared HRV before and after a 4-month intervention period. This study, which measured HRV during a period of regulated breathing at 12 breaths/min, reported decreases in LFn.u. and LF/HF in the breathing group compared to controls.[50]

Table 3 summarizes the 13 studies that involved slow breathing practices. Of these, ten are laboratory based and three are longitudinal studies that include one cohort, one NRCT, and one RCT that range from 2-month to 5-month.

Nine laboratory-based studies compared HRV before and either during or after various slow breathing practices. Of these, two studies reported increases in LFms²[47,53] and two reported increases in LFn.u. with increase in LF/HF observed during breathing practice,[54,56] while one study reported increased HR oscillations in the LF band.[51] Similarly increased HR oscillations in the LF band and significant decreases in respiratory frequency were also reported during mantra chanting and rosary prayer compared to post-session spontaneous breathing.[52] One study that examined extremely slow breathing at one breath/min in a single practitioner reported an increase in VLFms² and LF/HF and corresponding increases in HR while also reporting reductions in LFms² and HFms².[55] Furthermore, a recent study of slow yoga breathing in regular yoga practitioners reported no change in frequency measures compared to baseline despite improvement in time domain measures.[59] In addition,

Table 2: Heart rate variability and yoga rapid breathing

Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV* (only statistically significant changes are reported with '↓' decrease and '↑' increase)	Other outcomes	Jadad scale score for RCT†
Stancák *et al*., 1991[46]	Regular yoga practitioners (*n*=17)	Single practice in single session	*Kapalbhati* at 120 breaths/min	15 min (3 periods of 5 min each separated with 3 spontaneous breathing cycles)	Baseline versus during intervention	Frequency domain ↓ VLFms^{2}‡, ↓ LFms^{2}§ ↓ |HFms^{2}	↑ HR**, ↑ SBP††/ DBP‡‡ during *Kapalbhati*; ↓ BRS§§ during breathing	-
Peng *et al*. 2004[47]	Experienced *Kundalini* yoga meditators (*n*=11)	Multiple practices in single session each practice interspersed with 10 min of rest	*Kapalbhati* (rapid breath at 120 breaths/min	10 min	Baseline versus during intervention	Frequency domain ↓ LFms^{2} ($P<0.05$), ↓ HFms^{2} ($P<0.05$), ↑ LF/HF ($P<0.01$)	↑ HR	-
Raghuraj *et al*. 1998[48]	Regular male yoga practitioners (*n*=12)	Multiple practices in multiple session	*Kapalbhati* (120 breaths/min): ANB	1 min *Kapalbhati:* 15 min ANB	Baseline versus post-intervention	Frequency domain ↑ LFn.u.‖, ↓ HFn.u.***, and ↑ LF/HF after *Kapalbhati* No significant change after ANB	No change in HR with either breathing	-
Telles *et al*. 2011[49]	Regular male yoga practitioners (*n*=38)	Multiple practices in multiple session	*Kapabhati* at 60 breaths/min breath awareness	15 min session (three periods of 5 min each intermittent with 1 minute pause)	Baseline versus during and post	Frequency domain No significant change with *Kapabhati* or breath awareness Time domain *Kapalbhati*- ↓ pNN50††† during and postintervention Breath awareness - ↓ in pNN50 during and post intervention	↑ HR post-*Kapalbhati* and breath awareness	-
Santaella *et al*. 2011[50]	Elderly population >60 years (n=29)	RCT 4 months	*Bhastrika* breathing - rapid shallow breathing (*n*=15); control -stretching (*n*=14)	4 months	Pre- versus post-intervention	Frequency domain ↓ LFn.u., ↓ LF/HF in breathing group No significant change in controls	Improved respiratory variables ($P<0.005$) in breathing group	2

*HRV = Heart rate variability, †RCT = Randomized controlled trial, ‡VLFms^{2} = Very low frequency power, §LFms^{2} = Low frequency absolute value, |HFms^{2} = High frequency absolute value, **HR = Heart rate, ††SBP = Systolic blood pressure, ‡‡DBP = Diastolic blood pressure, §§BRS = Braoreflex sensitivity, ||LFn.u. = Low frequency normalized unit, ***HFn.u. = High frequency unit, †††pNN50 = Proportion of NN50

similar improvements in time domain measures have been reported in regular yoga practitioners compared to non-yoga practitioners during slow yoga breathing regulated at 6 breaths/min.[58]

Three studies examined combinations of breathing that include both fast and slow breathing practices. Of these, two studies reported increased LFms^{2} and reduced RMSSD during the practices[57] and decreased sympathovagal balance with increased HFn.u. and reduced LFn.u. after 2-month of regular practice.[60] Additionally, a 5-month RCT involving healthy non-yoga participants reported no change in frequency measures of HRV with *Sudarshan Kriya*.[62] A similar findings are reported in a 3-month NRCT involving chronic obstructive pulmonary disease patients with yoga breathing practice.[61]

Heart rate variability, yoga postures and integrated yoga practices

Table 4 summarizes 27 studies that investigated either yoga postures or integrated yoga practices that combine postures breathing and meditation. The majority of these studies reports enhanced autonomic balance.

Of the seven reported (3 with Jadad score of 3) ranging from 4-week to 36-week, two RCTs each with more than 20 healthy non-yoga practitioners[80,84] and four RCTs each with more than 60 participants[79,81-83] reported increased HFn.u., decreased LFn.u., and LF/HF with integrated yoga practices. While one RCT with 239 sedentary non-yoga practitioners reported increased heart rhythm coherence after 12 weeks of *Vinyasa* yoga.[85] A decrease in LFms^{2}

Table 3: Heart rate variability (HRV) and yoga slow breathing

Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV* (only statistically significant changes are reported with '↓' decrease and '↑' increase)	Other outcomes	Jadad scale score for RCT†
Peng *et al*. 1999[51]	*Kunadalini* meditators (n=4) Chi meditators (n=8)	Single practice in single session	*Kundalini* mediation group: Slow breathing and chanting Chi meditation group	Single session	Baseline versus during intervention	Frequency domain ↑ LFms^{2}‡ (higher amplitude of HR§ (oscillations in LF band) during both meditation		-
Bernardi *et al*. 2001[52]	Healthy non-yoga practitioners (n=23)	Single practice in single session	*Mantra* chanting Ave Maria rosary	Single session	During intervention versus postintervention	Frequency domain ↑ LFms^{2} (higher amplitude of HR oscillations in LF band) during mantra chanting and Ave Maria rosary (high peaks in LF band)	↑ BRS‖ and ↓ BR¶ during both intervention	-
Peng *et al*. 2004[47]	Experienced *Kundalini* yoga meditators (n=11)	Multiple practices in single session	Mindful, slow breathing with equal inhalation and exhalation Mindful focus on mantra	10 min each practice with equal duration of baseline	Baseline versus during intervention	Frequency domain ↑ LFms^{2} in slow breathing and mantra focusing ↑ LF/HF†† during mantra focusing	↑ in HR during segmented breathing	-
Ghiya and Lee 2012[53]	Non-yoga practitioners (n=20)	Multiple practices in multiple session	ANB‡‡ and paced breathing (5 breaths/min)	15 min	Baseline versus postintervention	Frequency domain ↑ TFms^{2}§§, ↑ LFms^{2}, ↑ HFms^{2} after ANB and paced breathing session	↑ HR after both the breathing session	-
Raghuraj and Telles 2008[56]	Regular male yoga practitioners (n=21)	Multiple practices in multiple session	ANB; RNB‖‖, LBN***	Each sequence for 45 min	Baseline versus during intervention	Frequency domain ANB - ↑ LF n.u., ↓ HF, ↑ LF/HF during breathing ranging to <10 breaths/min No significant change in frequency domain during RNB and LNB breathing	↑ HR and ↑ SBP†††/DBP‡‡‡ during ANB ↓ in BR during all breathing practices	-
Jovanov 2005[55]	Single male yoga practitioner (n=1)	Single practice in single session	ANB at 1 breath/min	10 min excluding baseline	Baseline versus during intervention	Frequency domain ↑ VLFms^{2}§§§, ↓ LFms^{2}, ↓ HFms^{2}, ↑ LF/HF	↑ HR during breathing	-
Raghavendra *et al*. 2013[54]	Regular male yoga practitioners (n=50)	Multiple practices in multiple session	Relaxation with breath regulation and breath regulation	12 min each session	Baseline versus during intervention	Frequency domain ↑ LFn.u.‖‖‖, ↓ in HFn.u.****, ↑ LF/HF during relaxation with breath regulation	↓ HR during relaxation with breath regulation	-
Selvaraj *et al*. 2008[57]	Regular male yoga practitioners (n=8)	Single practice in single session	*Shambhavi Mahamudra* (incorporates *sukh pranayama, aum* chanting, rapid breathing and relaxed sitting)	15 min	Baseline versus during intervention	Frequency domain ↑ LF/HF Time domain ↓ RMSSD‡‡‡‡, ↓ in pNN50§§§	↑ HR during pranayama, aum chanting and rapid breathing and ↓ in HR during relaxed sitting	-
Muralikrishnan *et al*. 2012[58]	Regular yoga practitioners (n=14) Non-yoga practitioners (n=14)	Multiple practices in single session	Deep breathing at 6 breaths/min	1 min	Comparison between group	Time domain ↑ SDNN§§§§, ↑ RMSSD, ↑ NN50‖‖‖‖, ↑ pNN50 in yoga practitioners compared to non-yoga practitioners	↓ HR in yoga practitioners compared to non-yoga practitioners	-

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Table 3: Contd...

Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV (only statistically significant changes are reported)	Other outcomes	Jadad scale score for RCT*
Telles *et al*. 2014[59]	Breathing group - Regular male yoga practitioners (*n*=26) Control group - non-yoga practitioners (*n*=15)	Multiple practices in single session	Breathing group - ANB and BA ***** Control group - quite sitting	25 min	Baseline versus during	Frequency domain No change in during ANB, breath awareness and quite sitting Time domain ↑ RMSSD, ↑ NN50 during ANB No change during breath awareness and quite sitting	↓ BR during ANB ↓ SBP during ANB	
Bhimani *et al*. 2011[60]	Healthy non-yoga practitioners (*n*=59)	Cohort study	Yogic breathings - (*Kapalbhati, Ujjayi*, right nostril breathing, *Sitkari and Shitali)*	2 months	Pre- versus post-intervention	Frequency domain ↓ LFn.u. ↑ HFn.u., and ↓LF/HF Time domain No significant change	No change in HR	-
Jaju *et al*. 2011[61]	COPD⁑⁑ patients (*n*=11) Healthy control (*n*=6)	NRCT‡‡‡‡‡	ANB at 5 breaths/min	3 months (30 min/5 days week)	Pre- versus post-intervention	Frequency domain No significant change in either group	Improvement in respiratory parameters in both groups	-
Kharya *et al*. 2014[62]	Healthy non-yoga practitioners (*n*=50)	RCT	*Sudarshan* Kriya (Rapid breathing, slow breathing and Om chanting) (*n*=19) *Prana* yoga (*n*=16) Controls leisure walk (*n*=20)	5 months	Pre- versus post-intervention	Frequency domain No significant difference in either group	Profound improvement in depression, anger and stress coping behavior in *Sudarshan Kriya* group	1

*HRV = Heart rate variability, †RCT = Randomized controlled trial, ‡LFms² = Low frequency absolute value, §HR = Heart rate, ǀBRS = Baroreflex sensitivity, **BR = Breath rate, ††HF = High frequency, ǀǀRNB = Right nostril breathing, ***LBN = Left nostril breathing, ‡‡ANB = Alternate nostril breathing; §§TF = Total frequency, †††SBP = Systolic blood pressure, ‡‡‡DBP = Diastolic blood pressure, §§§VLFms² = Very low frequency absolute value, ǀǀǀLFn.u. = Low frequency normalized units, ****HFn.u. = High frequency normalized units, ††††RMSSD = Root mean square of successive differences of interval, ‡‡‡‡pNN50 = Proportion of NN50, §§§§SDNN = Standard deviation of NN intervals, ǀǀǀǀNN50 = Pair of successive NN intervals that differ by more than 50 ms, ‡‡‡‡‡NRCT = Nonrandomized controlled trial

Table 4: Heart rate variability, yoga postures, and integrated yoga

Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV* (only statistically significant changes are reported with '↓' decrease and '↑' increase)	Other outcomes	Jadad scale score for RCT*
Howorka *et al*. 1995[63]	Healthy non-yoga practitioners (*n*=not reported)	Multiple practices in multiple session	Yoga session (headstand, shoulder stand and forward bend postures); aerobic exercise' rest	10 min each intervention	Baseline versus postintervention	Frequency domain ↓ LFms²†, ↑ HFms²‡, ↓ LF/HF after yoga No changes either after aerobic or rest		-
Manjunath and Telles 2003[64]	Regular male yoga practitioners (*n*=40)	Multiple practices in single session	Headstand without support (*n*=20) Headstand with support (*n*=20)	Single session	Baseline versus postintervention	Frequency domain ↓ HFn.u.§ and ↑ LF/HF after headstand without support Similar less significant change after headstand with support	↓ in HRǁ after both postures	-
Pitale *et al*. 2015[65]	Regular yoga practitioners (*n*=12)	Multiple practices in single session	Yoga session (standing, forward bend and inverted - shoulder and head stand postures)	Single session	Baseline versus intervention	Frequency domain ↑ LF and ↓ HF during standing postures ↓ LF, ↑ HF during inverted and forward bend postures		

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Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV (only statistically significant changes are reported)	Other outcomes	Jadad scale score for RCT*
Melville *et al*. 2012[66]	Sedentary healthy office employees (*n*=20)	Multiple practices in multiple session	Chair-based gentle integrated yoga; guided meditation Control during routine office work	15 min each intervention	Comparison between interventions	Frequency domain ↑ LFn.u.**, ↓ HFn.u., ↑ LF/HF during yoga compared to control session Time domain ↑ in SDNN# during yoga compared to control session	↓ BR‡‡ during yoga and meditation compared to control ↑ HR during yoga, ↓ in HR during mediation compared to control ↓ stress scores during yoga and meditation	-
Sarang and Telles 2006[67]	Regular male yoga practitioner (*n*=42)	Multiple practices in multiple session	CM§§; supine rest	Multiple sessions	Baseline versus during and postintervention	Frequency domain ↑ LFn.u., ↓ HFn.u., ↑ LF/HF during postural sequences of CM ↓ in LFn.u., ↑ HFn.u., ↓ LF/HF after CM No significant change with supine rest	↑ in HR and BR during CM and ↓ in HR and BR after CM	-
Vempati and Telles 2000[68]	Non-yoga practitioners with occupational stress (*n*=26)	Multiple practices in multiple session	CM with yoga philosophy including yogic management techniques	2 days	Pre- versus post-intervention	Frequency domain ↑ in HFn.u., ↓ LF/HF ↓ LFn.u	↓ BR after yoga intervention	-
An *et al*. 2010[69]	Healthy females non-yoga practitioners (*n*=28)	Multiple practices in multiple session	CM; supine rest	Multiple sessions	Baseline versus postintervention	Frequency domain ↓ LFn.u., ↑ HFn.u., ↓ LF/HF after CM Time domain ↑ pNN50‖ and RMSSD*** after CM No significant change in either domain with supine rest	↓ HR and respectively after CM and supine rest	-
Patra and Telles 2010[70]	Regular yoga male practitioners (*n*=30)	Multiple practices in multiple session	CM; Supine rest	Multiple session	Comparison between intervention	Frequency domain ↓ LFn.u., ↓ LF/HF during sleep after CM compared to supine rest Time domain ↑ pNN50 during sleep after CM compared to sleep	↓ HR during sleep after CM	-
Khattab *et al*. 2007[71]	Regular yoga practitioners (*n*=11)	Multiple practices in multiple session	Iyengar yoga, walking	Multiple sessions	Comparison between intervention	Time domain ↑ RMSSD, ↑ pNN50 with yoga practice compared to walking	↓ HR with yoga compared to walking	-
Shapiro *et al*. 2007[72]	Unipolar major depressive patients (*n*=17)	Cohort study	Iyengar yoga	8 weeks	Baseline versus postintervention	Frequency domain ↓ in LFms^2	Improvements in the scores of depression; hostility trait anxiety and anger	-

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Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV (only statistically significant changes are reported)	Other outcomes	Jadad scale score for RCT*
Dolgoff-Kaspar *et al*. 2012[73]	Patients awaiting organ transplant (*n*=6)	Cohort study	Laughter yoga - integrated gentle yoga practices with unconditional laughter for 3 weeks control period with open discussion for 1 week	4 weeks	Baseline versus postintervention	Time domain ↑ SDNN, ↑ RMSSD after yoga intervention compared to control period	Significant improvements in the scores of mood states, anxiety scores after yoga intervention compared to the control period	-
Papp *et al*. 2013[74]	Participants with elevated blood pressure (*n*=12)	Cohort study	Yoga postures (general, semi inversion and inversion)	8 weeks	Baseline versus postintervention	Time domain ↑ pNN50 after yoga intervention	No change in BP‡‡‡	-
Shankarappa and Prabha 2013[75]	Non-yoga practitioners (*n*=50)	Cohort study	Integrated yoga (yoga stretching, asana, and pranayama)	90 min daily/6 days a week (12 months)	Pre- versus post-intervention	Time domain ↑ in SDNN		-
Singh and Telles 2009[76]	Hypertensive (*n*=11) and diabetic patients (*n*=6)	Cohort study	Integrated yoga (asana, pranayama, and meditation)	7 days	Pre- versus post-intervention	No significant change in yoga group with integrated yoga in frequency and time domain in either group		-
Venkatesh *et al*. 2014[77]	Healthy female participants (*n*=22)	Cohort study	Integrated yoga (asana, pranayama, and meditation)	30 days	Pre- versus post-intervention	Frequency domain ↓ in LFms² Time domain No significant change	↑ FVC***; ↑ PEFR§§§	
Niranjan *et al*. 2009[78]	Hypertensive (*n*=46) and normotensive (*n*=31)	NRCT‖‖	Yoga group integrated yoga practice (*n*=16); exercise group - warming and treadmill (*n*=16) Yoga+exercise (*n*=15) Normotensive control (no intervention - *n*=31)	9 months	Pre- versus post-intervention	Time domain ↑ in inter-beat interval in exercise + yoga group after intervention and in exercise group No change in yoga group	↓ in SBP****/ DBP‡‡‡‡ in exercise + yoga group and exercise group	-
Satyapriya *et al*. 2009[79]	Non-yoga females in 18-20 weeks of pregnancy (*n*=90)	RCT	Integrated yoga and deep relaxation for second and third trimester (*n*=45) Control with prenatal exercises and supine rest (*n*=45)	Up to 36th week of pregnancy	Pre- versus post-intervention for each group	Frequency domain ↑ HFn.u., ↓ LFn.u., ↓ LH/HF after yoga and relaxation group Similar less significant changes in control group	↓ subjective stress scores yoga group	2
Patil *et al*. 2013[80]	Non-yoga junior athletes (*n*=24)	RCT	Integrated yoga intervention - asana, pranayama relaxation and meditation (*n*=12) Control - routine practice	4 weeks	Pre- versus post-intervention	Frequency Domain ↑ in HFn.u., ↓ in LFn.u., ↓ in LF/HF yoga group; no significant change in control		2
Huang *et al*. 2013[81]	Healthy non-yoga female practitioners (*n*=63)	RCT	Integrated yoga practice (*n*=30) No intervention control (*n*=33)	8 weeks	Pre- versus post-intervention for each group	Frequency domain ↑ HFn.u., ↓ LFn.u., ↓ LF/HF in yoga group No change in control group		2

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Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV (only statistically significant changes are reported)	Other outcomes	Jadad scale score for RCT*
Krishna *et al*. 2014[82]	Congestive heart failure patients (*n*=92)	RCT	Yoga group integrated yoga practice with standard medical therapy (*n*=44) Control group with standard medical therapy (*n*=48)	12 weeks (60 min session thrice weekly)	Pre- versus post-intervention and comparison between groups	Frequency domain ↑ HF, ↓ LF, ↓ LF/HF after yoga intervention group and in control group Profound improvements in yoga group compared to control group	↓ HR, ↓ SBP/DBP in yoga group and control group	2
Sawane and Gupta 2015[83]	Sedentary healthy participants (*n*=81)	RCT	Yoga intervention – (Iyengar)-asana and pranayama (*n*=41); Control-swimming (*n*=40)	12 weeks (60 min session, 6 days/week)	Pre- versus post-intervention and comparison between groups	Frequency domain ↑ HFn.u., ↓ LFn.u., ↓ LF/HF in both groups No significant difference between groups Time domain ↑ SDNN, ↑ RMSSD ↑ pNN50 in both groups Improvement were more profound in yoga group	↓ in SBP/DBP in both groups ↓ in HR in both groups No significant difference between groups	3
Nagendra *et al*., 2015[84]	Non-yoga healthy student (*n*=30)	RCT	Yoga intervention group – integrated yoga practices (*n*=15) Control group – no intervention (*n*=15)	5 months (90 min/day)	Pre- versus post-intervention	Frequency domain ↑ HFn.u., ↓ LFn.u., ↓ LF/HF in yoga group No change in controls Time domain ↑ SDNN, ↑ RMSSD in yoga group No change in controls	↓ HR Significant improvements in EEG‡‡‡‡ frequency bands in yoga group	3
Wolever *et al*. 2012[85]	Sedentary healthy office employees (*n*=239)	RCT	Yoga intervention (Vinyasa) - asana, pranayama, relaxation (*n*=90); mindfulness-based techniques (*n*=96) No intervention control (*n*=53)	12 weeks	Pre- versus post-intervention and comparison between groups	↑ heart rhythm coherence in both intervention group compared to control No significant change in inter-beat interval in either group	↓ perceived stress in both intervention group compared to control	3
Bowman *et al*. 1997[21]	Healthy sedentary elderly >62 years (*n*=40)	RCT	Integrated yoga group (*n*=20) Aerobic group (*n*=20)	6 weeks	Pre- versus post-intervention for each group	Frequency domain No change in either group	↓ HR following yoga training	1
Telles *et al*. 2010[86]	Posttraumatic stress symptom male patients (*n*=22)	RCT	Integrated yoga practice (*n*=11) Waitlist control (*n*=11)	7 days	Pre- versus post-intervention for each group	No change in frequency and time domain in either group	↓ in sadness score	2
Bidwell *et al*. 2012[87]	Mild to moderate female asthmatic patients; (*n*=19)	RCT	Integrated yoga twice weekly with home practice (*n*=12) No intervention control (*n*=8)	10 weeks	Comparison between groups	Frequency domain No change between group	↑ quality of life score in yoga group compared to control	2

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Table 4: Contd...

Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV (only statistically significant changes are reported)	Other outcomes	Jadad scale score for RCT*
Cheema *et al*. 2013[88]	Sedentary healthy office employees (*n*=37)	RCT	Yoga intervention (Vinyasa) - asana pranayama and relaxation (*n*=18) No intervention control (*n*=19)	10 weeks	Pre- versus post-intervention and comparison between groups	No change in time and frequency domain	↑ flexibility in yoga group compared to control	3

*HRV = Heart rate variability, †RCT = Randomized controlled trial, ‡LFms² = Low frequency absolute value, §HFms² = High frequency absolute value, ||HFn.u. = High frequency normalized unit, ¶HR = Heart rate, **LFn.u. = Low frequency normalized unit, ††BR = Breath rate, §§SDNN = Standard deviation of NN interval; ||||CM = Cyclic meditation; ***pNN50 = Proportion of NN50, ¶¶RMSSD = Root mean square of successive difference of interval, ***FVC = Forced vital capacity, ‡‡‡PEFR = Peak expiratory flow rate, †††NRCT = Nonrandomized controlled trial, ‡‡‡SBP = Systolic blood pressure, ****DBP = Diastolic blood pressure, §§§§EEG = Electroencephalogram

Table 5: Heart rate variability, yoga postures, and integrated yoga

Author	Population	Study design	Intervention	Length of intervention	Comparators	Outcome HRV* (only statistically significant changes are reported with '↓' decrease and '↑' increase)	Other outcomes	Jadad scale score for RCT*
Chaya *et al*., 2008[89]	Regular male yoga practitioners (*n*=15); male non-yoga practitioners (*n*=15)	Multiple practices in single session	Integrated yoga practices	-	Yoga practitioners versus non-yoga practitioners	Frequency domain ↑ LFn.u.‡, ↓ HFn.u.§, ↑ LF/HF in yoga practitioners compared to non-yoga practitioners		-
Muralikrishnan *et al*. 2012[58]	Regular yoga practitioners (*n*=14); non-yoga practitioners (*n*=14)	Multiple practices in single session	Isha yoga - (sun salutation, static postures, purifying techniques and *Shambhavi mahamudra*)	-	Yoga practitioners versus non-yoga practitioners	Frequency domain ↑HFn.u., ↓ LFn.u., and ↓ LF/HF in yoga practitioners in resting state compared to non-yoga practitioners	No significant difference in HR‖	-
Friis and Sollers Iii 2013[90]	Regular yoga practitioners (*n*=18) Metabolically matched non-yoga practitioners (*n*=17), aerobically fit participant (*n*=19)	Multiple practices in single session	Yoga practices, and Aerobic exercises	Single session	Comparison between the groups	Time domain resting pNN50** higher in yoga practitioners compared to aerobic group and non-yoga practitioners	Resting HR lower in aerobic group compared to yoga practitioners and non-yoga No difference between yoga and non-yoga group VO_2¶ max higher in aerobic group compared to yoga and non-yoga group	-
Satin *et al*. 2014[91]	Regular yoga practitioners (*n*=47) Regular runners (*n*=46) Sedentary individuals (*n*=52)	Multiple practices in singes session	Integrated yoga practices with minimum 2 years' experience; running practice with minimum 2 years' experience	Single Session	Comparison between groups	Frequency domain resting HFn.u. higher in yoga practitioners and runners compared to sedentary	HR lower in yoga practitioners and runners compared to sedentary BR†† lesser in yoga group compared to sedentary and runners	-

*HRV = Heart rate variability, †RCT = Randomized controlled trial, ‡LF n.u. = Low frequency normalized unit, §HFn.u. = High frequency normalized unit, ‖HR = Heart rate, **pNN50 = Proportion of NN50, ¶VO_2 = Volume of oxygen consumption, ††BR = Breath rate

is also reported in a 4-week longitudinal cohort study of healthy female participants practicing integrated yoga[77] and an 8-week study of depressive patients practicing *Iyengar* yoga.[72] Furthermore, increase in pNN50 is reported after 8-week in patients with elevated BP after practicing inverted or semi-inverted yoga postures.[74]

Of the reviewed laboratory studies, four involved cyclic meditation, which involves a series of postures interspersed with relaxation practices. Three of these studies report increased HFn.u. and decreased LFn.u. along with decreased LH/HF post-intervention compared to baseline,[67-69] while one reports higher sympathovagal balance and lower LFn.u. during sleep after the practice of cyclic medication compared to rest.[70]

Further laboratory studies report decreased LF and increased HF with yoga inversion postures.[63,65] In addition, laboratory studies also report decreased HF and increased LF/HF[64] with yoga inversion postures and increased time domain indicators of vagal activities with *Iyengar* yoga,[71] laughter yoga,[73] chair-based yoga practice,[66] and integrated yoga.[75] Other studies report no change in HRV with various yoga practices. These include four RCTs of integrated practices (only one of which had a Jadad scores of 3) involving <40 subjects,[21,86-88] one NRCT with hypertensive patients,[78] and a small cohort study of 11 hypertensive patients and 6 diabetic patients practicing integrated yoga for 7 days.[76]

Table 5 summarizes four studies comparing HRV in the resting state in non-yoga practitioners versus regular yoga practitioners. Three of these studies reported enhanced parasympathetic activity measured in the time and/or frequency domain in the regular yoga practitioners,[58,90,91] while one study reported lower parasympathetic activity in regular practitioners.[89]

DISCUSSION

The reviewed studies suggest that yoga can affect cardiac autonomic regulation. Most of these studies however, are of poor quality with few studies providing robust statistical analysis or estimation of effect sizes. Furthermore, as in many other studies of HRV,[14] few studies on yoga and HRV provide details of respiratory rate making it extremely difficult to distinguish changes in HRV due to changes in autonomic cardiac control and changes in HRV due to changes in respiration. This is compounded by the differences in yoga practices, procedures and their duration. Many yoga practices also, involve altered respiration and differences in instructions to subjects, the type of training given, and the respiration rates achieved, could lead to large differences in HRV measures.

Experimental and cohort studies report vagal dominance in both time and frequency domains, during and after various yoga practices including meditation, relaxation, breathing, and integrated practices. The reviewed studies further report that regular yoga practice increases vagal tone in yoga practitioners compared to non-yoga practitioners,[58,90] sedentary individuals,[91] and individuals who regularly practice aerobic exercise.[90] In addition, yoga is reported to improve vagal outflow in sedentary individuals[83] and to enhance vagal and inhibit sympathetic activity in congestive heart failure patients.[82]

Although the mechanism by which yoga influences autonomic activity is not well understood, some yoga practices appear to directly stimulate the vagus nerve and enhance parasympathetic output[20] leading to parasympathetic dominance and enhanced cardiac function, mood, and energy states, as well as enhanced neuroendocrine, metabolic, cognitive, and immune responses.[1,6] While the bidirectional flow of the vagus nerve allows adaptive and flexible interaction between the amygdala, prefrontal cortex, and the peripheral organs, an extensive body of literature suggests that this interaction also mediates cognitive behavioral and emotional responses.[1,6] HRV, therefore, appears well placed to reflect the emotional and cognitive influences on organ function and the mind-body integration that occurs with many yoga practices by directly linking the input and output of the central nervous system.[1]

The present review suggests that yoga breathing practices, which involve a variety of breathing patterns at frequencies ranging from <1 to >120 BPM, can have profound effects on HRV and RSA, both of which are highly sensitive to breath-rate. Studies of HF *Kapalbahti* breathing at either 120 BPM or 60 BPM are reported to decrease vagal activity measured in either the frequency and/or time domain, with reductions being maintained after the practice.[48,49] In contrast, slow yoga breathing practices are reported to increase HR fluctuations in the LF band[53,54,56] and/or increase the LF/HF ratio[47,54,56,57] with some studies reporting simultaneous increases in HR.[53,56] It is interesting to note that some slow breathing practices increase HR,[47,53,55,56] while some meditation practices associated with slow breathing can reduce HR.[22,35,36,42,43] This may be due to slow breathing being an active process that is associated with heightened attention and an increased metabolic rate while meditation is a passive practice that is associated with diminished attention and reduced metabolic rate.[32]

High-amplitude peaks in the LF range during rhythmical slow breathing between 4.5 and 6.5/min may reflect resonance characteristics of the cardiovascular system where RSA interacts with the baroreflex.[11] Breathing at this resonant frequency, or other rhythmical stimulation at this frequency such as rhythmical skeletal muscle contraction,[92,93] may increase HRV and be reflected in large increases in the LF band and simultaneous decreases in the HF band. Such resonance effects are reported with yoga slow breathing practices[51] as well as with yoga mantra chanting[47,52] and some meditative practices.[47,51] There is strong evidence that when the system is stimulated at this frequency, a phase relationship occurs between HR and

BP oscillations (at 180°) and between HR oscillations and respiration (at 0°) generating high-amplitude HR peaks in the LF range that account for higher total HRV[94] as well as a decrease in HR.[95] Thus, when people breathe at this rate, gas exchange is most efficient,[12] leading to better oxygen saturation and enhanced tolerance to exercise and altitude. Regular practice of such breathing may also lead to changes in resting RSA and improved baroreceptor activity with positive autonomic effects, such as those observed with HRV-biofeedback training[19,96] and regular yoga practice.[97,98]

While slow breathing leads to resonance in the LF range, very slow breathing may lead to resonance in the VLF range and activation of sympathetically mediated thermoregulatory mechanisms. This is suggested by one of the reviewed studies that reports feelings of warmth and reduced LF and increased "VLF" (0.0003–0.04 Hz) power in an advanced yoga breathing at a frequency of around 1 BPM.[55] This is further supported by another study of advanced Zen meditators who reported feelings of warmth while displaying increased oscillatory peaks in both LF and VLF bands accompanied with reductions in HR during meditation.[99]

It is interesting to note that advanced meditators appear to be able to voluntarily manipulate what are often considered involuntary autonomic functions such as peripheral temperature. For example, one advanced yoga practitioner is reported to voluntarily produce a temperature difference of 11°F on different parts of the same palm.[100] A further report suggests that advanced g-Tummo meditators are able to produce dramatic increases of up to 8.3°C in peripheral body temperature (finger and toes)[101,102] and use their body heat to dry previously wet bed-sheets placed over their shoulders in a 40°F room without shivering.[103] While the mechanisms behind conscious control over autonomic functions such as vasodilation and vasoconstriction remain unexplained, previous studies have shown that yoga practices can have profound effects on autonomic activity as well as on oxygen consumption and metabolic rate.[32]

The ability of yoga to influence autonomic function has been the subject of numerous studies that suggest that yoga practices reduce autonomic arousal and assist with a wide range of stress-related disorders.[104] This may be mediated by increased parasympathetic activity as indicated by the increased HF observed during TM.[37,38] Yoga practices have also been reported to reduce anxiety and induce relaxation, with effects comparable to other stress-reducing techniques such as cognitive behavioral therapy and African dance.[105] While at least some of the stress-relieving effects of yoga may be related to altered autonomic arousal, clinical improvements with yoga are not necessarily reflected by changes in HRV. For example, yoga practices are reported to reduce HR, without corresponding changes in HRV.[21,43] Improvements in high frontal coherence with TM[44] and improvements in quality of life,[87] flexibility,[88] and mood[86] with various yoga practices are also reported despite no change in HRV. It may be that many of the positive effects of yoga on autonomic function are due to resonance effects produced by changes in respiration or by other mechanism such as rhythmical skeletal muscle tension occurring during various yoga postures that may lead to vagal dominance and enhanced baroreflex gain without corresponding changes in HRV.[92,93]

While the finding of increased HRV and improved vagal tone with yoga are consistent across most studies, it is premature to draw firm conclusions about the influence of yoga on HRV. Not all studies report HRV changes with yoga and the quality of most studies published to date is poor with few studies providing adequate reporting of study design, study population, yoga practices, methods of measurements, or statistical methods. Furthermore, the majority of studies to date have been performed in India with small numbers of adult yoga practitioners without matched comparison groups, making it difficult to extrapolate results to other populations. Most studies also lack the standardized conditions required for accurate measurement of HRV and do not express HRV spectral components in n.u. as per international convention.[8,11,13] A lack of methodological rigor has also been noted within RCTs of yoga and HRV.[33] Further studies are therefore needed that include more rigorous disclosure about the study methodology, the population involved, and the yoga practices being performed before more definitive conclusions about the effects of yoga and HRV can be made.

CONCLUSIONS

Yoga practices, including meditation, relaxation, yoga postures, breathing, and integrated practices, appear to improve autonomic regulation and enhance vagal dominance as reflected by HRV measures; however, it is difficult to make conclusive statements about yoga and HRV as existing studies are of poor quality and use a range of heterogeneous measures. Changes in HRV with yoga may reflect resonance effects between respiration, muscle contractions, HR, and baroreflexes that enhance autonomic efficiency. More rigorous studies are required to elucidate the autonomic and clinical benefits of such practices and it is vital that future studies of yoga and HRV include detailed reporting of the yoga practices used and any corresponding changes in respiration.

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Conflicts of interest

There are no conflicts of interest.

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