Routledge
Taylor & Francis Group

Health Psychology Review

ISSN: 1743-7199 (Print) 1743-7202 (Online) Journal homepage: https://www.tandfonline.com/loi/rhpr20

How does yoga reduce stress? A systematic review of mechanisms of change and guide to future inquiry

Kristen E. Riley & Crystal L. Park

To cite this article: Kristen E. Riley & Crystal L. Park (2015) How does yoga reduce stress? A systematic review of mechanisms of change and guide to future inquiry, Health Psychology Review, 9:3, 379-396, DOI: 10.1080/17437199.2014.981778

To link to this article: https://doi.org/10.1080/17437199.2014.981778

Accepted author version posted online: 03 Jan 2015.
Published online: 15 Apr 2015.

Health Psychology Review, 2015
Vol. 9, No. 3, 379–396, http://dx.doi.org/10.1080/17437199.2014.981778

Routledge
Taylor & Francis Group

How does yoga reduce stress? A systematic review of mechanisms of change and guide to future inquiry

Kristen E. Riley* and Crystal L. Park

Department of Psychology, University of Connecticut, Storrs, CT, USA

(*Received 23 August 2013; accepted 26 October 2014*)

Yoga is increasingly used in clinical settings for a variety of mental and physical health issues, particularly stress-related illnesses and concerns, and has demonstrated promising efficacy. Yet the ways in which yoga reduces stress remain poorly understood. To examine the empirical evidence regarding the mechanisms through which yoga reduces stress, we conducted a systematic review of the literature, including any yoga intervention that measured stress as a primary dependent variable and tested a mechanism of the relationship with mediation. Our electronic database search yielded 926 abstracts, of which 71 were chosen for further inspection and 5 were selected for the final systematic review. These five studies examined three psychological mechanisms (positive affect, mindfulness and self-compassion) and four biological mechanisms (posterior hypothalamus, interleukin-6, C-reactive protein and cortisol). Positive affect, self-compassion, inhibition of the posterior hypothalamus and salivary cortisol were all shown to mediate the relationship between yoga and stress. It is striking that the literature describing potential mechanisms is growing rapidly, yet only seven mechanisms have been empirically examined; more research is necessary. Also, future research ought to include more rigorous methodology, including sufficient power, study randomisation and appropriate control groups.

Keywords: yoga; stress reduction; mindfulness; clinical interventions; methodology

Introduction

Accumulating experimental and clinical research demonstrates that yoga reduces stress (see Chong, Tsunaka, Tsang, Chan, & Cheung, 2011). The term *mechanism*, which will be used throughout this paper, refers to underlying psychological, social and neurophysiological processes or mediators through which therapeutic change occurs (Kazdin & Nock, 2003); in this case, mechanism refers to those processes caused by yoga that lead to reduction in stress. However, the mechanisms through which yoga may alleviate stress remain unclear and some healthcare professionals are reluctant to recommend yoga to their patients, in part due to this lack of clarity (Roehr, 2008). Many mechanisms have been proposed, but few studies have been conducted to assess these pathways (Black et al., 2012; Michalsen et al., 2005). The psychological benefits include positive affect, mindfulness and self-awareness; among the biological are lower levels of cortisol and nitric oxide.

No explicit reviews of the mechanisms through which yoga is purported to affect stress have been published. However, theories about why and how yoga affects health

*Corresponding author. Email: Kristen.Riley@UConn.edu

have been put forward, and many of these theories address stress and the proposed linkages between yoga and health. Specifying the paths through which yoga may reduce stress will increase the likelihood that it is recommended and implemented as a complement to psychological and pharmacological therapy for stress-related conditions. Knowledge of these paths will also allow for tailoring of yoga interventions to specific types of stress and the basing these interventions on the most efficacious components of yoga. This paper summarises the most commonly cited proposed links of yoga and stress and then systematically reviews the empirical tests of those mechanisms. Finally, this paper makes concrete methodological suggestions to improve future inquiry in this area.

Stress: definition and measurement

Aldwin (2007) suggested that stress refers to 'the quality of experience, produced through a person-environment transaction that, through either overarousal or underarousal, results in psychological or physiological distress' (p. 22). Stress has been measured in myriad ways; these ways can be broadly categorised as either subjective or objective (see Li & Goldsmith, 2012, for a review). Subjective measures of stress are self-report measures that assess perceived stress, the degree to which one appraises situations in one's life as stressful (Cohen, Kamarck, & Mermelstein, 1983). Objective measures of stress consist of biological markers (biomarkers) of stress (Li & Goldsmith, 2012). Juster, McEwen, and Lupien (2009) suggested 25 biomarkers that reflect a stress response (specifically, in studies assessing allostatic load). Because the number of biomarkers that may reflect stress processes are potentially innumerable, and also because biomarkers often reflect many other biological processes, we limited our yoga–stress empirical review of the objective measures to these 25 biomarkers that have been identified as particularly associated with stress. These stress biomarkers can be categorised as neuroendocrine, immune, metabolic, cardiovascular and anthropometric (see Appendix 1).

How yoga reduces stress

A recent review of yoga's effect on stress reported that 25 of 35 published articles reported a significant reduction in stress after a yoga intervention (Li & Goldsmith, 2012). The authors attributed the inconsistent or null findings of the other 10 studies largely to methodological flaws, including small sample size, lack of a control group, non-randomisation, lack of exclusion criteria and large standard deviations (Li & Goldsmith, 2012).

Proposed mechanisms: psychological

Psychological mechanisms that have been proposed as ways through which yoga ameliorates stress include increases in positive attitudes towards stress (Malathi & Damodaran, 1999; Taylor, 2003; Woodyard, 2011), self-awareness (Arora & Battacharjee, 2008), coping mechanisms (Heilbronn, 1992; Kinser, Bourgiognon, Whaley, Hauenstein, & Taylor, 2013; Rizzolo, Zipp, Stiskal, & Simpkins, 2009), appraisal of control (Bonura, 2008; Roehr, 2008), calmness (Brown & Gerbarg, 2005b; Sherman, Wellman, Cook, Cherkin, & Ceballos, 2013), spirituality (Evans, Cousins, Tsao, Sternlieb, & Zeltzer, 2011; Moadel et al., 2007), compassion (Braun, Park, & Conboy, 2012) and mindfulness (Brown & Ryan, 2003; Chiesa & Serretti, 2009; Evans et al., 2011).

Many researchers suggest that mindfulness is a powerful link between yoga practice and stress reduction (Dunn, 2008). Brown and Ryan (2003) define mindfulness as the

state of being attentive to and aware of what is taking place in the present. Its association with yoga practice, as well as its ability to combat stress, has been widely demonstrated (see Chiesa & Serretti, 2009, for a review). Studies suggest mindfulness is associated with measures of lower stress (Gilbert & Waltz, 2010). Yoga has been associated with higher levels of mindfulness. For example, Brisbon and Lowery (2011) found that advanced yoga practitioners had higher levels of mindfulness (and lower levels of stress) compared to new yogis.

Proposed mechanisms: biological

Proposed biological mechanisms through which yoga may reduce stress include the autonomic nervous system (Brown & Gerbarg, 2005a; Evans et al., 2011; Field, 2012; Malathi & Damodaran, 1999; Michalsen et al., 2005), hypothalamic–pituitary–adrenal (HPA) axis (Innes, Vincent, & Taylor, 2007; Purdy, 2013; Ross & Thomas, 2010), endothelial function and release of nitric oxide (Dunn, 2008; Michalsen et al., 2005), endogenous cannabinoids and opiates (Michalsen et al., 2005), inflammatory and endocrine responses (Kiecolt-Glaser et al., 2010; Yadav, Magan, Mehta, Sharma, & Mhapatra, 2012), limbic system activity (Riley, 2004), the peripheral nervous system including GABA (Streeter, Gerbarg, Saper, Ciraulo, & Brown, 2012) and gene expression (Black et al., 2012). There is a growing literature regarding the possible mediating effects of the autonomic nervous system, the HPA axis and inflammatory and endocrine responses.

Autonomic nervous system. Both sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) are often posited as the mechanism through which yoga reduces stress (e.g., Brown & Gerbarg, 2005a; Evans et al., 2011; Malathi & Damodaran, 1999; Michalsen et al., 2005). Yoga training has been shown to decrease sympathetic response (systolic pressure, diastolic pressure, mean pressure, heart rate and rate pressure product) after experiemental stressors (Vijayalakshmi, Madanmohan, Patil, & Kumar, 2004), though no mediation analyses were conducted. Field (2012) hypothesised that enhanced vagal activity caused by the stimulation of pressure receptors due to yoga would lead to decreased stress hormones such as cortisol.

The vagus nerve regulates heart rate, blood pressure, gastric acid secretion and functions in many other organs. Innes et al. (2007) pointed out that yoga has immediate beneficial effects on heart rate variability and baroreflex sensitivity, which are thought to reflect direct stimulation of the vagal nerve. Sengupta, Chaudhuri, and Bhattacharya (2013) posited that yoga decreases vagal stimulation, which causes parasympathetic activation, decreasing perceived stress while simultaneously decreasing activation and reactivity of the sympathoadrenal system and the HPA axis.

HPA axis. Purdy (2013) summarised the burgeoning research demonstrating that yoga down-regulates the HPA axis and SNS, both of which have been shown to prevent the release of the stress hormones cortisol and catecholamines (Ross & Thomas, 2010). Innes et al. (2007) examined the potential mediators of yoga's effect on cardiovascular disease, including stabilising HPA axis and sympathoadrenal activity, which have a regulating effect of stress. They pointed to studies that have demonstrated reductions in markers of sympathetic activation, including cortisol, catecholamines, renin–angiotension and basal skin conductance, and progressive attenuation of sympathoadrenal activation, including a decline in heart rate and a decline in blood pressure.

Inflammatory and endocrine responses. Yadav et al. (2012) found that there was a reduction in stress, as measured by plasma cortisol and beta-endorphin as well as inflammation [interleukin-6 (IL-6) and tumour necrosis factor] after a short-term yoga lifestyle intervention, suggesting that reductions in inflammation factors may contribute to a decrease in stress following a yoga intervention. Black et al. (2012) found reduced activity of the proinflammatory NF-κB factors and increased activity of antiviral interferon regulatory factor, both of which associated with chronic stress.

Methods

To examine the empirical evidence regarding the mechanisms through which yoga reduces stress, we conducted a systematic review of the literature. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for conducting systematic reviews (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). For this review, the inclusion criteria were: any study of a yoga intervention that measured stress as a primary dependent variable and that tested a mechanism of the relationship between yoga and stress with mediation analyses. Mediation analyses included those statistics meant to test direct or indirect effects, above and beyond simple bivariate correlations, such as regression analyses according to Baron and Kenny's (1986) mediation criteria.

Search

We conducted a multi-database literature search utilising the following databases: *Medline via PubMed* and *PsycInfo*, including dissertations. Databases were searched for the occurrence of keywords/phrases at any place in the record: 'stress AND yoga AND (mechanism OR mechanisms OR mediator OR mediators)'. In order to capture studies of effects of yoga on markers of stress, we then used the search terms 'yoga' and the indicators of stress as defined by Juster et al. (2009, Table 2: Biomarkers repeatedly used in allostatic load studies, see Appendix 1), for example, 'yoga AND cortisol'. We inspected the reference sections of retrieved studies as well as conceptual/theoretical articles on yoga and stress for additional manuscripts.

Coding and synthesis

We extracted the following information from articles: mechanism, mechanism type, outcome, type of yoga intervention, type of stress outcome and author/article information (see Table 2) and sample size, control group information and study randomisation (Table 3). We had two coders at each stage of the search and coding process.

Results

Figure 1 provides a flow chart of our search and selection process. Our electronic database search yielded 926 abstracts. We examined abstracts for evidence of an empirical quantitative study of a yoga intervention and a stress outcome, narrowing the 926 abstracts to 71 articles. We downloaded and examined these 71 articles, and narrowed by the inclusion criteria above, yielding five articles (n = 164; see Tables 2 and 3).

Table 1. Proposed mechanisms through which yoga reduces stress.

Mechanism type	Proposed mechanism	Authors
Psychological	Self-awareness	Arora and Bhattacharjee (2008)
	Attitudes towards stress	Malathi and Damodaran (1999), Taylor (2003)
	Strengthened coping mechanisms	Heilbronn (1992), Rizzolo et al. (2009), Evans et al. (2011)
	Appraisal of control	Roehr (2008)
	Calm (specifically from pranayama/breath work)	Brown and Gerbarg (2005b)
	Spiritual well-being	Moadel et al. (2007), Evans et al. (2011)
	Compassion, self-compassion	Braun et al. (2012)
	Mindfulness, acceptance	Brisbon and Lowery (2011), Evans et al. (2011)
Biological	HPA axis, SNS	Gururaja, Harano, Toyotake, and Kobayashi (2011); Michalsen et al. (2005), Moadel et al. (2007)
	Autonomic nervous system (vagus nerve) arousal	Evans et al. (2011)
	Endothelial function and release of nitric oxide	Dunn (2008); Michalsen et al. (2005)
	Endogenous endocannabinoids and opiates	Michalsen et al. (2005)
	Inflammatory and endocrine responses (e.g., cytokine levels, IL-6)	Arora and Bhattacharjee (2008); Kiecolt-Glaser et al. (2010); Yadav et al. (2012)
	Limbic system activity	Riley (2004)
	Immune cell gene expression	Black et al. (2012)
	SNS	Sieverdes et al. (2014)

Psychological mechanisms

Positive affect

In a study of novice and expert yoga practitioners, positive affect increased from pre- to post-yoga in a single-yoga session (Kiecolt-Glaser et al., 2010) and in a study of healthy college students, a Hatha yoga intervention created significant pre to post changes in positive affect; further, change in positive affect was negatively correlated with change in cortisol, suggesting a meditational relationship (West, Otte, Geher, Johnson, & Mohr, 2004).

Mindfulness and self-compassion

Gard et al. (2012) examined the mediating roles of mindfulness and self-compassion during a four-month residential yoga programme on perceived stress. They found that the yoga intervention's effect on perceived stress was mediated only by self-compassion.

Biological mechanisms

This review identified four biological mechanisms that have been empirically tested as mediating the effects of yoga on stress: the posterior hypothalamus (Bagga & Gandhi,

Table 2. Empirically studied mechanisms through which yoga may reduce stress.

Mechanism type	Mechanism	Outcome	Type of yoga	Type of stress	Authors
Psychological	Positive affect	Positive affect increased in yoga group, but no change in cortisol, so no mediation effects	Hatha yoga	Cortisol	Kiecolt-Glaser et al. (2010)
	Positive affect	Positive affect increased after a yoga session then was negatively correlated with cortisol	Hatha yoga	Perceived stress, cortisol	West et al. (2004)
	Mindfulness, self-compassion	Perceived stress was mediated by self-compassion but not mindfulness	Hatha yoga	Perceived stress	Gard et al. (2012)
Biological	Posterior hypothalamus	Yoga led to inhibition of the posterior area of the hypothalamus, decreasing blood pressure	Transcendental practice and Shavasana	Blood pressure	Bagga and Gandhi (1983)
	Inflammatory and endocrine responses (IL-6 and CRP)	There was no difference in IL-6 or CRP after the yoga session	Hatha yoga	Perceived stress	Kiecolt-Glaser et al. (2010)
	Salivary cortisol	Salivary cortisol decreased and mediated yoga and perceived stress	Hatha yoga (three-month intensive programme)	Perceived stress	Michalsen et al. (2005)

Table 3. Methodology of empirically studied mechanisms.

Mechanism type	Mechanism	Authors	Sample size (*N*)	Control group	Randomisation
Psychological	Positive affect	Kiecolt-Glaser et al. (2010)	Novices = 25 Experts = 25 (exposed to all three groups)	Movement control, passive video control	No
	Positive affect	West et al. (2004)	Yoga = 18 Dance = 21 Lecture = 18	African dance, biology lecture	No
	Mindfulness/ self-compassion	Gard et al. (2012)	33	No	No
Biological	Posterior hypothalamus	Bagga and Gandhi (1983)	Unknown	No	No
	Inflammatory and endocrine responses (IL-6 and CRP)	Kiecolt-Glaser et al. (2010)	Novices = 25 Experts = 25 (exposed to all three groups)	Movement control, passive video control	No
	Salivary cortisol	Michalsen et al. (2005)	Yoga = 16 Control = 8	Wait list control	No

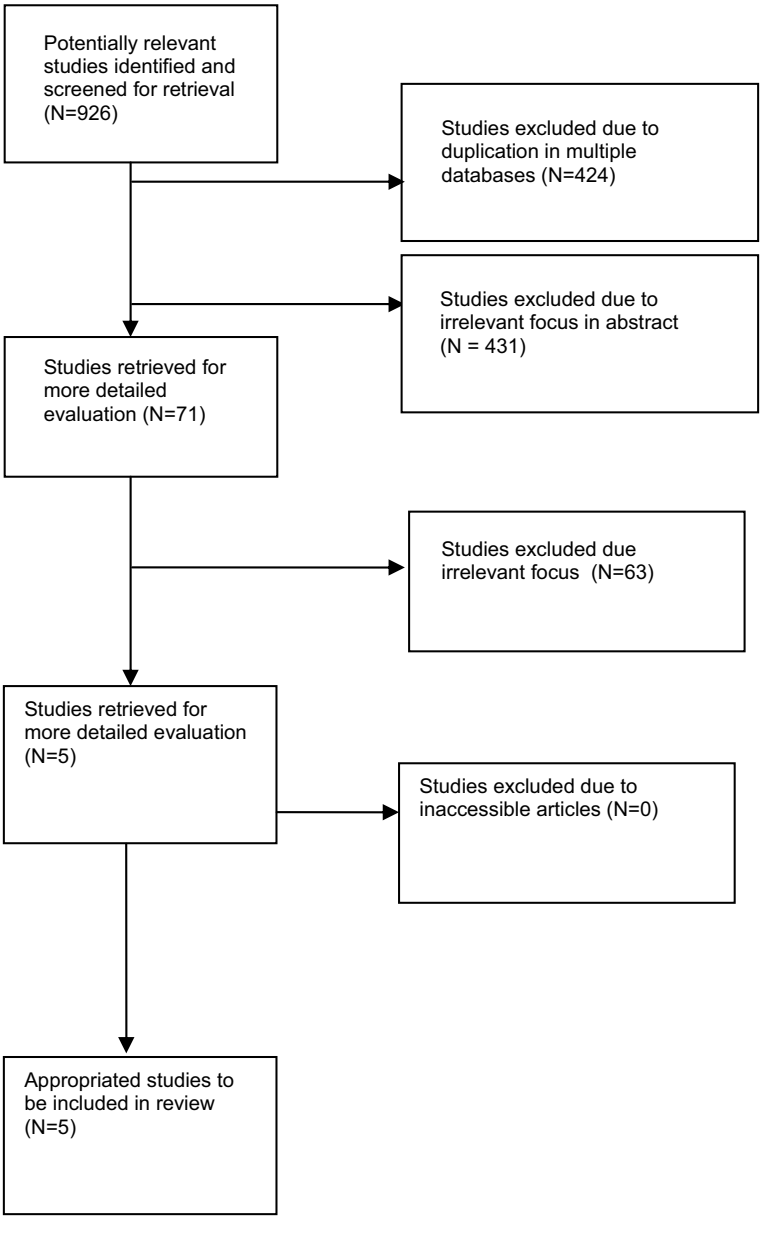

Figure 1. PRISMA article selection process.

1983) and three inflammatory and endocrine responses [IL-6, C-reactive protein (CRP) and cortisol; Kiecolt-Glaser et al., 2010; Michalsen et al., 2005].

Posterior hypothalamus

Bagga and Gandhi (1983) demonstrated that the Shavasana pose in a yoga session led to inhibition of activity in the posterior area of the hypothalamus, decreasing blood pressure, a stress biomarker, after a single session.

Inflammatory and endocrine responses

Kiecolt-Glaser et al. (2010) administered a stressor (Stroop, cold pressor task) before a yoga class then measured participants' physiological response to stress before, during and after one of three different interventions: a yoga session, a movement control condition and a video control condition. The researchers did not find any change in IL-6 or CRP in the yoga group as compared to the other groups following the stressful event.

Including cortisol

Michalsen et al. (2005) posited that salivary cortisol levels would act as a mechanism of a 12-week Iyengar yoga intervention on perceived stress and indeed found that salivary cortisol levels mediated this relationship. Namely, salivary cortisol decreased significantly after participation in a yoga class, and changes in cortisol significantly predicted decreased perceived stress over the course of the intervention.

Discussion

The literature linking yoga practice to lower stress levels is growing rapidly, as is the literature proposing mechanisms to explain this finding. Our systematic review of studies that have empirically examined as mechanisms of yoga's effect on stress identified only five studies, three of psychological variables and four of biological variables. This mismatch between the large number of potential mechanisms and paucity of empirical exploration of them leaves large gaps in the literature in need of exploration.

Discussion of psychological mechanisms

Positive affect

As evidenced in the systematic review, positive affect increased after 46 minutes of yoga (Kiecolt-Glaser et al., 2010). However, since markers of stress reduction in this study did not vary pre- to post-yoga class, positive affect could not be linked to a stress outcome, and therefore could not be claimed as a mechanism through which yoga affects stress. In future studies, it will be important to measure perceived stress as well as other biological stress markers in order to have an outcome variable with which to test positive affect as a mediator or mechanism. It will perhaps also be important to measure the effects of yoga on stress outcomes over time to detect the differential effects of shorter versus longer-term interventions on stress variables.

Mindfulness

Increased mindfulness has been empirically linked with both yoga and a decrease in stress in numerous studies. While Gard et al. (2012) found there was a significant positive correlation between yoga and mindfulness and a significant negative correlation between mindfulness and perceived stress, mindfulness was not found to mediate the yoga–stress relationship. This study included only two time points, and studies of mediation would ideally measure variables at least three time points. Future studies should include a longitudinal study of yoga, mindfulness and stress, with other related variables measured and included in the model. A cross-lagged panel analysis or a daily diary design would allow for more causal inference and insight into these relationships.

Self-compassion

Self-compassion is frequently viewed as another quality underlying the transformations that result from contemplative practices. Self-compassion has been described as 'being open to and moved by one's own suffering, experiencing feelings of caring and kindness towards oneself' (Neff, 2003). Pilot studies suggest yoga participation may increase self-compassion (Braun et al., 2012). Gard et al. (2012) posit that their increases in self-compassion (and resulting decreases in perceived stress) may have been due to students in this particular intervention receiving instruction to bring awareness and acceptance to their unique physical attributes as they moved through yoga postures, rather than emphasising the achievement of the 'perfect' pose. Research is needed to test whether it was this unique instruction in this yoga intervention that created increases in self-compassion.

Psychological mechanisms proposed but not studied

Most of the posited psychological mechanisms have not yet been studied empirically, including attitude towards stress, coping, self-awareness, appraisals of control, calm from pranayama and spirituality. It will be important to assess these potential psychological outcomes in future yoga intervention studies.

Woodyard (2011) suggests that yoga practice may create a change in attitudes towards stress, viewing stress and life in a more optimistic way. It will be important to conduct a study investigating the impact of yoga practice on these specific types of appraisals about stress and stressors.

Similarly, some researchers have hypothesised that yoga practice strengthens coping mechanisms, which allows practitioners to deal with stressors more effectively, thus reducing stress (e.g., Heilbronn, 1992; Rizzolo et al., 2009). Heilbronn (1992) suggested that a Hatha yoga workplace intervention could provide breathing and postural techniques that could be used as a 'means of quietly and unobtrusively coping with the crises that occur during the working day' (p. 132). Rizzolo et al. (2009) posited that a yoga intervention for students in health science programmes might help them learn to identify stress more quickly and develop coping mechanisms early in their career for managing the high stress of a professional practitioner, thus having long-lasting stress-reduction effects. A qualitative study of the effect of yoga on women's depressive symptoms found that women reported having learned more coping skills, which decreased their stress (Kinser et al., 2013).

Yoga has been posited to increases one's sense of control, thereby reducing stress (Roehr, 2008). Bonura (2008) suggested that self-control is a skill that is learned through regular yoga practice.

Brown and Gerbarg (2005b) suggested the ways in which Sudarshan Kriya yogic breathing affects psychopathology, including post-traumatic stress disorder (PTSD), pointing to four open unpublished datasets. PTSD symptoms did not decrease until Ujayi breath (audible whisper breath) was added to the yoga (asana, meditation and psychoeducation) intervention. These authors suggest that the calming Ujayi breath is one way in which yoga soothes post-traumatic stress symptoms. Sherman et al. (2013) conducted a qualitative analysis that suggested the importance of breath work in decreasing stress but did not quantitatively measure their mediation effects.

Increases in spirituality have been linked to both yoga practice (Bussing, Hedtstuck, Khalsa, Ostermann, & Heusser, 2012) and decreases in stress (Greeson et al., 2011).

Evans et al. (2011) mentions that a yoga intervention may promote psychospiritual resources, which he claims are protective against stress. Moadel et al. (2007) also suggested that spiritual well-being may underlie yoga's effect on perceived stress.

Discussion of biological mechanisms

Only three studies have examined four biomarkers as underlying yoga use and stress reduction.

Posterior hypothalamus

Bagga and Gandhi (1983) conducted very basic methodology and analysis in their 1983 study and only used the Shavasana pose in their inquiry. More sophisticated technology and data analytic techniques should be applied to examine the relationship of the posterior hypothalamic region to yoga and stress. FMRI studies are recommended.

Inflammatory and endocrine responses: IL-6, CRP and cortisol

Kiecolt-Glaser et al. (2010) did not find any change in IL-6 or CRP in the yoga group as compared to the other groups following the stressful event. A longer intervention may be important to detect changes in stress. Michalsen et al. (2005) demonstrated a mediation of cortisol on perceived stress. However, cortisol levels are often used as a measure of stress, so this finding is not surprising.

Biological mechanisms proposed but not studied

Mechanisms proposed but not yet studied include autonomic nervous system and vagal nerve activity, nitric oxide and endothelial function, endogenous endocannabinoids and opiates, cytokine levels and limbic system activity.

A review by Dunn (2008) noted that nitric oxide may be a potential mechanism underlying the relationship between yoga and well-being. Also, Michalsen et al. (2005) explained that vigorous postures in yoga interventions may cause repeated functional peripheral vessel occlusion which may modulate blood flow and alter endothelial function, which in turn may create an environment in which nitric oxide is constantly produced and released throughout the endothelium. Nitric oxide presence has been shown to reduce stress (Michalsen et al., 2005)

Streeter et al. (2012) asserted that yoga-based practices may correct underactivity of the PNS and GABA systems in part through stimulation of the vagus nerve, the main peripheral pathway of the PNS, thus reducing allostatic load.

Black et al. (2012) also found that 68 genes were found to be differentially expressed (19 up-regulated and 49 down-regulated) after a yoga intervention, even after adjusting for differences in sex, illness burden and body mass index. Although these changes were not directly connected to a stress outcome in that study, the many studies that have linked gene expression to stress suggest that gene expression may be an important mediator of yoga's effects on stress.

Other possible mechanisms

Many researchers posited other mechanisms through which contemplative interventions affect health. Though not specific to stress, these models may be helpful in understanding the broader mechanisms through which yoga or yoga-like interventions affect stress

reduction, an aspect of health. For example, in a study of the mechanisms through which yoga affects cardiovascular disease, Innes et al. (2007) describe yoga's reductions in psychological factors such as fatigue, which also contributes to stress.

Holzel et al. (2011) detail the potential mechanisms through which mindfulness meditation, often a component of yoga practice, may affect stress and well-being. This model posits that mindfulness meditation acts through psychological factors such as attention regulation, body awareness, emotion regulation, change in perspective on the self and neuroplastic changes.

Kuntsevich, Bushnell, and Theise (2010) also posited a number of biological pathways through which yoga may affect health. Namely, they claimed that yogic practices may restore physiologic set points to normal after disease or injury, promote homeostatic negative feedback loops over non-homeostatic positive feedback loops in molecular and cellular interactions and decrease abnormal 'noise' in cellular and molecular signalling networks arising from environmental or internal stresses.

Some studies have compared yoga experts and novices in an attempt to draw conclusions about the ways through which continued yoga practice affects stress. Additionally, Kiecolt-Glaser et al. (2010) compared adiponectin and leptin data from well-matched novice and expert yoga practitioners. These adipocytokines have counter-regulatory functions in inflammation; leptin plays a proinflammatory role, while adiponectin has anti-inflammatory properties. Leptin was 36% higher and adiponectin levels were 28% higher in novices compared to experts, a statistically significant difference. The authors point to this finding as promising evidence supporting the processes through which yoga may reduce stress, even though it was not studied longitudinally.

Several researchers have created comprehensive models proposing the pathways through which yoga decreases stress, including both psychological and biological variables (see Brown & Gerbarg, 2005a, 2005b; Evans et al., 2011; Kuntsevich et al., 2010; Sengupta et al. 2013; Streeter et al., 2012).

Recommendations for future research

In future studies, it will be important to empirically assess the suggested-but-not-yet-studied constructs as potential mechanisms by which yoga affects stress (Tables 1 and 2).

Earlier we noted the methodological shortcomings of much of the yoga literature; these shortcomings have also been noted by many of the authors of reviews of yoga research (e.g., Cooper, 2004; Li & Goldsmith, 2012). The methodology of yoga studies has generally lacked scientific rigour due to the nature of yoga research as a developing field and lack of consistency in operational definition (Li & Goldsmith, 2012). For example, Table 3 demonstrates that even the empirical studies of mechanisms we identified suffered from methodological limitations including small sample sizes, lack of control groups and non-randomisation. No studies used randomisation techniques, and two studies did not use comparison control groups. All studies had group sizes less than 33 participants, some as low as 8, which generally do not supply sufficient power to detect statistically significant group differences (Brown & Forsythe, 1974).

Choosing an appropriate control group is important in yoga intervention studies is also difficult (Park et al., 2014). This group of empirical studies reflects the wide variety of control groups used in yoga studies. For example, control groups in these five studies

include: wait list control, movement control, passive video control, African dance and a biology lecture.

Despite four of five studies describing their yoga intervention as 'Hatha yoga', there is wide variation in what might comprise a Hatha yoga intervention. Diversity in yoga practice makes comparison of findings across studies difficult and limits our ability to understand the mechanisms by which yoga affects stress and other aspects of well-being (Elwy et al., 2014). Nearly every published study testing yoga interventions implemented a combination of movement, mental exercise, both rigorous and gentle postures, breath work and meditative exercise. This heterogeneity, even within a certain type of yoga (e.g., Hatha, Iyengar, Integral) presents a problem: It is difficult to determine which component or combination of components is responsible for any outcome obtained, or whether it is the totality of the practice. Further, different yoga interventions, with varying emphases on the components of yoga such as asana, pranayama or meditation, may have differential effects on physiological stress responses, biomechanics and other pathways through which yoga may reduce stress. To date, these issues remain unexamined and await some way of classifying the components of the interventions before they can be addressed. A tool that should be helpful in classifying yoga in research, the Essential Properties of Yoga Questionnaire, is being designed to address current limitations in the yoga literature and advance the research on yoga (Park et al., 2014). Development of a reliable, valid tool to assess the essential dimensions of yoga should lead to the improvement and tailoring of yoga interventions that will result in their improved effectiveness with a range of different health conditions and problems.

Additionally, most studies examine the effects of Hatha yoga only (see Tables 1 and 2). While this is the most commonly practiced type of yoga (Barnes, Bloom, & Nahin, 2008), examining the differential affects and pathways through which various types of yoga affect stress will be important, as interventions can be tailored by type of yoga as well. Some types of yoga may be gentle and meditative (Integral, Svaroopa), some may be vigorous (Ashtanga, Power Yoga), or both (Iyengar, Kundalini) and some use heaters (Bikram). Ross and Thomas (2010) emphasise that the varying types of yoga may have different effects on the HPA and SNS axes in response to acute and chronic stress, and that studies to test relative effects are needed.

Another problem in this nascent research field is that proposed mediators in some studies are outcomes or measures of stress in other studies. For example, immune response is examined as both the mechanism and stress outcome in some studies (e.g., Arora & Bhattacharjee, 2008). Similarly, Michalsen et al. (2005) measured salivary cortisol levels as a mechanism of Iyengar yoga's effects on perceived stress; however, cortisol level is very often used as a measure of stress per se (Li & Goldsmith, 2012), and therefore should not be considered a mechanism of the yoga–stress relationship. It will be important to assure that operational definitions remain consistent.

There are some studies for which mechanisms could not be tied to stress-reduction outcomes because were no differences in stress biomarkers following the yoga intervention (e.g., Kiecolt-Glaser et al., 2010). In their article, Kiecolt-Glaser et al. (2010) speculated that, in designing the yoga to be appropriate for novices and experts, they were unable to include some more advanced and purportedly more powerful poses like full inversions. This may be a possible cause of the lack of biological stress-reduction changes; that is, the yoga session may not have been powerful enough to elicit stress-reduction responses. However, these authors postulated that, because novices and experts did show a group difference in IL-6, an indicator of inflammation, such that experts had

less inflammation, and because experts demonstrated a lower cardiovascular response and inflammation after a stressor test, long-term yoga practice could be responsible for a decrease in the inflammatory immune response (IL-6), which could dampen the body's responses to stressors. Ensuring that yoga interventions are robust and comprehensive enough to create measureable changes in measures of stress over time is vital for research examining mechanisms between yoga and stress, and these particular hypotheses should be tested. Additionally, appropriate methodology and analyses for testing mediation is warranted (Zhao, Lynch, & Chen, 2010).

Clinical implications

Understanding more about the ways in which yoga affects stress will allow us to inquire into the types or aspects of yoga that most affect these mechanisms and to focus interventions on these aspects of yoga (Elwy et al., 2014; Park et al., 2014).

If researchers know what mechanisms affect which type of stress outcome, we may customise interventions for populations with that stress issue. For example, if a health population's primary issue is a highly activated SNS, we may be able to identify the type of yoga that most effectively reduces SNS activity. In HIV/AIDS populations, the effect of stress on specific types of biomarkers that are already weakened by the disease is particularly harmful (Leserman, 2003). HIV/AIDS disturbs HPA axis function, so a type of yoga intervention shown to result in better regulation of the HPA axis, this intervention may be particularly useful for those with HIV/AIDS (Zapanti, Terzidis, & Chrousos, 2008).

Additionally, knowledge of why and how yoga affects stress will provide more credibility to the field of yoga research and interventions, which has important implications. Health care professionals may be more comfortable recommending yoga to patients in need of stress management if the mechanisms through which it operates are better known. Mental health care professionals' comfort in implementing yoga in the context of psychotherapeutic interventions could be useful as well (Yang, 2007). The use of yoga or yogic techniques in psychotherapy combines empirically supported benefits of traditional psychotherapy (e.g., cognitive behavioural therapy) with less commonly utilised components, including mindfulness, physical movement and exercise (Somerstein, 2010). This combined method of stress reduction, emphasising different paths through which to dampen stress levels, may be more helpful than either alone. The ability to implement yoga interventions to supplement current standards of care or pharmacological treatment can be transformative, providing better ways to reduce stress and improve health. These improvements may reduce the incidence of myriad diseases, including chronic illness, increase quality of life and provide more cost-efficient care and care with fewer side effects than expensive medications or procedures (Li & Goldsmith, 2012; Roehr, 2008; Woodyard, 2011).

Conclusions

Much additional more-rigorous research is needed to replicate findings, examine purported mechanisms, explore additional mechanisms and then determine whether a combination of these mechanisms underlies the relationship between yoga and stress. Research ought to include more rigorous methodology from this point forward, including sufficient power, study randomisation and appropriate control groups. Research must distinguish between indicators of stress reduction and possible mechanisms of stress reduction. The provision of

an additional stress-reduction strategy in the form of yoga has far-reaching effects. Implementation of yoga interventions has the potential to ameliorate stress and stress-related conditions (Duraiswamy, Thirthalli, Nagendra, & Gangadhar, 2007).

References

Aldwin, C. M. (2007). *Stress, coping, and development, second edition: An integrative perspective*. New York, NY: Guilford Press.

Arora, S., & Bhattacharjee, J. (2008). Modulation of immune responses in stress by yoga. *International Journal of Yoga*, *1*(2), 45–55. doi:10.4103/0973-6131.43541

Bagga, O. P., & Gandhi, A. (1983). A comparative study of the effect of transcedential meditation and Shavasana practice on cardiovascular system. *Indian Heart Journal*, *35*, 39–45.

Barnes, P. M., Bloom, B., & Nahin, R. L. (2008). Complementary and alternative medicine use among adults and children: United States, 2007. *National Health Statistics Reports*, *12*, 1–24.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research – Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*, 1173–1182. doi:10.1037/0022-3514.51.6.1173

Black, D. S., Cole, S. W., Irwin, M. R., Breen, E., St. Cyr, N. M., Nazarian, N., … Lavretsky, H. (2012). Yogic meditation reverses NF-kB and IRF-related transcriptome dynamics in leukocytes of family dementia caregivers in a randomized controlled trial. *Psychoneuroendocrinology*, *38*, 348–355. doi:10.1016/j.psyneuen.2012.06.011

Bonura, K. B. (2008). *The impact of yoga on psychological health in older adults* (Unpublished doctoral dissertation). The Florida State University, Tallahassee.

Braun, T. D., Park, C. L., & Conboy, L. A. (2012). Psychological well-being, health behaviors, and weight loss among participants in a residential, Kripalu yoga-based weight loss program. *International Journal of Yoga Therapy*, *22*, 9–21.

Brisbon, N. M., & Lowery, G. A. (2011). Mindfulness and levels of stress: A comparison of beginner and advanced Hatha yoga practitioners. *Journal of Religion and Health*, *50*, 931–941. doi:10.1007/s10943-009-9305-3

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology*, *84*, 822–848. doi:10.1037/0022-3514.84.4.822

Brown, M. B., & Forsythe, A. B. (1974). Robust tests for the equality of variance. *Journal of the American Statistical Association*, *69*, 374–397.

Brown, R. P., & Gerbarg, P. L. (2005a). Sudarshan Kriya yogic breathing in the treatment of stress, anxiety, and depression: Part I—Neurophysiologic model. *Journal of Alternative and Complementary Medicine*, *11*, 189–201. doi:10.1089/acm.2005.11.189

Brown, R. P., & Gerbarg, P. L. (2005b). Sudarshan Kriya yogic breathing in the treatment of stress, anxiety, and depression: Part II—Clinical applications and guidelines. *Journal of Alternative and Complementary Medicine*, *11*, 711–717. doi:10.1089/acm.2005.11.711

Bussing, A., Hedtstuck, A., Khalsa, S. B. S., Ostermann, T., & Heusser, P. (2012). Development of specific aspects of spirituality during a 6-month intensive yoga practice. *Evidence-based Complementary and Alternative Medicine*, *2012*, 1–7.

Chiesa, A., & Serretti, A. (2009). Mindfulness-based stress reduction for stress management in healthy people: A review and meta-analysis. *Journal of Alternative and Complementary Medicine*, *15*, 593–600. doi:10.1089/acm.2008.0495

Chong, C. S. M., Tsunaka, M., Tsang, H. W., Chan, E. P., & Cheung, W. M. (2011). Effects of yoga on stress management in healthy adults: A systematic review. *Alternative Therapies in Health and Medicine*, *17*, 32–38.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*, 385–396. doi:10.2307/2136404

Cooper, E. L. (2004). Complementary and alternative medicine, when rigorous, can be science. *Evidence-based Complementary and Alternative Medicine*, *1*(1), 1–4. doi:10.1093/ecam/neh002

Dunn, K. D. (2008). A review of the literature examining the physiological processes underlying the therapeutic benefits of Hatha yoga. *Advances in Mind-body Medicine*, *23*, 10–18.

Duraiswamy, G., Thirthalli, J., Nagendra, H. R., & Gangadhar, B. N. (2007). Yoga therapy as an add-on treatment in the management of patients with schizophrenia: A randomized control trial. *Acta Psychiatrica Scandinavica*, *116*, 226–232. doi:10.1111/j.1600-0447.2007.01032.x

Elwy, R. A., Groessl, E. J., Eisen, S. V., Riley, K. E., Maiya, M., Lee, J. P., Sarkin, A., & Park, C. L. (2014). A systematic scoping literature review of yoga intervention components and intervention quality. *American Journal of Preventative Medicine*, *47*, 220–232.

Evans, S., Cousins, L., Tsao, J. C., Sternlieb, B., & Zeltzer, L. K. (2011). Protocol for a randomized controlled study of Iyegar yoga for youth with irritable bowel syndrome. *Trials*, *12*(1), 1–15. doi:10.1186/1745-6215-12-1

Field, T. (2012). Exercise research on children and adolescents. *Complementary Therapies in Clinical Practice*, *18*(1), 54–59. doi:10.1016/j.ctcp.2011.04.002

Gard, T., Brach, N., Hölzel, B. K., Noggle, J. J., Conboy, L. A., & Lazar, S. W. (2012). Effects of a yoga-based intervention for young adults on quality of life and perceived stress: The potential mediating roles of mindfulness and self-compassion. *Journal of Positive Psychology*, *7*, 165–175. doi:10.1080/17439760.2012.667144

Gilbert, D., & Waltz, J. (2010). Mindfulness and health behaviors. *Mindfulness*, *1*, 227–234. doi:10.1007/s12671-010-0032-3

Greeson, J. M., Webber, D. M., Smoski, M. J., Brantley, J. G., Ekblad, A. G., Suarez, E. C., & Wolever, R. Q. (2011). Changes in spirituality partly explain health-related quality of life outcomes after Mindfulness-Based Stress Reduction. *Journal of Behavioral Medicine*, *34*, 508–518.

Gururaja, D., Harano, K., Toyotake, I., & Kobayashi, H. (2011). Effect of yoga on mental health: Comparative study between young and senior subjects in Japan. *International Journal of Yoga*, *4*, 7–12.

Heilbronn, F. S. (1992). The use of Hatha yoga as a strategy for coping with stress in management development. *Management Education and Development*, *23*, 131–139.

Holzel, B. K., Lazar, S. W., Gard, T., Schuman-Olivier, Z., Vago, D. R., & Ott, U. (2011). How does mindfulness work? Proposing mechanisms of action from a conceptual and neural perspective. *Perspectives on Psychological Science*, *6*, 537–559. doi:10.1177/1745691611419671

Innes, K. E., Vincent, H. K., & Taylor, A. G. (2007). Chronic stress and insulin resistance-related indices of cardiovascular disease risk, part 2: A potential role for mind-body therapies. *Alternative Therapies in Health and Medicine*, *13*, 44–51.

Juster, R.-P., McEwen, B. S., & Lupien, S. J. (2009). Allostatic load biomarkers of chronic stress and impact on health and cognition. *Neuroscience and Biobehavioral Reviews*, *35*(1), 2–16. doi:10.1016/j.neubiorev.2009.10.002

Kazdin, A. E., & Nock, M. K. (2003). Delineating mechanisms of change in child and adolescent therapy: Methodological issues and research recommendations. *Journal of Child Psychology and Psychiatry*, *44*, 1116–1129. doi:10.1111/1469-7610.00195

Kiecolt-Glaser, J. K., Christian, L., Preston, H., Houts, C. R., Malarkey, W. B., Emery, C. F., & Glaser, R. (2010). Stress, inflammation, and yoga practice. *Psychosomatic Medicine*, *72*(2), 113–121. doi:10.1097/PSY.0b013e3181cb9377

Kinser, P. A., Bourguignon, C., Whaley, D., Hauenstein, E., & Taylor, A. G. (2013). Feasibility, acceptability, and effects of gentle hatha yoga for women with major depression: Findings from a randomized controlled mixed-methods study. *Archives of Psychiatric Nursing*, *27*(3), 137–147. doi:10.1016/j.apnu.2013.01.003

Kuntsevich, V., Bushell, W. C., & Theise, N. D. (2010). Mechanisms of yogic practices in health, aging, and disease. *Mount Sinai Journal of Medicine*, *77*, 559–569. doi:10.1002/msj.20214

Leserman, J. (2003). HIV disease progression: Depression, stress, and possible mechanisms. *Biological Psychiatry*, *54*, 295–306. doi:10.1016/S0006-3223(03)00323-8

Li, A. W., & Goldsmith, C.-A. W. (2012). The effects of yoga on anxiety and stress. *Alternative Medicine Review*, *17*, 21–35.

Malathi, A., & Damodaran, A. (1999). Stress due to exams in medical students: Role of yoga. *Indian Journal of Physiology and Pharmacology*, *43*, 218–224.

Michalsen, A., Grossman, P., Acil, A., Langhorst, J., Ludtke, R., Esch, T., … Dobos, G. J. (2005). Rapid stress reduction and anxiolysis among distressed women as a consequence of a three-month intensive yoga program. *Medical Science Monitor*, *11*, 555–561.

Moadel, A. B., Shah, C., Wylie-Rosett, J., Harris, M. S., Patel, S. R., Hall, C. B., & Sparano, J. A. (2007). Randomized controlled trial of yoga among a multiethnic sample of breast cancer patients: Effects on quality of life. *Journal of Clinical Oncology*, *25*, 4387–4395. doi:10.1200/JCO.2006.06.6027

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine*, *151*, 264–269. doi:10.7326/0003-4819-151-4-200908180-00135

Neff, K. D. (2003). The development and validation of a scale to measure self-compassion. *Self and Identity*, *2*, 223–250. doi:10.1080/15298860309027

Park, C. L., Groessl, E., Maiya, M., Sarkin, A., Eisen, S., Riley, K. E., & Elwy, E. R. (2014). *Comparison groups in yoga research: A systematic review and critical evaluation of the literature*. Unpublished manuscript.

Purdy, J. (2013). Chronic physical illness: A psychophysiological approach for chronic physical illness. *Yale Journal of Biological Medicine*, *86*, 15–28.

Riley, D. (2004). Hatha yoga and the treatment of illness (commentary). *Alternative Therapies in Health and Medicine*, *10*, 20–21.

Rizzolo, D., Zipp, G. P., Stiskal, D., & Simpkins, S. (2009). Stress management strategies for students: The immediate effects of yoga, humor, and reading on stress. *Journal of College Teaching & Learning*, *6*, 79–88.

Roehr, B. (2008). Managing stress: Yoga, tai chi may help. *Dermatology Times*, pp. 22–23.

Ross, A., & Thomas, S. (2010). The health benefits of yoga and exercise: A review of comparison studies. *Journal of Alternative and Complementary Medicine*, *16*(1), 3–12. doi:10.1089/acm.2009.0044

Sengupta, P., Chaudhuri, P., & Bhattacharya, K. (2013). Male reproductive health and yoga. *International Journal of Yoga*, *6*(2), 87–95. doi:10.4103/0973-6131.113391

Sherman, K. J., Wellman, R. D., Cook, A. J., Cherkin, D. C., & Ceballos, R. M. (2013). Mediators of yoga and stretching for chronic low back pain. *Evidence-based Complementary and Alternative Medicine*, *2013*, 1–11. doi:10.1186/1747-5341-6-6

Sieverdes, J. C., Mueller, M., Gregoski, M. J., Brunner-Jackson, B., McQuade, L., & Treiber, F. A. (2014). Effects of Hatha yoga on blood pressure, salivary α-Amylase, and cortisol function among normotensive and prehypertensive youth. *The Journal of Alternative and Complementary Medicine*, *20*, 241–250.

Somerstein, L. (2010). Together in a room to alleviate anxiety: Yoga breathing and psychotherapy. *Procedia – Social and Behavioral Sciences*, *5*, 267–271. doi:10.1016/j.sbspro.2010.07.086

Streeter, C. C., Gerbarg, P. L., Saper, R. B., Ciraulo, D. A., & Brown, R. P. (2012). Effects of yoga on the autonomic nervous system, gamma-aminobutyric-acid, and allostasis in epilepsy, depression, and post-traumatic stress disorder. *Medical Hypotheses*, *78*, 571–579. doi:10.1016/j.mehy.2012.01.021

Taylor, M. J. (2003). Yoga therapeutics: An ancient, dynamic systems theory. *Techniques in Orthopaedics*, *18*(1), 115–125. doi:10.1097/00013611-200303000-00017

Vijayalakshmi, P., Madanmohan, B. A. B., Patil, A., & Kumar, B. P. (2004). Modulation of stress induced by isometric handgrip test in hypertensive patients following yogic relaxation training. *Indian Journal of Physiological Pharmacology*, *48*, 59–61.

West, J., Otte, C., Geher, K., Johnson, J., & Mohr, D. C. (2004). Effects of hatha yoga and African dance on perceived stress, affect, and salivary cortisol. *Annals of Behavioral Medicine*, *28*(2), 114–118. doi:10.1207/s15324796abm2802_6

Woodyard, C. (2011). Exploring the therapeutic effects of yoga and its ability to increase quality of life. *International Journal of Yoga*, *4*(2), 49–54. doi:10.4103/0973-6131.85485

Yadav, R. K., Magan, D., Mehta, N., Sharma, R., & Mahapatra, S. C. (2012). Efficacy of a short-term yoga-based lifestyle intervention in reducing stress and inflammation: Preliminary results. *Journal of Alternative and Complementary Medicine*, *18*, 662–667. doi:10.1089/acm.2011.0265

Yang, K. (2007). A review of yoga programs for four leading risk factors of chronic diseases. *Journal of Complementary and Alternative Medicine*, *4*, 487–491. doi:10.1093/ecam/nem154

Zapanti, E., Terzidis, K., & Chrousos, G. (2008). Dysfunction of the hypothalamic-pituitary-adrenal axis in HIV infection and disease. *Hormones*, *7*, 205–216. doi:10.14310/horm.2002.1200

Zhao, X., Lynch, J. G., & Chen, Q. (2010). Reconsidering Baron and Kenny: Myths and truths about mediation analysis. *Journal of Consumer Research*, *37*, 197–206. doi:10.1086/651257

Appendix 1. Biomarkers of stress response (Juster et al., 2009)

Neuroendocrine	
	Cortisol
	Dehydroepiandrosterone
	Epinephrine
	Norepinephrine
	Dopamine
	Aldosterone
Immune	
	Interleukin-6
	Tumor necrosis factor-alpha
	C-reactive protein
	Insulin-like growth factor-1
	Fibrinogen
	High-density lipoprotein cholesterol
	Low-density lipoprotein cholesterol
	Triglycerides
	Glycosylated hemoglobin
	Glucose
	Insulin
	Albumin
	Creatinine
	Homocysteine
Cardiovascular and respiratory	
	Systolic blood pressure
	Diastolic blood pressure
	Peak expiratory flow
	Heart rate/pulse
Anthropometric	
	Waist-to-hip ratio
	Body mass index