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REVIEW

# Psychobiological Mechanisms Underlying the Mental Health Benefits of Yoga-Based Interventions: a Narrative Review

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## Abstract

**Objectives** A comprehensive understanding of the mechanisms of action is important if yoga-based interventions are to be used in the prevention and/or treatment of mental health symptoms. We, therefore, aimed to examine the evidence base and mechanisms underlying the benefits of yoga-based interventions on mental health, with a focus on psychological, physiological and neurobiological mechanisms.

**Methods** A narrative review was conducted of scoping reviews, systematic reviews and meta-analysis of yoga-based interventions with a focus on psychological, physiological and neurobiological mechanisms linking yoga-based interventions with mental health. A single author conducted a search of the literature using a number of databases (PubMed, Web of Science, Scopus, Google Scholar). Search terms included but were not limited to "yoga*", "asana*," "psych*", "neuro*", "stress", "autonomic", "mental illness", "mental health", "cytokine" and "endocrine".

**Results** A total of 22 studies were included in this narrative review. These studies report that yoga-based interventions decrease stress reactivity, influence physiological markers of stress reactivity including changes in blood pressure, heart rate, cortisol or cytokine levels, resulting in overall improved health and well-being, in diverse populations of adults. Yoga-based interventions influence psychological processes involved in the regulation of mood and emotion, including self-compassion, dispositional mindfulness, rumination, meta-cognition, attention and memory. Finally, yoga-based interventions result in structural and functional changes in several brain regions.

**Conclusions** Yoga-based interventions impact multiple processes of mental health; however, further research should explore the potential interaction between these processes as it is possible that effects may be synergistic rather than in silos.

**Keywords** Brain · Yoga · Stress · Autonomic nervous system

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Yoga is a system (*darśana*) of the ancient Vedic tradition, aimed at enabling practitioners to facilitate changes in the mind–body, leading to improved health and well-being, and altered or higher states of consciousness, with a particular focus on the role and functioning of the mind. The system includes a large variety of practices and techniques, and a variety of approaches have developed throughout different periods of history. The classical system includes, among other features, a model of practice comprising eight components or limbs. These are cultivation of ethical, behavioural and relational values (*yama and niyama*), physical postures and movements (*asana*), regulation of breathing (*pranayama*), control of the senses and inner awareness (*pratyahara*), concentration of the mind (*dharana*), meditation (*dhyana*) and merging of individual consciousness with a greater consciousness (*samadhi*). In many countries all over the world, yoga is practiced in many ways, mostly in group classes, ranging from a purely physical practice used for fitness and well-being, to a spiritual practice more closely aligned with its eastern origins. While modern yoga classes mostly focus on the physical postures and movements (*asana*), other components may be included, such as the use of controlled breathing and meditative techniques (Pflueger, 2011).

The traditions of yoga and mindfulness are interrelated. Studies show that yoga practice can lead to an increase in dispositional mindfulness. Systematic review of RCTs shows that yoga practices, including Kundalini, Iyengar, Kripalu and Hatha yoga, result in higher levels of mindfulness in diverse populations, compared to control groups (Domingues, 2018). In a cross-sectional study of 455 individuals, those who rated themselves as highly involved in yoga had more dispositional mindfulness and religious/spiritual well-being as well as lower depression-like symptoms, compared to those who rated themselves as marginally/moderately or not at all involved in yoga, indicating that there might be a dose–response relationship between the amount of yoga practice and dispositional mindfulness (Gaiswinkler & Unterrainer, 2016).

A large body of research shows that yoga can improve psychological well-being. Meta-analyses show that yoga-based practices decrease the severity of symptoms of anxiety, depression, pain, stress and psychological distress, and improve mental health-related quality of life, in clinical populations (Brinsley et al., 2020; Cramer, et al., 2018a, b). In non-clinical settings, systematic reviews show that yoga-based interventions decrease stress (Chong et al., 2011) and improve psychological well-being in healthy adults (Hendriks et al., 2017). We propose that yoga practice improves mental health by reducing the distress experienced in response to psychological stressors, by impacting the key psychological process. We propose that by altering psychological processes that stressors result in less autonomic arousal and activation of the stress response, as well as less acute activation in brain regions associated with rumination and in the longer term, less stress derived damage to brain regions important in the regulation of mood and emotion. This article aims to explore the impact of yoga on psychological, physiological and neurobiological outcomes concurrently from the perspective of stress regulation and the impacts of this on mental health.

## Methods

We aimed to narratively review scoping reviews, systematic review and meta-analyses of yoga studies with a particular focus on those mechanisms involved in the stress response. This includes studies of (1) the autonomic nervous system processes (blood pressure, heart rate, heart rate variability, inflammation proteins and cortisol); (2) psychological processes (interoception, self-compassion, exposure, rumination, meta-cognition, attention and memory); and (3) neurobiological processes (brain structure and function). A single author conducted a search of the literature using a number of databases (PubMed, Web of Science, Scopus, Google Scholar). The cut-off point for the literature search was March 2021. Scoping reviews, systematic review and meta-analyses of all study types were eligible for inclusion including those containing randomized controlled trials and quasi-randomized studies and qualitative research. Journal articles and book chapters were included. Search terms included but were not limited to "yoga*", "asana*", "psych*", "neuro*", "stress", "autonomic", "mental illness", "mental health", "cytokine" and "endocrine". Searches only included studies published in English. Reviews and meta-analyses were screened by a single author and included if they examined the impact of a yoga-based intervention on autonomic, psychological or neurobiological outcomes in any population. Quality assessment of included studies was not conducted and thus all eligible articles were included. Data were coded as (1) psychological processes (self-compassion, dispositional mindfulness, rumination, exposure, meta-cognition, attention), (2) an autonomic nervous system process (heart rate, blood pressure, cytokines and cortisol) or (3) neurobiological processes (brain structure and function).

## Results

A total of 22 studies were included in this narrative review and are presented in Table 1.

### Psychological Processes Influenced by Yoga

#### Interoception

Interoception (or interoceptive awareness), the sense of awareness of the physiological condition of the entire body or the body's internal state, is recognized as an important factor in mental health and well-being (Craig, 2002). Interoception has been associated with a range of clinical mental health conditions, including depression and anxiety (Paulus & Stein, 2010). Interoception is an integral and inherent component of yoga practice, involving continuous conscious monitoring or mindfulness of bodily cues and sensations (Gard et al., 2014). It follows that clinical trials evaluating yoga-based interventions for various mental health outcomes inadvertently include a component of interoception.

No scoping review, systematic reviews or meta-analysis that assessed the impact of yoga on interoception was identified. Indeed, research generally in this area is limited. One

**Table 1** Main findings of the studies included in this narrative review

| Outcome assessed | Systematic review or meta-analysis | Finding | Study design | Level of evidence |
|---|---|---|---|---|
| Interoception | No SR or MA found | | | NA |
| Self-compassion | Domingues (2018) | Yoga increased self-compassion | SR | I |
| | Wong et al. (2021) | PA, including yoga, increased self-compassion | SR & MA | I* |
| Emotional regulation | No SR or MA found | Yoga improves emotional regulation in adolescents | RCT | II |
| Avoidance/exposure | No SR or MA found | | | NA |
| Rumination | Meister & Juckel (2018) | Yoga appears to decrease rumination in women with depression | SR | I* |
| Meta-cognition | No SR or MA found | | | NA |
| Attention and memory | Gothe and McAuley (2015) | Yoga provides small to moderate benefits for attention and memory | SR & MA | I* |
| | Brenes et al. (2019) | Yoga may have beneficial effects on cognitive functioning, particularly on attention and verbal memory in patients with mild cognitive impairment and dementia | Scoping review | |
| | Luu and Hall (2016) | Hatha yoga improves executive function | SR | I* |
| Blood pressure | Cramer et al. (2014) | Yoga lowers blood pressure | SR & MA | I |
| | Hagins et al. (2013) | Yoga had a modest but significant effect on systolic blood pressure and diastolic blood pressure | SR & MA | I* |
| | Innes et al. (2005) | Yoga reduces systolic and/or diastolic pressure | SR | I* |
| | Pascoe et al., (2017a, 2017b) | Yoga lowers systolic and diastolic blood pressure | SR & MA | I |
| | Tyagi and Cohen (2016) | Yoga reduces blood pressure in both normotensive and hypertensive populations | SR | I* |
| | Wu et al. (2019) | Yoga resulted in moderate reductions in systolic and diastolic blood pressure | SR & MA | I* |
| Heart rate | Cramer et al. (2014) | Yoga lowers blood pressure | SR & MA | I |
| | Reimers et al. (2018) | Yoga decreases resting heart rate | SR & MA | I* |
| | Pascoe et al., (2017a, 2017b) | Yoga decreases resting heart rate | SR & MA | I |
| Heart rate variability | Tyagi and Cohen (2016) | Yoga-based interventions increased HRV and vagal dominance | SR | I* |
| | Pascoe et al., (2017a, 2017b) | Yoga-based interventions increased both HF-HRV and LF-HRV | SR & MA | I |
| | Zou et al. (2018) | Yoga increase HRV (no impact on expiratory-to-inspiratory ratio) | SR & MA | I |
| | Posadzki et al. (2015) | Yoga practices improved several domains of HRV | SR & MA | I |
| Inflammatory proteins | Djalilova et al. (2019) | Yoga decreases IL-6, C-reactive protein and TNF-α | SR | I* |
| | McCall (2013) | Yoga reduces IL-6, interleukin-2, C-reactive protein | SR | |
| | Pascoe et al., (2017a, 2017b) | Mindfulness-based stress reduction decreased IL-6 | SR & MA | I |
| | Ye et al. (2020) | Yoga had no effect on C-reactive protein, ESR, IL-6, and TNF-α in patients with rheumatoid arthritis | SR & MA | I |
| | Falkenberg et al. (2018) | The existing evidence is not entirely consistent, a general pattern emerged suggesting that yoga can down-regulate pro-inflammatory markers (decrease in IL-1beta, IL-6 and TNF-alpha) | SR | I |
| Cortisol | Pascoe et al., (2017a, 2017b) | Yoga decreases cortisol | SR & MA | I* |
| | Meister & Juckel (2018) | Mixed findings regarding impact of yoga on cortisol | SR | I* |
| Structural brain changes | Gothe et al. (2019) | Yoga associated with anatomical changes in hippocampus, frontal cortex, anterior cingulate cortex and insula | SR | V |
| | Zhang et al. (2021) | Yoga associated with increased grey matter density in the hippocampus, increased cortical thickness or grey matter volume in prefrontal cortex, cingulate cortex and insula | SR | I* |
| Functional brain changes | Gothe et al. (2019) | Yoga associated with less activation in dorsolateral prefrontal cortex and functional connectivity increases in the default mode network | SR | V |
| | Zhang et al. (2021) | Increased functional connectivity in the default mode network | SR | I* |

I, II, V = roman numeral numbering; I* A combination of RCTs and non-RCTs was included. *ESR*, Erythrocyte sedimentation rate; *HF-HRV*, high-frequency heart rate variability; *LF-HRV*, low-frequency heart rate variability; *IL-1*, interleukin-1; *IL-6*, interleukin-6; *MA*, meta-analysis; *NA*, not applicable; *PA*, physical activity; *SR*, systematic review; *RCT*, randomized controlled trail; *TNF-α*, tumour necrosis factor-alpha mixed-methods case series study provides preliminary evidence that a yoga-based intervention improved interoceptive awareness, and reduced symptom severity in participants with PTSD (Neukirch et al., 2019). A further pilot study evaluated the effects of a single yoga class on interoceptive awareness among a clinical population of patients with anorexia nervosa and healthy controls. They found that patients with anorexia nervosa had lower interoceptive accuracy than healthy individuals at baseline and a significant improvement in interoceptive accuracy among the healthy individuals, but not in the group with anorexia nervosa, after the yoga intervention. They concluded that interoceptive awareness plays a role in mental health conditions such as eating disorders, where the interoceptive awareness system appears to be impaired, and healthy controls responded to yoga as an intervention to improve interoceptive awareness (Demartini et al., 2020). Based on these few studies, high-quality trials should be conducted to investigate the impact of yoga on interoception.

### Self-compassion

Self-compassion refers to extending compassion to one's self in instances of perceived failure, inadequacy or general suffering. A meta-analysis of studies showed that self-compassion is a robust predictor of psychological well-being (MacBeth & Gumley, 2012). Higher levels of self-compassion are associated with lower anxiety, stress, depression, increased life quality, happiness, positive affect, personal initiative, agreeableness, extroversion and conscientiousness (Neff et al., 2007).

A systematic review of two RCTs shows that hatha yoga increases self-compassion in nursing students and that Kripalu yoga increases self-compassion in health care providers (Domingues, 2018). In a systematic review and meta-analysis of six RCTs and four single group repeated measure design, eight of which focused on mind-and-body exercises including yoga, physical activity was seen to increase self-compassion (Wong et al., 2021).

### Emotional Regulation

The ability to regulate emotion is associated with greater well-being, life satisfaction and improved relationships while maladaptive emotional regulation strategies such as rumination and suppression are linked to less social closeness and support, higher intensity of negative emotions, and depressive symptoms (John & Gross, 2004).

No scoping review, systematic reviews or meta-analysis that assessed the impact of yoga on emotional regulation was identified and research in this area generally appears to be limited. An RCT shows that yoga delivered in schools improves emotional regulation in adolescents, compared to physical education (Daly et al., 2015). One cross-sectional study involving yoga practitioners found reduced emotional reactivity following yoga, and that several years of practice was associated with decreased respiratory arousal in the face of negative situations (Mocanu et al., 2018).

### Avoidance/Exposure

High avoidance of aversive stimuli may contribute to the onset and maintenance of depressive disorders (Trew, 2011). Conversely, exposure or sustained, non-judgmental observation of sensations, emotions, pain or other challenging experiences, without attempts to escape or avoid them, may lead to reductions in the emotional reactivity typically elicited by experience (Linehan, 2018). It is hypothesized that by intentionally focusing on experiences in a non-judgmental and open manner, individuals can undergo a process of desensitization through which distressing sensations (thoughts and emotions that might otherwise be avoided) become less distressing and consequently less frequently avoided (Linehan, 1993). This process may lead to the extinction of fear responses and avoidance behaviours previously elicited by these stimuli (Linehan, 1993).

No scoping review, systematic reviews or meta-analysis that assessed the impact of yoga on avoidance was identified. Data from a single-arm (pre-post) trial shows that participation in MBSR, which includes hatha yoga, is associated with increases in willingness to be exposed to unpleasant internal experiences and corresponds with reductions in symptoms of depression, anxiety and stress (Carmody et al., 2009). We suggest that high-quality trails should be conducted to investigate the impact of yoga on avoidance and exposure.

### Rumination

Rumination, or the focused attention on thoughts, past events and symptoms associated with one's distress, is generally considered a maladaptive emotional regulation strategy, as it tends to exacerbate emotional distress (Nolen-Hoeksema et al., 2008). It has been hypothesized that higher levels of self-compassion may improve psychological well-being by reducing avoidance and rumination. This is supported by findings that in depressed outpatients, rumination and avoidance mediate the relationship between self-compassion and depressive symptoms, suggesting that those with less self-compassion tend to be more avoidant (Krieger et al., 2013). In a small systematic review, yoga was found to decrease rumination in 1 RCT involving women with depression, but not in one uncontrolled study (Meister & Juckel, 2018).

### Meta-cognition

Metacognitive awareness is described as the ability to decenter or detach from thoughts and emotions, and view them as passing mental stimuli, as opposed to completely accurate representations of reality (Sheppard & Teasdale, 2000). High levels of meta-cognition appear to protect against depression relapse (Fresco et al., 2007) and high metacognitive awareness is speculated to reduce rumination (Sheppard & Teasdale, 2000). Repeated practice of monitoring sensations and thoughts without trying to interpret or judge them is argued to result in a gradual lessening of identification with those thoughts.

In the context of yoga-based practices, this process is hypothesized to first be applied primarily to bodily sensations and proprioceptive feedback related to the movement and breath, and subsequently also to arising emotions and thoughts (Schmalzl et al., 2015). Consistent with this view is evidence showing that yoga practitioners are able to tolerate physical pain for a longer duration than non-yoga practitioners, perhaps mediated by an ability to attend to the sensation, accept the associated experience and observe the pain without reacting (Villemure et al., 2014).

No scoping review, systematic reviews or meta-analysis that assessed the impact of yoga on the interoception was identified. One RCT involving depressed patients in remission or recovery, MBSR, which includes hatha yoga, has been shown to increase metacognition (Teasdale et al., 2002). We suggest that further research to be conducted to investigate the impact of yoga on meta-cognition.

### Attention and Memory

It has long been proposed that yoga-based interventions build a generalizable capacity for focused attention and can have demonstrable effects on cognitive function (Gothe & McAuley, 2015). One systematic review investigating the impacts of hatha yoga on executive function reported that yoga was seen to improve executive function in areas such as inhibitory control, working memory and attention, in 11 studies (both RCTs and non-RCTs) comprising diverse populations (Luu & Hall, 2016). Meta-analysis of 15 randomized controlled trials of yoga-based interventions found that yoga provides small to moderate benefits for attention and memory across a range of standardized neuropsychological measures (Gothe & McAuley, 2015). Though the mechanisms are unknown, one pathway may be the stress-alleviating benefits of regular yoga practice, which putatively frees cognitive resources otherwise hampered by stress (Gothe et al., 2016). A recent scoping review found that in patients with mild cognitive impairment and dementia yoga may have beneficial effects on cognitive functioning, particularly on attention and verbal memory, through improved sleep, mood and neural connectivity (Brenes et al., 2019). Future dismantling studies that examine the components of yoga-based interventions within a standardized neuropsychological framework will more firmly establish yoga's effects on attention and memory (Schmalzl et al., 2015).

## Yoga-Based Interventions and Autonomic Measures

A series of systematic reviews and meta-analyses, which examine the impact of yoga practices on these physiological markers of stress reactivity, including changes in blood pressure, heart rate, heart rate variability, cortisol or cytokine levels, in diverse populations of adults, are summarized in Table 2 (Pascoe & Bauer, 2015; Pascoe & Crewther, 2016; Pascoe et al., 2017a, b).

### Blood Pressure

There is strong evidence supporting beneficial effects of yoga-based interventions on blood pressure (BP), as shown from multiple meta-analyses of randomized controlled trials (RCTs) and systematic reviews. A meta-analysis of randomized controlled trials of multi-component yoga-based interventions, compared to a time/attention control group, in any population (Pascoe et al., 2017b), found that resting diastolic blood pressure (DBP) decreased DBP by 3.66 mm of mercury (mmHg), compared to the time/attention control group, in 16 studies comprising 887 individuals from diverse populations (Pascoe et al., 2017b). Subgroup analysis comparing different yoga-based practices did not find any meaningful differences in blood pressure changes between different types of yoga practices. Resting systolic blood pressure (SBP) was seen to decrease by 5.34 mmHg, compared to the time/attention control group, in 17 RCTs comprising 1058 individuals from diverse populations (Pascoe et al., 2017b).

**Table 2** Summary of meta-analysis of multi-component yoga-based interventions (Pascoe et al., 2017b)

| Outcome | SBP | DBP | HR | Cortisol | CRP | IL-6 |
|---|---|---|---|---|---|---|
| Change following yoga* | −5.62 ($n$ = 982) | −3.63 ($n$ = 765) | −3.2 ($n$ = 879) | −1.51 ($n$ = 386) | −0.15 ($n$ = 75) | −0.1 ($n$ = 75) |

Cortisol (salvia, waking) (nmol/l); *CRP*, C-reactive protein (serum) (mg/L); *DBP*, diastolic blood pressure (millimetre of mercury); *HR*, resting heart rate (beats per minute); *IL-6*, interleukin-6 (serum) (pg/ml); *SBP*, systolic blood pressure (millimetre of mercury); *compared to a time/attention control group

In seven studies measuring SPB, the control group received an exercise intervention (e.g. aerobic, resistance). This indicates that the yoga-based practices decreased resting SBP to a greater degree than non-yoga-based exercise. Therefore, it would seem that the effects of yoga-based practices on resting SBP may be related to a combination of the mindfulness practice and the cardiovascular effects associated with the physical practice of yoga asanas (Pascoe et al., 2017b). This is supported by the findings a meta-analysis reporting a modest but significant effect of yoga on SBP and DBP, with subgroup analysis showing effects from interventions incorporating postures, meditation and breathing, and that yoga decreased blood pressure compared to no treatment but not compared to exercise (Hagins et al., 2013). This is also consistent with a systematic review and meta-analysis of 44 RCTs showing that yoga decreased SBP and DBP (Cramer et al., 2014) and a systematic review and meta-analysis of both RCTs and non-RCTs, which showed the yoga elicited moderate reductions in SBP and DBP (Wu et al., 2019).

These results are consistent with an earlier systematic review which comprised of 12 RCTs, 12 nonrandomized clinical trials, 11 uncontrolled studies, 1 cross-sectional study and 1 single yoga session examination, and found that most studies reported a reduction of systolic and/or diastolic pressure (Innes et al., 2005). They are also supported by the findings of a systematic review including 39 cohort studies, 30 nonrandomized, controlled trials, 48 RCTs and 3 case reports, in which most studies reported that yoga reduced BP in individuals with and without hypertension (Tyagi & Cohen, 2014).

### Heart Rate

There is strong evidence showing that yoga decreases resting heart rate, from two meta-analyses. In a meta-analysis of 15 RCTs ($N = 879$) comparing yoga-based practices to time/attention control groups, involving any population (Pascoe et al., 2017b), the yoga-based interventions were found to decrease resting heart rate by 3.2 beats per minute (bpm). This is consistent with the findings from a meta-analysis comprising 21 yoga studies which found that yoga decreased resting heart rate in both males and females and that the decreases in resting heart rate were positively correlated with pre-intervention heart rate and negatively correlated with participant age (Reimers et al., 2018). An earlier systematic review and meta-analysis of 44 RCTs similarly reported that yoga lowered heart rate (Cramer et al., 2014).

### Heart Rate Variability

Heart rate variability (HRV) reflects the flexibility of the cardiovascular system to cope with physical/psychological challenges. The higher the HRV, the faster the heart is able to switch from "fight-or-flight" to a relaxed state. HRV is measured by the variation in the beat-to-beat interval (Perna et al., 2020). A systematic review of yoga-based interventions on HRV, including 59 studies involving a total of 2358 participants, found that yoga-based interventions increased HRV and vagal dominance, which indicates increased PNS activity during yoga-based practices (Tyagi & Cohen, 2016). The review also found that people who practice yoga regularly have increased activity of the vagus nerve at rest compared to people who do not practice yoga regularly (Tyagi & Cohen, 2016).

The vagus nerve is the main contributor of the PNS, as most organs receive parasympathetic efferents through the vagus nerve, and therefore, the vagus nerve activity has been studied as an antagonist of SNS activity and efferent nerve (Breit et al., 2018). Another systematic review of RCTs of yoga-based interventions compared to any type of control intervention, in healthy individuals or patients with any medical condition, found that 10 of the 14 included studies reported benefits of yoga practices on several domains of HRV (Posadzki et al., 2015). Their meta-analysis showed no effect of yoga practice on the HRV index expiratory-to-inspiratory ratio (E:I ratio), though only two studies were included in the analysis (Posadzki et al., 2015).

Analysis of HRV has also been studied in the frequency domain with heart rate (HR) oscillations being divided into frequencies, including low-frequency (LF) and high-frequency (HF) bands (Shaffer & Ginsberg, 2017). Increased HF-HRV is generally accepted to reflect increased PNS activity. LF-HRV is more complex and represents both branches of the PNS, but has been argued to have a dominant SNS component (Billman, 2011; Task Force of the European Society of Cardiology, 1996; Thayer et al., 2010). However, more recently, various authors have highlighted that accumulating evidence demonstrates that this interpretation oversimplifies the complex non-linear interactions between the SNS and the PNS (Billman, 2011, 2013).

A meta-analysis of 17 medium-to-high-quality RCTs showed significantly beneficial effects on HRV parameters including low frequency, high frequency, low-frequency to high-frequency ratio and stress level (Zou et al., 2018). A meta-analysis of forty-two studies overall, four of which measured HF-HRV and LF-HRV, and comprised of 367 participants showed that yoga-based interventions increased both HF-HRV and LF-HRV. All of the control groups in these four RCTs were exercise-based interventions, indicating that the effects of yoga practices on HRV cannot be attributed to the exercise-related effects of yoga alone (Pascoe et al., 2017b). Indeed, yoga practices incorporate philosophical teachings, mindful awareness, controlled breathing, meditative techniques and physical asanas (Pflueger, 2011; Travis & Pearson, 2000).

### Inflammatory Proteins

Cytokines are small cell signalling protein molecules that mediate and regulate immunity and inflammation (Salim et al., 2012). Many studies indicate that various stressors, including psychological stressors alone, can induce pro-inflammatory (interleukin-1 [IL-1], interleukin-6 [IL-6], tumour necrosis factor-alpha [TNF-α]) cytokine secretion (Dhabhar et al., 1996; Lemay et al., 1990; Ruzek et al., 1997). A bi-directional feedback loop between cytokines and cortisol is hypothesized to be central to the appropriate functioning of the HPA axis while maintaining homeostasis of the immune system (Petrovsky, 2001; Turnbull & Rivier, 1999). For example, stress-induced release of certain inflammatory cytokines such as IL-6, TNF-α and interleukin (IL-10) activates the HPA axis and cause the release of cortisol (Steensberg et al., 2003; Turnbull & Rivier, 1999). The increased cortisol-induced negative feedback then suppresses further release of cytokines (Chrousos, 1995; Elenkov & Chrousos, 1999; Reichlin, 1993; Turnbull & Rivier, 1999). However, glucocorticoid receptor abnormalities resulting from excessive cortisol can reduce the immune system's capacity to respond to cortisol and subsequently lower inflammation. This results in concurrently sustained levels of cortisol and cytokine release (Chrousos, 1995; Elenkov & Chrousos, 1999; Miller et al., 2002). This altered immune-endocrine interaction and increased inflammatory profile have been linked to chronic stress and inflammation can contribute to the onset of mental disorders such as depression and anxiety (Dantzer, 2012; Masi & Brovedani, 2011; Pascoe et al., 2011). Consistently, diagnosed anxiety and depressive disorder are associated with an increased expression of pro-inflammatory cytokines (Salim et al., 2012).

A systematic review of 15 studies examining the impact of yoga-based interventions on inflammatory biomarkers in adults with chronic inflammatory-related disorders provides evidence that yoga-based practices can reduce cytokine levels (Djalilova et al., 2019). Eleven of the 15 studies included in the review reported positive effects of yoga practices on inflammatory biomarkers, with the most commonly measured cytokines in the studies being IL-6 ($n = 11$ studies), C-reactive protein (CRP—a pentameric protein found in blood plasma, whose circulating concentrations rise in response to inflammation) ($n = 10$ studies) and TNF-α ($n = 8$ studies) (Djalilova et al., 2019). Interestingly, a longer duration of yoga-based practice was associated with larger improvements in inflammation (Djalilova et al., 2019). These finds are consistent with a recent systematic review that reports that yoga practice decreases IL-6, interleukin-2 and CRP (McCall, 2013) and partially consistent with the findings of a meta-analysis comparing the impact of yoga-based interventions and a time/attention control group on inflammatory markers (Pascoe et al., 2017b). In this meta-analysis, yoga practice was seen to decrease IL-6 in the three studies that delivered a mindfulness-based stress reduction (MBSR) intervention, which includes yoga-based postures and movement, but also focuses heavily on meditation, body awareness, self-acceptance and stress management education. There was, however, no effect on IL-6 in two studies that delivered a yoga-based intervention that was not MBSR, indicating that the observed differences in IL-6 are associated with MBSR, but not yoga-based interventions. This meta-analysis also reported no effect of yoga practice on interleukin-8 or CRP.

In a meta-analysis comprising 10 RCTs including individuals with rheumatoid arthritis, there was no impact of yoga on the inflammatory cytokines, CRP, Erythrocyte sedimentation rate IL-6 and TNF-α, indicating that yoga may be ineffective in impacting inflammation in individuals with chronic inflammatory autoimmune disease (Ye et al., 2020). This is partially consistent with the findings of an earlier systematic review of RCTs, which concluded that the qualitative evaluation of 10 RCTs showed decreases in IL-1beta, IL-6 and TNF-α, but that there was some variability between studies, for example, yoga was not seen to decrease IL-6 in three studies involving cancer survivors, but was seen to decrease IL-6 in individuals with heart failure (Falkenberg et al., 2018). In future research, it might be worthwhile exploring if some markers of inflammation are biomarkers of treatment response, in that individuals with depression and high inflammatory markers might be more or less likely to respond to yoga-based interventions compared to those with low levels of inflammatory markers.

### Cortisol

Increased cortisol is commonly seen in individuals with mental illness and likely reflects increased autonomic nervous system reactivity and dysregulation (Barker et al., 2012; Staufenbiel et al., 2013). A systematic review of two studies involving patients with depressive disorder reported mixed findings as one RCT showed no added benefit of yoga combined with anti-depressants, compared with anti-depressants alone, on cortisol levels while another non-randomized three arm controlled study found that yoga reduced cortisol compared with anti-depressants alone, and that there was a significant negative correlation between change in serum brain-derived neurotrophic factor (BDNF) and cortisol levels in the yoga-only group, indicating that serum BDNF and cortisol levels are reciprocal (Meister & Juckel, 2018).

A meta-analysis comparing the impact of yoga-based practices and a time/attention control group on inflammatory markers showed that yoga-based practices decreased waking salivary cortisol levels and evening salivary cortisol level in five studies comprising 386 individuals (Pascoe et al., 2017b). Insights from an RCT demonstrated that multi-component yoga-based programs which aim to incorporate aspects from all eight limbs of the yoga model may impact cortisol levels more greatly than yoga-based programs that are focused only on postures (Smith et al., 2011). In this RCT, university students with elevated symptoms of depression, anxiety and stress were randomized to either (1) an integrated multi-component yoga-based program; (2) yoga asana as exercise; or (3) a control group that completed surveys but did not practice yoga. While both the integrated yoga-based program and yoga asana as exercise were seen to decrease depression symptoms and subjective stress levels, compared to a control condition, the integrated multi-component yoga intervention was also seen to decrease anxiety symptoms and cortisol levels, compared to the yoga asana as an exercise group (Smith et al., 2011). Thus, multi-component yoga-based practices may influence other psychological processes which can also reduce objectively measured stress. Thus, the effects of yoga-based practices on stress reactivity likely results from a combination of philosophical teachings, mindful awareness, controlled breathing, meditative techniques and physical postures, among other factors. For example, the philosophical teachings of yoga may affect an individual's mindset or perception of stressful events and therefore could have an effect on stress reactivity and psychological well-being and could be a low stigma intervention for introducing concepts such as mindfulness meditation for mental well-being.

### Yoga-Based Interventions and Structural and Functional Brain Changes

A recent systematic review exploring the impact of yoga on brain structure and function determined that literature is limited, as only 11 relevant eligible studies were found, more than half of which ($n=6$) were cross-sectional while 5 were intervention studies. Nine of these studies assessed hatha yoga and physical postures in particular. These authors report that yoga practice is associated with anatomical changes including greater GM volume, greater hippocampus volume and greater cortical thickness especially in the prefrontal cortex and right anterior insula, in long-term yoga practitioners. Interestingly, in cross-sectional studies, the extent of yoga experience was positively related to the volume of frontal, limbic, temporal, occipital and cerebellar regions (Gothe et al., 2019).

This systematic review also reviewed the impact of yoga on brain function between individuals with and without yoga experience in three cross-sectional and two longitudinal studies following a yoga intervention. Yoga practitioners were found to have greater antero-posterior default mode network connectivity (representing healthier cognitive aging process), and greater connectivity between the caudate and other brain regions, than non-yoga practitioners (Gothe et al., 2019). However, as the studies exploring the impact of yoga on brain function are few and cross-sectional or longitudinal, the level of evidence for the impact of yoga practices on brain structure should be considered preliminary and there is a need for well-designed intervention studies.

A more recent systemic review of 15 studies focused on evaluating mind–body exercise and brain plasticity using MRI, and included five cross-sectional studies and two yoga intervention studies. This systematic review reported that yoga practitioners were found to have a number of structural and functional differences in the prefrontal cortex including greater corticol thickness in the left prefrontal lobe cluster, greater grey matter volume in the orbitofrontal cortex and the medial prefrontal cortex which were positively correlated with fewer cognitive failures. With regard to functional changes in the prefrontal cortex, yoga practitioners were seen to have less activation in the dorsolateral prefrontal cortex during a memory task and in the left superior frontal gyri during an affective task, than non-yoga practitioners (Zhang et al., 2021).

Yoga practitioners were also found to have greater cortical thickness and grey matter volume in the cingulate cortex, increased cortical thickness and grey matter volume in insula which correlated with pain tolerance and greater hippocampal grey matter volume, including compared to a sport group, implying that yoga is more effective in improving the hippocampal structure than physical exercise (Zhang et al., 2021).

Finally, greater resting-state functional connectivity within the dorsal attention network was seen in yoga practitioners as was resting-state functional connectivity between the medial prefrontal cortex and right angular gyrus showing increased resting-state functional connectivity within the default mode network (DMN) of yoga experts (Zhang et al., 2021). This is interesting as increases in DMN resting-state connectivity have been reported in individuals with depression, and this is associated with higher levels of maladaptive rumination, indicating that increased levels of DMN activity underlie dysfunctional emotional processing in depression (Hamilton et al., 2011; Zhou et al., 2010). Therefore, the relationship between yoga practice, DMN connectivity and mental health should be further explored to better understand this complex relationship.

## Discussion

The current review summarizes the purported psychobiological mechanisms underlying the benefits of yoga-based interventions on mental health. Findings suggest that the benefits of yoga-based practices have underlying psychological, physiological and neurobiological processes that are plausibly linked to better mental health, possibly by decreasing stress reactivity. In particular, yoga practice is seen to increase self-compassion, decrease rumination and improve attention and memory. Few studies have explored the impact of yoga on avoidance, interoception, emotional regulation or meta-cognition. Evidence consistently shows that yoga decreases physiological markers of stress reactivity including blood pressure, heart rate and inflammatory proteins, while it increases heart rate variability, in diverse populations. Finally, yoga practice is associated with structural and functional changes in brain regions and networks involved in the regulation of stress reactivity, mood and emotion, including the hippocampus, the amygdala, prefrontal cortex and default mode network; however, much of this evidence relies on cross-sectional data and therefore more high-quality RCTs investigating the impact of yoga on brain function and structure are required.

In addition, yoga-based exercise is shown to improve body awareness, strength, flexibility and (with sufficient effort) aerobic capacity (Barrows & Fleury, 2016; Green et al., 2019). This is consistent with the international physical activity guidelines that highlight the importance of strengthening and resistance activities across all age ranges, but with a particular focus on activities to enhance balance and protect against falls for older adults. These additional neuromuscular benefits may be especially important in those with poor mental health, where somatic health and physical fitness is often compromised (WHO 2004). Older adults in particular may benefit from yoga by reducing fall injuries (Nick et al., 2016). Thus, by impacting both physical and mental health synergistically, yoga-based exercises have additional therapeutic potential.

We propose that by impacting psychological, physiological and neurobiological mechanisms, yoga increases resilience against stressful experiences. This hypothesis is partially consistent with the findings of a recent systematic review of RCTs which reports that vinyoga increases resilience in adults with anxiety and depression symptoms, but not in adolescents and students, indicating that impacts may vary according to population or type of yoga practice (Domingues, 2018).

## Limitations and Future Research

The strengths of this review are that it examines the effects of yoga on physiological, psychological and neurobiological outcomes collectively, in the context of stress and mental health. Therefore, this work has provided a comprehensive synthesis demonstrating that yoga impacts multiple processes; however, further research should explore the potential interaction between these processes. Studies were not included or excluded based on quality assessment, to best capture the current state of research in this field, and therefore, the methodological rigour of the discussed studies is unknown. Not evaluating the quality of the papers reviewed impacts the overall validity and confidence in the conclusions of this review. In future research, it would be of value to include a formal assessment of the quality of reviewed research.

One outstanding question regarding the impact of yoga on mental health is the optimal dose and type. Most interventions, yoga-based or otherwise, follow the Yerkes-Dodson law of optimal arousal, whereby they reach an inflection point where their effects turn negative (Yerkes & Dodson, 1908). Yoga is unlikely to be an exception to this inverted U-shape curved principle (Britton, 2019). For example, while intentionally directing attention to one's present moment experience is associated with many positive psychological outcomes, high levels of self-focused attention have also been found to be associated with psychopathology and negative affect (Ingram, 1990; Mor & Winquist, 2002) (for an in-depth review of some of the more negative effects of too much mindfulness, see Britton (2019)). Studies examining dose–response might consider assessing the effects of yoga-based interventions at levels recommended for aerobic training by the American College of Sports Medicine (approximately 3 times per/week for 45–60 min) (Medicine, 2013).

Finally, more high-quality studies are needed to assess the effects of yoga-based practices on inflammatory markers, in conjunction with changes in brain function and/or structure. Assessing these concurrently with psychological changes will help to build a more complete picture of the impacts of yoga practices on mental health.

Individual preferences and affect may be important factors impacting the beneficial outcomes of yoga-based interventions and should be explored in future research. The results of the current narrative review show that few studies have included patient preference for the type and intensity of yoga-based intervention when designing clinical interventions or health promotion initiatives. This could be important considering such an approach may facilitate engagement, improve adherence and potentially effectiveness compared to approaches that prescribe the type and intensity of the yoga-based intervention. Experiencing positive emotions appears to be an important factor in predicting adherence to physical activity and exercise (Ekkekakis et al., 2011; Lee et al., 2016), and future research should also consider this importance of self-selection of the yoga type and intensity as autonomy is proposed as one of three basic psychological needs fundamental to positive mental health (Craft et al., 2008; Ryan & Deci, 2000).

Another tenable but currently largely unexplored hypothesis is that the mental health benefits of yoga could be mediated by changes in the gut. The gut microbiota is essential to human health, the immune system, and plays a major role in the bi-directional communication between the gut and the brain. In animals, the gut microbiota is associated with metabolic disorders such as obesity and diabetes mellitus, and with neuropsychiatric disorders (anxiety, depression) in humans (Zheng et al., 2020). Recently, population-scale evidence for the link between the gut microbiota and mental health has been provided (Valles-Colomer et al., 2019). Gut microorganisms are capable of producing and delivering neuroactive substances such as serotonin and gamma-aminobutyric acid which act on the gut-brain axis. Pre-clinical research in rodents suggests that certain probiotics have antidepressant and anxiolytic activities, effects that could be mediated via the immune system or neuroendocrine systems. The gut microbiota and brain communicate via the vagus nerve, gut hormone signalling, the immune system, tryptophan metabolism and microbial metabolites such as short-chain fatty acids. The importance of the gut-brain axis in regulating stress-related responses has been recognized for a long time. More recently, the microbiota has emerged as a "key player" in the control of this axis (Dinan & Cryan, 2017; Foster et al., 2017), with increased understanding of the neuroactive potential of the products of gut microbiota metabolism (Caspani et al., 2019). Possible links between yoga-induced microbiota change and mental health are plausible but have not been examined.

Overall, the current work demonstrates that yoga-based interventions likely improve mental health via physiological, psychological and neurobiological pathways and that the beneficial effects of yoga-based interventions cannot be attributed to exercise-related effects of yoga asana alone. Yoga practices incorporate philosophical teachings, mindful awareness, controlled breathing, meditative techniques and physical asana, all of which likely improve stress regulation and mental health outcomes, and is important to consider with regard to delivering yoga-based interventions in clinical and practice settings, as better outcomes are likely to be associated with yoga-based programs that include asanas plus other components of yoga practice.

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## Declarations

**Informed Consent** Informed consent was not required for the conduct of this narrative review as no participants were involved.

**Conflict of Interest** The authors declare no competing interests.

## References

Barker, E. T., Greenberg, J. S., Seltzer, M. M., & Almeida, D. M. (2012). Daily stress and cortisol patterns in parents of adult children with a serious mental illness. *Health Psychology, 31*(1), 130–134. https://doi.org/10.1037/a0025325

Barrows, J. L., & Fleury, J. (2016). Systematic review of yoga interventions to promote cardiovascular health in older adults. *Western Journal of Nursing Research, 38*(6), 753–781. https://doi.org/10.1177/0193945915618610

Billman, G. E. (2011). Heart rate variability - A historical perspective. *Frontiers in Physiology, 2*, 86. https://doi.org/10.3389/fphys.2011.00086

Billman, G. E. (2013). The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. *Frontiers in Physiology, 4*, 26. https://doi.org/10.3389/fphys.2013.00026

Breit, S., Kupferberg, A., Rogler, G., & Hasler, G. (2018). Vagus nerve as modulator of the brain–gut axis in psychiatric and inflammatory disorders. *Frontiers in Psychiatry, 9*, 44.

Brenes, G. A., Sohl, S., Wells, R. E., Befus, D., Campos, C. L., & Danhauer, S. C. (2019). The effects of yoga on patients with mild cognitive impairment and dementia: A scoping review. *The American Journal of Geriatric Psychiatry, 27*(2), 188–197.

Brinsley, J., Schuch, F., Lederman, O., Girard, D., Smout, M., Immink, M. A., Stubbs, B., Firth, J., Davison, K., & Rosenbaum, S. (2020). Effects of yoga on depressive symptoms in people with mental disorders: A systematic review and meta-analysis. *British Journal of Sports Medicine*, bjsports-2019–101242. https://doi.org/10.1136/bjsports-2019-101242

Britton, W. B. (2019). Can mindfulness be too much of a good thing? The value of a middle way. *Current Opinion in Psychology, 28*, 159–165. https://doi.org/10.1016/j.copsyc.2018.12.011

Carmody, J., Baer, R. A., Lykins, E. L. B., & Olendzki, N. (2009). An empirical study of the mechanisms of mindfulness in a mindfulness-based stress reduction program. *Journal of Clinical Psychology, 65*(6), 613–626. https://doi.org/10.1002/jclp.20579

Caspani, G., Kennedy, S., Foster, J. A., & Swann, J. (2019). Gut microbial metabolites in depression: Understanding the biochemical mechanisms. *Microbial Cell, 6*(10), 454–481. https://doi.org/10.15698/mic2019.10.693

Chong, C. S., 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*(1), 32–38.

Chrousos, G. P. (1995). The hypothalamic–pituitary–adrenal axis and immune-mediated inflammation. *New England Journal of Medicine, 332*(20), 1351–1363.

Craft, L. L., Perna, F. M., Freund, K. M., & Culpepper, L. (2008). Psychosocial correlates of exercise in women with self-reported depressive symptoms. *Journal of Physical Activity and Health, 5*, 469–480.

Craig, A. D. (2002). How do you feel? Interoception: The sense of the physiological condition of the body. *Nature Reviews Neuroscience, 3*(8), 655–666. https://doi.org/10.1038/nrn894

Cramer, H., Lauche, R., Haller, H., Steckhan, N., Michalsen, A., & Dobos, G. (2014). Effects of yoga on cardiovascular disease risk factors: A systematic review and meta-analysis. *International Journal of Cardiology, 173*(2), 170–183.

Cramer, H., Anheyer, D., Saha, F. J., & Dobos, G. (2018a). Yoga for posttraumatic stress disorder–A systematic review and meta-analysis. *BMC Psychiatry, 18*(1), 1–9.

Cramer, H., Lauche, R., Anheyer, D., Pilkington, K., de Manincor, M., Dobos, G., & Ward, L. (2018b). Yoga for anxiety: A systematic review and meta-analysis of randomized controlled trials. *Depression and Anxiety, 35*(9), 830–843.

Daly, L. A., Haden, S. C., Hagins, M., Papouchis, N., & Ramirez, P. M. (2015). Yoga and emotion regulation in high school students: A randomized controlled trial. *Evidence-Based Complementary and Alternative Medicine*. https://doi.org/10.1155/2015/794928.

Dantzer, R. (2012). Depression and inflammation: An intricate relationship [Comment Research Support, N.I.H., Extramural]. *Biological Psychiatry, 71*(1), 4–5. https://doi.org/10.1016/j.biopsych.2011.10.025

Demartini, B., Goeta, D., Marchetti, M., Bertelli, S., Anselmetti, S., Cocchi, A., Ischia, M., & Gambini, O. (2020). The effect of a single yoga class on interoceptive accuracy in patients affected by anorexia nervosa and in healthy controls: A pilot study. *Eating and Weight Disorders - Studies on Anorexia, Bulimia and Obesity*. https://doi.org/10.1007/s40519-020-00950-3

Dhabhar, F. S., Miller, A. H., McEwen, B. S., & Spencer, R. L. (1996). Stress-induced changes in blood leukocyte distribution. Role of adrenal steroid hormones. *The journal of Immunology*, *157*(4), 1638–1644.

Dinan, T. G., & Cryan, J. F. (2017). Gut-brain axis in 2016: Brain-gut-microbiota axis - mood, metabolism and behaviour. *Nature Reviews Gastroenterology Hepatology, 14*(2), 69–70. https://doi.org/10.1038/nrgastro.2016.200

Djalilova, D. M., Schulz, P. S., Berger, A. M., Case, A. J., Kupzyk, K. A., & Ross, A. C. (2019). Impact of yoga on inflammatory biomarkers: A systematic review. *Biological Research for Nursing, 21*(2), 198–209.

Domingues, R. B. (2018). Modern postural yoga as a mental health promoting tool: A systematic review. *Complementary Therapies in Clinical Practice, 31*, 248–255.

Ekkekakis, P., Parfitt, G., & Petruzzello, S. J. (2011). The pleasure and displeasure people feel when they exercise at different intensities decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Medicine, 41*(8), 641–671. https://doi.org/10.2165/11590680-000000000-00000

Elenkov, I. J., & Chrousos, G. P. (1999). Stress hormones, Th1/Th2 patterns, pro/anti-inflammatory cytokines and susceptibility to disease. *Trends in Endocrinology & Metabolism, 10*(9), 359–368.

Falkenberg, R., Eising, C., & Peters, M. (2018). Yoga and immune system functioning: A systematic review of randomized controlled trials. *Journal of Behavioral Medicine, 41*(4), 467–482.

Foster, J. A., Rinaman, L., & Cryan, J. F. (2017). Stress & the gut-brain axis: Regulation by the microbiome. *Neurobiology of Stress, 7*, 124–136. https://doi.org/10.1016/j.ynstr.2017.03.001

Fresco, D. M., Segal, Z. V., Buis, T., & Kennedy, S. (2007). Relationship of posttreatment decentering and cognitive reactivity to relapse in major depression. *Journal of Consulting and Clinical Psychology, 75*(3), 447–455. https://doi.org/10.1037/0022-006X.75.3.447

Gaiswinkler, L., & Unterrainer, H. (2016). The relationship between yoga involvement, mindfulness and psychological well-being. *Complementary Therapies in Medicine, 26*, 123–127.

Gard, T., Noggle, J. J., Park, C. L., Vago, D. R., & Wilson, A. (2014). Potential self-regulatory mechanisms of yoga for psychological health. *Frontiers in Human Neuroscience*, *8*, 770.

Gothe, N. P., & McAuley, E. (2015). Yoga and cognition: A meta-analysis of chronic and acute effects. *Psychosomatic Medicine, 77*(7), 784–797.

Gothe, N. P., Keswani, R. K., & McAuley, E. (2016). Yoga practice improves executive function by attenuating stress levels. *Biological Psychology, 121*, 109–116.

Gothe, N. P., Khan, I., Hayes, J., Erlenbach, E., & Damoiseaux, J. S. (2019). Yoga effects on brain health: A systematic review of the current literature. *Brain Plasticity, 5*(1), 105–122.

Green, E., Huynh, A., Broussard, L., Zunker, B., Matthews, J., Hilton, C. L., & Aranha, K. (2019). Systematic review of yoga and balance: Effect on sdults with neuromuscular impairment. *Am Journal of Occupational Therapy*, *73*(1), 7301205150p7301205151–7301205150p7301205111. https://doi.org/10.5014/ajot.2019.028944

Hagins, M., Selfe, T., & Innes, K. (2013). Effectiveness of yoga for hypertension: Systematic review and meta-analysis. *Evidence-Based Complementary and Alternative Medicine*. https://doi.org/10.1155/2013/649836

Hamilton, J. P., Furman, D. J., Chang, C., Thomason, M. E., Dennis, E., & Gotlib, I. H. (2011). Default-mode and task-positive network activity in major depressive disorder: Implications for adaptive and maladaptive rumination. *Biological Psychiatry, 70*(4), 327–333. https://doi.org/10.1016/j.biopsych.2011.02.003

Hendriks, T., de Jong, J., & Cramer, H. (2017). The effects of yoga on positive mental health among healthy adults: A systematic review and meta-analysis. *The Journal of Alternative and Complementary Medicine, 23*(7), 505–517.

Ingram, R. E. (1990). Self-focused attention in clinical disorders: Review and a conceptual model. *Psychological Bulletin, 107*(2), 156–176. https://doi.org/10.1037/0033-2909.107.2.156

Innes, K. E., Bourguignon, C., & Taylor, A. G. (2005). Risk indices associated with the insulin resistance syndrome, cardiovascular disease, and possible protection with yoga: A systematic review. *The Journal of the American Board of Family Practice, 18*(6), 491–519.

John, O. P., & Gross, J. J. (2004). Healthy and unhealthy emotion regulation: Personality processes, individual differences, and life span development. *Journal of Personality, 72*(6), 1301–1334.

Krieger, T., Altenstein, D., Baettig, I., Doerig, N., & Holtforth, M. G. (2013). Self-compassion in depression: Associations with depressive symptoms, rumination, and avoidance in depressed outpatients. *Behavior Therapy, 44*(3), 501–513. https://doi.org/10.1016/j.beth.2013.04.004

Lee, H. H., Emerson, J. A., & Williams, D. M. (2016). The exercise-affect-adherence pathway: An evolutionary perspective. *Frontiers in Psychology, 7*, 1285. https://doi.org/10.3389/fpsyg.2016.01285

Lemay, L. G., Vander, A. J., & Kluger, M. J. (1990). The effects of psychological stress on plasma interleukin-6 activity in rats. *Physiology & Behavior, 47*(5), 957–961.

Liguori. (2013). *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins.

Linehan, M. M. (1993). *Skills training manual for treating borderline personality disorder*. Guilford Press.

Linehan, M. M. (2018). *Cognitive-behavioral treatment of borderline personality disorder*. Guilford Publications.

Luu, K., & Hall, P. A. (2016). Hatha yoga and executive function: A systematic review. *The Journal of Alternative and Complementary Medicine, 22*(2), 125–133.

MacBeth, A., & Gumley, A. (2012). Exploring compassion: A meta-analysis of the association between self-compassion and psychopathology. *Clinical Psychology Review, 32*(6), 545–552. https://doi.org/10.1016/j.cpr.2012.06.003

Masi, G., & Brovedani, P. (2011). The hippocampus, neurotrophic factors and depression: Possible implications for the pharmacotherapy of depression. *CNS Drugs, 25*(11), 913–931. https://doi.org/10.2165/11595900-000000000-00000

McCall, M. C. (2013). How might yoga work? An overview of potential underlying mechanisms. *Yoga and Physical Therapy*, *3*(1). https://doi.org/10.4172/2157-7595.1000130

Meister, K., & Juckel, G. (2018). A systematic review of mechanisms of change in body-oriented yoga in major depressive disorders. *Pharmacopsychiatry, 51*(03), 73–81.

Miller, G. E., Cohen, S., & Ritchey, A. K. (2002). Chronic psychological stress and the regulation of pro-inflammatory cytokines: A glucocorticoid-resistance model. *Health Psychology, 21*(6), 531.

Mocanu, E., Mohr, C., Pouyan, N., Thuillard, S., & Dan-Glauser, E. S. (2018). Reasons, years and frequency of yoga practice: Effect on emotion response reactivity. *Frontiers in Human Neuroscience, 12*, 264.

Mor, N., & Winquist, J. (2002). Self-focused attention and negative affect: A meta-analysis. *Psychological Bulletin, 128*(4), 638–662. https://doi.org/10.1037/0033-2909.128.4.638

Neff, K. D., Rude, S. S., & Kirkpatrick, K. L. (2007). An examination of self-compassion in relation to positive psychological functioning and personality traits. *Journal of Research in Personality, 41*(4), 908–916. https://doi.org/10.1016/j.jrp.2006.08.002

Neukirch, N., Reid, S., & Shires, A. (2019). Yoga for PTSD and the role of interoceptive awareness: A preliminary mixed-methods case series study. *European Journal of Trauma & Dissociation, 3*(1), 7–15. https://doi.org/10.1016/j.ejtd.2018.10.003

Nick, N., Petramfar, P., Ghodsbin, F., Keshavarzi, S., & Jahanbin, I. (2016). The effect of yoga on balance and fear of falling in older adults. *PM&R: The Journal of Injury, Function and Rehabilitation, 8*(2), 145–151.

Nolen-Hoeksema, S., Wisco, B. E., & Lyubomirsky, S. (2008). Rethinking rumination. *Perspectives on Psychological Science, 3*(5), 400–424.

Pascoe, M. C., & Bauer, I. E. (2015). A systematic review of randomised control trials on the effects of yoga on stress measures and mood. *Journal of Psychiatric Research, 68*, 270–282. https://doi.org/10.1016/j.jpsychires.2015.07.013

Pascoe, M., & Crewther, S. (2016). A systematic review of randomised control trials examining the effects of mindfulness on stress and anxious symptomatology. In *Anxiety Disorders* (Vol. 1). SMGroup.

Pascoe, M. C., Crewther, S. G., Carey, L. M., & Crewther, D. P. (2011). Inflammation and depression: Why poststroke depression may be the norm and not the exception. *International Journal of Stroke, 6*(2), 128–135. https://doi.org/10.1111/j.1747-4949.2010.00565.x

Pascoe, M. C., Thompson, D. R., Jenkins, Z. M., & Ski, C. F. (2017a). Mindfulness mediates the physiological markers of stress: Systematic review and meta-analysis. *Journal of Psychiatric Research, 95*, 156–178. https://doi.org/10.1016/j.jpsychires.2017.08.004

Pascoe, M. C., Thompson, D. R., & Ski, C. F. (2017b). Yoga, mindfulness-based stress reduction and stress-related physiological measures: A meta-analysis. *Psychoneuroendocrinology, 86*, 152–168. https://doi.org/10.1016/j.psyneuen.2017.08.008

Paulus, M. P., & Stein, M. B. (2010). Interoception in anxiety and depression. *Brain Structure and Function, 214*(5), 451–463. https://doi.org/10.1007/s00429-010-0258-9

Perna, G., Riva, A., Defillo, A., Sangiorgio, E., Nobile, M., & Caldirola, D. (2020). Heart rate variability: Can it serve as a marker of mental health resilience? *Journal of Affective Disorders, 263*, 754–761.

Petrovsky, N. (2001). Towards a unified model of neuroendocrine–immune interaction. *Immunology and Cell Biology, 79*(4), 350–357.

Pflueger, L. W. (2011). Yoga body: The origins of modern posture practice. *Religious Studies Review, 37*(3), 235–235. https://doi.org/10.1111/J.1748-0922.2011.01543_4.X

Posadzki, P., Kuzdzal, A., Lee, M. S., & Ernst, E. (2015). Yoga for heart rate variability: A systematic review and meta-analysis of randomized clinical trials. *Applied Psychophysiology and Biofeedback, 40*(3), 239–249.

Reichlin, S. (1993). Neuroendocrine-immune interactions. *New England Journal of Medicine, 329*(17), 1246–1253.

Reimers, A. K., Knapp, G., & Reimers, C.-D. (2018). Effects of exercise on the resting heart rate: A systematic review and meta-analysis of interventional studies. *Journal of Clinical Medicine, 7*(12), 503.

Ruzek, M. C., Miller, A. H., Opal, S. M., Pearce, B. D., & Biron, C. A. (1997). Characterization of early cytokine responses and an interleukin (IL)-6–dependent pathway of endogenous glucocorticoid induction during murine cytomegalovirus infection. *Journal of Experimental Medicine, 185*(7), 1185–1192.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68–78.

Salim, S., Chugh, G., & Asghar, M. (2012). Inflammation in anxiety. *Advances in Protein Chemistry and Structural Biology, 88*, 1–25. https://doi.org/10.1016/B978-0-12-398314-5.00001-5

Schmalzl, L., Powers, C., & Henje Blom, E. (2015). Neurophysiological and neurocognitive mechanisms underlying the effects of yoga-based practices: Towards a comprehensive theoretical framework. *Frontiers in Human Neuroscience, 9*, 235.

Shaffer, F., & Ginsberg, J. (2017). An overview of heart rate variability metrics and norms. *Frontiers in Public Health, 5*, 258.

Sheppard, L. C., & Teasdale, J. D. (2000). Dysfunctional thinking in major depressive disorder: A deficit in metacognitive monitoring? *Journal of Abnormal Psychology, 109*(4), 768–776. https://doi.org/10.1037//0021-843x.109.4.768

Smith, J., Greer, T., Sheets, T., & Watson, S. (2011). Is there more to yoga than exercise? *Alternative Therapies in Health and Medicine*, *17* (3), 22–29.

Staufenbiel, S. M., Penninx, B. W., Spijker, A. T., Elzinga, B. M., & van Rossum, E. F. (2013). Hair cortisol, stress exposure, and mental health in humans: A systematic review. *Psychoneuroendocrinology, 38*(8), 1220–1235. https://doi.org/10.1016/j.psyneuen.2012.11.015

Steensberg, A., Fischer, C. P., Keller, C., Møller, K., & Pedersen, B. K. (2003). IL-6 enhances plasma IL-1ra, IL-10, and cortisol in humans. *American Journal of Physiology-Endocrinology and Metabolism, 285*(2), E433–E437.

Task Force of the European Society of Cardiology (1996). Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *European Heart Journal*, *17*(3), 354–381.

Teasdale, J. D., Moore, R. G., Hayhurst, H., Pope, M., Williams, S., & Segal, Z. V. (2002). Metacognitive awareness and prevention of relapse in depression: Empirical evidence. *Journal of Consulting and Clinical Psychology, 70*(2), 275–287. https://doi.org/10.1037//0022-006x.70.2.275

Thayer, J. F., Hansen, A. L., & Johnsen, B. H. (2010). The non-invasive assessment of autonomic influences on the heart using impedance cardiography and heart rate variability. In A. Steptoe (Ed.), *Handbook of behavioral medicine* (pp. 723–740). Springer

Travis, F., & Pearson, C. (2000). Pure consciousness: Distinct phenomenological and physiological correlates of "consciousness itself." *International Journal of Neuroscience, 100*(1–4), 77–89. https://doi.org/10.3109/00207450008999678

Trew, J. L. (2011). Exploring the roles of approach and avoidance in depression: An integrative model. *Clinical Psychology Review, 31*(7), 1156–1168. https://doi.org/10.1016/j.cpr.2011.07.007

Turnbull, A. V., & Rivier, C. L. (1999). Regulation of the hypothalamic-pituitary-adrenal axis by cytokines: Actions and mechanisms of action. *Physiological Reviews, 79*(1), 1–71.

Tyagi, A., & Cohen, M. (2014). Yoga and hypertension: A systematic review. *Alternative Therapies in Health and Medicine*, *20*(2),32–59.

Tyagi, A., & Cohen, M. (2016). Yoga and heart rate variability: A comprehensive review of the literature. *International Journal of Yoga, 9*(2), 97–113.

Valles-Colomer, M., Falony, G., Darzi, Y., Tigchelaar, E. F., Wang, J., Tito, R. Y., Schiweck, C., Kurilshikov, A., Joossens, M., Wijmenga, C., Claes, S., Van Oudenhove, L., Zhernakova, A., Vieira-Silva, S., & Raes, J. (2019). The neuroactive potential of the human gut microbiota in quality of life and depression. *Nature Microbiology, 4*(4), 623–632. https://doi.org/10.1038/s41564-018-0337-x

Villemure, C., Čeko, M., Cotton, V. A., & Bushnell, M. C. (2014). Insular cortex mediates increased pain tolerance in yoga practitioners. *Cerebral Cortex, 24*(10), 2732–2740.

World Health Organization. (2004). Global strategy on diet, physical activity and health. https://www.who.int/dietphysicalactivity/strategy/eb11344/strategy_english_web.pdf. Accessed July 2020

Wong, M. Y. C., Chung, P.-K., & Leung, K.-M. (2021). The relationship between physical activity and self-compassion: A systematic review and meta-analysis. *Mindfulness, 12*(3), 547–563.

Wu, Y., Johnson, B. T., Acabchuk, R. L., Chen, S., Lewis, H. K., Livingston, J., Park, C.L. & Pescatello, L. S. (2019). Yoga as antihypertensive lifestyle therapy: A systematic review and meta-analysis. *Mayo Clinic Proceedings, 94*(3), 432–446.

Ye, X., Chen, Z., Shen, Z., Chen, G., & Xu, X. (2020). Yoga for treating rheumatoid arthritis: A systematic review and meta-analysis. *Frontiers in Medicine, 7*, 876.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*(5), 459–482. https://doi.org/10.1002/cne.920180503

Zhang, X., Zong, B., Zhao, W., & Li, L. (2021). Effects of mind–body exercise on brain structure and function: A systematic review on MRI studies. *Brain Sciences, 11*(2), 205.

Zheng, P., Yang, J., Li, Y. F., Wu, J., Liang, W. W., Yin, B. M., Tan, X. M., Huang, Y., Chai, T. J., Zhang, H. P., Duan, J. J., Zhou, J. J., Sun, Z. L., Chen, X., Marwari, S., Lai, J. B., Huang, T. T., Du, Y. L., Zhang, P. F., Perry, S. W., Wong, M. L., Licinio, J., Hu, S. H., Xie, P., & Wang, G. (2020). Gut microbial signatures can discriminate unipolar from bipolar depression. *Advanced Science*. 1902862. https://doi.org/10.1002/advs.201902862

Zhou, Y., Yu, C., Zheng, H., Liu, Y., Song, M., Qin, W., Li, K., & Jiang, T. (2010). Increased neural resources recruitment in the intrinsic organization in major depression. *Journal of Affective Disorders, 121*(3), 220–230. https://doi.org/10.1016/j.jad.2009.05.029

Zou, L., Sasaki, J. E., Wei, G.-X., Huang, T., Yeung, A. S., Neto, O. B., Chen, K. W., & Hui, S.S.-C. (2018). Effects of mind–body exercises (Tai Chi/Yoga) on heart rate variability parameters and perceived stress: A systematic review with meta-analysis of randomized controlled trials. *Journal of Clinical Medicine, 7*(11), 404.