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REVIEW

The Influence of Meditative Interventions on Immune Functioning: A Meta-Analysis

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Abstract

Objectives Meditative practices have grown in popularity, but the results of meditative intervention studies on immune functioning have been inconsistent. Although prior reviews have been conducted, the present meta-analysis provides a more comprehensive and updated examination.

Methods One hundred and five eligible studies, including mindfulness-based, movement-based, and meditation-focused, meditative interventions with biological markers of immune functioning were analyzed. The current work (a) incorporates a greater number of studies available for review, (b) examines the overall magnitude of the effect of meditative interventions on immune functioning, (c) examines the effects of health on some individual level biomarkers (i.e., NF-κB, IgA, and IL-6), (d) compares different types of meditative interventions and (e) reveals the effect of various theoretical (e.g., the health of participants) and methodological (e.g., delivery of interventions) moderators.

Results The meta-analysis indicated that meditative interventions, including formal meditation, mindfulness-based, and movement-based, have a small but significant effect on immune functioning ($g = 0.181$, $k = 105$, $p < 0.001$) as compared to controls ($g = -0.001$, $p = 0.982$). Furthermore, the results indicated that the effect of meditative interventions on immune functioning remained robust, regardless of the type of control condition.

Conclusions The present meta-analysis suggests a small and significant effect of meditative interventions on immune functioning and serves to clarify inconsistent results in the literature. Further, it provides insight into both theoretical and methodological moderators for future research. Meditative interventions could be implemented in various formats and modalities, especially among those with physiological and psychological disorders.

Preregistration The present meta-analysis was not preregistered.

Keywords Meditation · Meta-Analysis · Immune · Health · Stress

Until a few decades ago, mind–body practices were considered fringe, and any benefits were readily dismissed, but their potential to improve health by facilitating the mind–body connection has become widely acknowledged by scientists and medical professionals in Western contexts (Brower, 2006; Dossett et al., 2020; Gilbert, 2003). Mind–body practices include a broad category of practices and techniques to influence the bidirectional relationship between the mind and the body (Taylor et al., 2010). Examples include meditation, tai chi, and yoga (Carlson & Bultz, 2008). Several meta-analyses have shown that mind–body practices improve psychological and physiological functioning (Garland et al., 2020; Khoury et al., 2015; Kwok et al., 2016; Younge et al., 2015; Zhang et al., 2017). Moreover, the extant literature examining the influences of meditative practices and interventions has focused on immune functioning as one component of physiological functioning. Immune functioning is critical to psychological and physiological heath. Thus, further understanding the influences of meditative and mind–body practices on

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immune functioning has relevance to a variety of disciplines, including psychology, medicine, and nursing.

Stressors are psychological, physiological, or environmental stimuli that evoke biological responses to maintain homeostasis and increase the probability of survival (de Kloet, 2003). These usually beneficial biological responses to stress, however, result in homeostatic imbalance when people experience chronic stress (Yaribeygi et al., 2017). Chronic stress has been identified as a major precipitator of pathological outcomes. One example of the deleterious consequence of stress on the immune system is chronic systemic inflammation (Cohen et al., 2012). Although inflammation serves as a healthy component of a well-functioning immune system (e.g., combating bacterial infection), *chronic* inflammation elicits a series of adverse downstream effects that can cause irreversible damage to tissues and organs in the body (Mauri & Menon, 2017) and further dysregulate immune response (Powell et al. 2013). Once immune system dysregulation occurs, chronic inflammation and pathological outcomes are further exacerbated (Gouin, 2011). Cancer, heart disease, psoriasis, and depression are just a few examples of disorders precipitated by stress and inflammation (Kiecolt-Glaser et al., 2002). Thus, an important approach for improving or maintaining psychological and physiological health is to mitigate psychological stress and optimize immune functioning.

Meditative practices likely improve a wide variety of health outcomes because they impact psychological and physiological regulation and reactivity to stressors, thereby reducing the likelihood and progression of stress-related pathologies (Creswell & Lindsay, 2014; Hoge et al., 2018). Meditative practices may improve or maintain psychological and physiological health, in large part, through enhanced immune functioning (Bower & Irwin, 2016). Because meditative practices plausibly buffer stress and subsequent declines in immune functioning, populations under chronic stress or with inflammation-related diagnoses should be expected to exhibit the greatest benefit when examining biomarkers of immune functioning. Immune system effectors are maintained within an ideal, specific healthy range. If the population of interest is already within that healthy range, it suggests that the immune system is functioning appropriately. Thus, in some circumstances, researchers may not expect to see statistically significant changes in immune functioning among healthy populations.

Meditative practices enhance one's capacity to affect physiological and psychological functioning through awareness and acceptance of thoughts, feelings, and experiences (Astin et al., 2003). These practices promote mindfulness and offer a multi-faceted approach for improving psychological well-being as well as physical health (Chiesa & Serretti, 2009; Grossman et al., 2007; Hofmann et al., 2010), including immune functioning (Davidson et al., 2003; Jacobs et al., 2011). A great deal of heterogeneity exists in the types of meditative practices that are included in research studies that examine the effects of meditative interventions. Although some components of practice are shared across these interventions, a more nuanced examination is required to understand which practices are effective at improving immunological outcomes. One way to address this heterogeneity is to categorize meditative interventions into descriptive categories (e.g., Sauer-Zavala et al., 2013).

Mindfulness is often defined as the awareness and non-judgement of the present moment (Kabat-Zinn, 2015). Typically, mindfulness-based interventions (MBIs) are manualized and include structured educational components and activities that teach participants mindfulness skills over eight weeks. Mindfulness-Based Stress Reduction (MBSR) was formally developed by Jon Kabat-Zinn in 1979 (Kabat-Zinn, 2003), and it is the most widely studied MBI. It was developed to improve physical health symptoms (e.g., chronic pain) by managing stress. A prototypical MBI (e.g., MBSR) is delivered by a trained instructor in an 8-week group format, with weekly sessions ranging from 60 to 150 min in duration, a 1-day retreat ranging from 2 to 8 hr, daily at-home meditation and gentle Hatha yoga practices, and informal practices such as reading a mindfulness handbook and practicing mindfulness while engaging in daily routines (e.g., washing dishes).

Mindful physical movement is the primary component of meditative movement interventions (MMI). Although MBIs may include some gentle movement, physical movement or exercise is the primary focus of MMIs. The type of movement is also more varied among MMIs, primarily teaching participants tai chi, qigong, or yoga, with only brief periods of formal meditation (e.g., 2 to 10 min). MMI sessions typically last between 30 to 60 min and may occur anywhere from one to six times a week. Although each of these MMI practices can be executed with varying degrees of intensity (Larkey et al., 2009), MMIs typically require greater physical exertion than that of MBIs. Further, MMIs tend to be longer in duration than MBIs (e.g., median = 12 weeks; Kelley & Kelley, 2015).

Meditation is a general umbrella term for an extremely complex and diverse set of practices (Lutz et al., 2008; Nash et al., 2013). Although functionally grouped together, particular types of meditation have been shown to be associated with different neural responses; thus, presumably, each type may have different health-related outcomes (Fox et al., 2014, 2016). Meditation-focused interventions can include other components (e.g., breathing exercises), but the primary component is formal meditation practice, such as concentration-focused meditation (e.g., breath, mantra) or open-monitoring meditation. For example, during body scan meditation, the participant sits or lies down and directs their attention to

various parts of the body to increase awareness of bodily sensations, such as the breath (Anālayo, 2020). Meditation-focused interventions are, in some cases, shorter in duration and more intensive than other intervention types. For example, some study interventions last only several days (e.g., 2, 3, or 6 days), whereas others can last several weeks (e.g., 6 or 8) or even months (e.g., 3 or 6 months). Participant involvement may be the most intensive for formal meditation retreats because they typically involve participants spending days or weeks in a retreat center. In many cases, meditation retreats require participants to have some prior meditative experience.

Immune biomarkers implicated in inflammatory processes (i.e., inflammatory mediators and cellular transcription) are of particular interest to researchers because inflammation plays a profound role in the development and progression of various diseases. Although inflammation serves as a healthy component of a well-functioning immune system (e.g., combating bacterial infection), chronic inflammation, like chronic stress, elicits a series of adverse downstream effects. Inflammation causes irreversible damage to tissues and organs in the body (Mauri & Menon, 2017) and dysregulates the immune response (Powell, 2012). Chronic inflammation, whether caused by obesity (Park et al., 2010), pollution (Aggarwal et al., 2009), or bacterial and viral infections (De Martel and Franceschi, 2009), has negative health consequences such as increased cancer risk, progression, metastasis, and recurrence (Mundy-Bosse et al., 2011; Pierce et al., 2009; Salgado et al., 2003). In addition, cytokine-related inflammation influencespsychological states (e.g., mood). For example, cytokine-related inflammation modulates serotonin activity (Miura et al., 2008) which, in turn, induces depression-like states (Miller & Raison, 2016). Thus, reductions in stress and inflammation associated with meditative practices should improve both psychological and physiological functioning.

The length of time since two of the prior meta-analyses, the increased number of studies available since they were conducted, the growing use of meditative interventions in clinical and non-clinical populations as well as the inconsistent pattern of findings among the empirical studies and the previous reviews, suggest that an extensive meta-analysis is warranted. Further, the scope of the current meta-analyses allowed for the examination of moderators that have not been examined in prior reviews, including the duration and type of intervention. Immune functioning assessed in the studies eligible for the meta-analytic review may be categorized as (1) inflammatory mediators (e.g., anti-inflammatory and proinflammatory cytokines), (2) leukocytes (e.g., lymphocyte subsets), (3) cellular aging of immune cells (e.g., telomere length), (4) immunoglobulins (e.g., IgG), and (5) NF-κB (cellular transcription); Black & Slavich, 2016; Bower & Irwin, 2016). These classifications have been used to functionally differentiate between immune effectors (e.g., Bower & Irwin, 2016). See Supplementary Table S1 for a brief overview of biomarkers for immune functioning included in the current review. Meditative interventions were divided into three categories: (a) primarily mindfulness-based (e.g., MBSR), (b) primarily meditative movement (e.g., tai chi), and (c) primarily meditation-focused (e.g., meditation retreat).

The current meta-analysis aimed to understand whether meditative interventions are associated with improvements in immune functioning and whether intervention features moderate the magnitude of the effect size for meditative interventions (e.g., type of delivery, duration of intervention) and by categories of immune functioning (e.g., inflammatory mediators, immune cell aging). Given the suggestive findings of the previous narrative and meta-analytic reviews, we predicted that, overall, compared to control conditions, the meditative interventions would reveal a positive effect size suggesting immune-functioning improvement from pre- to post-test intervention (i.e., larger effect size). Based on prior research (Chin et al., 2019) and theory (Creswell, 2017) suggesting that more intensive interventions are associated with greater benefits, we predicted that meditative interventions administered for longer time periods would be associated with greater positive effects on immune functioning. We organized the immune biomarkers into established immune categories (Black & Slavich, 2016) and coded the studies by the type of meditative intervention (i.e., MMI, MBI, MED), sample (i.e., Healthy vs. Clinical populations), and whether the delivery was provided via a live, group format, or a self-paced individual format (i.e., synchronous vs. asynchronous). Also, we coded whether studies had control groups and, if so, what type of control group was adopted (active vs. waitlist or treatment-as-usual). Our research questions asked whether intervention features, such as the type of meditative intervention, sample, and delivery, moderated the magnitudes of the immune change (pre- to post-test) effect sizes for meditative interventions of the effect of meditative interventions on immune functioning. Additionally, we sought to understand which categories of immune functioning were associated with positive effect sizes for the meditative interventions. Importantly, our meta-analytic approach allowed us to examine the influences of these moderators on the effect of the meditative interventions on immune functioning—comparative examinations rarely invoked by empirical studies. Finally, when the findings suggested that further investigation of the pattern of effects was warranted, exploratory analyses were conducted.

Method

Search Strategy and Study Selection

This meta-analysis followed methods proposed in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement (PRISMA; Hutton et al., 2015). We searched CINAHL, Medline, PubMed, and PsycINFO for papers through December 2020; subsequently, the literature search was updated to the end of January 2021. Using "AND" each of the following terms mindful*, "mindfulness-based stress reduction," MBSR, meditat*, qigong, tai chi, yoga was searched with all of the following terms cytokine* OR antibod* OR immunoglob* OR inflam* OR lymphocyt* OR leukocyt* OR nfkb OR NF-κB OR telomer* OR immun* OR biomarker OR IL-6 or CD4 or IGA or CRP or IFN or TNF or "NK Cells." The searches were limited to the abstract. The reference sections of several relevant review articles (e.g., Schutte et al., 2020) and all eligible articles were also examined to identify additional articles. Authors with at least two eligible reports were also contacted for other eligible studies. See Fig. 1 for the PRISMA flowchart.

Studies were included if they: (a) explicitly stated that formal meditation was a component of the intervention, (b) included at least one biomarker of an immune functioning, and (c) if they had sufficient statistics to calculate effect sizes, using Comprehensive Meta-Analysis (CMA; Borenstein et al., 2005). If data were missing, the corresponding author of the article was contacted with a request for additional descriptive data (e.g., means, standard deviations, etc.). Studies were eligible regardless of whether they included a control group; for studies with two measurement periods (i.e., pre and post), meta-analytic procedures do not preclude those without control groups. To avoid publication bias, unpublished studies were eligible. There were no restrictions regarding sample size or sample type. If an article was in a language other than English and could be translated, it was included. Quasi-experimental studies that compared long-term experienced meditators to non-meditators were excluded. A total of 104 reports were eligible.

Data Coding and Extraction

Table 1 reports the first author, date, and country in which the study was conducted, as well as details about the samples, methodologies, measures, and study-level effect sizes. The meditative interventions were coded into three categories (1) MBIs designed to develop mindfulness (e.g., MBSR); (2) meditative movement interventions with at least some period of formal meditation (MMIs, e.g., qi gong, tai chi, and yoga); and (3) primarily meditation-focused

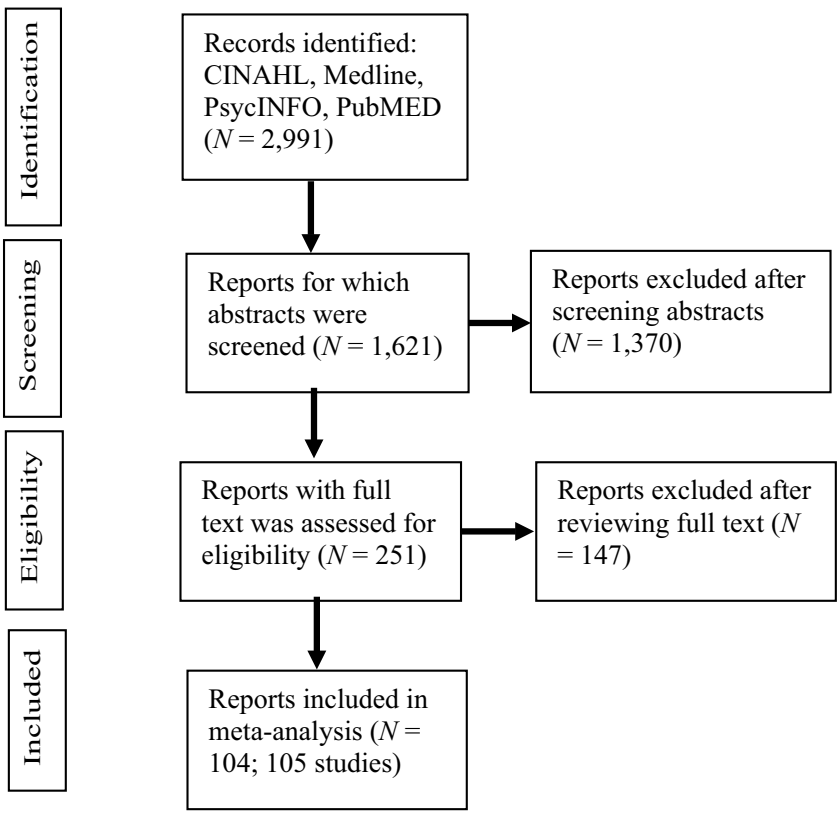

Fig. 1 PRISMA flowchart of search strategies and inclusion criteria

Table 1 Demographics and study characteristics ($N = 104$ reports; $k = 105$ studies)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Agnihotri et al. (2014) India	Patients with mild to moderate asthma	Pretest = 276 Post-test = 241	*M* age = 37.86 % Female = 43	MMI. 6-mo standard medical treatment plus yoga treatment with breathing and meditation, 30 min. sess., five times per week with teacher	WL/TAU	Leukocytes: Total leukocytes count, lymphocytes, polymorphs, eosinophils, monocytes	Interv: $g = 0.78$ Cont: $g = 0.84$
Andrés-Rodríguez et al. (2019) Spain	Persons with fibromyalgia	Pretest = 66 Posttest = 56	*M* age = 53.37 % Female = 100	MBI. 8 wk. MBSR. 120 min. sess., optional 6 h. retreat, 45 min daily practice	WL/TAU	Inflammatory mediators: CRP, IL-6, IL-10	Interv: $g = 0.07$ Cont: $g = -0.02$
Arefnasab et al. (2016) Iran	Veterans with pulmonary injury from previous exposure to mustard gas	Pretest = 40 Posttest = 40	*M* age = 49.40 % Caucasian = 100 % Female = 0	MBI. 8 wk. MBSR. 120 min. sess., no retreat, daily practice	WL/TAU	Inflammatory mediators: IL-17 Leukocytes: CD4, CD8, NK Cell	Interv: $g = 0.01$ Cont: $g = 0.13$
Black et al. (2014) USA	Lonely older adults (> 60 years)	Pretest = 26 Posttest = 22	*M* age = 67.1 % Caucasian = 65.0 % Female = 80.8 *M* Ed. = 16.9	MMI. 12-wk. Tai Chi Chuan 120 min. sess., moderate physical activity, deep breathing, and meditation	6 wk. Sleep Hygiene and Education program. 120 min. sess., daily practice	Cellular transcription: NF-κB	Interv: $g = 0.66$ Cont: $g = -0.27$
Black et al. (2015) USA	Older adults (> 55 years) with active sleep disturbance	Pretest = 49 Posttest = 49	*M* age = 66.3 % Caucasian = 83.7 % Female = 67.3 *M* Ed. = 16.6 % Marital = 51.0	MBI. 6 wk. Mindful Awareness Practice. 120 min. sess., daily practice	6 wk. Sleep Hygiene and Education program. 120 min. sess., daily practice	Cellular transcription: NF-κB	Interv: $g = 1.16$ Cont: $g = 1.12$
Bower et al.[a] (2015) USA	Persons diagnosed with stage I, II, or III breast cancer under the age of 50	Pretest = 65 Posttest = 52	*M* age = 46.82 % Caucasian = 76 % Female = 100 % College = 82.93 % Marital = 64.56	MBI. 6 wk. Mindful Awareness Practice. 120 min. sess., Daily practice	WL/TAU	Inflammatory mediators: CRP, IL-6, TNF-α Cellular transcription: NF-κB	Interv: $g = 0.19$ Cont: $g = -0.02$
Buijze et al. (2019) The Netherlands	Persons diagnosed with moderate axial spondylarthritis	Pretest = 24 Posttest = 19	*M* age = 35.00 % Female = 37.5	MED. 8wk. training program with breathing exercises, gradual cold exposure, and meditation. Daily practice	WL/TAU	Inflammatory mediators: CRP	Interv: $g = 0.58$ Cont: $g = 0.37$
Cahn et al. (2017) USA	Healthy adults with yoga and meditation experience	Pretest = 38 Posttest = 33	*M* age = 34.28 % Female = 50	MMI. 3-mo residential yoga and meditation retreat 2 h. of sitting meditation, 1–2 h. of yoga, and 1-h of chanting per day	None	Inflammatory mediators: IL-1β, IL-6, IL-8, IL-10, IL-12, TNF-α, IFN-γ	Interv: $g = -0.20$
Carlson et al. (2007) Canada	Persons with breast (N = 49) or prostate (N = 10) cancer	Pretest = 59 Posttest = 51 6-mo = 47 12-mo = 41	*M* age = 54.52 % Female = 83 *M* Ed. = 14.71 % Marital = 69.5	MBI. 8 wk. MBSR 90 min. sess., 3 h. retreat, daily practice with audio recordings	None	Leukocytes: Total Lymphocytes, B Cells, Eosinophils, Monocytes, Neutrophils, CD3, CD4, CD8, CD19, CD56 Inflammatory mediators: IFN-γ, IL-4, IL-10, TNF-α	Interv: $g = 0.00$

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Carlson et al. (2015) Canada	Breast cancer survivors	Pretest = 128 Posttest = 92	*M* age = 54.60 % Female = 100 % Marital = 75	MBI. 8 wk. Mindfulness-Based Cancer Recovery (MBCR), 90 min. sess., 6 h. retreat, CD guided at home practice	1-Day Stress Management Seminar	Cellular Aging: Telomere length	Interv: *g* = -0.07 Cont: *g* = -0.28
Chacko et al. (2016) USA	Patients who had undergone bariatric surgery	Pretest = 18 Posttest = 18	*M* age = 53.95 % Caucasian = 72.5 % Female = 84 % College = 83.33	MBI. 10 wk. Mindfulness-Based Intervention to prevent weight regain after bariatric surgery. 90 min sess., 4 h. retreat, and six days of audio-guided exercises at home	1-h individualized counseling session with dietician about efforts in weight management	Inflammatory Mediators: CRP, IL-6, TNF-α	Interv: *g* = 0.25 Cont: *g* = -0.10
Chen et al. (2016) China	Healthy students	Pretest = 30 Posttest = 30	% Female = 100	MMI. 8 wk. Hatha yoga with meditation. 60 min. sess., twice per week	WL/TAU	Inflammatory mediators: IL-8, MCP-1, TNF-α	Interv: *g* = -0.09 Cont: *g* = 0.29
Cheung et al. (2019) China	Women survivors of intimate partner violence	Pretest = 247 Post-test = 223	*M* age = 41.75 % Female = 100 % Marital = 93.0	MMI. 22 wk. Qigong group training. Week 1–6: 2 h. biweekly sessions; weeks 7–22: 1 h. weekly sessions, 30 min. daily home practice	Optional monthly health education sessions	Inflammatory mediators: TNF-α, IL-6 Cellular Aging: Telomerase activity	Interv: *g* = 0.07 Cont: *g* = -0.01
Conklin et al. (2018) USA	Healthy participants	Pretest = 62 Posttest = 53	*M* age = 50.74 % Female = 59.7 % College = 86.6	MED. 1-mo residential Insight meditation (vipassana) silent retreat. 10-h/day of meditation	Comparison group of meditators with previous two 5–10-day retreat experiences	Cellular Aging: Telomere length, telomerase activity	Interv: *g* = 0.12 Cont: *g* = -0.04
Creswell et al. (2009) USA	Persons with HIV/AIDS	Pretest = 67 Posttest = 39	*M* age = 40.63 % Caucasian = 21 % Female = 10	MBI. 8 wk. MBSR. 120 min. sess., 6 h. retreat, daily audio-guided exercises provided	One-day stress-education MBSR class	Leukocytes: CD4	Interv: *g* = 0.03 Cont: *g* = -0.64
Creswell et al. (2012) USA	Healthy older adults (> 55 years)	Pretest = 40 Posttest = 34	*M* age = 64.99 % Caucasian = 64 % Female = 80 %Graduate = 56 %College = 41 %High school = 3	MBI. 8 wk. MBSR. 120 min. sess., 7 h. retreat, 30 min. daily practice	WL/TAU	Inflammatory mediators: IL-6, CRP	Interv: *g* = 0.06 Cont: *g* = 0.09
Creswell et al. (2016) USA*	Stressed and job-seeking unemployed adults	Pretest = 35 Posttest = 34	*M* age = 39.43 % Caucasian = 65.7 % Female = 42.86 % Grad Degree = 20.0	MED. 3-day intensive mindfulness meditation training	3-day relaxation residential retreat	Inflammatory mediators: IL-6	Interv: *g* = 0.30 Cont: *g* = -0.18
Daubenmeir et al. (2012) USA	Overweight/Obese women	Pretest = 47 Posttest = 37	% Caucasian = 62 % Female = 100	MBI. 9 sessions over 4 months of MBSR and MB-Eat combination. 150 min. sess., 7 h. retreat, 30 min. formal mindfulness and mindful eating daily	WL/TAU	Cellular Aging: Telomerase activity	Interv: *g* = 0.79 Cont: *g* = 0.37

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Dunne et al. (2019) Ireland*	Emergency medical department interdisciplinary team at risk of burnout	Pretest = 47 Posttest = 42	None	MED. 7 wk. Attention-based training with mantra meditation. 4, 4 h. sessions with 20 min. twice daily practice	WL/TAU	Inflammatory mediators: IL-6, TNF-α	Interv: $g = 0.03$ Cont: $g = -0.09$
Duraimani et al. (2015) USA	Persons with hypertension	Pretest = 48 Posttest = 48	*M* age = 58.05 % Caucasian = 0 % African American = 100 % Female = 54.2	MED. 16 wk. Transcendental meditation and health education program. 20-min meditation session twice/day. Total intervention time was 24 h	16 wk. Health education program	Cellular Aging: Telomere length	Interv: $g = 0.10$ Cont: $g = 0.04$
Elsenbruch et al. (2005) Germany	Persons in remission with ulcerative colitis	Pretest = 30 Posttest = 30	*M* age = 42.65 % Female = 66	MBI. 10 wk. Mind- Body Intervention Program (Modified MBSR). Included stress management, moderate exercise, Mediterranean diet, cognitive behavioral techniques, and self-care strategies. 6 h. sess. once a week	WL/TAU	Leukocytes: Granulocytes, Lymphocytes, Monocytes, Total Leukocytes	Interv: $g = 0.16$ Cont: $g = 0.08$
Epel et al. (2016) USA[b]	Healthy women aged 30–60	Pretest = 64 Posttest = 63 1-mo = 60 10-mo = 45	*M* age = 48.35 % Caucasian = 76.2 % Female = 100 %College = 66.7 % Marital = 49.2	MED. 6-day meditation and yoga retreat at vacation resort. Up to 12 h of meditation practice, 9 h of yoga, several contemplative lectures and self-reflection exercises over course of intervention	6-day relaxing vacation at resort	Leukocytes: Basophils, Eosinophils, Total, Lymphocytes, Monocytes, Neutrophils, Inflammatory mediators: TNF-α Cellular Aging: Telomerase activity	Interv: $g = -0.24$ Cont: $g = -0.15$
Fan et al. (2010) China*	Healthy Chinese undergraduate students	Pretest = 35 Posttest = 35	*M* age = 21.31 % Female = 51.4	MED. 4 wk. Integrative meditation 20 min. nightly sessions	Relaxation training	Immunoglobulins: sIgA	Interv: $g = 1.01$ Cont: $g = 0.75$
Fang et al. (2010) USA[c]	Adults with a variety of diagnoses	Pretest = 24 Posttest = 18	*M* age = 50.82 % Female = 67 %College or > = 86	MBI. 8 wk. MBSR. 150 min. sess., no retreat, 20–30 min. daily practice	None	Leukocytes: NK cell %, NK cell #, NK cell Activity Inflammatory mediators: CRP	Interv: $g = 0.10$
Gallegos et al. (2015) USA	Women with trauma-exposure histories	Pretest = 50 Posttest = 42 4-week = 42	*M* age = 44.09 % Caucasian = 54 % Female = 100	MBI. 8 wk. MBSR. 120 min. sess., 4 h. retreat, daily practice	None	Inflammatory mediators: IL-6, TNF-α, CRP	Interv: $g = 0.12$
Ganesan et al. (2020) India	Patients with rheumatoid arthritis	Pretest = 166 Post-test = 143	*M* age = 41.33 % Female = 92.64	MMI. Yoga therapy. 12 wk. 30 min. sess., 3 times per week	WL/TAU	Inflammatory mediators: IL-1a, IL-6, TNF-a	Interv: $g = 0.52$ Cont: $g = 0.13$

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Gautam et al. (2019) India	Persons with rheumatoid arthritis	Pretest = 72 Posttest = 62	*M* age = 43.9 % Female = 77.8	MMI. 8 wk. yoga-based mind–body intervention. 120 min. sess., 5 times per week with 15 min. of meditation each sess	WL/TAU	Inflammatory mediators: IL-6, IL-17, TNF-α, CRP Cellular Aging: Telomere length, telomerase activity	Interv: *g* = 0.66 Cont: *g* = -0.11
Gerbarg et al. (2015) USA	Persons with inflammatory bowel disease	Pretest = 29 Posttest = 27 20-week = 25	*M* age = 53.76 % Female = 59	MMI. 2-day Breath-Body-Mind Workshop (9 h. total). Included breathing, Qigong movement, and open focus meditation. Optional 90-min weekly follow-up sess. For 6 weeks and monthly for 5 months, 20 min. daily practice with CD recording	2-day Education seminar (9 h. total)	Inflammatory mediators: CRP	Interv: *g* = -0.19 Cont: *g* = -0.06
Gopal et al. (2011) India*	Stressed first year medical students	Pretest = 60 Posttest = 60	*M* age = 39.2 % Caucasian = 82.3 % Female = 100	MMI. 12 wk. integrated yoga practice with meditation. 35 min daily with teacher	WL/TAU	Inflammatory mediators: IL-4, IFN-γ	Interv: *g* = 0.00 Cont: *g* = -0.24
Gonzalez-Garcia et al. (2013) Spain	Persons with HIV	Pretest = 39 Posttest = 39 5-mos = 35	*M* age = 49.4 % Female = 48.7	MBI. 8 wk. MBCT. 150 min sess. weekly, home practice 6 days a wk for 45 min a day	WL/TAU	Leukocytes: CD4	Interv: *g* = 0.30 Cont: *g* = 0.10
Groesbeck et al. (2018) USA	Convenience sample of individuals at a residential conference center	Pretest = 34 Posttest = 34	*M* age = 48.9 % Caucasian = 82.3 % Female = 70.6	MED. 12 h. Weekend Eco Meditation workshop. 6 h. discussion on physiological effects of meditation and 6 h. of group meditation with feedback	None	Immunoglobulins: sIgA	Interv: *g* = 0.23
Hardgrave (2010) USA	Faculty, staff and students from the UNLV community	Pretest = 44 Posttest = 13	M age = 43.57 % Female = 0.08	MED. 3 wk. Cellular Theta Breathing & mindfulness guided meditation. 40 min. practice for 5 consecutive days in a different order	Reading control group	Immunoglobulins: Epstein-Barr Virus Antibody Response	Interv: *g* = 0.04 Cont: *g* = 0.22
Hecht et al. (2018) USA	Persons with HIV	Pretest = 177 Post-test = 152	*M* age = 40.0 % Caucasian = 61.6 % Female = 0.3 % College = 54.7 % Marital = 31.3	MBI. 8 wk. MBSR. 150 min sess., 8 h. retreat, daily home practice	8 wk. Education control group. 90 min. sessions	Leukocytes: CD4 Inflammatory mediators: IL-6, CRP	Interv: *g* = -0.05 Cont: *g* = -0.06
Heckenberg et al. (2019) Australia*	Direct-care workers	Pretest = 22 Posttest = 22	*M* age = 43.2 % Female = 85.7	MBI. Asynchronous. 8 wk. Online MBSR. 30 min guided sess. For 6 days/wk	None	Immunoglobulins: sIgA	Interv: *g* = 0.44
Hidderley and Holt (2004) UK	Women with early-stage breast cancer	Pretest = 31 Posttest = 31	% Female = 100	MED. 8 wk. Autogenic mediation training. Included meditation, relaxing mental exercises, and easy breathing	WL/TAU	Leukocytes: CD4, CD8, NK Cells, Monocytes, Neutrophils, B cells	Interv: *g* = -0.04 Cont: *g* = 0.15

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Ho et al. (2012) China	Persons with chronic fatigue	Pretest = 64 Posttest = 55 4-mo = 52	*M* age = 42.29 % Female = 79.7 % College = 54.7 % Marital = 31.3	MMI. 5 wk. Group Qigong exercises with meditation. 2 h. sess., twice/wk., followed by 12-wk home qigong practice	WL/TAU	Cellular Aging: Telomerase activity	Interv: *g* = 0.41 Cont: *g* = 0.28
Hoge et al. (2018) USA	Adults with generalized anxiety disorder	Pretest = 70 Posttest = 56	*M* age = 39.2 % Caucasian = 82.3 % Female = 45.7	MBI. 8 wk. MBSR. 120 min. sess., 4-h retreat, 20 min. daily practice	8 wk. Stress Management Education program with one 4-h weekend class, 20 min. daily homework	Inflammatory mediators: IL-6, TNF- α	Interv: *g* = 0.27 Cont: *g* = -0.41
Huberty et al. (2019) USA[d]	Patients with myeloproliferative neoplasm	Pretest = 62 Posttest = 48	*M* age = 56.9 % Female = 45 % Caucasian = 45 % Marital = 41 % High School = 2	MMI. Asynchronous. 12 wk. 60 min. sess, Yoga intervention, home-based online yoga	WL/TAU	Inflammatory mediators: TNF- α	Interv: *g* = 0.84
Hung et al. (2016) Taiwan	Persons at increased risk for CAD	Pretest = 149 Post-test = 139	*M* age = 62.05 % Female = 79.8 % Marital = 72.6 % High School = 24.1	MMI. Qigong 12 wk. 3 times per week 150 min/week no more than 60 min. continuous exercise per session	WL/TAU	Inflammatory mediators: CRP	Interv: *g* = 0.13 Cont: *g* = 0.31
Hur et al. (2014) South Korea	Middle-aged women	Pretest = 46 Posttest = 46	*M* age = 47.20 % Female = 100.0	MMI. 10 mo. Exercise and meditation training. 40 min. exercise, 20 min. meditation, 3 times per wk	WL/TAU	Inflammatory mediators: IL-6, TNF- α	Interv: *g* = 0.78 Cont: *g* = -0.02
Innes et al. (2018) USA	Older adults with subjective cognitive decline	Pretest = 53 Posttest = 45	*M* age = 60.4 % Caucasian = 94.3 % Female = 86.8 % Marital = 64.2 % High school = 81.1	MED. Asynchronous. 12 wk. Kirtan Kriya Meditation. 12-min. daily chanting meditation	12 wk. Music listening program. 12-min daily music listening	Cellular Aging: Telomere length and Telomere activity	Interv: *g* = 0.05 Cont: *g* = -0.01
Irwin and Olmstead (2012) USA	Healthy older adults	Pretest = 112 Posttest = 83	*M* age = 71.0 % Caucasian = 80.7 % Female = 81.4 % Marital = 55.4 *M* education = 16.2 years	MMI. 16-wk. Tai Chi Chuan with moderate physical activity and meditation. 40 min. sess., 3 times per wk	16 wk. Health education program matched for time, attention, and other nonspecific factors	Inflammatory mediators: IL-6, IL-18, CRP	Interv: *g* = 0.02 Cont: *g* = -0.17
Irwin et al. (2014) USA	Breast cancer survivors	Pretest = 90 Posttest = 90	*M* age = 59.8 % Caucasian = 38.5 % Marital = 23.5	MMI. 3 mo. 120 min. sess., Tai Chi Chuan	3 mo. CBT-I standard treatment for the behavioral management of insomnia	Inflammatory mediators: IL-6, CRP, TNF-α	Interv: *g* = 0.22 Cont: *g* = -0.08
Jam et al. (2010) Iran	Persons with HIV	Pretest = 10 Posttest = 6	*M* age = 34.99 % Female = 50	MBI. 8 wk. MBSR. 120 min sess., 6-h retreat, 60 min. daily practice	None	Leukocytes: CD4	Interv: *g* = 0.42

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Janelsins et al. (2011)[d] USA	Breast cancer survivors	Pretest = 21 Posttest = 19	*M* age = 53.47 % Caucasian = 100 % Female = 100 % Marital = 52.6	MMI. 12 wk. Tai Chi Chuan with breathing and meditation. 60 min sess., three times per week	Psychosocial therapy	Inflammatory mediators: IL-2, IL-6, IL-8, IGF-b1, IGF-b3, IFN-γ	Interv: *g* = 0.04 Cont: *g* = 0.01
Keng et al. (2020) China	Healthy individuals	Pretest = 158 Post-test = 137	*M* age = 27.24 % Female = 63.3 % Single = 80.4	MBI. MBSR 8 wk. 1 sess 2.5 h per week. Half day mindfulness retreat. Home daily 30–40 min	Music therapy-based stress reduction	Cellular Aging: Telomere length	Interv: *g* = -0.12 Cont: *g* = -0.08
Lavretsky et al. (2011) USA	Adults with major depression	Pretest = 73 Posttest = 68	*M* age = 69.1 % Female = 64	MMI. Tai Chi Chuan 10 wk., 2-h sess	Health Education classes	Inflammatory mediators: CRP	Interv: *g* = 0.49 Cont: *g* = 0.18
Lavretsky et al. (2013) USA	Caregivers of relatives with dementia	Pretest = 45 Posttest = 39	*M* age = 60.54 % Female = 95 *M* Ed. = 15.69	MED. Asynchronous. 8 wk. Kirtan Kriya Meditation, daily 12-min. chanting meditation	Relaxing music control group, daily 12-min. listening	Cellular Aging: Telomerase activity	Interv: *g* = 0.67 Cont: *g* = -0.15
Lee et al. (2019) South Korea	Persons with hypertension and/or type 2 diabetes	Pretest = 48 Posttest = 35	M age = 68.68 % Female = 50.0	MMI. 8 wk. Brain-education based meditation training. Bi-weekly sess. that included meditation and yoga	Health education class	Inflammatory mediators: IL-1 Cellular transcription: NF-κB	Interv: *g* = 1.66 Cont: *g* = 0.00
Lengacher et al. (2012) USA*	Persons diagnosed with advanced-stage breast cancer, colon, lung, or prostate cancer and their caregivers	Pretest = 52 Posttest = 47	M age = 52.50 % Caucasian = 90.4 % Female = 65.4 % College = 67.3	MBI. 6 wk. modified MBSR. 3 in-person and 3-at home 120 min sess., daily meditation and yoga practice	None	Inflammatory mediators: IL-6	Interv: *g* = 0.94
Lengacher et al. (2013) USA	Persons diagnosed with stage 0-III breast cancer who received a lumpectomy and adjuvant radiation and/or chemotherapy	Pretest = 84 Posttest = 82	M age = 57.99 % Caucasian = 83 % Female = 100 % College = 45.2 % Married = 76.9	MBI. 6 wk. MBSR. 120 min sess., daily meditation and yoga practice	WL/TAU	Leukocytes: Total lymphocytes, CD3, CD4, CD8, NK Cells, B cells, T cells	Interv: *g* = 0.13 Cont: *g* = 0.25
Lengacher et al. (2014) USA	Persons diagnosed with stage 0-III breast cancer who received a lumpectomy and adjuvant radiation and/or chemotherapy	Pretest = 142 Post-test = 134	M age = 55.31 % Caucasian = 71.1 % Female = 100 % College = 60	MBI. 6 wk. MBSR(BC). 120 min sess., 15–45 min. formal and informal mindfulness practice daily	WL/TAU	Cellular Aging: Telomere length and Telomere activity	Interv: *g* = 0.33 Cont: *g* = 0.14

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
MacDonald & Minahan (2018) Australia*	Wheel-chair basketball players during competition period	Pretest = 16 Posttest = 16	M age = 25.9 % Female = 31.3	MBI. Asynchronous. 8 wk. Online mindfulness training through smartphone app. 45 min. guided practice with 5 min. exercises for 5 days/wk	WL/TAU	Immunoglobulins: sIgA	Interv: $g = 0.52$ Cont: $g = 0.25$
Malarkey et al. (2013) USA	Adults with elevated CRP (> 3.0 mg/ml or had or were at risk for cardiovascular disease)	Pretest = 186 Posttest = 170	*M* age = 49.99 % Caucasian = 98 % Female = 87.5	MBI. 8 wk. MBI-Id, (Modified MBSR). 60 min sess., 2 h. retreat, and 20 min daily practice with music	8-wk. Education Control Group. 1 h. weekly lectures and 30 min daily reading and quizzes	Inflammatory mediators: IL-6, CRP	Interv: $g = 0.10$ Cont: $g = -0.07$
Marciniak et al. (2020) Czech Republic	Patients with Mild Cognitive Impairment	Pretest = 28 Posttest = 23 Follow-up = 20	*M* age = 74 % Female = 65	MBI. MBSR 8 wk. 2.5 h weekly sess., 6 h retreat. Materials given for home practice	8 wk cognitive training	Inflammatory mediators: IL-6, CRP, TNF-a	Interv: $g = 0.00$ Cont: $g = 0.13$
McCarthy et al. (2017) Australia[d]	Persons with combat-related PTSD	Pretest = 30 Posttest = 28	*M* age = 63.5 % Female = 3.6	MMI. Yoga. 8 wk. 90 min. sess., guided body-awareness meditation provided	WL/TAU	Inflammatory mediators: CRP, TNF-a	Interv: $g = -0.14$
McIntyre et al. (2018) South Africa	Persons with HIV	Pretest = 10 Posttest = 7 3-mo = 5	% Female = 100	MBI. 8 wk. MBSR adapted for local context. 120 min sess., 6 h. retreat, and daily practice	None	Leukocytes: CD4, T-cells	Interv: $g = -0.11$
Memon et al. (2017) Sweden	Patients with mild to moderate depression and anxiety	Pretest = 196 Posttest = 166	*M* age = 41.5 % Female = 87.5	MBI. 8 wk. Mindfulness-based group therapy	Cognitive behavioral therapy	Inflammatory mediators: CRP, IL-8	Interv: $g = -0.09$ Cont: $g = 0.01$
Meyer et al. (2019) USA	Healthy adults	Pretest = 413 Posttest = 385	*M* age = 49.7 % Caucasian = 86 % Female = 76 % College = 78	MBI. 8 wk. MBSR. 150 min sess. No retreat, 45 min. daily practice	WL/TAU and a moderate intensity exercise control group	Inflammatory mediators: IL-6, CRP, IFN-γ	Interv: $g = -0.04$ Cont: $g = 0.06$
Mirmahmoodi et al. (2020) Iran	Females with breast cancer	Pretest = 51 Posttest = 44	*M* age = 44.14 % College = 50 % Female = 100 % Employed = 40.9	MBI. MBSR. 8 wk. completed Beck anxiety inventory and Beck-II depression inventory. Group counseling	WL/TAU	Inflammatory mediators: CRP	Interv: $g = 0.22$ Cont: $g = 0.09$
Naoroibam et al. (2016) India	Persons with HIV	Pretest = 44 Posttest = 44	*M* age = 36.14 % Female = 45.5 *M* Ed. = 13.6	MMI. 4-wk yoga treatment with breathing and meditation, 60 min. sess., six times per week	WL/TAU	Leukocytes: CD4	Interv: $g = 0.26$ Cont: $g = -0.19$
Ng et al. (2020) Singapore	Older adults with mild cognitive impairment	Pretest = 55 Posttest = 49 Follow-up = 40	*M* age = 71.89 % Female = 71.4 % College = 11.1 % Chinese = 96.4 % Marital = 66.7	MBI. Mindful Awareness Practice (MAP). 1st 3 months: 12 weekly 1 h sess. 3–9 months: monthly booster sessions. Asked to record at home practice	Health Education program	Inflammatory mediators: IL-1, IL-6, CRP	Interv: $g = -0.01$ Cont: $g = -0.19$

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Nguyen et al. (2019) USA	Healthy adults	Pretest = 176 Post-test = 142	*M* age = 49.15 % Female = 74 % Caucasian = 83.33	MMI. Mindfulness meditation or loving-kindness meditation. 6 wk workshop, 1 h sess. 20 min. guided meditation as homework	WL/TAU	Cellular Aging: Telomere length	Interv: *g* = -0.24 Cont: *g* = -0.44
Nugent et al. (2021) USA	Persons with major depression	Pretest = 87 Posttest = 87	*M* age = 45.20 % Caucasian = 88.5 % Female = 83.9	MMI. 10 wk Hatha yoga intervention. 80 min. sess., 1–2 times per week, included sitting meditation and breathing exercises	10 wk. Group healthy living workshop. 1 h. biweekly classes	Inflammatory mediators: IL-6, CRP, TNF- α	Interv: *g* = 0.11 Cont: *g* = -0.12
Oh et al. (2010)[f] Australia	Patients with different types of cancers	Pretest = 162 Post-test = 108	*M* age = 60.00 % Caucasian = 65.4 % Female = 57.4 % College = 46.9 % Marital = 66.7	MMI. 10-wk. Medical Qigong with breathing and meditation. 90 min sess., twice per week, 30 min daily home practice	WL/TAU	Inflammatory mediators: CRP	Interv: *g* = 0.07 Cont: *g* = -0.15
Oh et al. (2012)Australia	Cancer patients	Pretest = 81 Posttest = 54	*M* age = 64.6 % Female = 50 % Caucasian = 82.4 % Marital = 66.7 % Breast cancer = 32.4	MMI. Medical Qigong program. 10 wk. 90 min wkly sess., given home practice	WL/TAU	Inflammatory mediators: CRP	Interv: *g* = 0.13 Cont: *g* = -0.11
Oken et al. (2010) USA*	Caregivers of close relatives with dementia	Pretest = 31 Posttest = 27	*M* age = 64.55 % Caucasian = 90 % Female = 81 % Marital = 74	MBI. 7 wk. mindfulness intervention (MBCT & MBSR combo). 90 min. sess., no retreat, daily practice with audio	Dementia education class	Inflammatory mediators: IL-6, CRP, TNF-α	Interv: *g* = 0.27 Cont: *g* = -0.09
Ornish et al. (2008) USA	Men with prostate cancer	Pretest = 30 Posttest = 24	*M* age = 62.3 % Caucasian = 84 % Female = 100 % Marital = 66.7	MMI. 12 wk. Comprehensive lifestyle modification program. 60 min. daily stress management practices (meditation, yoga, breathing exercises, imagery, and progressive relaxation) for 6 days/wk. Included 3-day intensive retreat followed by contact with nurse for 4 h/wk. Other modifications were diet, exercise, group support, and supplements	None	Inflammatory mediators: CRP Cellular Aging: Telomerase activity	Interv: *g* = 0.30
Pace et al. (2009) USA*	Healthy university students under stress	Pretest = 89 Posttest = 61	*M* age = 18.51 % Female = 52	MED. 6 wk. Compassion meditation. First 2 weeks were attentional and mindfulness techniques 50 min sess., twice a week and daily practice with audio	Health discussion	Inflammatory mediators: IL-6	Interv: *g* = -0.15 Cont: *g* = -0.03

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Park and Oh (2012) Korea[d]	Gynecologic cancer patients	Pretest = 30 Posttest = 27	*M* age = 47.82 % Female = 100 % Employed = 23.5 % Marital = 11.8 % College = 17.6	MBI. Cognitive behavior therapy, MBSR, psychoeducation, and supportive therapy. 12 wk	WL/TAU	Inflammatory mediators: IL-2, IL-12, IFN-y	Interv: *g* = 0.22
Prakhinkit et al. (2014) Thailand	Elderly adults with mild to moderate depressive symptoms	Pretest = 45 Posttest = 40	*M* age = 76.6 % Female = 100	MMI. 12-wk Buddhist walking meditation. 20–30 min. sess., three times per week	12 wk. traditional walking exercise training and WL/TAU	Inflammatory mediators: IL-6, CRP	Interv: *g* = 0.25 Cont: *g* = -0.13
Puhlmann et al. (2019) Germany	Healthy adults with no meditation experience	Pretest = 315 Posttest = 298	*M* age = 41.15 % Female = 59.3	MED. 3, 3-mo meditation modules: Presence, Affect, and Perspective Taking. 120 min. sess., 3-day retreat, 30 min. daily practice	WL/TAU	Inflammatory mediators: IL-6, CRP	Interv: *g* = 0.04 Cont: *g* = -0.20
Pullen et al. (2008) USA	Patients with chronic heart failure	Pretest = 19 Posttest = 19	*M* age = 51.26 % Female = 53	MMI. Yoga 8-wk with breathing and meditation. 70 min. sess., twice per week, one home practice sess. per week	WL/TAU	Inflammatory mediators: IL-6, CRP	Interv: *g* = 0.83 Cont: *g* = 0.33
Pullen et al. (2010) USA	African American patients with chronic heart failure	Pretest = 40 Posttest = 34	*M* age = 54.15 % AA = 100 % Female = 42.5	MMI. Yoga 8 wk. twice per week, 60 min, sess. and three home sess. Per week	WL/TAU	Inflammatory mediators: IL-6, CRP	Interv: *g* = 1.26 Cont: *g* = 0.11
Rao et al. (2015) India	Healthy adults	Pretest = 108 Posttest = 103	Range age = 18–90 % Female = 64.8	MED. 3 wk. residential retreat with 2 h. of meditation/day, 1 h. yoga/day, breathing exercises twice/day, and vegetarian diet	None	Cellular Aging: Telomerase activity	Interv: *g* = 0.26
Rao et al. (2017) India	Patients with metastatic breast cancer	Pretest = 91 Posttest = 66	*M* age = 48.9 % Female = 100	MMI. 12 wk Integrated yoga-based stress reduction program. Also, included breathing, mediation, imagery and relaxation practices. 60 min sess., twice per week. Daily practice encouraged	Education and supportive therapy sessions	Leukocytes: NK cells	Interv: *g* = 0.18 Cont: *g* = -0.18
Reich et al. (2017)[g] USA	Breast cancer survivors	Pretest = 322 Posttest = 299 6-wk = 299	*M* age = 56.6 % Caucasian = 69.4 % Female = 100 % Graduate = 43.6 % College = 38.6 % High school = 17.8 % Marital = 64.4	MBI. 6 wk. MBSR(BC). 120 min. sess., no retreat, daily practice with audio	WL/TAU	Inflammatory mediators: IL-6, TNF-α	Interv: *g* = 0.05 Cont: *g* = -0.03

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Robinson et al. (2003) USA[h]	Persons with HIV	Pretest = 46 Posttest = 34	*M* age = 41.03 % Caucasian = 85.29 % Female = 6 % Graduate = 26.47 % College = 47.5	MBI. 8 wk. MBSR. 150 min sess., 8 h. retreat, 45 min daily practice with audio recordings	WL/TAU	Leukocytes: NK Cell %, NK cell activity	Interv: *g* = 0.66 Cont: *g* = -0.27
Rodriguez-Peña et al. (2014) Spain	Persons with a subjective feeling of emotional distress, stabilized by drug treatment	Pretest = 16 Posttest = 16	M age = 39.9 % Female = 56	MED. 8 wk. mindfulness meditation practice. 30 min. guided session twice a week and 3 sessions of at home practice	None	Immunoglobulins: IgA, IgM, IgG	Interv: *g* = 0.44
Rosenkranz et al. (2013) USA	Community volunteers	Pretest = 49 Posttest = 43 4-mo = 36	*M* age = 45.89	MBI. 8 wk MBSR. 150 min sess., day-long retreat, 45–60 daily practice	Health enhancement program	Inflammatory mediators: IL-8, TNF-α	Interv: *g* = -0.14 Cont: *g* = -0.17
Sanabria-Mazo et al. (2020) Spain	Women with Fibromyalgia	Pretest = 64 Posttest = 58 3-mo = 57	*M* age = 52.21 % Female = 100 % Marital = 68.4 % Employed = 26.2 % College = 42.1	MBI. Mindfulness plus amygdala and insula retraining (MAIR). 8 wk, 2 h sess., followed by 3 h sess. Daily homework	Relaxation program	Inflammatory mediators: IL-6, IL-10, CRP, TNF-α	Interv: *g* = 0.11 Cont: *g* = -0.01
Sarenmalm et al. (2017) Sweden	Women with breast cancer	Pretest = 177 3-mo Posttest = 166	*M* age = 57.2 % Female = 100 % College = 47.6 % Marital = 74.1	MBI. Asynchronous and synchronous conditions. 8 wk. MBSR. 120 min sess., no retreat, 20 min daily practice	WL/TAU	Leukocytes: CD3, CD19, Lymphocytes, NK cells	Interv: *g* = 0.00 Cont: *g* = 0.03
Seyed Alinaghi et al. (2012) Iran	Persons with HIV	Pretest = 245 Posttest = 173	*M* age = 35.10 % Caucasian = 90 % Female = 31 % College = 8.0 % Marital = 74	MBI. 8 wk. MBSR. 6–7 h. retreat	Education and support group	Leukocytes: CD4	Interv: *g* = 0.14 Cont: *g* = 0.01
Sharma et al. (2015) India	Persons with inflammatory bowel disease	Pretest = 100 Posttest = 87	None	MMI. Asynchronous. 8-wk standard medical therapy plus yoga treatment with breathing and meditation. 60 min. sess., every day, first week only with teacher	WL/TAU	Inflammatory mediators: serum ECP, IL-2	Interv: *g* = -0.11 Cont: *g* = -0.11
Shields et al. (2020) USA	Healthy persons with prior meditation experience	Pretest = 60 Posttest = 59	*M* age = 49.3 % Female = 53.33	MED. Meditation retreat. 12 wk. 6–7 h meditation per day	WL/TAU	Inflammatory mediators: IL-6/IL-10 ratio	Interv: *g* = 0.28 Cont: *g* = 0.03
Smith et al. (2018) USA	Post-menopausal obese women	Pretest = 40 Posttest = 36	*M* age = 58.46	MBI. Mindfulness and eating behaviors. 6 wk, 2-h sess	Weight-loss discussion group	Inflammatory mediators: IL-6, CRP	Interv: *g* = 0.45 Cont: *g* = -0.20

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Sohl et al. (2016) USA	Adults with colorectal cancer	Pretest = 28 Posttest = 15	*M* age = 57.5 % Female = 40 % Caucasian = 80	MMI. Yoga. 8 wk, 4x per week at home. 3 in person sess., 15 min sess	Attention control	Inflammatory mediators: IL-1, TNF-α	Interv: *g* = -0.06 Cont: *g* = -0.31
Taylor (1995) USA	Persons with HIV	Pretest = 10 Posttest = 10	*M* age = 28.44 % Caucasian = 100 % Female = 0	MED. 10 wk. Behavioral stress management program. Program consisted of progressive muscle relaxation, EMG biofeedback, hypnotic training and meditation. 70 min Bi-weekly sess., daily at home practice	WL/TAU	Leukocytes: T-Cells	Interv: *g* = 0.20 Cont: *g* = -0.07
Tenfelde et al. (2019) USA	Women with urgency urinary incontinence	Pretest = 12 Posttest = 12	*M* age = 54.58 % Caucasian = 50 %African American = 41.7 % Female = 100 % Marital = 75	MMI. 8 wk. yoga intervention. 1 h. bi-weekly classes with yoga postures, breathing exercises, and meditation	None	Inflammatory mediators: CRP, IL-6, TNF-α	Interv: *g* = 0.19
Thokchom et al. (2018) India	Patients diagnosed with COPD	Pretest = 53 Posttest = 41	*M* age = 57.8 % Female = 23.8	MMI. Yoga 12 wk., 50 min sess	WL/TAU	Inflammatory mediators: TNF-α	Interv: *g* = 1.21 Cont: *g* = 0.66
Tolahunase et al. (2017) India	Healthy individuals	Pretest = 96 Posttest = 94	*M* age = 40.26 % Female = 55.3	MMI. 12 wk. yoga and meditation lifestyle intervention. 120 min. sessions, 5 days/wk. with yoga postures, breathing exercises, and meditation	None	Cellular Aging: Telomere length, Telomerase activity	Interv: *g* = 0.28
Tolahunase et al. (2018) India	Persons with major depressive disorder	Pretest = 58 Posttest = 58	*M* age = 38.02 % Female = 53.4	MMI. 12 wk. yoga and meditation lifestyle intervention. 120 min. sessions, 5 days/wk. with yoga postures, breathing exercises, and meditation	WL/TAU	Cellular Aging: Telomere length, Telomerase activity	Interv: *g* = 0.70 Cont: *g* = -0.01
Turner et al. (2020) UK*	Healthy students with exam stress	Pretest = 54 Posttest = 48	% age 17–30 = 88.88 % Female = 70.37 % Caucasian = 66.67	MBI. 8 wk, 75–90 min sess	Mental health support	Inflammatory mediators: IL-8, CRP, TNF-a Leukocytes: CD4, NK cells	Interv: *g* = -0.20 Cont: *g* = -0.27
Villalba et al. (2019) 1 USA*	Healthy community adults under stress	Pretest = 153 Post-test = 149	*M* age = 32.00 % Caucasian = 53 % Female = 33 % College = 84.3	MED. Asynchronous. 2-wk. smartphone-based mindfulness training. One intervention taught attention monitoring and acceptance skills and another intervention only taught attention monitoring skills. Both included 20 min. daily audio sess., with 3–10 min. daily practice	2-week smartphone-based stress management coping active control training	Inflammatory mediators: CRP	Interv: *g* = 0.09 Cont: *g* = -0.12

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Villalba et al. (2019) 2 USA*	Healthy community adults under stress	Pretest = 137 Post-test = 125	*M* age = 37.68 % Caucasian = 66 % Female = 67 % College = 89.1	MBI. Two versions of an 8-wk. MBSR. One intervention taught attention and acceptance skills and the other taught attention monitoring skills only. Both were 120 min. sess., with 7-h. retreat and 45 min. daily practice	WL/TAU	Inflammatory mediators: CRP	Interv: $g = 0.10$ Cont: $g = 0.03$
Walsh et al. (2016) USA	Young women with depressive symptoms	Pretest = 64 Posttest = 62	*M* age = 19.13 % Caucasian = 85.9 % Female = 100 % College Freshman = 76.6	MBI. 4 wk. MBI. 50 min. sess., recommended home practice	4 wk. Contact-control group, 50 min sess. of completing surveys	Inflammatory mediators: IL-6, TNF-α	Interv: $g = 0.19$ Cont: $g = 0.17$
Wang et al. (2017) Sweden	Patients diagnosed with depression, anxiety, or stress and adjustment disorders	Pretest = 181 Post-test = 177	*M* age = 41.9 % Caucasian = 86 % Female = 87.8	MBI. 8 wk. Mindfulness-based group therapy. 120 min. sess., no retreat, 20 min. daily practice	WL/TAU	Cellular Aging: Telomere length	Interv: $g = 0.09$ Cont: $g = 0.00$
Webb et al. (2018) USA	Youth with HIV	Pretest = 96 Posttest = 52 3-mo = 40	*M* age = 18.71 % Female = 39.5	MBI. 8 wk., 9 sess. Including meditation, yoga, and cultivating mindfulness	Health education	Leukocytes: CD4	Interv: $g = -0.06$ Cont: $g = 0.11$
Wetherell et al. (2020) USA	Persons with age-related cognitive decline	Pretest = 29 Posttest = 29 6-mo = 29 18-mo = 29	*M* age = 71.8 % Female = 65.5 % Caucasian = 93.1 % College = 72.4	MBI. Two weekly sess. for 6-mo. Weekly for 12-mo	None	Inflammatory mediators: IL-1, IL-6, IL-17, TNF-α	Interv: $g = -0.18$
Wirth et al. (2019) USA	Cancer survivors (53% breast cancer, 20% prostate cancer, 9% gynecological cancer, 18% other)	Pretest = 36 Posttest = 36	*M* age = 63.9 % Caucasian = 83 % Female = 72.0 % Marital = 74.0	MBI. 4 wk. MBI developed for cancer survivorship. Recommended daily home practice	4 wk. Breathing control intervention	Inflammatory mediators: CRP, TNF-α	Interv: $g = 0.04$ Cont: $g = 0.09$
Witek-Janusek et al. (2019) USA	Women newly diagnosed with breast cancer	Pretest = 164 Posttest = 36	*M* age = 55 % Caucasian = 80.8 % Female = 100	MBI. MBSR. 8 wk, 2.5 h/week. 6-h silent mindful retreat after 5th week. Breath awareness, sitting meditation, and yoga	Cancer recovery and health education classes	Inflammatory mediators: IL-6, IFN-γ, TNF-α Leukocytes: NK cells	Interv: $g = 0.04$ Cont: $g = -0.04$
Yadav et al. (2012) India	Patients with chronic inflammatory diseases and overweight/obese subjects	Pretest = 86 Posttest = 86	*M* age = 40.07 % Female = 51.2	MMI. 10-day yoga-based lifestyle intervention. 2 h. daily session, with yoga postures, breathing exercises, and meditation	None	Inflammatory mediators: IL-6, TNF-α	Interv: $g = 0.28$

Table 1 (continued)

Study and Country	Population	*N* and Follow-ups	Demographics	Intervention Category and Description	Control or Comparison Group	Immune Category and Measure	Study-level Effect Size
Zautra et al. (2008) U.S.A	Patients with rheumatoid arthritis, with and without depression	Pretest = 144 Post-test = 137 6-mo = 131	*M* age = 54.19 % Caucasian = 87 % Female = 68	MBI. 8 wk. Mindfulness meditation and emotion regulation therapy (elements of MBSR & MBCT). 120 min sess., no retreat, home practice suggested	Education control and 8 wk. CBT for pain management, 120 min sess	Inflammatory mediators: IL-6	Interv: *g* = -0.14 Cont: *g* = -0.15
Zgierska et al. (2016) USA	Persons with chronic low back pain	Pretest = 35 Posttest = 34 26-wk = 33	*M* age = 51.8 % Employed = 66.66	MED. 8 week, 2 h sess	WL/TAU	Inflammatory mediators: IL-6, IFN-γ	Interv: *g* = -0.10 Cont: *g* = -0.14
Zgierska et al. (2019) USA	Alcohol dependent adults in early recovery	Pretest = 123 Post-test = 112	*M* age = 41 % Female = 56.2 % Caucasian = 91 % College = 83.9	MBI. 8 wk., 2-h sess. Formal and informal home practice	WL/TAU	Inflammatory mediators: IL-6, TNF-α	Interv: *g* = -0.15 Cont: *g* = -0.14

Demographics not included in the table were not reported in the article. All interventions were delivered synchronously, unless otherwise noted. Full refences can be found in supplemental materials. MBI = mindfulness-based intervention; MED = meditation-focused intervention; MMI = Meditative movement intervention; mo = months; min = minutes; sess = sessions; wk = week; MBSR = mindfulness-based stress reduction. Interv = intervention; Cont = control. * Included healthy samples that the authors defined as under stress

[a]Boyle et al. (2019) and Dutcher et al. (2021) include the same sample as Bower (2015), but the measures were combined into one report here

[b]The experienced meditators from Epel et al. (2016) were not included in the meta-analysis

[c]The majority of adults had physical diagnoses; 39% were anxiety or depression diagnoses

[d]Janelsins et al. (2011) includes the same sample as Sprod et al. (2012) but the measures were combined into one report here

[e]Meyer et al. (2019) includes the same sample as Barrett et al. (2012) and Hayney et al. (2014) but do not include new data

[f]Oh et al. (2010) includes the same sample as Oh et al. (2012), but the measures were combined into one report here

[g]Reich et al. (2017) includes the same sample as Lengacher et al. (2019) but do not include new data

interventions (e.g., meditation retreats). Studies were coded for type of (1) sample (i.e., psychological disorder, physiological disorder, healthy), (2) control group (i.e., active control, waitlist-control/treatment as usual none), (3) and delivery (synchronous, asynchronous). Additional details regarding coding can be found in the Supplementary Information section.

Immune functioning has been previously categorized and well-described by Black and Slavich (2016) as (1) inflammatory mediators (e.g., anti-inflammatory and proinflammatory cytokines), (2) cellular transcription factors (e.g., NF-κB transcription, which is involved in regulating proinflammatory cytokine production), (3) leukocytes (e.g., leukocyte/ lymphocyte subsets, cell counts), (4) immune cell aging (e.g., telomerase activity), and (5) antibodies/immunoglobulins, which primarily includes markers of adaptive immune function (e.g., IgA, IgM, and IgG). This categorization approach was used in the current review.

Data Analyses

Comprehensive Meta-Analysis (CMA; Borenstein et al., 2005) was used to calculate and meta-analyze the effect sizes. The effect-size metric used in this report is Hedge's *g* index (Hedges & Olkin, 2014). Because descriptive or inferential statistics were drawn from studies using within-subjects designs, a correlation ($r = 0.50$) among the dependent variables was introduced for the calculation of the *g* index and its variance (Lipsey & Wilson, 2001).

Consistent with approaches adopted by other meta-analysts (e.g., Goessl et al., 2017), we calculated pre-post *within*-group effect sizes for our primary analyses and pre-post *between*-group effect sizes for our secondary effect sizes. For the primary set of effect sizes, the *g* index indicates the magnitude of the within-group improvement in immune functioning at post-test, compared to pretest, *separately* for the intervention group and the control group (i.e., pre-post, within-group effect size). Primary effect sizes with a positive sign indicate improvement in immune functioning from pre- to post-test. We also conducted a secondary analysis that compared the difference in change between the intervention to the control groups; these included only those studies that had intervention and control groups and for which this type of effect size could be calculated (i.e., pre-post, between-group effect sizes). Positive effect sizes for this secondary approach indicate that the intervention groups improved more from pre- to post-test interventions than did the control groups.

It should be noted that the primary effect size allows for an examination of the average magnitude of the effect of size specifically associated with immune categories and specific biomarkers. Using the primary effect size strategy also allows for a (separate) comparison of the meditative interventions to the control conditions – this can be observed by the *Q*-between statistic, which compares the magnitude of the difference between the average effect size for the meditative condition and the control condition. The secondary approach allows for the *difference* between the conditions to be observed. The magnitude of the effect of the meditative condition, in and of itself, on immune functioning (i.e., small = 0.20, medium = 0.50, large ≥ 0.80), however, remains unobserved. That is, the observation of the magnitude of the effect, specifically for meditative interventions, is masked using the secondary approach because the calculation includes both conditions. Also, as will be demonstrated in the results, requirements for the calculations of the secondary effect size render few numbers of effect sizes that can be estimated (partly because some statistics cannot be used with the secondary approach in CMA; secondary effect sizes: $k = 193$, primary effect sizes: $k = 473$), which reduces the power of the meta-analysis. Nevertheless, for comprehensiveness, we report the overall effect sizes using both approaches.

Q-within and I^2 statistics (Higgins & Thompson, 2002) were used to determine heterogeneity among the effect sizes, and *Q-between* (*Q-b*) statistic was used to determine whether the magnitudes of the average effect sizes for each of the two conditions (i.e., meditative interventions versus control conditions) or the moderator categories (i.e., healthy, psychological disorder, or physiological disorder) were significantly different from each other. We utilized a random effects model to allow the effect sizes among interventions to vary and for inferences from the eligible studies to be generalizable (Borenstein et al., 2010). A mixed-effects model was used for comparison between the categories, consistent with recommendations (Borenstein, 2019). A meta-regression analysis was conducted to test whether the duration of the interventions was associated with the magnitudes of the effect sizes; the *Z,* *p*-value, and Knapp-Hartug adjustment (2001) are reported, the latter of which estimates the variance in the model based on studies included in the meta-analysis (Borenstein, 2019).

Results

One hundred and four reports were eligible for the meta-analysis of the primary effect sizes, and of these reports, one report (Villalba et al., 2019) included two independent studies ($k = 105$). Because more than one measure of immune function (e.g., IL-6, CD4, telomere length) could be derived from most reports, 475 primary effect sizes were calculated for the primary meta-analysis. Of the 105 studies from which the primary effect sizes could be derived, 80 of these could be included in the secondary meta-analysis; these 80 studies yielded 193 secondary effect sizes.

Assessments of Bias

For the primary dataset, the Classic Failsafe *N* analysis showed that a large number of missing studies ($n = 5{,}141$) would be needed to render the average effect size for the meditative conditions insignificant and trivial; Orwin's Failsafe *N* (Orwin, 1983) similarly showed that a fairly large number of studies ($n = 165$) would be necessary to render the observed average effect size in the meta-analysis trivial. The funnel plot of the Hedges *g* effect sizes is shown in Fig. 2. The plot was somewhat asymmetric, and the standard errors tended to be small, indicating the high precision of the studies. Importantly, studies falling outside of the funnel do not indicate publication bias, as sometimes assumed (Borenstein, 2019). In addition, Egger's regression analysis was conducted to examine whether studies with smaller sample sizes had larger effect sizes on average. Results indicated a significant relationship between smaller samples and larger effects, $t(103) = 2.690$, $p = 0.008$. Nevertheless, Egger's regression is not a direct indicator of publication bias; it merely identifies small study effects (Egger et al., 1997). Both the funnel plot and Egger's tests are influenced by heterogeneity, which was high in the current studies (Borenstein, 2019; Page et al., 2021). The trim and fill statistics (Duval & Tweedie, 2000) showed that estimated missing studies ($n = 7$) were more likely to the *right* of the mean of the plotted distribution – not to the left, suggesting that the observed average effect size ($g = 0.181$) may be somewhat smaller than the true population effect size ($g = 0.214$). In addition, to examine a potential proteus effect in which the largest effect sizes are associated with early studies and dwindle over time (Trikalinos & Ioannidis, 2005), a meta-regression was conducted in which the effect sizes were the dependent variable, and sample size and year of publication were included as two independent variables. Results indicated that neither the sample size ($p = 0.255$) nor the year of publication ($p = 0.302$) significantly predicted effect size. Thus, considering these analyses, publication bias is an unlikely issue in the literature eligible for review.

Additionally, Cochrane's risk of bias assessment tool (e.g., Higgins et al., 2019) was used to examine potential systematic error associated with poor internal validity that could lead to the under-or overestimation of true intervention effects. Each study eligible for review was coded by a minimum of two authors for the following biases: selection, performance, detection, attrition, reporting, and "other" bias. Any coding discrepancies were discussed and resolved. The majority of the studies ($n = 74$) had an overall low risk of bias, although some studies were coded as having some concern of risk (i.e., unclear risk; $n = 24$) or high risk ($n = 8$). The overall low risk of bias suggests that a meta-analytic examination of the meditative literature is appropriate and reliable (Table 2).

Overall Effect Sizes

The first set of analyses treated the study as the unit of analysis, with each study contributing an effect size for either a meditative intervention condition (i.e., no control) or effect sizes for both the meditative and control conditions. As such, the immune categories are not considered in the first set of analyses, but the immune categories are the unit of analysis in the second set of analyses. Tables 3, 4, 5 report the number of effect sizes (*k*), average effect sizes (*g*), confidence intervals (CIs), and other meta-analytic results.

As shown in the upper panel of Table 3, the average effect size, $g = 0.181$, for the meditative interventions was small but significant, $Z = 6.818$, $p < 0.001$, and revealed a small effect on immune function. The 95% CI [0.128, 0.230] suggests that the precision of the effect size is relatively high, given the small CI range, and the mean effect size for comparable populations falls within this range. Additionally, the prediction interval indicates the dispersion of true effect sizes across various populations; in 95% of cases, an additional study will fall within the meta-analytic prediction interval (Borenstein, 2019). The prediction interval for the current meta-analysis indicated that any additional study conducted would likely demonstrate an effect size of $g = 0.12$ and $g = 0.29$. By contrast, for the control conditions, the average effect size was equivalent to zero, $g = -0.001$, $Z = -0.023$, $p = 0.982$, 95% CI = [-0.058, 0.056]. Consistent with these results, the *Q-between* statistic, $Q\text{-}b(1) = 20.963$, $p < 0.001$, suggested that the average effect size for the meditative interventions was larger than that for the control conditions,

The finding for the secondary effect sizes was highly consistent with that for the primary effect sizes. The meta-analytic results indicated that meditative interventions were associated with greater improvements from pre- to post-change in immune functioning when directly compared to the change for the control conditions, $g = 0.16$, $k = 80$; 95% CI = [0.09, 0.23], $Z = 4.66$, $p < 0.001$. These results suggest that the mediative conditions were associated with a larger pre- to post-intervention effect than the control conditions.

Meta-Analytic Comparisons Regarding Control Groups

To examine our research questions about the inclusion of control groups included in the studies, we conducted two sets of analyses. As shown in the second panel of Table 3, a comparison between the average effect size for the studies that included control conditions to that for studies *without*

control conditions revealed that these effect sizes were *not* different from each other, Q-$b(1) = 0.118$, $p = 0.731$. These results suggest that the magnitudes of the effect sizes for the meditative interventions were similar, regardless of whether the studies were observational or included control groups. In addition, we compared the average effect sizes for the meditative interventions to that for control conditions, separately for studies that included *active* controls to those that included either WL or TAU conditions. As shown in the third panel of Table 3, for the studies that included WL/TAU controls, the average effect size for the meditative interventions was significantly different from zero, and the magnitude was larger than that for the control conditions, Q-$b(1) = 9.813$, $p = 0.002$. Similarly, for the studies that included active controls, the average effect size for the meditative interventions was significantly different from zero, though small, and this effect size magnitude was larger than that for the control conditions, Q-$b(1) = 11.408$, $p = 0.001$. This set of analyses suggests that the average effect of meditative interventions on immune functioning was similar, regardless of whether the studies included a control condition. Not surprisingly, the difference between the magnitude of effect sizes among active control and meditative interventions was smaller than the difference between treatment-as-usual controls and meditative interventions. Nevertheless, regardless of whether the study included an active or WL/TAU control, the effect of the meditative interventions on immune functioning was significant and larger than that for controls.

Moderators of the Effect of Meditative Interventions

Health of Participant-Samples The findings for the meditative interventions revealed heterogeneity among the primary effect sizes, Q-*within* $(104) = 379.86$, $p < 0.001$; $I^2 = 77.62\%$, suggesting the need to examine moderators. For the meta-analyses of the coded categories—the type of sample and intervention—we included the effect sizes for only the meditative interventions because the effect sizes for the control conditions were not expected to be affected by these moderators.

The three categories of samples (i.e., healthy, physiological disorder, psychological disorder) were compared to understand whether health status was associated with the magnitude of the average effect sizes. Although the results suggested that the three average effect sizes for these three categories were not statistically different from each other, Q-$b(2) = 4.845$, $p = 0.089$. As shown in the upper panel of Table 4, the average effect size for the healthy category was not different from zero (insignificant), but both those associated with the physiological and psychological categories were significant, which may suggest improved immune function from pre- to post-test for participants with physiological or psychological disorders.

Because the average effect size for the healthy samples was not significant, we conducted two exploratory analyses. First, given that the observed average effect sizes for the physiological disorder and the psychological disorder were quite similar (i.e., gs $= 0.220$ and 0.218, respectively), we combined these two "health-challenged" samples into one category and compared the resulting average effect size to that for the healthy-sample category. This analysis showed that the average effect size for the healthy category, $g = 0.087$, 95% CI = [-0.014, 0.188], $Z = 1.697$, $p = 0.090$, was nonsignificant and smaller than that for the health-challenged category, $g = 0.219$, 95% CI = [0.158, 0.281], $Z = 7.014$, $p < 0.001$; Q-$b(1) = 4.827$, $p < 0.001$. Second, because some of the reports identified their healthy samples as under situations of stress, we divided the healthy samples accordingly into a healthy-stressed category ($k = 12$) and a healthy-low-stress category ($k = 17$), as categorized by the original researchers. The results showed that, for the healthy-low-stress category, the average effect sizes were nonsignificant, $g = 0.037$, $Z = 0.720$, $p = 0.472$, 95% CI = [-0.064, 0.139], but that for the healthy-stressed category was significant, $g = 0.146$, $Z = 1.973$, $p < 0.05$, 95% CI = [0.001, 0.292]. Nevertheless, the comparison between the two average effect sizes did not reach significance, Q-$b(1) = 1.446$, $p = 0.229$. The stress-buffering hypothesis (Creswell & Lindsay, 2014) provided the rationale for these additional analyses. That is, biomarkers of immune functioning among healthy participants are much more likely to be within optimal range than those with dysregulated systems (i.e., greater stress and inflammation). These sets of exploratory analyses may suggest that meditative interventions do not influence immune functioning among healthy participants unless these otherwise healthy participants are experiencing stressful life conditions. Importantly, because these findings were exploratory, they must be interpreted with caution.

Intervention Type and Delivery As shown in the middle panel of Table 4, the results revealed no difference between whether the meditative interventions were delivered synchronously or asynchronously, Q-$b(1) = 0.880$, $p = 0.348$; both the effect sizes for the asynchronous and the synchronous categories were significant. Also, as shown in the bottom panel of Table 4, the average effect sizes were significant for all categories of meditative interventions (i.e., MBI, Primarily Meditation, MMI). Nevertheless, the comparison between the three categories suggested that the magnitudes of the average effect sizes were different, Q-$b(2) = 7.828$, $p = 0.020$. Although each of the meditative interventions was associated with significant average effect sizes, this analysis suggested that the magnitude was largest for mindful-movement interventions (MMI). This result, however, was clarified by the results of a meta-regression reported in the following paragraph.

Duration Meta-regression results revealed that longer interventions were associated with larger effect sizes, $Z = 2.97$, $p = 0.003$ (Knapp-Hartug adjustment: $t = 2.57$, $p = 0.01$). Based on the Q-value, 8.83, $p = 0.003$, the model explains significant variance in the effect sizes, and the R^2 for the model indicates 13% of the variance in the true effect sizes (Bornstein, 2016). Importantly, these results support Creswell's (2017) theory that larger "doses" of meditative interventions are likely to have more influence on outcomes.

Because the three types of meditative interventions (i.e., on average: MMI = 11 weeks, MBI = 7 weeks, meditation-focused = 6 weeks) seemed to employ different intervention durations, we conducted an exploratory meta-regression. To do so, we entered the intervention category (MBI, Primarily Meditation, MMI) into the meta-regression along with study-level intervention duration. Consistent with the first meta-regression, this analysis showed, again, that longer interventions were associated with larger effect sizes, $Z = 2.27$, $p = 0.02$, but that the difference between the intervention categories was no longer significant, Q-$b(2) = 4.18$, $p = 0.12$. This latter result may suggest that the difference between the average effect sizes for the three categories of interventions, reported in the previous paragraph, may be attributable to differences in intervention durations than to specific components of the meditative interventions.

Categories of Immune Function

We conducted a meta-analysis that considered the immune categories as the unit of analysis—these five categories included inflammatory mediators, cellular aging, antibodies/immunoglobulins, transcription factors, and leukocytes. As Table 5 shows, the average effect sizes for these categories of immune functioning were significant. These results clarify the conclusions of former reviews (e.g., Black & Slavich, 2016) and suggest that meditative interventions have positive influences on all five categories of immune functioning. Further, the results suggested that the magnitudes of these effect sizes were different from each other, Q-$b(4) = 18.805$, $p = 0.001$. The pattern of effect sizes suggested that those for antibodies/immunoglobulins and transcription factors were the largest, but this finding must be interpreted with caution because these two categories had relatively small numbers of effect sizes.

Single-Level Biomarkers

We also conducted meta-analyses with the specific biomarkers that had been reviewed by Black and Slavich (2016), Bower and Irwin (2016), and Morgan et al. (2014). The biomarkers included in the meta-analysis conducted by Morgan et al. were CRP, IL-6, TNF-α, CD4 + T lymphocytes, and NK cells. In addition to these biomarkers, because of the greater number of effect sizes available for the current meta-analyses, we were able to meta-analyze additional single-level biomarkers, including interferon gamma (IFN-γ) and immunoglobulin-A (IgA).

For biomarkers in the inflammatory mediator category, the average effect size for CRP was small but significant, $k = 37$, $g = 0.099$, 95% CI = [0.029, 0.169], $Z = 2.773$, $p = 0.006$; this finding is consistent with the prior reviews. Additionally, the current meta-analytic results provided evidence not revealed in the prior reviews regarding IL-6; the average effect size was small but significant (IL-6: $k = 40$, $g = 0.169$, 95% CI = [0.073, 0.264], $Z = 3.457$, $p = 0.001$). As revealed in the prior reviews, the average effect sizes for TNF-α ($k = 32$, $g = 0.10$, 95% CI = [-0.040, 0.243], $Z = 1.412$ $p = 0.158$) and NK cells ($k = 10$, $g = 0.068$, 95% CI = [-0.113, 0.249], $Z = 0.736$, $p = 0.462$) were not significant. Finally, the current results showed that the magnitude of the average effect size for IFN-γ cells was not significant ($k = 8$, $g = -0.099$, 95% CI = [-0.271, 0.169], $Z = -0.943$, $p = 0.346$).

There were only an adequate number of effect sizes for CD4 + in the leukocyte category; the findings showed that the magnitude of the average effect sizes was not significant (CD4 + : $k = 13$, $g = 0.001$, 95% CI = [-0.112, 0.114], $Z = 0.024$, $p = 0.981$). In the antibody-immunoglobulin category, the magnitude of the effect size for IgA was significant ($k = 5$, $g = 0.353$, 95% CI = [0.55, 0.550], $Z = 3.501$, $p < 0.001$).

Finally, following from Schutte and Malouff's (2011) meta-analysis examining the influence of meditation on telomerase activity, the meta-analysis conducted by Schutte et al. (2020) examining telomere length, and the narrative review by Conklin et al. (2019), we conducted separate meta-analyses to examine telomerase activity and telomere length (both within the category of cellular aging). The analyses showed that, whereas the magnitude of the effect size for telomerase activity was significant and of medium magnitude, $k = 13$; $g = 0.376$, 95% CI = [0.217, 0.535], $Z = 4.635$, $p < 0.001$, that for telomere length was small and not significant, $k = 11$; $g = 0.079$, 95% CI = [-0.083, 0.240], $Z = 0.958$, $p = 0.338$). Although this latter finding may seem surprising, given that studies show improvements in telomere length among expert and long-time meditators (e.g., Schutte et al., 2020), the pattern may suggest that meditative interventions, which tend to last approximately eight weeks on average, may not be long enough to influence telomere length.

Discussion

The current meta-analytic review provides a more comprehensive understanding of the association between participation in meditative interventions and enhanced immune functioning than has been available in the literature. Meta-analyses indicate that meditative interventions have the capacity to reduce stress in both clinical and non-clinical populations (Álvarez-Pérez et al., 2022; Chiesa & Serretti, 2009; Eberth & Sedlmeier, 2012; Khoury et al., 2015; Pascoe et al., 2017a, 2017b). Stress is an antecedent to immune dysregulation—especially chronic inflammation (Godbout & Glaser, 2006; Gouin, 2011; Padget & Glaser, 2003). Although prior studies and meta-analyses have sought to understand the effect of meditative practices on specific immune biomarkers (i.e., telomeres; Schutte et al., 2020), the current meta-analysis was designed to examine whether meditative interventions affect immune functioning, more generally, including many biomarkers (e.g., monocytes, CD3, IL-8) available in empirical reports. To our knowledge, the current findings revealed the overall magnitude of the effect size associated with meditative interventions on immune functioning. Whether comparing pre- to post-intervention changes in immune functioning (primary effect size), comparing the control conditions directly to the intervention conditions (secondary effect size), or using prediction intervals, the meta-analyses indicated the effect of meditative interventions on immune functioning is likely small but robust. Furthermore, the meta-analysis uncovered the importance of key theoretical and methodological moderators, including the duration of the intervention and the health status of the participants.

Theoretical Moderators

Duration The duration or "dosing" of meditative interventions necessary for beneficial changes has been a longstanding question in the field of mindfulness research (e.g., Creswell, 2017). This question becomes further complicated when considering the various types of meditative interventions. The meta-analytic results revealed that longer meditative interventions were associated with more adaptive basal immune profiles. This finding supports theory and research (Chin et al., 2019; Creswell, 2017) that suggest that greater immune benefits should result from longer, sustained meditative practice. Although the meta-analysis by Schutte et al. (2020) meta-analysis revealed that more intensive practice was associated with greater immune benefit among experienced meditators, their results did not demonstrate a dose–response relationship among intervention studies, which typically include novice meditators. Similarly, Strohmaier (2020) found no relationship between the dose of mindfulness-based interventions among novice practitioners and psychological outcomes, but immune outcomes were not assessed. As such, the current results provide evidence that future research should seek to examine the optimal dose–response relationship for improving immune functioning.

Health of Participant Samples The meta-analytic results suggested that immune benefits for healthy participants in meditative interventions were weak and nonsignificant. These results support the predictions by Morgan et al. (2014) as well as those by Bower and Irwin (2016), which were based on their narrative reviews of the literature. Specifically, that type of population likely determines whether detectable changes in immune functioning will occur. For example, among healthy individuals, CRP should be undetectable; thus, researchers would only expect reductions in CRP among those experiencing elevated stress or other proinflammatory diagnoses. Our exploratory analysis showed that when healthy participants were categorized as either healthy or healthy-stressed, as defined by the primary researchers, a positive effect of the meditative interventions emerged among those experiencing acute stress. Consistent with the stress-buffering hypothesis (Creswell & Lindsay, 2014), immune effects appear to be more reliable for those with elevated stress. In comparison to individuals at risk for immune dysfunction and systemic inflammation, relatively healthy individuals who participate in meditative interventions are less likely to have detectable changes in immune functioning as they are more likely to have biomarkers within optimal levels (Puhlmann et al., 2019). Nevertheless, meditative interventions may provide immuno-protective benefits for healthy individuals by buffering stress that could ultimately cause immune dysregulation (e.g., Nguyen et al., 2019).

The meta-analytic results indicated that meditative interventions improved immune functioning among participants with physiological and psychological diagnoses. Meditative interventions likely improve the regulation of and reactivity to stressors (Creswell & Lindsay, 2014). Stress has deleterious effects on immune functioning and contributes to chronic inflammation (Cohen et al., 2012). Thus, buffering stress may improve proinflammatory conditions and reduce pathological outcomes. Meditative interventions had significant effects on each of the biomarkers indicative of inflammation (i.e., CRP, NF-κB, IgA, IL-6). This suggests that meditative interventions have the capacity to modulate dysregulated inflammatory responses that are implicated in psychological and physiological pathological outcomes.

Methodological Moderators

Control Conditions The included studies utilized a variety of active control conditions, including exercise, health education, and therapy; other studies relied on waitlisted or treatment-as-usual control groups, and a relative minority included no control group. The results revealed that the magnitude of the effects of the meditative interventions did not differ between studies utilizing control groups ($n = 87$) and those without control groups ($n = 18$). Similarly, regardless of whether studies included active controls ($n = 43$) or waitlisted controls ($n = 44$), the results revealed that the meditative interventions were associated with improved immune functioning. Nevertheless, researchers (e.g., Rosenkranz et al., 2019) have emphasized the need for the inclusion of active control groups because they allow for stronger conclusions by controlling for non-specific treatment factors (e.g., time, attention, group setting, education, etc.).

Intervention Delivery The meta-analytic results suggested that meditative interventions were effective whether delivered in the more traditional synchronous format or asynchronously; this finding has not been revealed in prior reviews. These findings suggest that improvements in immune functioning following meditative interventions are not merely consequences of the social support that might be offered by face-to-face interventions with other participants and an instructor. Further, this finding is important because some populations (e.g., rural persons, homebound persons) may require asynchronous delivery of meditative therapies (i.e., online, app-based, or pre-recorded interventions). The current results suggest that there is flexibility in developing and implementing remote meditative interventions that are viable options for improving immune functioning and health.

Intervention Type Overall, the current meta-analysis suggests that meditative interventions were associated with immune functioning for all three categories of meditative practices, mindfulness-based, primarily formal meditation, or meditative-movement. The analysis that compared the magnitudes of the respective average effect sizes suggested that MMIs were associated with the largest positive effect size. An exploratory analysis, however, suggested that this difference may be attributable to MMIs being typically longer in duration. Nevertheless, it is also possible that the exercise component (e.g., yoga, qigong) combined with other meditative components (e.g., meditation, focused breathing) affords the greatest benefit, as exercise is associated with improvements in immune functioning among both healthy and clinical populations (Chastin et al., 2021; Khosravi et al., 2019). As was the case for delivery, these results suggest that there is flexibility in the implementation of meditative interventions that can be designed for and offered to populations with specific abilities and needs—for example, for individuals who are able to engage in more rigorous movement compared to those who cannot. Although the meta-analyses compared intervention categories, future studies should compare the relative benefits of different types of meditative practices experimentally.

Immune Categories and Single-Level Biomarkers

Consistent with the results for the overall effect size for immune functioning, the meta-analytic findings revealed that meditative interventions had significant effects on each of the five immune categories. There were small but significant effects on inflammatory mediators, cellular aging, and leukocytes. The results also showed moderate effects on antibodies/immunoglobulins and large effects on NF-κB though these latter findings should be interpreted with caution because the number of effect sizes available and the number of participants in these categories were relatively small. Single-level biomarkers with an adequate number of effect sizes were also analyzed to further elucidate the effect of meditative interventions on immune functioning. Supporting prior reviews, the findings of the current work suggested small but reliable effect size for the inflammatory mediator, CRP.

Inflammatory Mediators Unsurprisingly, given the relationships among stress, inflammation, and dysregulated immune functioning, inflammatory mediators were the most studied immune category in the studies eligible for review. As their name suggests, inflammatory mediators play a critical role in facilitating pro and anti-inflammatory innate and adaptive immune functioning, but also facilitate the release of neurotransmitters, stress responses, and communication between the immune system and the brain (Irwin, 2002). In the studies eligible for review, proinflammatory (rather than anti-inflammatory) cytokines were assessed most often. Chronic inflammation is a consequence of dysregulated immune functioning, and it results in various pathological outcomes, including arthritis, cancer, atherosclerosis, neurodegenerative conditions, and early death (Heikkila et al., 2007; McKoy & Tansey, 2008; Ridker, 2002). Because chronic inflammation is a major antecedent to disease, even the small effect of meditative interventions on inflammatory response could have clinical significance for disease progression and severity. Prior empirical research examining MBIs as a means to decrease disease severity have mixed results (perhaps because of the vast heterogeneity of studies; Greeson & Chin, 2019). The findings of the current meta-analysis suggest that changes in inflammatory biomarkers following meditative interventions

should be further explored as a possible mechanism of action contributing to the relationship between meditation and improved immune function.

Cellular Aging The meta-analytic results revealed a small effect size for cellular aging. Further analysis revealed the average effect size for telomerase, but not telomere length, was statistically significant. One reason for this apparent difference in effect sizes may be that it takes more time to influence telomere length than telomerase activity (Conklin et al., 2018). It is noteworthy that the variety in durations among the meditative interventions that measured telomerase ranged from 6 days to 22 weeks with a mode of 8 weeks. This may suggest that intervention durations of 8 weeks may be sufficient for detecting changes in telomerase activity and may offer guidance regarding the minimum duration necessary for future intervention designs. However, meditative practices may need to be sustained for longer than eight weeks to show reliable changes in telomere length (Schutte et al., 2020). Further, post-intervention changes in cellular aging may be component specific. For example, Nguyen et al. (2019) found that loving-kindness meditation, but not mindfulness meditation, buffered telomere length attrition when compared to participants in the control condition.

Cellular aging is a normal consequence of aging, but telomere attrition is also exacerbated by chronic stress and unhealthy lifestyle choices (e.g., smoking) and is associated with increased disease risk and mortality (Epel et al., 2004). Cellular aging can be modulated through lifestyle modifications, and the current results suggest that meditative interventions may be one approach, although more research is warranted (Denham & Sellami, 2021).

Leukocytes The results also indicated a small but significant effect size for leukocytes. This finding suggests that meditative interventions may bolster both adaptive and innate immune functioning, and, thereby, may help protect against fungal, bacterial, and viral infections, as well as some cancers and autoimmune reactivity. Although meditative interventions revealed a significant effect size for this immune category, the results indicated nonsignificant effect sizes for CD4 and NK cells; this was not surprising because prior narrative meta-analytic reviews have suggested the same (Black & Slavich, 2016; Bower & Irwin, 2016; Morgan et al., 2014). CD4 is typically used to assess disease progression among those diagnosed with HIV and may not be a meaningful marker in other populations (Phillips & Lundgren, 2006). Other individual level biomarkers in the leukocyte category had too few effect sizes to analyze individually. Evaluation of changes in leukocytes is highly dependent on health status and the specific subtype of leukocyte. For example, B lymphocyte cells have a variety of subsets and functions, which can promote or inhibit tumor progression (Fremd et al., 2013; Martin & Chan, 2006; Nelson, 2010). Similarly, Neutrophils (neutrophilic polymorphonuclear leukocytes) are white blood cell phagocytes of the innate immune system that can phenotypically differentiate and either inhibit or promote cancer progression (Coffelt et al., 2016, for review). The vast differences in leukocyte effector cells and functions suggest that continued empirical research is needed to understand the effect of meditative interventions on specific effector cells

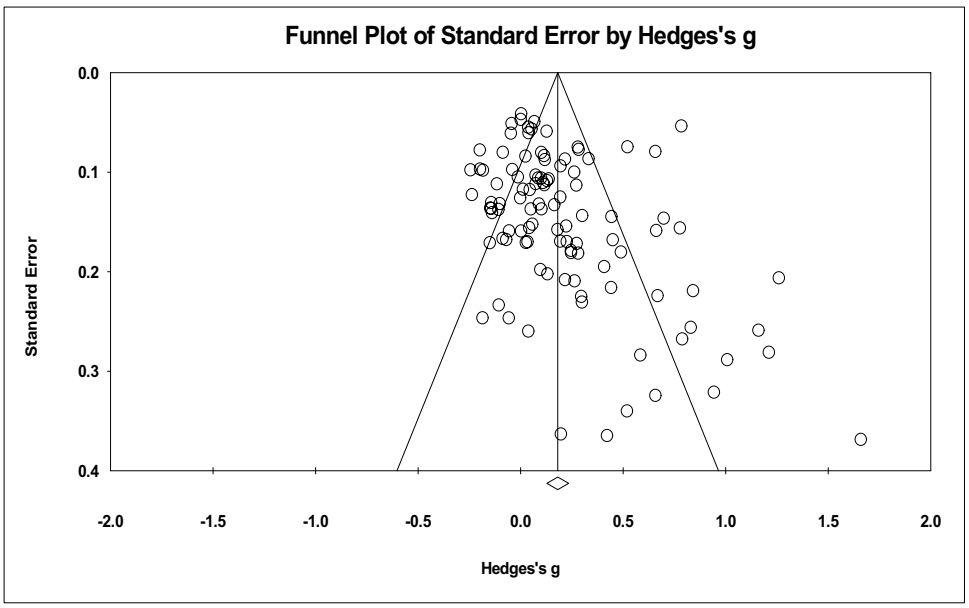

Fig. 2 Funnel plot for the meditative intervention primary effect sizes

Table 2 Results of Risk of Bias Assessment

Report	Domain 1: Randomization	Domain 2: Deviation from Intervention	Domain 3: Missing Data	Domain 4: Measurement of Outcome	Domain 5: Selection of Reported Results	Other Bias	Overall Rob
Agnihotri et al. (2014)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Andrés-Rodrígues et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Arefnasab et al. (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Black et al. (2014)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Black et al. (2015)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Bower (2015)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Buijze et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Cahn (2017)	HIGH	LOW	LOW	LOW	SC	LOW	SC
Carlson et al. (2007)	HIGH	LOW	LOW	LOW	LOW	SC	SC
Carlson et al. (2015)	LOW	LOW	LOW	LOW	SC	LOW	LOW
Chacko et al. (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Chen (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Cheung (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Conklin (2018)	SC	LOW	LOW	LOW	LOW	LOW	LOW
Creswell (2009)	LOW	LOW	SC	LOW	LOW	LOW	LOW
Creswell (2012)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Creswell (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Daubenmier et al. (2012)	LOW	LOW	SC	LOW	LOW	LOW	LOW
Duraimani et al. (2015)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Dunne (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Elsenbruch et al. (2005)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Epel et al. (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Fan et al. (2010)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Fang et al. (2010)	HIGH	LOW	SC	LOW	LOW	LOW	SC
Gallegos et al.(2015)	HIGH	LOW	LOW	LOW	LOW	LOW	SC
Ganesan et al. (2020)	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
Gautam (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Gerbarg et al. (2015)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Gonzalez-Garcia et al. (2014)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Gopal et al. (2011)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Groesbeck et al. (2018)	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
Hardgrave (2010)	LOW	LOW	LOW	LOW	HIGH	LOW	SC
Hecht et al. (2018)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Heckenberg et al. (2019)	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
Hidderley and Holt (2004)	SC	LOW	SC	LOW	LOW	LOW	SC
Ho (2012)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Hoge et al. (2018)	LOW	LOW	SC	LOW	LOW	LOW	LOW
Huberty et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Hung et al. (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Hur et al. (2014)	HIGH	LOW	LOW	LOW	HIGH	SC	HIGH
Innes et al. (2018)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Irwin and Olmstead (2012)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Irwin et al. (2014)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Jam (2010)	HIGH	LOW	HIGH	LOW	LOW	LOW	HIGH

Table 2 (continued)

Report	Domain 1: Randomization	Domain 2: Deviation from Intervention	Domain 3: Missing Data	Domain 4: Measurement of Outcome	Domain 5: Selection of Reported Results	Other Bias	Overall Rob
Janelsins (2011)	LOW	LOW	SC	LOW	LOW	LOW	SC
Keng et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Lavretsky et al. (2011)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Lavretsky et al. (2013)	LOW	LOW	SC	LOW	LOW	SC	SC
Lee (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Lengacher et al. (2012)	HIGH	LOW	HIGH	LOW	LOW	LOW	HIGH
Lengacher et al. (2013)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Lengacher et al. (2014)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
MacDonald et al. (2018)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Malarkey et al. (2013)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Marciniak et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
McCarthy et al. (2017)	HIGH	LOW	LOW	LOW	LOW	LOW	SC
McIntyre et al. (2018)	HIGH	LOW	HIGH	LOW	LOW	HIGH	HIGH
Memon et al. (2017)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Meyer et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Mirmahmoodi et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Naoroibam et al. (2016)	SC	LOW	SC	LOW	LOW	SC	SC
Ng et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Nguyen et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Nugent et al. (2021)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Oh et al. (2010)	LOW	LOW	HIGH	LOW	LOW	LOW	SC
Oh et al. (2012)	LOW	LOW	LOW	LOW	LOW	N	LOW
Oken et al. (2010)	LOW	LOW	HIGH	LOW	LOW	LOW	SC
Ornish et al. (2008)	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
Pace et al. (2009)	LOW	LOW	HIGH	LOW	LOW	SC	SC
Park and Oh (2012)	HIGH	LOW	HIGH	SC	LOW	LOW	LOW
Prakhinkit et al. (2014)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Puhlmann et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Pullen et al. (2008)	LOW	LOW	LOW	LOW	LOW	SC	LOW
Pullen et al. (2010)	SC	LOW	SC	LOW	LOW	SC	SC
Rao et al. (2015)	HIGH	LOW	LOW	LOW	LOW	SC	SC
Rao et al. (2017)	LOW	LOW	SC	LOW	LOW	N	LOW
Reich et al. (2017)	LOW	LOW	HIGH	LOW	LOW	SC	SC
Robinson et al. (2003)	HIGH	LOW	HIGH	LOW	LOW	SC	HIGH
Rodriguez-Pena et al. (2014)	HIGH	LOW	LOW	LOW	LOW	SC	SC
Rosenkranz et al. (2013)	SC	LOW	HIGH	N/A	LOW	SC	HIGH
Sanabria-Mazo et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Sarenmalm et al. (2017)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
SeyedAlinaghi et al. (2012)	LOW	LOW	SC	LOW	LOW	SC	SC
Sharma et al. (2015)	SC	LOW	LOW	LOW	LOW	LOW	SC
Shields et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Smith et al. (2018)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Sohl et al. (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Taylor (1995)	SC	LOW	SC	LOW	LOW	HIGH	HIGH
Tenfelde et al. (2019)	HIGH	LOW	LOW	LOW	LOW	LOW	SC

Table 2 (continued)

Report	Domain 1: Randomization	Domain 2: Deviation from Intervention	Domain 3: Missing Data	Domain 4: Measurement of Outcome	Domain 5: Selection of Reported Results	Other Bias	Overall Rob
Thokchom et al. (2018)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Tolahunase et al. (2017)	HIGH	LOW	LOW	LOW	LOW	LOW	SC
Tolahunase et al. (2018)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Turner et al. (2020)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Villalba et al. (2019) 1	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Villalba et al. (2019) 2	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Walsh et al. (2016)	HIGH	LOW	HIGH	LOW	LOW	LOW	HIGH
Wang (2017)	LOW	LOW	LOW	LOW	LOW	SC	SC
Webb et al. (2018)	LOW	SC	LOW	SC	LOW	LOW	SC
Wetherell et al. (2020)	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
Wirth (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Witek-Janusek (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Yadav et al. (2012)	HIGH	LOW	SC	LOW	LOW	SC	SC
Zautra et al. (2008)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Zgierska et al. (2016)	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Zgierska et al. (2019)	LOW	LOW	LOW	LOW	LOW	LOW	LOW

belonging to the leukocyte category. Furthermore, leukocytes produce both pro and anti-inflammatory cytokines, and the examination of this category alone does not clearly specify which outcome is more likely to be impacted. Thus, questions remain about which specific immune cells and processes may be associated with the greatest benefit from meditative interventions.

Immunoglobulins Meditative interventions were associated with a moderate effect size for immunoglobulins, also suggesting that these practices may protect against bacterial and viral infections, as well as reduce the risk of diseases associated with dysregulated immunoglobulin levels (Ludvigsson et al., 2015; Perez et al., 2017). Furthermore, a significant effect size was revealed for the single-level biomarker, sIgA. IgA is often considered in terms of its ability to prevent infection, but it also serves a proinflammatory role (Hansen et al., 2019), and dysregulated IgA levels are associated with activated NF-κB and release of IL-6 and TNF-α in some diseases (Apeland et al., 2020).

Table 3 Meta-analyses for primary effect sizes of the effect of meditative interventions

Effect Sizes for Control and Meditative Conditions								
	k	*N*	*g*	SE	Lower	Upper	*Z*	*p*
Control Condition	86[b]	3003	-0.001	0.029	-0.058	0.056	-0.023	.982
Meditative Intervention	105	3826	0.181	0.026	0.128	0.230	6.818	.000
Effect Sizes by Inclusion of Control Condition								
No	18	591	0.161	0.066	0.032	0.29	2.438	.015
Yes	87	3235	0.186	0.030	0.127	0.25	6.139	.000
Effect Sizes by Type of Control Condition								
	k[ab]	*N*	*g*	SE	Lower	Upper	*Z*	*p*
Active Control	43	1304	-0.053	0.030	-0.112	0.006	-1.765	.077
Mind–body	43	1457	0.089	0.029	0.031	0.146	3.031	.002
WL/TAU	44	1712	0.043	0.046	-0.047	0.134	0.935	.350
Mind–body	44	1765	.248	0.046	0.157	0.339	5.356	.000

All *p*-values equal to .000 are < .00005. [a]Huberty et al. (2019), McCarthy et al. (2017), Park and Oh (2012) included a wait-list-control but did not assess biomarkers pre and post. [b] Prakhinkit et al., (2014) included both an active and WL/TAU control group. WL/TAU = waitlist and treatment-as-usual groups. *k* = number of effect sizes in the category, *g* = effect size

Lower = 95% lower confidence interval, Upper = 95% upper confidence interval, *Z* = *Z* statistic

p = significance level

Table 4 Meta-Analysis of Moderators of the Effect of Meditative Interventions

Category of Sample[a]								
	k[b]	N	g	SE	Lower	Upper	Z	p
Healthy	29	1097	0.087	0.05	-0.014	0.188	1.693	.090
Physiological disorder	58	2034	0.220	0.036	0.149	0.292	6.035	.000
Psychological disorder	20	713	0.218	0.061	0.099	0.338	3.585	.000
Category of Delivery								
	k[c]	N	g	SE	Lower	Upper	Z	p
Asynchronous	7	213	0.283	0.114	0.060	0.505	2.488	.013
Synchronous	99	3670	0.173	0.028	0.118	0.228	6.141	.000
Category of Intervention								
	k	N	g	SE	Lower	Upper	Z	p
MBI	48	1097	0.111	0.037	0.038	0.184	2.994	.003
Meditation-Focused	22	2034	0.177	0.060	0.060	0.295	2.950	.003
MMI	35	1329	0.273	0.044	0.186	0.360	6.154	.000

All p-values equal .0000 are < .00005. MBI = Mindfulness-based intervention; Meditation = Interventions primarily focused on meditation; MMI = Mindful-movement interventions. [a]For category of sample, the effect sizes are reported three digits to the right of the decimal to distinguish the values for the effect size and the p-value in the healthy category and to distinguish the effect sizes for the physical and psychological categories. [b]Lengaucher et al. (2012) included both healthy participants and those with physiological disorders, and Hur et al. (2014) included both healthy participants and those with psychological diagnoses. [c]Sarenemalm et al. (2017) included both an asynchronously delivered intervention and a synchronously delivered intervention. k = number of effect sizes in the category, g = effect size

Lower = 95% lower confidence interval, Upper = 95% upper confidence interval, Z = Z statistic

p = significance level

Thus, the significant effect size for IgA may be indicative of decreased inflammatory responses as well as protection against infection.

NF-κB Finally, results indicated that meditative interventions were associated with a large effect size for NF-κB. The cellular transcription biomarker, NF-κB, influences inflammatory genes responsible for encoding TNF-α and IL-6 (among others), and these proinflammatory cytokines further activate NF-κB pathways (Liu et al., 2017). The significant effect size for NF-κB, alongside the other findings for TNF-α, IL-6, and IgA, may suggest that epigenetic changes are a critical mechanism of meditative interventions for improving health outcomes. This supposition is supported by other research, more broadly, which indicates that mind–body practices have epigenetic effects (Cozzolino et al., 2017). Nevertheless, very few studies eligible for review included assessments of cellular transcription, and thus firm conclusions are unwarranted.

Limitations and Future Directions

Several limitations of the meta-analytic review must be considered. Although we adopted various strategies to uncover unpublished studies, only a few were eligible for inclusion. Yet, the "file drawer problem" unlikely had any undue effect on the current meta-analyses for several reasons. First, many of the published articles reported nonsignificant findings for the immune measures, and second, the meta-analytic indices suggested a lack of publication bias. Additionally, the risk of bias assessment indicated that the majority of the studies included in the meta-analysis were unlikely influenced by systemic reporting biases. This suggests that, overall, the studies in the meditative literature are high in internal validity. Nevertheless, we acknowledge that the meta-analysis included observational studies without control groups, which could be considered a limitation. There was no evidence that the average effect of these studies was different

Table 5 Meta-analyses by immune categories of the effect of meditative interventions

	k[a]	N	g	SE	Lower	Upper	Z	p
Antibodies/Immunoglobulins	6	110	0.419	0.134	0.157	0.680	3.134	.002
Inflammatory Mediators	68	2447	0.149	0.034	0.083	0.215	4.417	.000
Leukocytes	20	695	0.124	0.063	0.001	0.247	1.977	.048
NF-κB	4	64	0.890	0.192	0.514	1.266	4.643	.000
Cellular aging	18	959	0.212	0.065	0.085	0.339	3.263	.001

from (or larger than) those that included control groups. As with most meta-analyses, our findings are limited by heterogeneity across sample types (healthy, psychological, or physiological disorders and meditative intervention protocols. The considerable variability in the meditative interventions (e.g., type, duration and amount of practice, additional intervention components) hampers firm conclusions about the active components of the interventions responsible for the observed effects. Arguably, meditative interventions are best implemented prior to (preventatively) or early in disease processes, but not enough research has been conducted to examine how the timing of the intervention impacts immune functioning. In addition, statistically significant improvements in immune functioning may not always have clinically meaningful implications. Further, it is unclear whether and for how long changes in immune functioning are sustained following interventions. Certainly, much additional research is needed to fully understand the effects of meditation on immune functioning among a variety of interventions and populations.

Reports in the popular media regarding the benefits of meditative interventions on immune function have been based on mixed yet promising, empirical evidence. Furthermore, misinformation regarding meditation-related research is currently being disseminated in the media based on assumptions that are yet to be proven, creating a risk of public misinformation regarding the effects of meditative interventions on immune functioning (National Center for Complementary & Integrative Health, 2016). Importantly, stakeholders interested in meditative intervention research (i.e., clinicians, patients, and policymakers) require additional evidence to understand more fully how meditative interventions may influence immunity and health. Nevertheless, the current meta-analysis advances our understanding of unresolved questions in the literature, including whether the health of the sample as well as whether the type and length of interventions are associated with immunity and health. Our meta-analytic findings provide compelling evidence that several moderating factors influence the effect size indicating the possible association between meditative interventions and immune function (e.g., the health status of the sample, intervention subtype and duration, and category of the immune function). Meditative interventions appear to offer favorable immune benefits to individuals diagnosed with physiological and psychological disorders, though there is far less evidence regarding healthy populations. Further, meditative interventions with longer durations appear to have greater influence on immune functioning, which has implications for the designs of meditative interventions and meditative practices, more generally.

Directions for future research include the need for studies to further delineate the benefits of specific types of meditative intervention on specific categories of immune functioning. Our meta-analysis highlights a need for thoughtful consideration in the design of future studies that aim to examine improvements in immune function associated with meditation, given normal baseline immune function among healthy participants. Although resource-intensive, longitudinal approaches may be required to answer these questions. Finally, a critical next step is for studies to compare the specific effects of various types of meditative interventions to each other as well as to other established therapies and treatments (Hunt et al., 2018; Kinser & Robins, 2013).

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Author Contributions Danielle L. Oyler coded studies, assisted with analyses, as well as wrote and edited the manuscript. Jennifer M. Hulett coded studies, made decisions regarding biomarker directionality, and provided edits to the manuscript. Steven D. Pratscher performed literature searches, coded studies, and wrote and edited the manuscript. Mollie A. Price-Blackshear performed literature searches, coded studies, and provided edits to the manuscript. E. Angela Murphy coded studies and made decisions regarding biomarker directionality. B. Ann Bettencourt performed literature searches, coded studies, analyzed data, and contributed to writing and editing manuscripts.

Data Availability The data are being further analyzed and are not publicly available at this time.

Declarations

Ethical Approval The current work analyzed existing data only.

Informed Consent The current work analyzed existing data only.

Conflict of Interest The authors declare that they have no conflict of interest.

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