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REVIEW PAPER

Yoga, Mindfulness, and Meditation Interventions for Youth with ADHD: Systematic Review and Meta-Analysis

Alyssa L. Chimiklis[1,2] · Victoria Dahl[2] · Angela P. Spears[2] · Kelly Goss[2] · Katie Fogarty[2] · Anil Chacko[2]

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is a chronic developmental disorder affecting 3–7% of children. In light of the growing utilization of yoga, mindfulness, and meditation in ADHD populations and potential benefits it has on ADHD symptoms, executive function deficits, and social functioning, we sought to evaluate these interventions for youth with ADHD. The primary aim of this review paper is to identify the efficacy of these programs for the treatment of youth with ADHD through a systematic review and meta-analysis. A systematic literature search was conducted in the following electronic databases: PsychINFO, ERIC, PubMed, and MEDLINE. Studies were included in the meta-analytic review if participants were between 5–17 years old, had a diagnosis of ADHD or met symptom threshold on psychometrically-validated measure of ADHD symptoms, was a treatment outcome study, and was published in a peer-reviewed English-language journal. The effect sizes of eleven studies demonstrate that yoga, mindfulness-based interventions, and/or meditation had a statistically significant effect on the outcomes of ADHD symptoms, hyperactivity, and inattention (parent and teacher report), as well as parent-child relationship, executive functioning, on-task behavior, parent stress, and parent trait-mindfulness ($p < 0.05$). The effect sizes range from small to large effects across these outcomes. Considerable risk for bias was found across studies. Given significant methodological limitations of the literature, positive effect sizes found in studies should be interpreted with caution; these interventions should not be considered first-line interventions for ADHD. However, preliminary findings suggest yoga, mindfulness, and meditation may be beneficial for youth with ADHD, but extensive research is required to validate the efficacy of these interventions.

Keywords Attention deficit/hyperactivity-disorder · ADHD · Yoga · Mindfulness · Meditation

Attention-deficit/hyperactivity disorder (ADHD) is a chronic neurodevelopmental disorder affecting 3–7% of school-aged children and is characterized by developmentally inappropriate levels of inattention, hyperactivity, and impulsivity (APA 2013). Individuals with ADHD are at greater risk of interpersonal difficulties, poor grades, as well as lower rates of secondary education, all of which are irrespective of socioeconomic status (Barkley 2002; Loe and Feldman 2007). There is extensive support that individuals with ADHD frequently exhibit multiple core deficits, as many children with ADHD have impairment in working memory, attention, emotion dysregulation, as well as response inhibition (Anastopoulos et al. 2011; Fried et al. 2016; Sonuga-Barke et al. 2010). Moreover, comorbidity with other mental health disorders (e.g., depression, anxiety) is common (Borden et al. 2016; Overgaard et al. 2016).

Evidenced-based psychosocial (behavioral) and pharmacological interventions are the two most frequently utilized treatments for ADHD. While effective, both treatment approaches have limitations, including lack of significant effects on some key outcomes such as academic achievement (Langberg and Becker 2012; Raggi and Chronis 2006) and executive functioning (Evans et al. 2017b; Jarrett 2013; Steeger et al. 2016). Furthermore, parental perceptions of stimulant medication on their child's overall health and preference for non-medication treatments have resulted in the limited use and compliance of stimulant medication (Chacko et al. 2010). Lastly, the effects of behavioral

✉ Alyssa L. Chimiklis
achimiklis@gmail.com

[1] Department of Psychology, The Graduate Center—The City University of New York, New York, NY, USA

[2] Department of Applied Psychology, New York University, New York, NY, USA

interventions do not appear to generalize to non-target settings or behaviors (Rajwan et al. 2012). Given the limitations of current evidence-based treatments for ADHD, there is ongoing investigation of novel and complementary approaches to treatment (Chacko et al. 2014).

The traditions of yoga and mindfulness are two separate, but interrelated practices focusing on the well-being of the individual and may be useful in the treatment of ADHD. Yoga is a holistic system comprised of several components, which include physical postures, breathing exercises, deep relaxation, as well as mindfulness-based and meditation practices (Butzer et al. 2015). Yoga has been shown to positively affect physical and mental states and reduce stress in both clinical and non-clinical settings (Büssing et al. 2012; Hagen and Nayar 2014).

Recent studies on yoga have also reported improvements in the core domains associated with ADHD (e.g., self-regulation, attention, academic performance, executive function; Bergen-Cico et al. 2015; Butzer et al. 2015; Luu and Hall 2016). Furthermore, yoga has also been shown to decrease anxiety and depression symptoms across a range of populations by increasing the regulation sympathetic nervous system and hypothalamic-pituitary-adrenal system (Pascoe and Bauer 2015). These findings are pertinent because ADHD is often co-morbid with these psychiatric disorders. Although still in its infancy, research on the potential benefits of yoga in clinical populations is expanding (Jeter et al. 2015). Systematic reviews of the literature a decade ago suggested that the clinical application of yoga may be beneficial for pediatric populations, but further research with a higher standard of methodology is needed (Birdee et al. 2009; Galantino et al. 2008).

Multiple definitions of meditation have been identified. For example some scientists define meditation as mental training techniques where as others view it as an altered state of consciousness (Nash and Newberg 2013). For the purposes of this paper, we will focus on mindfulness as a type of meditative technique. Mindfulness meditation encompasses directing attention to present thoughts, emotions or bodily sensations such as the movement of the belly while breathing in and out. According to Bishop et al. (2004), mindfulness is cognitive and intention-based and involves the self-regulation of attention to the present moment with an accepting orientation to one's experiences. Multiple mindfulness studies have shown that acting with openness and nonjudgmental awareness leads to both physical and mental health benefits (Davidson et al. 2003; Miller et al. 1995). Mindfulness approaches, as well as more structured treatment (i.e., mindfulness-based stress reduction [MBSR] and mindfulness-based cognitive therapy [MBCT]) has been shown to promote one's overall well-being, improve executive function, academic performance, attention, and self-regulatory abilities, as well as reduce stress and social problems (Hylander et al. 2017; Schonert-Reichl et al. 2015; Tang et al. 2014; Tsai and Chou 2016).

Given the effects of yoga, mindfulness, and meditation on key processes (e.g., executive functions; Tsai and Chou 2016) and outcomes (e.g., academic performance, behavioral self-regulation, attention; Bergen-Cico et al. 2015; Butzer et al. 2015; Schonert-Reichl et al. 2015; Tang et al. 2014) associated with ADHD, it comes as no surprise that these approaches have been evaluated as treatments for individuals with ADHD or concerns related to attention, overactivity, and impulsivity. Preliminary research suggests that individuals with attentional difficulties who participated in mindfulness trainings benefited significantly in the domains of inhibition, objective aspects of attention, and self-reported ADHD symptoms (Zylowska et al. 2008). Similarly, initial studies of yoga practices have also demonstrated improvements in ADHD symptoms and aspects of attention (Harrison et al. 2004; Jensen and Kenny 2004). Overall, these findings indicate that yoga, mindfulness, meditation practices may have the potential to provide relief of ADHD symptoms, improve executive functions, and the behaviors associated with inattention and impulsivity.

Given the increased empirical evaluation of yoga, mindfulness, and meditation approaches for the treatment of ADHD, there is also a need to systematically review and evaluate this burgeoning literature. To our knowledge, there have been three reviews of this literature. Krisanaprakornkit et al. (2010) conducted a systematic review of meditation therapies to assess the effectiveness of these therapies as a potential treatment for ADHD. However, only four studies were included in the review, two of which were dissertations. The small sample size, as well as high risk of bias prohibited Krisanaprakornkit et al. (2010) from determining whether meditation therapy was effective for individuals with ADHD.

Household and Solanto (2016) reviewed mindfulness as a potential intervention for individuals with ADHD. More specifically, a qualitative synthesis of the literature was provided as the search process focused broadly on both adults and children with ADHD and did not employ standard guidelines for conducting systematic reviews (e.g., PRISMA or inclusion criteria). Overall, their review concludes that mindfulness should be further explored as it that has been shown to increase attention and emotional regulation in healthy and clinical populations. While this review is optimistic about the merits of mindfulness; the review was both unsystematic and qualitative in nature. Therefore, a quantitative review is needed to in order to provide more clear support regarding the potential merits of mindfulness.

Most recently, Evans et al. (2017a) conducted a systematic review and qualitative summary of the yoga,

mindfulness, and meditation literature for youth with ADHD. Importantly, they found that compared to meditation-based interventions that involved the child only, interventions that involved both the parent and the child demonstrated more consistently improved ADHD symptoms and well-being, less incidence of poorer outcomes, and more favorable outcomes for parents (i.e. parent stress, parent psychopathology, and adaptive parenting strategies). However, results indicated more limited support for a reduction in internalizing/externalizing symptoms associated with ADHD and for an improvement in parent-child relationships. Importantly, given the poor methodological quality of the reviewed studies, the authors determined that no definitive conclusions could be drawn regarding the utility of meditation-based interventions for children with ADHD. Our goal is to extend the literature by focusing on key questions that have yet to be explored. More specifically, this review includes determining the effects of interventions on key outcomes yet evaluated in previous studies (e.g., parent trait mindfulness), exploring the impact of standardized interventions (MBSR and MBCT), as well as determining the role of potential moderators to treatment outcome (e.g., intervention type, study design, length and number of intervention sessions). Collectively, this review has the potential to further provide clarity on the potential benefits of yoga, mindfulness, and meditation as well as point to areas for further research.

To our knowledge, a systematic review and meta-analysis of yoga, mindfulness, and meditation focusing specifically on children with ADHD has not been completed. Importantly, there are some notable limitations to systematic, as well as qualitative, reviews of the ADHD literature (i.e., Evans et al. 2017a, b; Household and Solanto 2016; Krisanaprakornkit et al. 2010), including the fact that, without a quantitative approach to summarize the literature, they are only able to make inferences about the consistency of findings, and to speculate about how findings might significantly vary by subgroups and/or moderator variables (e.g. intervention type, children formally diagnosed with ADHD vs. those who are not, etc.). Additionally, there is the possibility that the conclusions drawn in systematic reviews may be biased in favor of studies with smaller sample sizes, given that studies with small sample sizes tend to have much larger positive effect sizes than do studies with larger sample sizes (Slavin and Smith 2009).

Alternatively, meta-analysis offers several advantages that address these issues. A meta-analysis uses statistical analyses to mathematically combine the data from the individual studies, which increases the size of the "overall sample" (i.e. the sample sizes of all of the studies combined) and thus enhances the statistical power of the analysis and reduces the size of the confidence interval for the point estimate of the effect—this provides a more precise estimate of the "true effect" of the intervention, rather than just an inference (Garg et al. 2008). Additionally, when computing the combined effect size, a meta-analysis is able to take into account the sample size of each included study and adjust how much weight each study has on the combined effect size accordingly. A meta-analysis also controls for studies with small sample sizes, which can inaccurately inflate the combined effect size (Slavin and Smith 2009). This is achieved by assigning greater weight to studies with larger sample sizes. In addition, meta-analytic approaches allow for estimating the effect of a moderator on the effect size, thereby allowing for the determination of potential moderators of treatment. Moderator analysis not only offer insights into subgroups for which an intervention may have differential impact but also allows for further investigation into treatment modifications to improve potency. Collectively, meta-analyses provide the field with a clearer picture of the effect of an intervention and provides greater confidence when considering future directions.

In light of the growing utilization of yoga, mindfulness, and meditation in ADHD populations and its potential benefits, we sought to conduct a systematic review and meta-analysis of the literature. While all three promising interventions are interrelated, there are variations among each intervention, which ultimately may yield different beneficial outcomes. For instance, yoga involves the movement of physical postures; whereas mindfulness and meditation practices encompass attention to the breath, bodily sensations, as well as emotions and generally does not involve physical movement. Consideration should be given to how these variations influence the processes, mechanisms, and outcomes of each intervention. MBSR and MBCT also warrant further examination as these interventions were designed specifically for adults with anxiety and depression and may be less effective for school-aged children with ADHD. Thus, the primary aim of this meta-analysis was to analyze how these three interventions influence ADHD related outcomes. The secondary aim was to evaluate how certain moderators including intervention type may impact the effectiveness of these interventions, as well as ADHD related outcomes.

Method

A systematic literature search to identify potential studies that utilized yoga, mindfulness and meditation for the treatment of ADHD in youth was conducted using the following electronic databases: PsychINFO, ERIC, PubMed, and MEDLINE. We employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (http://www.prisma-statement.org) as part of the search process. In addition, the

reference section of empirical articles as well as the review papers identified through the initial database search were reviewed to identify additional studies. We used the following key terms for our search on each database: yoga, mindfulness, meditation, Attention Deficit Hyperactivity Disorder, ADHD, Attention Deficit Disorder, hyperactivity, hyperkinesis, inattention, and impulsivity.

A study was included if it (a) included youth (ages 5–17) diagnosed with ADHD or 50% of the sample identified exhibited significant symptoms of inattention, hyperactivity, or impulsivity (parent or teacher rated), (b) determined the short- and/or longer term treatment effects of yoga and/or mindfulness programs (c) was published from 1990–2015 in a peer-reviewed English language journal, (d) summarized specific yoga and/or mindfulness interventions, and (e) was either a randomized controlled, non-randomized controlled, or non-controlled treatment outcome study. The identified studies were then coded using the following variables: authors and year of publication, total sample size, age range of study participants, comparison group, and the outcome measures used.

In an effort to compare the findings across studies, the dependent variables for each study were classified into categories based on measures of the same construct. The constructs measured as a dependent variable by more than one study, and therefore included in the meta-analysis, include: ADHD symptoms, inattention/attention problems, and hyperactivity, reported by parents and teachers, as well as on-task behavior, executive functioning, child-parent relationships, parenting stress, and parent trait-mindfulness.

To determine the size and direction of treatment effects for each category of dependent variable, effect size estimates were computed using computer-based software (i.e., CMA 2.0; Borenstein et al. 2005). The direction of treatment effects was set so that positive values implied greater improvement in subjects receiving the intervention across outcomes. Estimates of the effect size for each study were calculated from the information provided from the article; if information was missing, the authors of the study were contacted to obtain the information. Individual study and summary effect sizes were calculated using the Hedges' g formula (Hedges and Olkin 1985). Effect size estimates were analyzed using conventional random-effects meta-analytic procedures (Hedges and Olkin 1985). The random-effects model was utilized because for the vast majority of meta-analyses the random-effects model is the more appropriate choice (vs. the fixed-effect model) because the studies in most meta-analyses—including this one—differ in the mixes of participants and in the implementations of interventions (Borenstein et al. 2010). Additionally, the random-effects model is more likely to yield results that can be generalized to a wider array of situations, increasing the external validity of the analysis.

A single meta-analysis was conducted that included a variety of study designs, including randomized controlled trial (RCT), [non-randomized] controlled trial, single arm (i.e. pre/post-test, non-controlled design), and single arm with multiple baselines (i.e. pre/post, non-controlled design with multiple groups with different baselines). While there is a reasonable concern that studies utilizing different designs differ from each other in substantive ways, there are no technical barriers to using studies with different designs in the same analysis (Borenstein et al. 2009). To account for these possible differences, study design was included as a potential moderator, as recommended by Borenstein et al. (2009).

For each summary effect size, we calculated 95% confidence intervals and statistical significance. Q statistics were calculated to infer the presence or absence of heterogeneity. For all statistically significant Q values, I^2 was calculated to determine the proportion of observed variance that reflects real differences—as opposed to differences due to sampling error—in effect size (Borenstein et al. 2009). For interpretation purposes, I^2 values of 25, 50, and 75% are interpreted as low, moderate, and high proportions, respectively, of real differences in effect size (Higgins et al. 2003). Additionally, given the lack of prior relevant meta-analyses to provide indication of the magnitude of effect obtained on different types of outcomes by yoga/mindfulness/meditation interventions for children with ADHD, we utilize Cohen's (1988) conventions to interpret the summary effect sizes obtained by our meta-analysis (i.e., effects sizes of 0.20 are "small" in magnitude, those around 0.50 are "medium", and those around or above 0.80 are "large").

Risk of bias was assessed using the Cochran Methods of Bias (Higgins et al. 2011) and includes the following six domains: (1) Selection bias; (2) Performance bias; (3) Detection bias; (4) Attrition bias; (5) Reporting bias; and (6) Other biases. Risk of Bias was further investigated at the individual study level using the ROBINS-I tool (Risk of Bias in Non-randomized Studies of interventions; Sterne et al. 2016). A total of seven domains were assessed (1) Confounding; (2) Selection; (3) Classification; (4) Deviations from Intended Interventions; (5) Missing Data; (6) Outcome measurement; and (7) Selective Reporting.

Results

Characteristics of the Studies

As shown in the flowchart depicted in Fig. 1, we identified seven hundred and seventy two publications through our initial database search; after duplicates were removed and articles screened, twenty three articles were identified for

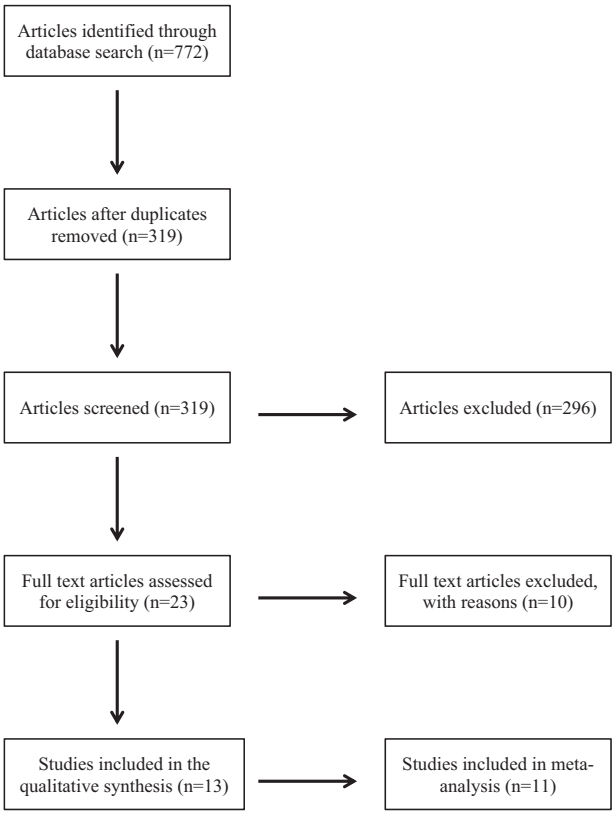

Fig. 1 Flowchart describing the process for identifying relevant literature

possible inclusion in the review. Ten additional articles were further excluded following full-text review because these articles did not meet inclusion criteria (e.g., ADHD was not primary diagnosis or sample contained adults). Of the thirteen articles that met inclusion criteria, two (Singh et al. 2010; Murrell et al. 2015) were excluded from the meta-analysis (but are included in the qualitative synthesis in the discussion section of this paper) because they did not measure constructs in common with the other included studies.

Coding and Reliability

The members of a team of trained coders (3 coders per team) individually rated each article that met inclusion criteria using a detailed coding manual. The agreement rate between coders was 93% across the thirteen studies. Disagreements between coders were resolved by consulting the respective paper and by group discussion and consensus.

Characteristics of Included Studies

Table 1 provides a summary of the major characteristics of the studies included in the meta-analysis. Most of the studies included in the meta-analysis were conducted in the period of time from 2011 to 2015 (55%). The majority of the studies used a within-subjects study design (73%), while only 18% of the included studies were considered randomized-controlled trials. The most frequently evaluated

Table 1 Percentage and frequency of study characteristics ($n = 11$)

Characteristics	Percentage	Frequency
Type of intervention		
Yoga	27%	3
Meditation	18%	2
Mindfulness training	37%	4
Yoga and meditation	18%	2
Experimental design		
Between-subjects	27%	3
Within-subjects	73%	8
Participant assignment		
Randomized	18%	2
Nonrandomized	82%	9
Sample size		
1–20	73%	8
21–40	9%	1
41+	18%	2
Children on medication for ADHD		
Included	73%	8
Excluded	0%	0
Not specified	27%	3
Treatment fidelity assessed		
Yes	64%	7
No	18%	2
Not specified	18%	2
Employed manualized treatment		
Yes	45%	5
No	55%	6
Treatment delivered by		
Trained research staff	27%	3
Not specified	18%	2
Yoga/meditation teacher	18%	2
Licensed clinician	36%	4
Number of intervention sessions		
1–10	45%	5
11–20	37%	4
31–40	9%	1
51–60	9%	1
Length of intervention sessions (min)		
1–25	18%	2
26–50	27%	3
51–75	18%	2
76–100	37%	4

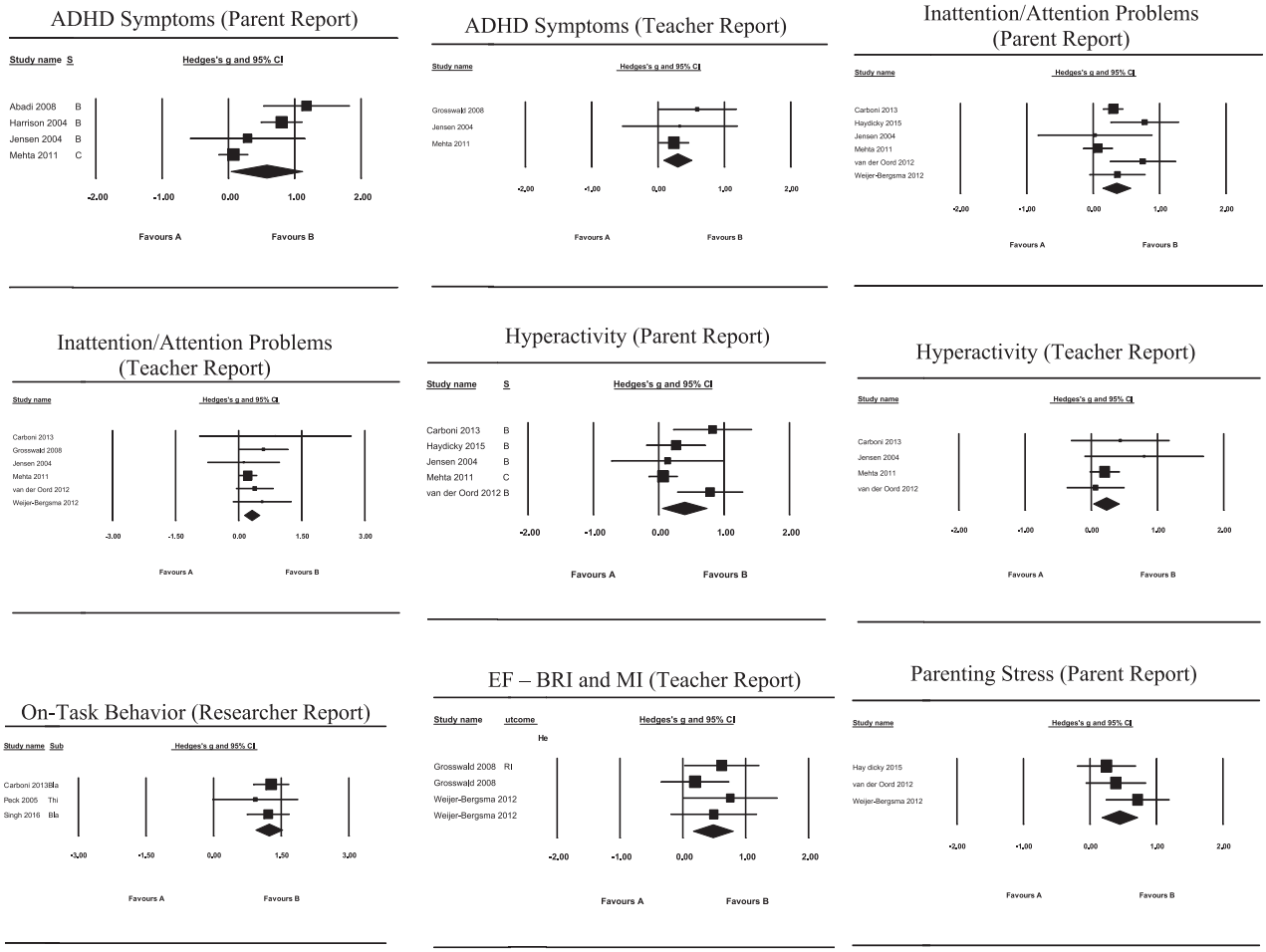

Fig. 2 Forest plots of effect size outcomes

type of intervention was "mindfulness training" (37%), which included interventions derived from mindfulness-based cognitive therapy (MBCT) and mindfulness-based stress reduction (MBSR). The average number of intervention sessions delivered was 23 ($SD = 20.71$ sessions), and the average length of those sessions was 57 min ($SD =$ 29.95 min). The treatment was most frequently delivered by trained research staff (27%), and of the remaining studies, the same percentage (18%) had a licensed clinician, a licensed school psychologist, a specialized yoga/meditation teacher, or an unspecified individual deliver the treatment. A majority of the studies assessed treatment fidelity (64%), though fewer than half employed a manualized treatment (45%). The total participant sample sizes of the included studies ranged from 4 to 69, with an average sample size of 23 ($SD = 20.74$) and with a total of 251 participants across the 11 studies. The majority of the studies included participants who were already on medication for the treatment of ADHD (73%).

Meta-Analysis Results

ADHD symptoms

There were four studies that measured parent reported total ADHD symptoms as an outcome, with a combined sample size of $n = 176$. The Hedges' g for ADHD symptoms as reported by parents was 0.570 (95% CI [.029; 1.110]; $p = .039$; see Fig. 2 for effect sizes). Total ADHD symptoms effect sizes, as reported by parents, were significantly heterogeneous (Q_{total} [3] = 18.980, $p < .001$; $I^2 = 84\%$); thus moderator analyses were conducted. A significant moderation effect by the length of intervention session (i.e. how long each individual yoga/meditation/mindfulness session was in minutes) was found (Q_{Model} [1] = 4.779, $p = .029$), with longer intervention sessions being associated with larger effect sizes ($B = 0.013$, $p = .029$). A significant moderation effect by study design (i.e. controlled trial vs. RCT vs. single arm vs. single arm with multiple baselines) was also found (Q_{Between} [3] = 18.980, $p < .001$, $I^2 = 84\%$). The studies using a controlled trial design or a single arm

multiple baseline design demonstrated a large, significant effect of the intervention on ADHD symptoms (parent report), while studies using a single arm or RCT design reported small, insignificant effects. There were no significant differences among effect sizes as a function of intervention type (yoga or yoga and meditation; the studies evaluating mindfulness training and meditation did not measure ADHD symptoms as reported by parents as an outcome), sample size, formal ADHD diagnosis, or number of intervention sessions.

There were three studies that measured teacher-reported total ADHD symptoms as an outcome, with a combined sample size of $n = 99$. The summary ES for ADHD symptoms as reported by teachers was 0.228 (95% CI [.076, .50]; $p = 0.008$; see Fig. 2). ADHD symptoms effect sizes, as reported by teachers, were not significantly heterogeneous (Q_{total} [2] = 1.156, $p = .561$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

Inattention and attention problems

There were six studies that measured parent-reported inattention and attention problems as an outcome, with a combined sample size of $n = 146$. The summary ES for inattention and attention problems as reported by parents was 0.345 (95% CI [.133, .556]; $p = .001$; see Fig. 2 for effect sizes). Inattention and attention problems effect sizes, as reported by parents, were not significantly heterogeneous (Q_{total} [5] = 10.397, $p = .065$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

There were six studies that measured teacher-reported inattention and attention problems as an outcome, with a combined sample size of $n = 128$. The Hedges' g for inattention and attention problems as reported by teachers was 0.305 (95% CI [.121, .489]; $p = .001$; see Fig. 2 for effect sizes). Inattention and attention problems effect sizes, as reported by teachers, were not significantly heterogeneous (Q_{total} [5] = 2.561, $p = .767$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

Hyperactivity

There were five studies that measured parent-reported hyperactivity as an outcome, with a combined sample size of $n = 127$. The summary ES for hyperactivity as reported by parents was 0.388 (95% CI [.046, .731]; $p = .023$; see Fig. 2 for effect sizes). Hyperactivity effect sizes, as reported by parents, were significantly heterogeneous (Q_{total} [4] = 10.112, $p = .039$; 60%); thus moderator analyses were conducted. A significant moderation effect by the use of a formal diagnosis of ADHD was found, (Q_{Between} [1] = 6.173, $p = .013$, $I^2 = 60\%$), with those studies that required a form diagnosis of ADHD having large, significant effects on hyperactivity (as reported by parents), while the one study measuring hyperactivity (Mehta et al. 2011) that did not require a formal diagnosis had small, insignificant effects. A significant moderation effect by intervention type (i.e. mindfulness training, Yoga, or Yoga and Meditation) was also found (Q_{Between} [2] = 7.049, $p = .029$, $I^2 = 60\%$). The studies using mindfulness-based training interventions (i.e. interventions adapted from MBCT or MBSR) demonstrated a large, significant effect of the intervention on measures of hyperactivity (parent report), while studies using yoga (only) or a yoga and meditation (combined) intervention reported small, insignificant effects. There were no significant differences among effect sizes as a function of study design, sample size, or number or length of intervention sessions.

There were four studies that measured teacher reported hyperactivity as an outcome, with a combined sample size of $n = 110$. The Hedges' g ES for hyperactivity as reported by teachers was 0.219 (95% CI [.025, .413]; $p = .027$; see Fig. 2 for effect sizes). Hyperactivity effect sizes, as reported by teachers, were not significantly heterogeneous (Q_{total} [3] = 2.377, $p = .498$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

On-task behavior

There were three studies that measured researcher-observed on-task behavior as an outcome (teachers were not blind to the treatment), with a combined small sample size of $n = 18$. The summary ES for on-task behavior as observed by researchers was 1.219 (95% CI [.921, 1.516]; $p < .001$). On-task behavior effect sizes, as observed by researchers, were not significantly heterogeneous (Q_{total} [2] = 0.439, $p = .803$), indicating no heterogeneity among these estimates; no moderator analyses were conducted.

Executive function

There were two studies that measured teacher-reported executive function, specifically using the metacognitive index (MI; i.e. the child's ability to initiate, plan, organize, self-monitor, and sustain working memory) of the BRIEF (Gioia et al. 2000), as an outcome, with a combined sample size of $n = 18$. The summary ES for executive function (MI) as reported by teachers was 0.310 (95% CI [−.122, .742]; $p = .159$; see Fig. 2 for effect sizes). Executive function (MI) effect sizes, as reported by teachers, were not significantly heterogeneous (Q_{total} [1] = 0.435, $p = .510$), indicating no

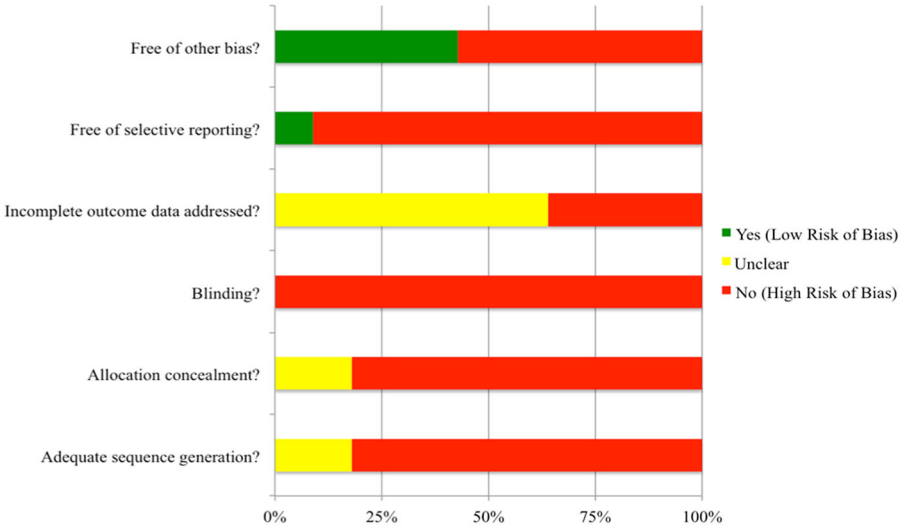

Fig. 3 Cochrane methodological quality graph: review authors' judgements about each methodological quality item presented as percentages across all included studies

heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

There were two studies that also measured teacher-reported executive function using the behavioral regulation index (BRI; i.e. the child's ability to shift cognitive set and modulate emotions and behavior via appropriate inhibitory control) of the BRIEF, as an outcome, with a combined sample size of $n = 18$. The Hedges' g for executive function (BRI) as reported by teachers was 0.673 (95% CI [.201, 1.145]; $p = .005$; see Fig. 2 for effect sizes). Executive function (BRI) effect sizes, as reported by teachers, were not significantly heterogeneous (Q_{total} [1] = 0.076, $p = .783$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

Child-parent relationship

There were two studies that measured child reported child-parent relationship as an outcome, with a combined sample size of $n = 66$. The summary ES for child reported child-parent relationship was 0.499 (95% CI [.248, .749]; $p < .001$; *Note:* outcome data not included in Fig. 3 due to space limitations). Child-parent relationship effect sizes, as reported by children, were not significantly heterogeneous (Q_{total} [1] = 0.095, $p = .758$) indicating no heterogeneity among these estimates—as such, no moderator analyses were conducted.

Parent outcomes

There were two studies that measured parent trait mindfulness (mindfulness awareness) as an outcome, with a combined sample size of $n = 37$. The Hedges' g ES for parent trait mindfulness as reported by parents was 0.307 (95% CI [−.003, .616]; $p = .052$; *Note:* outcome data not included in Fig. 3 due to space limitations). Parent trait mindfulness effect sizes, as reported by parents, were not significantly heterogeneous (Q_{total} [1] = 0.861, $p = .353$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

There were three studies that measured parent-reported parent stress as an outcome, with a combined sample size of $n = 55$. The summary ES for parent stress as reported by parents was .439 (95% CI [.171, .707]; $p = .001$; see Fig. 2 for effect sizes). Parent stress effect sizes, as reported by parents, were not significantly heterogeneous (Q_{total} [2] = 2.001, $p = .368$), indicating no heterogeneity among these estimates. Given the absence of significant heterogeneity, no moderator analyses were conducted.

Risk of Bias

The assessment of the risk of bias is summarized in Fig. 3. Risk of bias was assessed using the Cochrane Risk of Bias Tool for randomized controlled trials and the ROBINS-I for non-randomized trials. Of the eleven included studies only two reported randomization (Abadi et al. 2008; Jensen and Kenny 2004). These two studies had significant methodological limitations (e.g., lack of details regarding methods of randomization; concealment of allocation of sequence; no reported blinding of participants and personnel) (Fig. 4).

Nine of the studies were within-subjects. Therefore participants were aware of the intervention received. Confounding factors such as lack of randomization or control group resulted in the majority of studies being classified as either of critical or serious risk. Participant's poor adherence to intervention, as well as the inadequate implementation of

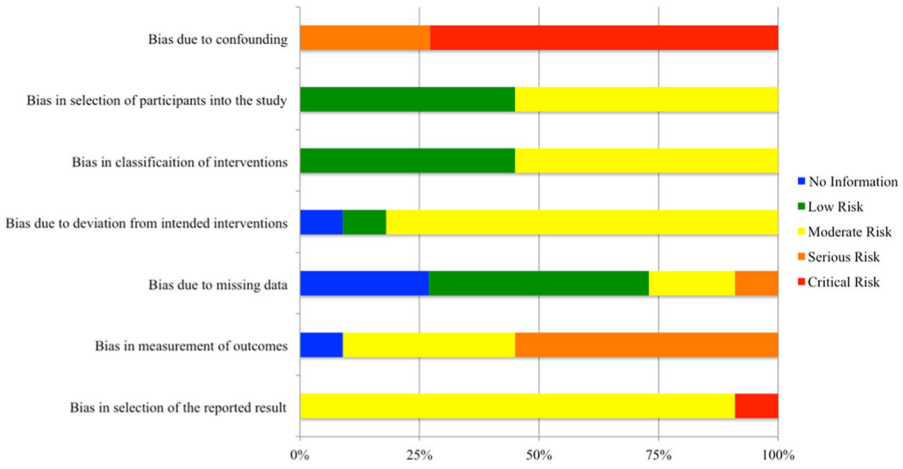

Fig. 4 ROBINS-1 methodological quality graph: review authors' judgements about each methodological quality item presented as percentages across all included studies

the intervention by researchers resulted in nine studies being at moderate risk of deviating from the intended intervention. These studies did not often report on key information (deviations from intervention; missing data), and incomplete information regarding attrition. As an example, while eight studies reported use of medication only three of the studies held medication constant (Singh et al. 2015; Van der Oord et al. 2012; Van de Weijer-Bergsma et al. 2012). Furthermore, three of the studies failed to report medication status (Abadi et al. 2008; Mehta et al. 2011; Peck et al. 2005), thereby increasing the likelihood of biased results.

Discussion

Given the growing utilization of yoga, mindfulness, and meditation in ADHD populations and potential benefits it has on ADHD symptoms, executive function deficits, and social functioning, we sought to systematically review and evaluate these interventions for youth with ADHD. A total of thirteen peer-reviewed studies were identified in which mindfulness-based, yoga and/or meditation interventions were administered to youth with ADHD. Mindfulness training (37%) was the most frequently evaluated treatment intervention.

The results of the meta-analysis demonstrate that yoga, mindfulness-based interventions, and/or meditation had a statistically significant effect on the outcomes of ADHD symptoms, hyperactivity, and inattention (as reported by both parents and teachers), the parent-child relationship, executive functioning, on-task behavior, parent stress, and parent trait-mindfulness ($p < 0.05$). The review's findings are not surprising as prior research has demonstrated these interventions had significant effects on key processes of executive function, behavioral self-regulation, and attention in clinical, as well as healthy populations (Bergen-Cico et al. 2015; Coatsworth et al. 2010; Pascoe and Bauer 2015; Schonert-Reichl et al. 2015; Tsai and Chou 2016).

Tests of heterogeneity were applied to each outcome to determine if the observed variation in effect size between the studies can be attributed to sampling error; if the variation is too great, it indicates that there is variance in the true effect. ADHD symptoms (reported by parents) revealed that the variation between studies might have been the result of something other than sampling error. A moderator analysis determined that session length and study design were the only significant moderators. The regression analysis of session length as a moderator demonstrated a positive relation between length of session and effect size in that an increase in session length is associated with an increase in effect size. The moderator analysis of study design demonstrated that studies using a controlled trial design (Abadi et al. 2008) or a single arm multiple baseline design (Harrison et al. 2004) demonstrated a large, significant effect of the intervention on ADHD symptoms (parent report), while studies using a single arm (Mehta et al. 2011) or RCT (Jensen and Kenny 2004) design reported small, insignificant effects.

The outcome hyperactivity (parent report) was also significantly heterogeneous. A moderator analysis revealed two significant moderators, intervention type and ADHD diagnosis. More specifically, mindfulness-based interventions had a greater effect size than a yoga intervention alone or a combined yoga + mediation intervention. A positive relationship between ADHD diagnosis and effect size was also identified as studies that required a formal ADHD diagnosis had greater effect size than the one study that did not require a formal diagnosis (Mehta et al. 2011). For the remainder of the outcomes, any variance in effect size between the studies is likely due to sampling error.

Given the limited quality of the studies, drawing any well-evidenced conclusions is difficult. However, significant moderators indicate that these differences

(intervention length and type) should be explored more in depth by high quality RCTs. Intervention sessions ranged from 10 to 90 min. Overall, the trend was that longer intervention sessions resulted in greater improvements in ADHD symptoms (per parent report). Longer treatment interventions may be indicative of better outcomes because it allows children the opportunity to become comfortable with, acquire, and consistently utilize skills. Additionally, a longer potency may strengthen neural mechanisms (executive function), as well as improve physiological responses (decrease cortisol) associated with ADHD (Bergen-Cico et al. 2015; Butzer et al. 2015; Luu and Hall 2016) and as such warrants further examination.

Conclusions based on this meta-analysis are limited by several factors. First, the majority of the study formats consisted of within-subjects study design (73%), which limits determining causality of treatment effects. Only two studies were randomized clinical trials (RCT; Abadi et al. 2008; Jensen and Kenny 2004). This likely resulted in inaccurately inflated effect sizes for those studies which used controlled (but non-randomized) or single-arm designs. For example, none of the studies that assessed "on-task behavior"—which was observed and rated in all studies—used a RCT design; as a result, the outcome effect sizes may be inflated due to bias (Carboni et al. 2013; Peck et al. 2005; Singh et al. 2015). Additionally, there were significant methodological limitations across both randomized and non-randomized studies. As an example, neither RCT study reported methods of randomization utilized or concealment of allocations prior to assignment. Generally, studies were also at high risk of attrition and reporting bias. The majority of studies did report rates of attrition but did not report utilizing statistical techniques to address incomplete data. Of importance, 27% of the studies failed to report the medication status of participants. Although most studies allowed participants to remain on medication throughout the course of the study, some studies did not report whether medication status was held constant throughout the intervention, which place these studies at high risk of medication bias. As a result, it is likely that medication could serve as a confound for interpreting the effect sizes for yoga and mindfulness-based, and meditation interventions across outcomes.

The foci of outcome assessments across studies also influenced conclusions of this meta-analysis. For instance, in order to calculate the combined effect size of a particular outcome, at least two of the included studies need to calculate the same outcome. As a result of this requirement, two of the studies (Singh et al. 2010; Murrell et al. 2015) that met inclusion criteria for the review had to be excluded from the meta-analysis because these studies shared no outcomes in common with any of the other studies. Additionally, many of the outcomes were measured by only two or three of the included studies, further indicating that studies evaluating the effects of yoga and mindfulness-based interventions for children with ADHD have chosen considerably disparate outcomes to assess.

A limitation of the meta-analysis itself is that, while the random-effects model is typically the appropriate choice for conducting a meta-analysis (Borenstein et al. 2010), there are some caveats. Importantly, if the number of studies is very small, then the estimate of between study variance will have poor precision and therefore the results should be interpreted with caution. In the case of this meta-analysis, the mean effect size for one outcome (on-task behavior) was based on only three studies (Carboni et al. 2013; Peck et al. 2005; Singh et al. 2015), and four outcomes which included child reported inattention and attention problems (Haydicky et al. 2015; Van de Weijer-Bergsma et al. 2012), teacher reported executive function [MI and BRI of the BRIEF] (Grosswald et al. 2008; Van de Weijer-Bergma et al. 2012), parent-trait mindfulness (Van der Oord et al. 2012; Van de Weijer-Bergsma et al. 2012), and child reported child-parent relationship (Harrison et al. 2004; Haydicky et al. 2015) were based on only two studies.

The outcomes found in this meta-analytic review saw small to large effects as a result of the intervention. However, the low quality of the studies, which is the result of small sample sizes, lack of a control group, and the use of non-manualized treatments, may have potentially inflated the efficacy of the intervention on those outcomes that saw moderate to large effects. Relative to the existing systematic reviews (Evans et al. 2017a, b; Househam and Solanto 2016; Krisanaprakornkit et al. 2010), this meta-analysis concurs with their findings that there is limited support for the positive effects of yoga, mindfulness-based, and or meditation-based interventions on the reduction of internalizing/externalizing symptoms of children with ADHD, in addition to having positive effects on other outcomes.

Notably, this meta-analysis does not support the inference made by Evans et al. (2017a, b) that different meditation-based interventions may have greater efficacy in treating ADHD, as shown by the insignificant effect of intervention type as a moderator on the outcome effect size of ADHD symptoms. As such, the current analyses highlight the important of meta-analytic approaches to determining moderator effects given the limitations of qualitative analyses. Moreover, study design did have a significant effect on the outcome effect size of ADHD symptoms, with those studies using a controlled trial design or a single arm design demonstrating a large effect of the intervention on ADHD symptoms (parent report), while studies using an RCT design reported a small effect, which may account for the lack of difference between intervention types. This same moderator analysis does, however, support the conclusion drawn by the three reviews, that the low methodological

quality of the studies (i.e. their almost universal lack of the use of control groups and/or randomization) does effect the results and therefore decrease their reliability and our ability to draw conclusions about the efficacy of yoga, mindfulness, and/or meditation interventions on ADHD treatment in children.

Importantly, this meta-analysis does extend the literature by providing aggregate effect size estimates across studies. The current meta-analysis identified that the outcomes most effected in yoga, mindfulness and meditation studies are: ADHD symptoms, hyperactivity, and inattention (as reported by both parents and teachers); parent-child relationship, executive functioning, on-task behavior, and parent stress. However, while these outcomes are the most affected in the current review there are likely critical mechanisms, as well as treatment goals that require further attention. For example, investigation into various outcomes that are often problematic in children with ADHD, such as alerting (maintaining alertness) and conflict (shifting attention from one object to another object) (Mullane et al. 2011) is merited. Given that "mindfulness is a mental state of consistent and flexible attention to the present moment", consideration of how mindfulness impacts attentional networks is another area that warrants further investigation (Zylowska 2012). Additionally, mindfulness appears to address deficits in executive function, as well as impulse control by fostering one's capacity to observe impulses without acting upon them (Smalley et al. 2009; Tsai and Chou 2016)—an additional area for future investigation. As such further exploration into key mechanisms and outcomes will allow researchers to determine the process of how yoga, mindfulness and meditation interventions impact key outcomes associated with ADHD in children.

Parents frequently face many stressors related to their child's ADHD and research suggests that engaging in mindful parenting may increase positive parent-child interactions and decreases negative parental reactions (Lippold et al. 2015). Therefore, the next generation of studies would benefit greatly from designing higher quality studies that include parents in the intervention and focus also on parent-related outcomes. The present review identified that mindful or meditation parent training (Harrison et al. 2004; Haydicky et al. 2015; Van der Oord et al. 2012; Van de Weijer-Bergsma et al. 2012) demonstrated moderate effects in outcomes such as parent-stress and parent-child relationship in comparison to other treatment outcomes. Importantly, these conclusions were drawn by comparing the effects across multiple studies versus a well-designed evaluation of these interventions with and without parental involvement. As such future studies should strongly consider directly comparing the influence of parental involvement.

Standardization of the interventions, such as manualized treatments (less than half of the studies used manualized treatments) will allow for improved assessment of key features of an intervention (e.g., treatment fidelity, engagement, and attendance) that is necessary to validate the efficacy for yoga, mindfulness, and meditation interventions for individuals with ADHD. This is particularly important given the requirement of treatment manuals for dissemination of interventions. In addition, closer attention must be paid to length (e.g., 30 min) and number of classes (once per week vs. twice per week), as well as the duration of the intervention (e.g., 12 weeks), given the moderating role of these factors on effect size outcomes.

Some research supports that the physical aspects of yoga (Vysniauske et al. 2016; Neudecker et al. 2015) may contribute to its effectiveness as intervention versus mindfulness or mediation alone, particularly for children with ADHD. Overall, these studies have found that longer interventions of yoga have led to modest improvements in domains closely associated with ADHD such as executive functions and motor skills. Interestingly, the present review found that studies using mindfulness-based training interventions (i.e. interventions adapted from MBCT) demonstrated a large, significant effect of the intervention on measures of hyperactivity while studies using yoga (only) or a yoga and meditation intervention reported only small, insignificant effects. Therefore future studies should give consideration to how components of mindfulness (breath) and yoga (postures) may impact behavioral, as well as neurocognitive outcomes.

To critically evaluate the efficacy of yoga, mindfulness, and mediation interventions, blinded ratings of behavior should also be implemented. While the current review found studies using a controlled trial design or a single arm multiple baseline design reported a large significant effect of the intervention on ADHD symptoms via parent report, these studies were within-in subject and thus parents were not blind to the intervention. Outcomes assessed through blinded raters, particularly of treated children engaging in key natural contexts (e.g., classrooms, playgrounds) and with key people (e.g., teachers, peers, siblings, parents) would be particularly useful. Moving beyond significance levels and effect sizes and incorporating clinical significance would be important (Rajwan et al. 2014).

Our findings suggest that yoga, mindfulness, and meditation interventions are not first-line interventions for the treatment of ADHD in children relative to other approaches (i.e., pharmacological and behavioral; Chacko et al. 2014). Poor methodology and high risk of bias across studies make it difficult to confirm whether yoga, mindfulness, and meditation are clinically efficacious. Methodologically rigorous RCTs with larger samples, utilizing well-manualized yoga, mindfulness, and meditation approaches that collectively assess ADHD- and intervention-relevant outcomes are needed to fully validate the benefits of these

interventions. Moreover, further comparison of yoga, mindfulness, and meditation relative to other evidence-based treatment modalities for ADHD (medication and/or behavioral interventions), within the context of rigorously-designed RCTs, would be needed to fully appreciate the potential of these approaches for ADHD in children.

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Compliance with Ethical Standards

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

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