Mindfulness (2021) 12:1332–1349
https://doi.org/10.1007/s12671-021-01593-w

REVIEW

Meditation, Mindfulness, and Attention: a Meta-analysis

David Sumantry[1] · Kathleen E. Stewart[1]

Accepted: 15 January 2021 / Published online: 2 February 2021

Abstract

Objectives Despite being an ancient tradition, meditation has only become a popular inquiry of research over the past few decades. This resurgence can partially be attributed to the popularization of Eastern meditative practices, such as mindfulness, into Western culture. Though the mechanisms of meditation are not yet scientifically well-understood, systems of attention and executive control may play an important role. The present study aimed to examine potential attentional mechanisms of attention-based meditations across studies.

Methods This paper examines behavioral measures of attention across literature. Studies ($K = 87$) that assigned participants to or recruited participants who use techniques common in mindfulness practices (focused attention, open monitoring, or both) were meta-analyzed. Outcomes were coded according to attentional network (alerting, orienting, executive control) or facet of executive control (inhibition, shifting, updating).

Results Meta-analytic results suggest that generalized attention ($g = 0.171$, 95% CI [0.119, 0.224]), its alerting ($g = 0.158$, 95% CI [0.059, 0.256]) and executive control ($g = 0.203$, 95% CI [0.143, 0.264]) networks, and the inhibition ($g = 0.159$, 95% CI [0.064, 0.253]) and updating ($g = 0.256$ [0.176, 0.337]) facets of executive control are improved by meditation. There was significant heterogeneity in attention, the alerting and executive control networks, and the inhibition facet. Studies that taught both FA and OM techniques did not show attentional improvements over those that taught the techniques in isolation. Meditation led to greater improvements in accuracy-based tasks than reaction time tasks.

Conclusions This meta-analysis suggests that attention is likely implicated in meditation, and meditation may improve some, but not all, attentional processes. Implications for understanding meditational mechanisms and moderator-related differences are discussed.

Keywords Meditation · Meta-analysis · Attention · Executive control

Meditation—particularly mindfulness meditation—has dramatically risen in popularity in western cultures over the last several decades (see Van Dam et al. 2018). Despite empirical support that meditation may be beneficial for a variety of populations and may both improve quality of life (e.g., Reibel et al. 2001) and reduce negative mental health outcomes (e.g., Tickell et al. 2019), understanding the mechanisms through which meditative practices work is crucial for further refinement. Exploring mechanisms will help to highlight the potentially crucial components of meditation, which in turn can help to maximize the benefits of practice. One of the key components of various meditations is a trained ability to focus on the present moment (Hölzel et al. 2011; Wallace 2007). As such, improved attentional ability may be one mechanism that drives the outcomes of meditative practices (Kok et al. 2013).

Understanding the mechanisms behind meditation are only possible after answering the question, “which meditation?” as meditative traditions and techniques can be drastically different from one another. Moreover, Western versions of mindfulness and other meditative practices tend to prioritize quantifiable outcomes that can be readily studied (e.g., symptom relief or productive gains) rather than embrace the holistic Eastern perspectives from which they came (see Monteiro et al. 2015, for a review). Dahl et al. (2015) described three families of meditative practices into which many can be classified. The attentional family includes focused attention (FA) and open monitoring (OM; alternatively, open presence) practices, which are centered around attention regulation (see also

✉ David Sumantry
David.Sumantry@ryerson.ca

[1] Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2L3, Canada

Lutz et al. 2008; Lutz et al. 2007). FA involves narrow, sustained attention on an object of attention, which may be internal (e.g., breath) or external (e.g., sound), whereas OM involves taking a broad and open approach to noticing experiences as they appear. The constructive family, which includes compassion and values-based practices, for example, centers around cultivating empathy or cognitive reappraisal. The deconstructive family, including Vipassana and Zen practices, centers around fostering self-inquiry and gaining insight into one's own thoughts and behaviors.

Popular clinical mindfulness meditations, such as mindfulness-based stress reduction (MBSR) and mindfulness-based cognitive therapy (MBCT), typically integrate both FA and OM in their practices. Often, FA techniques are taught prior to OM techniques. Once foundations of focusing on the present moment have been established, practitioners are encouraged to pursue a broader focus. Researchers have begun to dismantle these mindfulness-based interventions into discrete FA and OM components (Britton et al. 2018) and have shown that both lead to improvements in emotional regulation (Lohani et al. 2020). However, mental states, including those which could ostensibly be described as FA or OM, should best be understood as continuous among many dimensions (Lutz et al. 2015), and there is likely functional overlap between FA and OM techniques. Nevertheless, to date, most studies examining the attentional effects of mindfulness meditation have not distinguished FA and OM (see Ainsworth et al. 2013 for an exception), much less plotted their dimensionality.

To connect literature on meditation to that of attention, Hölzel et al. (2011) presented the mechanisms of mindfulness as being comprised of four parts: (1) increased attention regulation, or ability to maintain focus during mediation; (2) stronger body awareness, or ability to recognize and distinguish physical sensations; (3) acute emotion regulation, or meta-awareness and non-reactivity; and (4) a change in perspective on the self, or utilizing a growth mindset (see Dweck 2000). On the other hand, Bishop et al. (2004) posited two primary mechanisms: trained self-regulation of attention (sustained attention) and a growing orientation to experience, which can be described as presentism and meta-awareness. Common to these two theories is a focus on attentional mechanisms: mindfulness training improves practitioners' ability to sustain attention and inhibit distractions. If meditation's benefits are due at least partially to improvements in attention, it is important to understand which aspects of attention are being trained and which types of meditations are training attention.

Posner and Petersen (1990) developed a seminal model of attention consisting of three networks that are distinct from other cognitive functions: alerting (or vigilance), orienting, and executive control (sometimes referred to as target detection, conflict monitoring, cognitive control, attentional control, executive function, etc.). The alerting network is responsible for initial attentional capture as well as sustained attention. In other words, the alerting network represents attentive temporal readiness; an alerting network that is running well will quickly attend to a novel stimulus and be prepared for the occurrence of other new stimuli. The orienting network, on the other hand, is responsible for using spatial information to anticipate stimuli in a specific direction. For example, a parent reading a book may have their attention oriented to where their child is playing, despite not looking in that direction: they are ready for something to happen. Quickly reacting to the child falling would be indicative of a high-functioning orienting network. Finally, the executive control network distinguishes between competing stimuli. Attentional functions that relate to prioritizing stimuli, such as moving attention from one stimulus to another, relies on the executive control network. The existence and relative independence of these three attentional networks have been well-researched using behavioral methods (e.g., Fan et al. 2002) and neuroimaging (e.g., Fan et al. 2005).

The definition of executive control in Posner and Petersen (1990) has been expanded upon. Multiple functions are involved in attentional juggling; Miyake et al. (2000) presented three interrelated subsystems of executive control. The shifting (or, switching) aspect of executive control refers to the ability to move quickly and accurately from one stimuli or task to another. A poorly operating shifting function might be illustrated by difficulty disengaging from a stimulus. The updating (or, updating working memory) aspect of executive control involves the constant refreshing of information in the attentional area. For example, during a busy shift, a server may be holding the orders and statuses of tables in their mind, updating their working memory as customers come, go, order food, and ask for their individual bills. The inhibition function of executive control refers to the cognitive ability to refrain from updating or shifting attention to another stimulus. Simply, it is the ability to not be distracted, and requires volition.

Multiple meta-analyses and systematic reviews have already been published on the effects of mindfulness and meditation on attention and related cognitive variables. Eberth and Sedlmeier (2012) published a brief meta-analysis, examining 39 experimental studies with inactive control groups. Across eight studies, they found a mean effect size of $\bar{r} = 0.301$ (equivalent to $d = 0.630$) where meditation predicted attentional improvements. In a second meta-analysis across 163 studies, Sedlmeier et al. (2012) distinguished different types of meditation: transcendental meditation, mindfulness meditation, and other meditative practices. Furthermore, they investigated a host of different cognitive variables. Across the studies, the relations between meditation and attention/cognition produced mean weighted effect sizes of $\bar{r} = 0.28$ (equivalent to $d = 0.58$). However, these effects were not explicated to subsystems of attention.

On the other hand, Chiesa et al. (2011) conducted a systematic review examining the neuropsychological consequences of mindfulness meditation based on the Posner and Petersen (1990) attentional networks. Based on the results across studies, the authors concluded that alerting, orienting, and executive control networks all benefited from mindfulness meditation. Further, mindfulness meditators seemed to perform better on working memory tasks that could also be considered measures of updating, relative to controls. Therefore, the review's conclusions emphasize attentional improvements for meditators on both the general and subsystem-specific levels.

In a comprehensive systematic review, Gallant (2016) examined the effects of mindfulness meditation on executive control. Relying on the Miyake et al. (2000) model of executive control, outcomes within studies were classified as measuring shifting, updating, or inhibition. The author reviewed 12 experimental or quasi-experimental studies that each used at least one of 10 tasks. Gallant concluded that there was sufficient evidence for an effect of mindfulness on inhibition across the studies: mindfulness meditators were better at inhibition of distractors than controls. Results for shifting and updating were mixed, however.

Considering the findings of previous reviews, the purpose of the present meta-analysis is to re-examine the attentional benefits of attentional meditation techniques (FA and/or OM) in terms of the subsystems of attention and executive control. We hypothesize that (1) there will be generally positive effects of meditation on attention and executive control; (2) meditation will specifically predict improvements in the alerting attentional network and the inhibition component of executive function; (3) studies that utilized randomization will show smaller effect sizes than those that did not; and (4) differences between meditation experimental groups and active control groups will be smaller than with inactive control groups. Examination of differences in findings between FA and OM techniques is exploratory.

Method

Search Strategy

Published studies and dissertations were identified for inclusion first via database search on September 2, 2019. The PsycINFO database, which includes articles from the ProQuest database that relate to psychology, the Scopus database, and the PubMed database, was queried using the following search string within study abstracts: (*mindfulness* OR *meditation*) AND ("*cognitive control*" OR *cognition* OR *executive* OR (*attention** NOT "*mindful attention awareness scale*")). In simpler terms, the search string identified abstracts which contained either the words *mindfulness* or *meditation*, and mentions of *cognitive control*, *cognition*, *executive*, or *attention*, the latter of which could be suffixed in any way (e.g., *attentional*). If the only mention of attentional constructs was the Mindful Attention Awareness Scale, the study was excluded. The search was not limited by date. After studies were classified, a lateral search was conducted to find other studies that may have been missed by our original search terms.

The following inclusion criteria were used for the meta-analysis: (1) Studies were published in an academic journal or as a dissertation. Conference presentations or book chapters are not held to the same standard of peer review as academic articles or dissertations. (2) Studies were unique, empirical, and relied on statistical modeling. (3) Studies targeted to the general, healthy, and adult population. A recent meta-analysis examined the effects of mindfulness on executive control in adolescents (Dunning et al. 2019). Another examined attentional and executive function results in older adults who used mind-body exercises (Chan et al. 2019). These findings may not extend to the broader adult population. Therefore, studies that exclusively targeted healthy older adults or adolescents were excluded. (4) Studies used objective, behavioral measures relevant to attention. People have limited capacity to gauge their attentional ability (Buchanan 2016). Though studies often included self-report or physiological measures, only behavioral data were extracted. (5) Studies used experimental or quasi-experimental designs. These designs are better suited to test the causal effects of practice than correlational designs. (6) Studies had a control group. Papers that only compared meditation styles (e.g., comparing FA and OM) or exclusively recruited experienced meditators were excluded because they did not provide comparable effect sizes. (7) Meditative practices used either FA or OM techniques. Transcendental meditation (TM) and lovingkindness meditation (LKM) were excluded, as they rely on techniques different to FA or OM. Consequently, the attentional mechanisms affected by these meditations may also be dissimilar. (8) Physical activity was not a primary component of the meditation. Exercise provides benefits both physically and psychologically (e.g., Guiney and Machado 2013). To avoid misattributing the effects of physical activity to meditation, we excluded studies involving techniques that merged meditation and physical activity as the primary meditative practice (e.g., hatha yoga). Techniques or interventions that utilized physical activity to a lesser extent and in the context of a larger program (e.g., MBSR) were not excluded. (9) Studies were written in English or had readily accessible translations.

Coding of Study Variables

Behavioral data were extracted from the studies included in the analyses. Tasks were classified by the authors into seven different outcome types (Online Resource 1), reflecting distinctions outlined in literature on attentional networks and executive control (see Fig. 1). Using the Posner and Petersen (1990) model of attention, task outcomes were categorized as either pertaining to the alerting, orienting, or executive control networks. Tasks classified as measuring executive control were further sorted into inhibition, shifting, and updating categories, as outlined by Miyake et al. (2000). Several outcomes were not easily classifiable into a single category or could be perceived as measuring attention more broadly (e.g., anagram performance) or non-specific executive control (e.g., the defined intensity stressor simulation). These outcomes were thus classified only by the appropriate superordinate category (i.e., general attention, executive control).

Importantly, behavioral measures often have multiple ways of measuring a theoretical construct. For example, the most commonly reported effect in the Stroop color–word task is the "interference effect," calculated as the difference in reaction time (RT) between the incongruent and congruent conditions. Yet, the Stroop task also provides a measure of accuracy (or error) across trials. It is possible that a participant may shorten their RT after an intervention but increase their error rate. To test whether meditation leads to genuine attentional improvements (vs. a speed-accuracy trade-off) effect sizes for RTs and accuracy were compared. Further, to ensure parsimony, data extraction was limited to one RT and one accuracy measurement per outcome type in each task.

Some studies included multiple experimental or control groups. In these cases, data were extracted from the experimental group that had the strongest meditation component (e.g., a meditation retreat vs. a one-time lab intervention) and the control group that was most active (most likely to lead to attentional improvements).

Each measure for which an effect size was calculated was coded according to study characteristics and moderator variables. The following nine moderator variables were coded: (1) task type: whether the behavioral measure was reliant on accuracy, reaction time, a combination of both, or neither; (2) meditative practice: whether participants were taught (for experimental designs) or practiced (for designs which recruited experienced meditators) FA techniques, OM techniques, or both; (3) meditative experience: experienced meditators' experience in years; (4) intervention length: the hours of meditative practice assigned; (5) random assignment: if the study conducted analyses comparing randomly assigned treatment and control groups; (6) control group: whether the study had an active control group that would likely lead to attentional improvements, an active control group that would not lead to attentional improvements, or a no-contact (NC) control group (e.g., waitlist); (7) risk of bias: studies coded having low/some/high risk of bias; (8) publication status: an unpublished dissertation or published journal article; and (9) publication year.

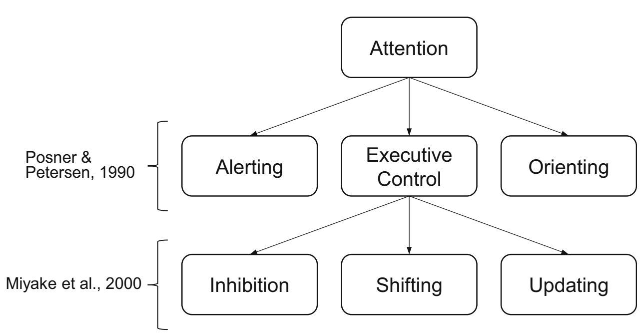


Fig. 1 Models of attention and executive control

Statistical Analyses

All extracted data (Online Resource 2) and conversion formulas (Online Resources 3.1 and 3.2) are available as supplementary material. Effect sizes were extracted from studies using data readily available in papers, presented in appendices, or sent by contacted authors. Using suggestions found in the literature, effect sizes were converted to standardized mean differences (Cohen's *d*). Effects at a single time point were converted using (1) from Cohen (1988), where the denominator is the pooled standard deviation, and the formula uses means (*M*), standard deviations (*SD*), and sample sizes (*n*) from each condition. This formula was also used for within-subjects designs, as recommended by Westfall (2016).

$$d = \frac{M_2 - M_1}{\sqrt{\frac{(n_1-1)\times \mathrm{SD}_1^2 + (n_2-1)\times \mathrm{SD}_2^2}{n_1+n_2-2}}} \tag{1}$$

For pre-post control (PPC) and pre-post quasi-experimental (PPQ) designs, standardized effect sizes from factorial ANOVAs tend to be reported in terms of eta-squared or omega-squared. However, these effect sizes are restrictive, as they are not easily compared across multiple studies and designs. Standardized mean differences are more amenable to comparisons but interpolating them from ANOVA results is uncommon and crude. Still, quantifying these effects for the sake of meta-analyses and comparability across studies is important for literature synthesis. This meta-analysis used (2) from Morris (2008) to estimate Cohen's *d* for PPC and PPQ designs, where the bias correction where the bias correction c_j can be calculated via (3).

$$d = \frac{c_2\left(M_{2\ \mathrm{post}} - M_{2\ \mathrm{pre}}\right)}{\mathrm{SD}_{2\ \mathrm{pre}}} - \frac{c_1\left(M_{1\ \mathrm{post}} - M_{1\ \mathrm{pre}}\right)}{\mathrm{SD}_{1\ \mathrm{pre}}} \tag{2}$$

$$c_j = 1 - \frac{3}{4\left(n_j - 1\right) - 1} \tag{3}$$

Effect sizes were then bias-corrected to Hedge's *g*. Higher numbers indicate a more positive attentional outcome for the meditators relative to control data. Equations (4) and (5) represent the conversion formulas for Hedge's g and its standard error respectively, where d is Cohen's d, df is the degrees of freedom, and SE_d is the standard error of Cohen's d.

$$g = \left(1 - \frac{3}{4(df) - 1}\right) * d \quad (4)$$

$$SE_g = \left(1 - \frac{3}{4(df) - 1}\right) * SE_d \quad (5)$$

All analyses were conducted using three-level meta-regressions (see Cheung 2019) with the *metafor* R package (Viechtbauer 2010). Code is available in Online Resource 4. Meta-analyses are conventionally two-level multilevel models, where level 1 constitutes sampling error and level 2 constitutes between-sample error. To account for non-independence due to extracting multiple effect sizes from studies, three-level meta-analyses add an additional level between these two: one that represents within-sample error. Consequently, three-level meta-analyses can estimate heterogeneity proportions, represented by I^2, at the sampling (level 1), within-sample (level 2), and between-sample (level 3) levels. Where significant heterogeneity exists as determined by three-level tests or likelihood ratio tests, moderator subgroup analyses were conducted.

Assessment of Bias

Assessment of bias was measured in five ways. Studies published in academic journals may have greater effect sizes than unpublished work (Franco et al. 2014). Studies with positive results are published more quickly than those with null or negative results (Hopewell et al. 2007). On the other hand, a discipline-wide increase in demand for methodological rigor coupled with an increase in comprehensive reporting over time may also lead to smaller effect sizes in newer studies (Fritz et al. 2012). Consequently, publication status and publication year were tested as moderators across all outcomes. Rank correlation tests were conducted as well, examining the correlation between effect sizes and sampling variances (Begg and Mazumdar 1994). Next, trim-fill tests were conducted to probe funnel plot asymmetry (Duval and Tweedie 2000). Analyses with asymmetrical funnel plots were corrected to account for publication bias, providing an estimate of the true value of Hedge's g for the given outcome. Importantly, however, trim-fill tests are intended to be conducted for two-level meta-analyses and thus three-level results should be interpreted cautiously. Finally, authors coded randomized control trials according to Cochrane's Risk of Bias 2 (RoB 2; Sterne et al. 2019). The RoB 2 provides criteria for labeling studies as low risk of bias, some concerns, or high risk of bias. This variable was then used as a moderator in statistical analyses.

Results

The PRISMA statement (Liberati et al. 2009) is seen on Fig. 2. The literature search produced 1248 results. Of these, 1103 were excluded at the abstract evaluation stage. To enhance inclusion accuracy, studies were not filtered at the title stage. From the 145 remaining articles, one was excluded for not studying a healthy population, three for not using FA- or OM-based meditations, 20 for not including applicable behavioral measures, 32 for not reporting sufficient data to extract effect sizes, five that used correlational designs, two that reported data from an already-included study, three that did not include a relevant control group, one that used a meditative practice paired with high physical activity, and one that could not readily be translated to English. In cases where data reporting was not sufficient, authors were contacted to provide missing data. A lateral search provided 12 additional studies to include in the analysis. The full list of studies found in the database searches, along with codes and reasons for exclusion at the abstract and full-text phases are available in an Excel document as Online Resource 5.

Outcome measures within each study were classified by which attentional network(s) or facets of executive control were measured. General attention was measured in 12 outcomes. The alerting aspect of attention was measured 77 times, the orienting aspect 21 times, and executive control 26 times. For specific facets of executive control, inhibition was measured 71 times, shifting 18 times, and updating 40 times. Altogether, data from 265 outcomes were extracted from 87 studies (Table 1).

Data were coded in terms of all applicable moderators. Outcomes were classified as measuring participant accuracy (κ = 107), reaction times (κ = 127), both (κ = 29), or neither (κ = 2). Details of these classifications are in the supplementary materials. Examining study designs, 41 used random assignment but 47 did not. Among studies with control groups, 26 used no-contact (NC) controls, 17 used active control groups with interventions that might improve attention (Active+), and 11 used active control groups with interventions that should not improve attention (Active−). Most studies taught or recruited participants that used both FA and OM techniques (K = 67). FA meditation was exclusively used by participants in 21 studies, whereas OM meditation was used in two studies. One study did not report FA vs. OM practitioner information.

Risk of Bias Assessment

All randomized control trials (K = 44) were classified by the authors according to five categories from the Cochrane RoB 2 (Sterne et al. 2019): randomization process (the extent to which studies were randomized blindly), deviations from intended interventions (adherence to conditions), missing outcome data (dropout or unreported data), measurement of the

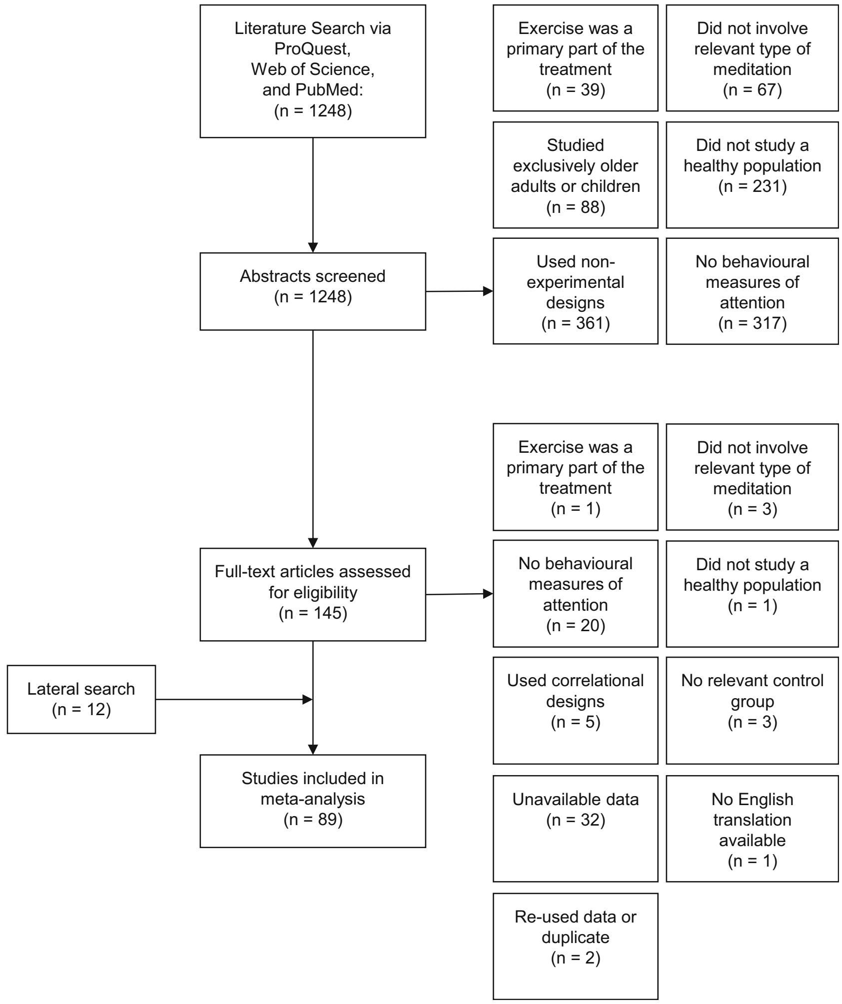


Fig. 2 PRISMA statement outlining study exclusion at each stage

outcome (bias due to selective measurement), and selection of the reported result (analyzed according to preregistration). As per the algorithm, any studies that received a classification of "high risk" across any of the five categories was classified as high risk overall. Similarly, those classified as "some concerns" in a category were classified (at least) as having some concerns of bias overall. Only if a study were coded as having low risk of bias across all five categories would it be classified as having a low overall risk of bias. Altogether, one study was classified as low risk, 30 as there being some concerns of bias, and 13 as having high risk of bias (Fig. 3). Interrater agreement was 95.5% with a Cohen's kappa of .898. Any disagreements were resolved through discussion. The most common reasons for the "some concerns" classification were non-blinded randomization or lack of a prespecified analysis plan.

Global Effects of Meditation

General results, including breakdowns by outcome, heterogeneity tests, and funnel plot tests are displayed in Table 2. See Online Resource 6 for a forest plot containing all effect sizes and confidence intervals; additional plots are found in Online Resource 7. Overall, meditation predicted greater attention and executive control than controls (κ = 265, g = 0.171, SE = 0.027, z = 6.41, p < .001). Meditation led to greater alerting (κ = 77, g = 0.158, SE = 0.050, z = 3.14, p = .002), executive control (κ = 155, g = 0.203, SE = 0.031, z = 6.54, p < .001), inhibition (κ = 71, g = 0.159, SE = 0.048, z = 3.30, p = .001), shifting (κ = 18, g = 0.185, SE = 0.074, z = 2.52, p = .012), and updating (κ = 40, g = 0.256, SE = 0.041, z = 6.24, p < .001), but not orienting (κ = 21, g = − 0.086, SE = 0.074, z = − 1.16, p = .248). There was significant heterogeneity for generalized attention, both within (I^2_{within} = 18.71%, LRT = 6.82, p = .009) and between studies ($I^2_{between}$ = 18.41%, LRT = 9.55, p = .002). Further, there was significant between-study heterogeneity for measures of executive control ($I^2_{between}$ = 27.40%, LRT = 8.88, p = .003) and, specifically, the inhibition component ($I^2_{between}$ = 28.51%, LRT = 5.54, p = .019). Though a three-level test indicated there was heterogeneity among alerting outcomes, likelihood ratio tests did not reach the threshold for statistical significance of heterogeneity within or between studies.

Table 1 Studies and codes

Study (K = 87)	Control group	Tasks	Outcomes	Med. tech.	Assign.	Number	Exp. (years)	Int. length (hours)	Participant age (years)
Ainsworth et al. (2013)	NC	ANT	Alerting, EC, orienting	FA, OM	RA	49		4.25	20.3 (4.1)
Allen et al. (2012)	Active+	EAT	Inhibition	Both	RA	38		12	18–50
Anderson et al. (2007)	NC	Attention switching task	Shifting	Both	RA	72		16	41.7/37.0
Badart et al. (2018)	NA	RST-V	Alerting	FA	No RA	40	4.3		20–55
Bailey et al. (2019a)	NA	eStroop, Stroop	Inhibition	FA	No RA	42	8.3		36.56/35.68
Bailey et al. (2019b)	NA	Go/no-go	Inhibition	FA	No RA	58	8.72		35.32/35.20
Banks et al. (2015)	Active−	AOSPAN	Updating	Both	RA	62		2	21.91/19.82
Basso et al. (2019)	Active−	Flanker, N-back, reading span, Stroop, Wisconsin Card Sorting	Inhibition, updating	FA	RA	42		12.42	18–45
Becerra et al. (2017)	NC	ANT	Alerting, EC, orienting	FA	RA	46		22.4	20–61
Bhayee et al. (2016)	Active−	d2, Digit Span -, Stroop	Inhibition, orienting, updating	FA	RA	26		7	33.3/32.0
Bornemann and Singer (2017)	NC	Heartbeat perception	Alerting	Both	RA	72		95.5	20–55
Burger and Lockhart (2017)	NC	ANT	Alerting, EC, orienting	Both	RA	60		4.67	18–40
Campillo et al. (2018)	NA	TMT-A, TMT-B	Alerting, shifting	FA	No RA	25		0.5	22–61
Chambers et al. (2008)	NC	Digit Span -, IST	EC, updating	Both	No RA	40		110	21–63
Cheng et al. (2017)	NC	Go/no-go	Alerting, inhibition	FA	RA	26		1.05	20–27
Cohen et al. (2017)	NA	Set shifting	Shifting	Both	No RA	195		63	47.63/49.15
Cusens et al. (2010)	Active+	CPT	Alerting	Both	No RA	24		57.52	46.7/48.4
Daubenmier et al. (2013)	NA	Respiratory detection task, respiratory discrimination task, respiratory tracking task	Alerting, attention	Both	No RA	34	9		41.9/35.4
Deepeshwar et al. (2015)	NA	Stroop	Attention	Both	No RA	22		21.67	22.9 (4.6)
Eisenbeck et al. (2018)	Active−	Concentrated attention task	Alerting	Both	RA	39		0.22	20–52
Esch et al. (2017)	NC	ANT	Alerting, attention, EC, orienting	Both	RA	31		7.5	27.8/25.5
Fabio and Towey (2018)	NA	Backmasking, N-back, Stroop, visual search	EC, inhibition, shifting, updating	FA	No RA	36	8.77		45.72/44.9
Flook et al. (2013)	NC	Affective go/no-go, rapid visual information processing task	Alerting, inhibition	Both	RA	18		65	25–56
Gackenbach et al. (2015)	NA	Change blindness	Alerting	UK	No RA	110			~ 18–25
Green and Black (2017)	Active+	Anagram	Updating	FA	RA	170		0.33	19.26 (2.76)
Helber et al. (2012)	NC	Stroop -, TMT-B	Inhibition, shifting	Both	No RA	27		12.46	20.37/21.67
Hodgins and Adair (2010)	NA	Change blindness, Gorilla, SAT	Alerting, orienting, shifting, updating	Both	No RA	96			21–79
Isbel and Mahar (2015)	NA	ANT, Stroop		Both	No RA	44	10		44.5/40.8

Table 1 (continued)

Study (K = 87)	Control group	Tasks	Outcomes	Med. tech.	Assign.	Number	Exp. (years)	Int. length (hours)	Participant age (years)
			Alerting, attention, EC, inhibition, orienting						
Jensen et al. (2012)	Active+	CombinTVA, d2, DART, Stroop	Alerting, inhibition, shifting, updating	Both	RA	31		27	20–36
Jo et al. (2014)	NA	Intentional binding	Attention	Both	No RA	38			28–50
Jo et al. (2016)	NA	ANT	Alerting, attention, EC, orienting	Both	No RA	40	13.1		40.6 (8.64)
Johnson et al. (2015)	Active+	Digit Span -, N-back, SDMT, TMT-A, TMT-B	Alerting, shifting, updating	Both	RA	66		0.42	18–57
Josefsson and Broberg (2011)	NA	SART, Stroop	Alerting, inhibition	Both	No RA	92	7.21		43.2/25.9
Josefsson et al. (2014)	Active+	Stroop	Inhibition	Both	RA	73		5.25	48.9/45.1
Khalsa et al. (2008)	NA	Heartbeat detection	Alerting	Both	No RA	30	24.7		48.8/50.6
Klempel (2018)[a]	Active+	ANT	Alerting, attention, EC, orienting	Both	RA	43		1.25	
Kozasa et al. (2012)	NA	Stroop	Inhibition	Both	No RA	39	8.53		46.39/43.80
Kozasa et al. (2018)	NA	Stroop	Inhibition	OM	No RA	31		84	43.26/46.79
Kozhevnikov et al. (2009)	NC	Visual memory task	Alerting	Both	No RA	28	11		37/41
Kumari et al. (2015)	NA	Verbal attention task, visuospatial attention task	EC	Both	No RA	60			39.90/36.54
Kumari et al. (2017)	NA	Saccades	Alerting, inhibition, orienting	Both	No RA	56			39.90/36.93
Lacerda et al. (2018)	NC	Digit symbol	Updating	Both	RA	44		9	35.68/37.55
Larson et al. (2013)	Active−	Flanker	Inhibition	Both	RA	55		0.23	19.9/20.6
Lebares et al. (2019)	Active+	NIH-EXAMINER	EC, updating	Both	RA	21		16	29.0/27.4
Leite et al. (2010)	NC	Digit symbol	Updating	Both	RA	39			19–59
Li et al. (2018)	NC	AXCPT	Alerting	Both	RA	30		20	30.4/28.4
Lutz et al. (2009)	NA	Dichotic listening	Alerting	Both	No RA	31			20–64
Lykins et al. (2012)	NA	Color Trails, CPT, CVLT, eStroop, letter-number sequencing, Ruff 2&7, Stroop, subitizing range	Alerting, inhibition, shifting, updating	Both	No RA	66	6.19		18–64
Lymeus et al. (2017)	Active+	Letter-digit substitution Task	Updating	Both	RA	16		52.5	25.00 (5.46)
Lymeus et al. (2018)	NA	Letter-digit substitution task, TMT-A, TMT-B	Alerting, shifting, updating	FA, both	No RA	27		9.5/13.25	18–61
Mallya and Fiocco (2019)	Active+	Digit span -, TMT-B, WAIS	EC, shifting, updating	Both	RA	57		16	64.18/69.13
Mann (2012)[a]	NC	ANT, AOSPAN	Alerting, EC, orienting, updating	Both	No RA	47		5.58	
McMorran (2018)[a]	Active−	ANT, SART	Alerting, attention, EC, inhibition, orienting, shifting	FA	RA	74		2.5	19.88/19.67
Meland et al. (2015)	NC	Attentional capture, SART	Alerting, inhibition, orienting, shifting	Both	No RA	36		72.33	18–62
Melloni et al. (2013)	NA	Stroop	Inhibition	Both	No RA	20	4.35		41.12/37.30

Table 1 (continued)

Study (K = 87)	Control group	Tasks	Outcomes	Med. tech.	Assign.	Number	Exp. (years)	Int. length (hours)	Participant age (years)
Menezes and Bizarro (2015)	NC	Concentrated attention task	Alerting	FA	RA	33		7.5	23.9/24.9
Mirams et al. (2013)	Active−	Somatic signal detection	Alerting, inhibition	FA	RA	62		1.75	19.21 (0.75)
Moore and Malinowski (2009)	NA	d2, Stroop	Inhibition, orienting	Both	No RA	50			20–40
Morrison et al. (2014)	NC	AOSPAN, delayed recognition, SART	Alerting, inhibition, Updating	Both	RA	42		7	18.20 (1.29)
Noone and Hogan (2018)	Active+	N-Back	Updating	Both	RA	64		0.17	21.09 (5.46)
Otten et al. (2015)	NA	ANT, heartbeat detection, TAP divided attention	Alerting, attention, EC, orienting, updating	Both	No RA	42	10.4		39.7/39.5
Quaglia et al. (2019)	Active−	Emotional go/no-go	Inhibition	Both	RA	64		1.33	20–59
Rahl et al. (2017)	Active−	SART	Inhibition	FA, both	RA	79		1.33	21 (3.25)
Rodrigues et al. (2018)	NA	Stroop	Inhibition	Both	No RA	40			45.43/45.35
Rodriguez Vega et al. (2014)	NC	CPT, Stroop	Alerting, inhibition	Both	No RA	101		20	29.6/28.4
Roeser et al. (2013)	NC	OSPAN	Updating	Both	RA	113		36	27–64
Saunders et al. (2016)	NA	Go/No-go	Alerting, inhibition	Both	No RA	22		0.22	18.9 (2.84)
Schofield et al. (2015)	Active−	Inattentional blindness	Updating	Both	RA	774		0.12	19.64 (3.24)
Semple (2010)	Active+	CPT, digit symbol, Stroop	Alerting, inhibition, updating	Both	RA	29		21.5	23–56
Srinivasan and Singh (2017)	NA	2-Back	Updating	FA	No RA	25			40.41/37.61
Taraban et al. (2017)	Active−	Mind-wandering reading	Alerting	Both	RA	43		0.2	22.3 (3.47)
Teng and Lien (2016)	NC	Attentional switching task, OSPAN, Stroop	Inhibition, shifting, updating	FA	RA	36		0.67	37.61/38.89
Teper and Inzlicht (2013)	NA	Stroop	Inhibition	Both	No RA	38	3.19		33.00/37.47
Tsai and Chou (2016)	NA, NC	ANT	Alerting, attention, EC, orienting	Both, FA	No RA, RA	60	9.8	10	S1: 46/44
Valentine and Sweet (1999)	NA	Wilkins' counting test	Alerting	Both	No RA	43			19–43
van den Hurk et al. (2010a)	NA	ANT	Attention, EC, orienting	Both	No RA	40	14.5		30–60
van den Hurk et al. (2010b)	NA	Choice reaction time task	Alerting	Both	No RA	26	14		26–67
Verhoeven et al. (2014)	NC	eStroop Neutral, SART, Stroop	Alerting, inhibition	Both	RA	54		68	48.6/45.6
Walsh et al. (2019)	Active+	CRSD-ANT, respiration integration task	Alerting, attention, EC, orienting	Both	RA	86		3.5	20.24/19.78
Wang et al. (2012)	NC	Stroop	Inhibition	Both	RA	31		20	17–25
	Active+	eStroop, recognition memory	Inhibition, updating	Both	RA	48		0.17	17–46

Table 1 (continued)

Study (K = 87)	Control group	Tasks	Outcomes	Med. tech.	Assign.	Number	Exp. (years)	Int. length (hours)	Participant age (years)
Watier and Dubois (2016)									
Wenk (1997)[a]	Active+	Letter ID d', Stroop	Alerting, inhibition	FA	RA	40		2	19.5
Wong et al. (2018)	NA	Psychomotor Vigilance Task	Alerting	Both	No RA	36		26	30.3 (8.52)
Yosai (2017)[a]	Active+	AOSPAN, Stroop, TMT-A, TMT-B	Alerting, inhibition, shifting, updating	Both	RA	23		0.8	20.11 (1.94)
Zhang et al. (2019)	NC	Stroop	Inhibition	Both	RA	36		36	19–32
Zhu et al. (2019)	NC	CPT-AX, Stroop	Alerting, inhibition	Both	RA	48		36	24.13/24.25
Ziegler et al. (2019)	Active+	Change localization task, CVDAD, test of variables of attention	Alerting, attention, updating	FA	RA	41		5	18–35

Total *N* = 5003. Ages are reported as sample *M(SD)*, sample age range, or $M_{\text{meditation}}/M_{\text{control}}$

NC no contact, *Active+* attention should improve in controls, *Active−* attention should not improve in controls, *ANT* Attention Network Test, *AOSPAN* Automated Operation Span Task, *CPT* Continuous Performance Task, *CVLT* California Verbal Learning Test, *DART* Dual Attention to Response Task, *SDMT* Symbol-Digit Modalities Test, *SART* Sustained Attention to Response Task, *TAP* Test of Attentional Performance, *TMT* Trail-Making Test, *WAIS* Weschler Adult Intelligence Scale, *EC* executive control, *FA* focused attention, *OM* open monitoring, *UK* unknown; *RA* random assignment

[a] Unpublished dissertation

Moderator Analyses

For outcomes with significant heterogeneity of effects (general attention, alerting, executive control, inhibition), moderator analyses were conducted (Table 3). Across general attention, task type emerged as a significant moderator. Reaction time tasks had smaller effect sizes ($g = 0.12$, SE = 0.03, $p < .001$) than tasks measuring accuracy ($g = 0.21$, SE = 0.04, $p < .001$; $B = 0.09$, SE = 0.04, $p = .040$) and tasks measuring both ($g = 0.27$, SE = 0.07, $p < .001$; $B = 0.15$, SE = 0.07, $p = .039$). Studies published in academic journals had larger effect sizes ($g = 0.19$, SE = 0.03, $p < .001$) than dissertations ($g = -0.01$, SE = 0.09, $p = .907$; $B = 0.19$, SE = 0.10, $p = .39$).

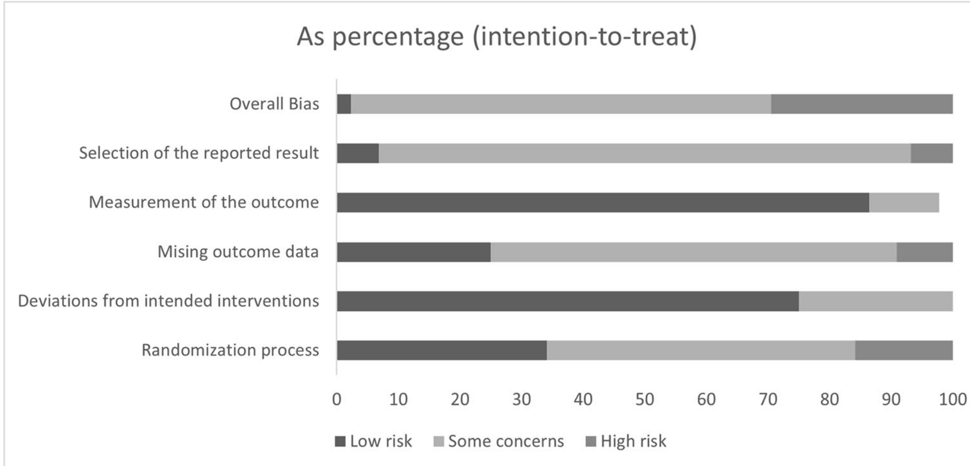
The alerting outcome was significantly moderated by two variables: intervention length and publication date. At the average intervention length, there was an effect size of $g = 0.17$ (SE = 0.05, $p < .001$). For every 10-h increase in intervention length, the attentional improvement attributable to the alerting network decreased by $g = 0.04$ (SE = 0.02, $p = .044$). Similarly, newer studies showed smaller effects than older studies ($B = -0.03$, SE = 0.01, $p = .004$). These findings should be interpreted cautiously, as the distributions for intervention length and publication year were non-normal.

Effects of meditation on executive control were moderated by coded random assignment and publication status. Studies that did not use random assignment ($g = 0.28$, SE = 0.04, $p < .001$) provided stronger effect sizes than those that did ($g = 0.14$, SE = 0.04, $p < .001$; $B = -0.14$, *SE* = 0.06, $p = .022$). Studies that were published in an academic journal ($g = 0.22$, SE = 0.03, $p < .001$) provided stronger evidence for meditation's improvements to executive control than those which were not published ($B = -0.26$, SE = 0.12, $p = .034$). Moreover, unpublished studies provided null results ($g = -0.04$, SE = 0.12, $p = .742$). Though the three-level test indicated significant heterogeneity in inhibition-related outcomes, the effect was not moderated by any of the tested variables (*p*s > .05).

Discussion

This meta-analysis examined the effects of meditation on behavioral measures of attention and executive control. Results from 87 papers were aggregated, coded, and analyzed. Outcomes for each task were classified according to Posner and Petersen's (1990) model of attentional networks—specifically, the alerting, executive control, and orienting networks, and Miyake et al.'s (2000) model of executive control—focusing on shifting, inhibition, and updating. Overall, data indicated that meditation—whether practitioners used FA or OM techniques—increased attentional capabilities across the studies. This effect was small, however, and was contingent on which aspect of attention was being examined. These

Fig. 3 Risk of bias assessment



results are largely in line with previous reviews on the effects of mindfulness meditation that point to the roles of inhibition and updating in mindfulness (Chan et al. 2019; Gallant 2016).

The first hypothesis tested in this meta-analysis was that there would be positive effects of meditation on attention and executive control. Both global and network-specific measures of attention and executive control showed improvements due to meditation. Consequently, the results support theories positing that one mechanism behind meditation and mindfulness is increased attentional ability. Importantly, however, the magnitude of this effect tempers the one reported by Eberth and Sedlmeier et al. (2012): g = 0.171 ($d \approx 0.191$) vs. d = 0.630. This decrease should affect the sample sizes that researchers use to study meditation and attention. Underpowered analyses will result in frequent type II errors. Therefore, we strongly recommend researchers conducting this vein of study adjust their a priori power analyses to be more conservative.

The second hypothesis stated that the alerting attentional network and the inhibition aspect of executive control would show meditation-related benefits. This hypothesis was supported by the meta-analysis. In summary, people who meditate (either assigned to meditate or those who have prior experience meditating) were more skilled at maintaining their focus, juggling multiple objects in their attention, and inhibiting distracting stimuli than were nonmeditators (those who were not assigned to meditate or who did not have meditation experience). These results are in line with theory of how both FA and OM meditations work (see Lutz et al. 2008). FA involves being able to sustain attention on an object for an increasingly long duration. Meditators must inhibit directing their attention to intrusive thoughts, anxieties, or external stimuli and remain focused. Similarly, OM meditation requires developing the ability to stay in the present moment, directing attention to different aspects of experience, but not allowing the mind to become deeply absorbed in thought.

Table 2 Tests of heterogeneity, funnel plot asymmetry, and trim-fill corrected estimates for outcomes

Outcome	Original 3-level estimate (Hedge's g)	Trim-fill 2-level estimate (Hedge's g)	3-level test for heterogeneity	Rank test		I^2 heterogeneity %		
				τ	p value	Sampling	Within	Between
Attention	**0.171 [0.119, 0.224]**	–	**Q(264) = 419.21, p < .001**	0.05	.191	62.88	**18.71**	**18.41**
Alerting	**0.158 [0.059, 0.256]**	–	**Q(76) = 155.10, p < .001**	0.10	.215	49.93	20.95	29.12
Orienting	− 0.086 [− 0.232, 0.060]	− 0.051 [− 0.214, 0.113]	Q(20) = 31.04, p = .055	− 0.20	.215	66.89	33.11	0.00
Executive control	**0.203 [0.143, 0.264]**	–	**Q(156) = 202.46, p = .005**	0.04	.460	72.60	0.00	**27.40**
Inhibition	**0.159 [0.064, 0.253]**	–	**Q(70) = 102.87, p = .006**	0.10	.218	67.77	3.72	**28.51**
Shifting	**0.185 [0.041, 0.329]**	0.110 [− 0.044, 0.265]	Q(17) = 21.25, p = .215	0.04	.820	80.84	0.00	19.16
Updating	**0.256 [0.176, 0.337]**	**0.233 [0.152, 0.313]**	Q(39) = 38.57, p = .489	− 0.02	.834	94.76	0.00	5.24

95% confidence intervals. Bolded results were statistically significant at p < .05. The attention outcome includes all subgroups as well as effect sizes from measures classified as capturing generalized attention. Executive control includes the inhibition, shifting, and updating subgroups as well as generalized executive control measures. Studies with trim-fill estimates marked with – had no estimated studies missing from the forest plot. I^2 significance was measured using likelihood ratio tests

Table 3 Tests for moderation of outcomes

Outcome	Attention		Alerting	
Moderator	κ	Moderator test	κ	Moderator test
Task type (accuracy/RT/both)	107/127/29	**$Q(2) = 6.72, p = .034$**	31/41/4	$Q(2) = 3.21, p = .201$
Meditation techniques (FA/OM/both)	65/5/193	$Q(2) = 0.21, p = .899$	16/[1]/58	$Q(1) = 1.17, p = .279$
Experience (years)	66	$Q(1) = 0.08, p = .772$	21	$Q(1) = 0.75, p = .386$
Intervention length (hours)	170	$Q(1) = 0.11, p = .742$	47	**$Q(1) = 4.07, p = .044$**
Random assignment (no RA/RA)	133/132	$Q(1) = 0.42, p = .518$	43/34	$Q(1) = 3.58, p = .058$
Control group (NC/active−/active+)	73/29/53	$Q(2) = 0.29, p = .864$	26/6/11	$Q(2) = 3.34, p = .188$
Risk of bias (low/concerns/high)	[1]/97/27	$Q(1) = 0.87, p = .352$	0/28/8	$Q(1) = 1.33, p = .250$
Published in journal (no/yes)	**26/239**	**$Q(1) = 4.25, p = .039$**	7/70	$Q(1) = 0.03, p = .870$
Publication year	265	$Q(1) = 2.10, p = .147$	77	**$Q(1) = 8.12, p = .004$**
Outcome	Executive control		Inhibition	
Moderator	κ	Moderator test	κ	Moderator test
Task Type (accuracy/RT/both)	61/68/25	$Q(2) = 1.61, p = .446$	36/30/4	$Q(2) = 0.55, p = .760$
Meditation techniques (FA/OM/both)	42/3/110	$Q(2) = 0.53, p = .769$	20/[2]/49	$Q(1) = 0.19, p = .662$
Experience (years)	34	$Q(1) = 0.24, p = .624$	18	$Q(1) = 0.03, p = .874$
Intervention length (hours)	105	$Q(1) = 2.90, p = .089$	29	$Q(1) = 0.47, p = .494$
Random assignment (No RA/RA)	72/83	**$Q(1) = 5.26, p = .022$**	33/38	$Q(1) = 0.61, p = .434$
Control group (NC/active−/active+)	36/21/37	$Q(2) = 3.54, p = .171$	16/14/12	$Q(2) = 3.92, p = .141$
Risk of bias (low/concerns/high)	[1]/58/17	$Q(1) = 0.20, p = .656$	0/25/11	$Q(1) = 0.10, p = .752$
Published in journal (no/yes)	13/142	**$Q(1) = 5.37, p = .021$**	5/66	$Q(1)^a = 0.29, p = .589$
Publication year	155	$Q(1) = 0.24, p = .625$	71	$Q(1) = 0.15, p = .696$

Bolded results emphasize statistical significance at $p < .05$

RT reaction time, *FA* focused attention, *OM* open monitoring, *RA* random assignment, *NC* no contact, *Active−* active control groups that undergo interventions not likely to improve attention, *Active+* active control groups that undergo interventions likely to improve attention

[a] A univariate two-level meta-analysis was run using averages of outcomes within studies due to model nonconvergence in the three-level model

Though the improvements in updating were not hypothesized to emerge in the meta-analysis, this finding mirrors conclusions made by Chiesa et al. (2011). This result is not surprising, particularly for OM meditation, given the meditation style underscores expanding awareness. However, meditators practicing both OM and FA techniques did not show greater improvements than those only practicing FA techniques. It is thus possible that FA meditators have also trained updating through their meditation. Improved updating could be representative of generally improved self-monitoring: keeping track of when attention is been divided and being aware of potential distractors entering the attentional field. Moreover, from a functional, training perspective, listening to and understanding instructions while maintaining focus requires an aspect of divided attention. Further research and theory are necessary to assess these possibilities.

Meta-analyses for orienting and shifting (when corrected for publication bias) indicated null results. Given the small number of outcomes investigating these constructs (orienting $\kappa = 21$, shifting $\kappa = 18$), it is difficult to make definitive conclusions about effects. Chiesa et al. (2011) suggested that meditation should lead to increases in the orienting network based on results in previous studies. Yet, meditation does not often actively engage the visual system. Further, while OM might encourage re-orienting attention to newly noticed aspects of the environment, it does not necessitate doing so quickly or accurately—qualities key to a strong orienting network. Thus, we believe it is unlikely that meditation improves orienting. Shifting, on the other hand, may have theoretical basis for being trained during meditation. People who practice FA techniques, when failing to maintain attention on an object, must re-focus their attention. Similarly, if meditators practicing OM techniques succumb to mind-wandering or if their thoughts are no longer in the moment, they must realign their attention. Though the effect size estimate for shifting was significantly different from zero, there was evidence of publication bias, with a two-level trim-fill analysis indicating that a corrected estimate would not be different from zero. This finding could be due to the lack of urgency that meditation places in re-focusing. Meditations tend to encourage a forgiving attitude toward mind-wandering: re-orienting attention back to the object of focus does not necessarily need to be quick, in contrast to what measures of shifting often test.

Comparing behavioral measures, reaction time tasks had smaller effect sizes than accuracy-based tasks. This finding suggests that improvements on attentional tasks are not simply a result of a speed-accuracy trade-off, whereby participants become faster but not more accurate. Rather, meditational may improve attentional speed and accuracy, but to a greater degree for accuracy than speed. Speed and urgency are not prioritized during meditation, whereas recognizing mind-wandering and successfully re-focusing attention and inhibiting distractors is.

For the hypotheses investigating methodological factors, results were mixed. Moderator analyses of control group type and study risk of bias did not indicate differences for any outcome type. On the other hand, for executive control, studies utilizing random assignment had smaller effect sizes than those that did not use randomization to condition. This finding is to be expected. Experienced meditators (often with many years of training) should be more strongly distinguished from controls than those who had only recently been introduced to meditation via an intervention. This finding being specific to the executive control network might indicate that regular meditative practice provides increased benefits to executive function over time compared to what can be improved through brief interventions.

Interestingly, the present meta-analysis found that length of meditation practice increased, there was a decrease in alerting. It is possible that these results may be due to a non-normal distribution of intervention lengths, where heterogeneity of variance in the meta-regression skewed the results. Alternatively, it is possible that longer attentional interventions could overburden the attentional system for a brief period of time; the present meta-analysis did not distinguish length of time between practice and assessment. On the other hand, decreased alerting could represent a benefit in the attentional system. Although greater alerting is typically viewed as desirable, it could also reflect frequent attentional capture, which may occur less frequently with increased meditation practice.

Fortunately, publication bias was only evident to a mild extent in the present meta-analysis. Though studies that were published had higher effect sizes than dissertations, patterns of results did not change by publication year or if the studies were sufficiently powered. Still, the finding that dissertations did not find any attentional benefits to meditation should be concerning. The tests of publication bias in this paper assumes that symmetry and heterogeneity of effect sizes indicates a lack of bias. However, the file drawer problem can still result in a misrepresentation of effects in current literature. We encourage researchers to contact us with relevant unpublished raw data or manuscripts, so we can update our meta-analysis at a later date.

Implications

Given the findings of the present meta-analysis, there are implications for researchers and clinicians who study meditation. First, the steady increase in literature tying meditation and attentional benefits has provided substantial evidence for its benefits. Particularly, these benefits seem to occur for the alerting attentional network and the updating and inhibition executive functions. Meditations—OM meditations in particular—have been theoretically associated with these attentional functions as potential mechanisms for change; however, it appears that FA meditation also may also affect these processes. Future research should investigate which of these mechanisms are most important in bringing about benefits associated with meditation. In developing treatment, it is important to remain parsimonious—that is, to remain as simple as possible, without wasting the time and energy of the clients. Deconstructing mindfulness and meditative practices in this way may help lead to more effective treatment with fewer adverse consequences. However, we also encourage researchers to distinguish between interventions that train meditative mechanisms (e.g., the attention training technique) and those that use meditative practice. It would be remiss to consider these heavily secularized techniques "meditations," given the cultural, religious, and historical significance of meditative practices.

Limitations and Future Research

There are several prominent limitations to the present meta-analysis that must be considered before drawing conclusions from the results. First, findings cannot be generalized to younger or older populations. Though recent reviews have suggested similar findings for these groups (i.e., Chan et al. 2019; Dunning et al. 2019), excluding papers that exclusively examined these populations prevents age-based comparison. Future meta-analyses should examine how participant age moderates meditation's effects on attention across the lifespan.

Second, the meta-analysis was broader in scope than many other literature reviews. Rather than examining a specific meditative teaching (e.g., MBSR), demographic, or quantitative methodology, all attentional studies broadly concerning FA and OM meditations in healthy adults were included. Though this may have the benefit of being comprehensive, it has the disadvantage of being too heterogenous in results. Indeed, a more detailed analysis would have been able to test more fine-grained moderators, such as whether meditators (or an intervention) used secular- vs. spirituality-based meditations. Using more refined categories, such as including only experimental/PPC studies, or limiting the attentional factors investigated would have allowed for a broader gray literature search, as well. Because of the larger scope of this meta-analysis, we were unable to contact all authors about additional, unpublished data they might have. Using actual data, rather than relying on statistical indicators of publication bias (e.g., trim-fill), would help elucidate the attentional effects of meditation in greater detail.

Third, outcomes within measures may not measure the construct to which they were classified. Despite thorough research into the behavioral tasks included in the analysis, certain tasks were difficult to sort. Can it be said definitively that the interference effect in the Stroop color–word task captures the same attentional construct as the difference score between the incongruent trials? This subjectivity leaves room for researcher error. Fortunately, many researchers explicitly outlined what they theorized each task would measure (e.g., Josefsson and Broberg 2011). Yet, this limitation extends more broadly into how behavioral measures are interpreted. The n-back task, for example, was classified as measure of updating, but it is difficult to disentangle updating from working memory capacity. Therefore, it is possible that the effects found in the analyses represent advantages that can be attributed to other, highly correlated cognitive processes. This limitation is likely to be present in all research that uses performance on behavioral tasks in order to generalize to attentional processes. Nevertheless, meditation shows clear attentional benefits, irrespective of the neurocognitive path it takes to get there.

Acknowledgements The authors thank Dr. Julia Spaniol and Dr. Lixia Yang for their invaluable feedback and input. They would also like to acknowledge the reviewers for their comments, which were integral to the development of this manuscript.

Authors' Contribution DS: designed and co-executed the study, completed the data analyses, wrote the first draft of the paper, and co-wrote the final version of the manuscript. KES: co-executed the study and co-wrote the manuscript. All authors approved the final version of the manuscript for submission.

Data Availability All online resources are available at the Open Science Framework (https://osf.io/aj8cv/?view_only=941f7c5c9fd4471bb0f59c56b27c1f26).

Declarations

Conflict of Interest The authors declare no competing interests.

References

References marked with an asterisk indicate studies included in the meta-analysis.

*Ainsworth, B., Eddershaw, R., Meron, D., Baldwin, D. S., & Garner, M. (2013). The effect of focused attention and open monitoring meditation on attention network function in healthy volunteers. *Psychiatry Research, 210*(3), 1226–1231. https://doi.org/10.1016/j.psychres.2013.09.002.

*Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., Lutz, A., & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *The Journal of Neuroscience, 32*(44), 15601-15610. https://doi.org/10.1523/JNEUROSCI.2957-12.2012.

*Anderson, N. D., Lau, M. A., Segal, Z. V., & Bishop, S. R. (2007). Mindfulness-based stress reduction and attentional control. *Clinical Psychology & Psychotherapy, 14*(6), 449–463. https://doi.org/10.1002/cpp.

*Badart, P., McDowall, J., & Prime, S. L. (2018). Multimodal sustained attention superiority in concentrative meditators compared to nonmeditators. *Mindfulness, 9*(3), 824–835. https://doi.org/10.1007/s12671-017-0822-y.

*Bailey, N. W., Freedman, G., Raj, K., Sullivan, C. M., Rogasch, N. C., Chung, S. W., Hoy, K. E., Chambers, R., Hassed, C., Van Dam, N. T., Koenig, T., & Fitzgerald, P. B. (2019a). Mindfulness meditators show altered distributions of early and late neural activity markers of attention in a response inhibition task. *PLoS One, 14*(8), e0203096. https://doi.org/10.1371/journal.pone.0203096.

*Bailey, N. W., Raj, K., Freedman, G., Fitzgibbon, B. M., Rogasch, N. C., Van Dam, N. T., & Fitzgerald, P. B. (2019b). Mindfulness meditators do not show differences in electrophysiological measures of error processing. *Mindfulness, 10*, 1350-1380. https://doi.org/10.1007/s12671-019-1096-3.

*Banks, J. B., Welhaf, M. S., & Srour, A. (2015). The protective effects of brief mindfulness meditation training. *Consciousness and Cognition, 33*, 277-285. https://doi.org/10.1016/j.concog.2015.01.016.

*Basso, J. C., McHale, A., Ende, V., Oberlin, D. J., & Suzuki, W. A. (2019). Brief, daily meditation enhances attention, memory, mood, and emotional regulation in non-experienced meditators. *Behavioural Brain Research, 356*, 208-220. https://doi.org/10.1016/j.bbr.2018.08.023.

Becerra, R., Dandrade, C., & Harms, C. (2017). Can specific attentional skills be modified with mindfulness training for novice practitioners? *Current Psychology, 36,* 657–664. https://doi.org/10.1007/s12144-016-9454-y.

Begg, C. B., & Mazumdar, M. (1994). Operating characteristics of a rank correlation test for publication bias. *Biometrics, 50*(4), 1088–1101. https://doi.org/10.2307/2533446.

*Bhayee, S., Tomaszewski, P., Leen, D. H., Moffat, G., Pino, L., Moreno, S., & Farb, N. A. S. (2016). Attentional and affective consequences of technology supported mindfulness training: a randomized, active control, efficacy trial. *BioMed Central Psychology, 4*(6), https://doi.org/10.1186/s40359-016-0168-6.

Bishop, S. R., Lau, M. A., Shapiro, S. L., Carlson, L., Anderson, N. D., Carmody, J., et al. (2004). Mindfulness: a proposed operational definition. *Clinical Psychology: Science and Practice, 11*(3), 230–241. https://doi.org/10.1093/clipsy/bph077.

*Bornemann, B., & Singer, T. (2017). Taking time to feel our body: stead increases in heartbeat perception accuracy and decreases in alexithymia over 9 months of contemplative mental training. *Psychophysiology, 54*, 469-482. https://doi.org/10.1111/psyp.12790.

Britton, W. B., Davis, J. H., Loucks, E. B., Peterson, B., Cullen, B. H., Reuter, L., Rando, A., Rahring, H., Lipsky, J., & Lindahl, J. R. (2018). Dismantling mindfulness-based cognitive therapy: creation and validation of 8-week focused attention and open monitoring interventions within a 3-armed randomized control trial. *Behaviour Research and Therapy, 101*, 92–107. https://doi.org/10.1016/j.brat.2017.09.010.

*Buchanan, T. (2016). Self-report measures of executive function problems correlate with personality, not performance-based executive function measures, in nonclinical samples. *Psychological Assessment, 28*, 373-285. https://doi.org/10.1037/pas0000192.

*Burger, K. G., & Lockhart, J. S. (2017). Meditation's effect on attentional efficiency, stress, and mindfulness characteristics of nursing students. *Journal of Nursing Education, 56*(7), 430-434. https://doi.org/10.3928/01484834-20170619-08.

*Campillo, E., Ricarte, J. J., Ros, L., Nieto, M., & Latorre, J. M. (2018). Effects of the visual and auditory components of a brief mindfulness intervention on mood state and on visual and auditory attention and memory task performance. *Current Psychology*, *37*(1), 357–365. https://doi.org/10.1007/s12144-016-9519-y.

*Chambers, R., Lo, B. C. Y., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy and Research*, *32*(3), 303–322. https://doi.org/10.1007/s10608-007-9119-0.

Chan, J. S. Y., Deng, K., Wu, J., & Yan, J. H. (2019). Effects of meditation and mind – body exercises on older adults' cognitive performance: a meta-analysis. *Gerentologist, 59*(6), e782–e790. https://doi.org/10.1093/geront/gnz022.

*Cheng, K. S., Chang, Y. F., Han, R. P. S., & Lee, P. F. (2017). Enhanced conflict monitoring via a short-duration, video-assisted deep breathing in healthy young adults: an event-related potential approach through the Go/NoGo paradigm. *PeerJ*, 5e38572017. https://doi.org/10.7717/peerj.3857.

Cheung, M. W.-L. (2019). A guide to conducting meta-analysis with non-independent effect sizes. *Neuropsychology Review, 29*, 387–396. https://doi.org/10.1007/s11065-019-09415-6.

Chiesa, A., Calati, R., & Serretti, A. (2011). Does mindfulness training improve cognitive abilities? A systematic review of neuropsychological findings. *Clinical Psychology Review, 31*, 449–464. https://doi.org/10.1016/j.cpr.2010.11.003.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Routledge.

*Cohen, J. N., Jensen, D., Stange, J. P., Neuburger, M., & Heimberg, R. G. (2017). The immediate and long-term effects of an intensive meditation retreat. *Mindfulness*, *8*(4), 1064–1077. https://doi.org/10.1007/s12671-017-0682-5.

*Cusens, B., Duggan, G. B., Thorne, K., & Burch, V. (2010). Evaluation of the breathworks mindfulness-based pain management programme: effects on well-being and multiple measures of mindfulness. *Clinical Psychology & Psychotherapy, 17*(1), 63–78. https://doi.org/10.1002/cpp.653.

Dahl, C. J., Lutz, A., & Davidson, R. J. (2015). Reconstructing and deconstructing the self: cognitive mechanisms in meditation practice. *Trends in Cognitive Sciences, 19*(9), 515–523. https://doi.org/10.1016/j.tics.2015.07.001.

*Daubenmier, J., Sze, J., Kerr, C. E., Kemeny, M. E., & Mehling, W. (2013). Follow your breath: respiratory interoceptive accuracy in experienced meditators. *Psychophysiology*, *50*(8), 777–789. https://doi.org/10.1111/psyp.12057.

*Deepeshwar, S., Vinchurkar, S. A., Visweswaraiah, N. K., & Nagendra, H. R. (2015). Hemodynamic responses on prefrontal cortex related to meditation and attentional task. *Frontiers in Systems Neuroscience*, *8*(February), 1–13. https://doi.org/10.3389/fnsys.2014.00252.

Dunning, D. L., Griffiths, K., Kuyken, W., Crane, C., & Foulkes, L. (2019). The effects of mindfulness-based interventions on cognition and mental health in children and adolescents – a meta-analysis of randomized controlled trials. *Journal of Child Psychology and Psychiatry, 60*(3), 244–258. https://doi.org/10.1111/jcpp.12980.

Duval, S. J., & Tweedie, R. L. (2000). A nonparametric "trim and fill" method of accounting for publication bias in meta-analysis. *Journal of the American Statistical Association, 95*, 89–98. https://doi.org/10.1080/01621459.2000.10473905.

Dweck, C. S. (2000). *Self-theories: their role in motivation, personality, and development*. Psychology Press.

Eberth, J., & Sedlmeier, P. (2012). The effects of mindfulness meditation: a meta-analysis. *Mindfulness, 3*(3), 174–189. https://doi.org/10.1007/s12671-012-0101-x.

*Eisenbeck, N., Luciano, C., & Valdivia-Salas, S. (2018). Effects of a focused breathing mindfulness exercise on attention, memory, and mood: the importance of task characteristics. *Behaviour Change, 35*(1), 54–70. https://doi.org/10.1017/bec.2018.9.

*Esch, T., Winkler, J., Auwärter, V., Gnann, H., Huber, R., & Schmidt, S. (2017). Neurobiological aspects of mindfulness in pain autoregulation: unexpected results from a randomized-controlled trial and possible implications for meditation research. *Frontiers in Human Neuroscience, 10*(January), 1–15. https://doi.org/10.3389/fnhum.2016.00674.

*Fabio, R. A., & Towey, G. E. (2018). Long-term meditation: the relationship between cognitive processes, thinking styles and mindfulness. *Cognitive Processing*, *19*(1), 73–85. https://doi.org/10.1007/s10339-017-0844-3.

Fan, J., Mccandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340–347. https://doi.org/10.1162/089892902317361886.

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *NeuroImage, 26*(2), 471–479. https://doi.org/10.1016/j.neuroimage.2005.02.004.

*Flook, L., Goldberg, S. B., Pinger, L., Bonus, K., & Davidson, R. J. (2013). Mindfulness for teachers: a pilot study to assess effects on stress, burnout, and teaching efficacy. *Mind, Brain, and Education, 7*(3), 182-195. https://doi.org/10.1111/mbe.12026.

Franco, A., Malhotra, N., & Simonovits, G. (2014). Publication bias in the social sciences: unlocking the file drawer. *Science, 345*(6203), 1502–1505. https://doi.org/10.1126/science.1255484.

Fritz, A., Scherndl, T., & Kuhberger, A. (2012). A comprehensive review of reporting practices in psychological journals: are effect sizes really enough? *Theory & Psychology, 23*(1), 98–122. https://doi.org/10.1177/0959354312436870.

*Gackenbach, J., Swanston, D., & Stark, H. (2015). Effects of video game play versus meditation/prayer in waking and dreaming experiences. *Journal of Transpersonal Psychology, 47*(2), 188–218.

Gallant, S. (2016). Mindfulness meditation practice and executive functioning: breaking down the benefit. *Consciousness and Cognition, 40*, 116–130. https://doi.org/10.1016/j.concog.2016.01.005.

*Green, J. P., & Black, K. N. (2017). Meditation-focused attention with the MBAS and solving anagrams. *Psychology of Consciousness: Theory, Research and Practice*, *4*(4), 348–366. https://doi.org/10.1037/cns0000113.

Guiney, H., & Machado, L. (2013). Benefits of regular aerobic exercise for executive functioning in healthy populations. *Psychonomic Bulletin & Review, 20*(1), 73–86. https://doi.org/10.3758/s13423-012-0345-4.

*Helber, C., Zook, N. A., & Immergut, M. (2012). Meditation in higher education: does it enhance cognition? *Innovative Higher Education, 37*(5), 349–358. https://doi.org/10.1007/s10755-012-9217-0.

*Hodgins, H. S., & Adair, K. C. (2010). Attentional processes and meditation. *Consciousness and Cognition*, *19*(4), 872–878. https://doi.org/10.1016/j.concog.2010.04.002.

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

Hopewell, S., Clarke, M. J., Stewart, L., & Tierney, J. (2007). Time to publication for results of clinical trials. *The Cochrane Database of Systematic Reviews, 2007*(2), MR000011. https://doi.org/10.1002/14651858.MR000011.pub2.

*Isbel, B., & Mahar, D. (2015). Cognitive mechanisms of mindfulness: a test of current models. *Consciousness and Cognition*, *38*, 50–59. https://doi.org/10.1016/j.concog.2015.10.005.

*Jensen, C. G., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2012). Mindfulness training affects attention-or is it attentional effort? *Journal of Experimental Psychology: General*, *141*(1), 106–123. https://doi.org/10.1037/a0024931.

*Jo, H. G., Wittmann, M., Hinterberger, T., & Schmidt, S. (2014). The readiness potential reflects intentional binding. *Frontiers in Human Neuroscience, 8*(June), 1–9. https://doi.org/10.3389/fnhum.2014.00421.

*Jo, H. G., Schmidt, S., Inacker, E., Markowiak, M., & Hinterberger, T. (2016). Meditation and attention: a controlled study on long-term meditators in behavioral performance and event-related potentials of attentional control. *International Journal of Psychophysiology*, *99*, 33–39. https://doi.org/10.1016/j.ijpsycho.2015.11.016.

*Johnson, S., Gur, R. M., David, Z., & Currier, E. (2015). One-session mindfulness meditation: a randomized controlled study of effects on cognition and mood. *Mindfulness*, *6*(1), 88–98. https://doi.org/10.1007/s12671-013-0234-6.

*Josefsson, T., & Broberg, A. (2011). Meditators and non-meditators on sustained and executive attentional performance. *Mental Health, Religion and Culture*, *14*(3), 291–309. https://doi.org/10.1080/13674670903578621.

*Josefsson, T., Lindwall, M., & Broberg, A. G. (2014). The effects of a short-term mindfulness based intervention on self-reported mindfulness, decentering, executive attention, psychological health, and coping style: examining unique mindfulness effects and mediators. *Mindfulness*, *5*(1), 18–35. https://doi.org/10.1007/s12671-012-0142-1.

*Khalsa, S. S., Rudrauf, D., Damasio, A. R., Davidson, R. J., Lutz, A., & Tranel, D. (2008). Interoceptive awareness in experienced meditators. *Psychophysiology*, *45*(4), 671–677. https://doi.org/10.1111/j.1469-8986.2008.00666.x.

*Klempel, N. M. (2018). *The effect of brief mindfulness meditation training on attention, affect, and mindfulness skills*. Hofstra University, Hempstead.

Kok, B. E., Waugh, C. E., & Fredrickson, B. L. (2013). Meditation and health: the search for mechanisms of action. *Social and Personality Psychology Compass, 7*(1), 27–39. https://doi.org/10.1111/spc3.12006.

*Kozasa, E. H., Sato, J. R., Lacerda, S. S., Barreiros, M. A. M., Radvany, J., Russell, T. A., … Amaro, E. (2012). Meditation training increases brain efficiency in an attention task. *NeuroImage*, *59*(1), 745–749. https://doi.org/10.1016/j.neuroimage.2011.06.088.

*Kozasa, E. H., Balardin, J. B., Sato, J. R., Chaim, K. T., Lacerda, S. S., Radvany, J., Mello, L. E. A. M., & Amaro, E. (2018). Effects of a 7-day meditation retreat on the brain function of meditators and non-meditators during an attention task. *Frontiers in Human Neuroscience*, *12*(June), 1–9. https://doi.org/10.3389/fnhum.2018.00222.

Kozhevnikov, M., Louchakova, O., Josipovic, Z., & Motes, M. A. (2009). The enhancement of visuospatial processing efficiency through Buddhist deity meditation. *Psychological Science, 20*(5), 645–653. https://doi.org/10.1111/j.1467-9280.2009.02345.x.

*Kumari, V., Hamid, A., Brand, A., & Antonova, E. (2015). Acoustic prepulse inhibition: one ear is better than two, but why and when? *Psychophysiology, 52*(5), 714–721. https://doi.org/10.1111/psyp.12391.

*Kumari, V., Antonova, E., Wright, B., Hamid, A., Hernandez, E. M., Schmechtig, A., & Ettinger, U. (2017). The mindful eye: smooth pursuit and saccadic eye movements in meditators and non-meditators. *Consciousness and Cognition*, *48*, 66–75. https://doi.org/10.1016/j.concog.2016.10.008.

*Lacerda, S. S., Little, S. W., & Kozasa, E. H. (2018). A stress reduction program adapted for the work environment: a randomized controlled trial with a follow-up. *Frontiers in Psychology, 9*(May), 1–12. https://doi.org/10.3389/fpsyg.2018.00668.

*Larson, M. J., Steffen, P. R., & Primosch, M. (2013). The impact of a brief mindfulness meditation intervention on cognitive control and error-related performance monitoring. *Frontiers in Human Neuroscience*, *7*(July), 1–12. https://doi.org/10.3389/fnhum.2013.00308.

*Lebares, C. C., Guvva, E. V., Olaru, M., Sugrue, L. P., Staffaroni, A. M., Delucchi, K. L., … Harris, H. W. (2019). Efficacy of mindfulness-based cognitive training in surgery: additional analysis of the mindful surgeon pilot randomized clinical trial. *JAMA Network Open, 2*(5), e194108. https://doi.org/10.1001/jamanetworkopen.2019.4108.

*Leite, J. R., de Mornellas, F. L., Amemiya, T. M., de Almeida, A. A. F., Dias, A. A., Afonso, R., Little, S., & Kozasa, E. H. (2010). Effect of progressive self-focus meditation on attention, anxiety, and depression scores. *Perceptual and Motor Skills*, *110*(3), 840–848. https://doi.org/10.2466/pms.110.3.840-848.

*Li, Y., Liu, F., Zhang, Q., Liu, X., & Wei, P. (2018). The effect of mindfulness training on proactive and reactive cognitive control. *Frontiers in Psychology, 9*(June). https://doi.org/10.3389/fpsyg.2018.01002.

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., et al. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Journal of Clinical Epidemiology, 62*(10), 1–34. https://doi.org/10.1016/j.jclinepi.2009.06.006.

Lohani, M., McElvaine, K., Payne, B., Mitcheom, K., & Britton, W. (2020). A longitudinal training study to delineate the specific causal effects of open monitoring versus focused attention techniques on emotional health. *Complementary Therapies in Medicine, 53*, 102525. https://doi.org/10.1016/j.ctim.2020.102525.

Lutz, A., Dunne, J. D., & Davidson, R. J. (2007). Meditation and the neuroscience of consciousness: an introduction. In *The Cambridge handbook of consciousness* (pp. 497–550).

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences, 12*(4), 163–169. https://doi.org/10.1016/j.tics.2008.01.005.

*Lutz, A., Slagter, H. A., Rawlings, N. B., Francis, A. D., Greischar, L. L., & Davidson, R. J. (2009). Mental training enhances attentional stability: neural and behavioral evidence. *Journal of Neuroscience*, *29*(42), 13418–13427. https://doi.org/10.1523/JNEUROSCI.1614-09.2009.

Lutz, A., Jha, A. P., Dunne, J. D., & Saron, C. D. (2015). Investigating the phenomenological matrix of mindfulness-related practices from a neurocognitive perspective. *American Psychologist, 70*(7), 632–658. https://doi.org/10.1037/a0039585.

*Lykins, E. L. B., Baer, R. A., & Gottlob, L. R. (2012). Performance-based tests of attention and memory in long-term mindfulness meditators and demographically matched nonmeditators. *Cognitive Therapy and Research*, *36*(1), 103–114. https://doi.org/10.1007/s10608-010-9318-y.

*Lymeus, F., Lundgren, T., & Hartig, T. (2017). Attentional effort of beginning mindfulness training is offset with practice directed toward images of natural scenery. *Environment and Behavior, 49*(5), 536–559. https://doi.org/10.1177/0013916516657390.

*Lymeus, F., Lindberg, P., & Hartig, T. (2018). Building mindfulness bottom-up: meditation in natural settings supports open monitoring and attention restoration. *Consciousness and Cognition, 59*(February), 40–56. https://doi.org/10.1016/j.concog.2018.01.008.

*Mallya, S., & Fiocco, A. J. (2019). The effects of mindfulness training on cognitive and psychosocial well-being among family caregivers of persons with neurodegenerative disease. *Mindfulness, 10*(10), 2036-2037. https://doi.org/10.1007/s12671-019-01155-1.

*Mann, C. (2012). *The effect of mindfulness on racial stereotype activation and application*. (Unpublished doctoral dissertation). Bryn Mawr College, Bryn Mawr.

*McMorran, K. E. (2018). *Changes in attention and depressive symptoms following a brief, internet-delivered mindful breathing intervention in an undergraduate sample*. (Unpublished doctoral dissertation). The Catholic University of America, Washington, D.C.

*Meland, A., Ishimatsu, K., Pensgaard, A. M., Wagstaff, A., Fonne, V., Garde, A. H., & Harris, A. (2015). Impact of mindfulness training on physiological measures of stress and objective measures of attention control in a military helicopter unit. *The International Journal of Aviation Psychology*, *25*(3–4), 191–208. https://doi.org/10.1080/10508414.2015.1162639.

*Melloni, M., Sedeno, L., Couto, B., Reynoso, M., Gelormini, C., Favaloro, R., Canales-Johnson, A., Sigman, M., Manes, F., & Ibanez, A. (2013). Preliminary evidence about the effects of meditation on interospective sensitivity and social cognition. *Behavioral and Brain Functions, 9*(47). https://doi.org/10.1186/1744-9081-9-47.

*Menezes, C. B., & Bizarro, L. (2015). Effects of a brief meditation training on negative affect, trait anxiety and concentrated attention. *The International Journal of Aviation Psychology, 25*(62), 393–401. https://doi.org/10.1590/1982-43272562201513.

*Mirams, L., Poliakoff, E., Brown, R. J., & Lloyd, D. M. (2013). Brief body-scan meditation practice improves somatosensory perceptual decision making. *Consciousness and Cognition*, *22*(1), 348–359. https://doi.org/10.1016/j.concog.2012.07.009.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734.

Monteiro, L. M., Musten, R. F., & Compson, J. (2015). Traditional and contemporary mindfulness: finding the middle path in the tangle of concerns. *Mindfulness, 6*, 1–13. https://doi.org/10.1007/s12671-014-0301-7.

*Moore, A., & Malinowski, P. (2009). Meditation, mindfulness and cognitive flexibility. *Consciousness and Cognition*, *18*(1), 176–186. https://doi.org/10.1016/j.concog.2008.12.008.

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods, 11*(2), 364–386. https://doi.org/10.1177/1094428106291059.

*Morrison, A. B., Goolsarran, M., Rogers, S. L., & Jha, A. P. (2014). Taming a wandering attention: short-form mindfulness training in student cohorts. *Frontiers in Human Neuroscience*, *7*(January), 1–12. https://doi.org/10.3389/fnhum.2013.00897.

*Noone, C., & Hogan, M. J. (2018). Improvements in critical thinking performance following mindfulness meditation depend on thinking dispositions. *Mindfulness*, *9*(2), 461–473. https://doi.org/10.1007/s12671-017-0789-8.

*Otten, S., Schötz, E., Wittmann, M., Kohls, N., Schmidt, S., & Meissner, K. (2015). Psychophysiology of duration estimation in experienced mindfulness meditators and matched controls. *Frontiers in Psychology*, *6*(August), 1–12. https://doi.org/10.3389/fpsyg.2015.01215.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*(1), 25–42. https://doi.org/10.1146/annurev.ne.13.030190.000325.

Quaglia, J. T., Zeidan, F., Grossenbacher, P. G., Freeman, S. P., Braun, S. E., Martelli, A., et al. (2019). Brief mindfulness training enhances cognitive control in socioemotional contexts: Behavioral and neural evidence. *PLOS ONE, 14*(7), 1–21. https://doi.org/10.1371/journal.pone.0219862.

Rahl, H. A., Lindsay, E. K., Pacilio, L. E., Brown, K. W., & Creswell, J. D. (2017). Brief mindfulness meditation training reduces mind wandering: The critical role of acceptance. *Emotion, 17*(2), 224–230. https://doi.org/10.1037/emo0000250.

Reibel, D. K., Greeson, J. M., Brainard, G. C., & Rosenzweig, S. (2001). Mindfulness-based stress reduction and health-related quality of life in a heterogeneous patient population. *General Hospital Psychiatry, 23*, 183–192. https://doi.org/10.1016/S0163-8343(01)00149-9.

*Rodrigues, D. B. G., Lacerda, S. S., Balardin, J. B., Chaim, K. T., Portes, B., Sanches-Rocha, L. G., Rodvany, J., Sato, J. R., Mello, L. E. A. M. , Amaro, E., Jr., & Kozasa, E. H. (2018). Posterior cingulate cortex/precuneus blood oxygen-level dependent signal changes during the repetition of an attention task in meditators and nonmeditators. *NeuroReport*, *29*(17), 1463–1467. https://doi.org/10.1097/WNR.0000000000001133.

*Rodriguez Vega, B., Melero-Llorente, J., Bayon Perez, C., Cebolla, S., Mira, J., Valverde, C., & Fernández-Liria, A. (2014). Impact of mindfulness training on attentional control and anger regulation processes for psychotherapists in training. *Psychotherapy Research*, *24*(2), 202–213. https://doi.org/10.1080/10503307.2013.838651.

*Roeser, R. W., Schonert-Reichl, K. A., Jha, A., Cullen, M., Wallace, L., Wilensky, R., Oberle, E., Thomson, K., Taylor, C., & Harrison, J. (2013). Mindfulness training and reductions in teacher stress and burnout: results from two randomized, waitlist-control field trials. *Journal of Educational Psychology, 105*(3), 787–804. https://doi.org/10.1037/a0032093.

*Saunders, B., Rodrigo, A. H., & Inzlicht, M. (2016). Mindful awareness of feelings increases neural performance monitoring. *Cognitive, Affective, & Behavioral Neuroscience, 16*(1), 93–105. https://doi.org/10.3758/s13415-015-0375-2.

*Schofield, T. P., Creswell, J. D., & Denson, T. F. (2015). Brief mindfulness induction reduces inattentional blindness. *Consciousness and Cognition*, *37*, 63–70. https://doi.org/10.1016/j.concog.2015.08.007.

Sedlmeier, P., Eberth, J., Schwarz, M., Zimmermann, D., Haarig, F., Jaeger, S., & Kunze, S. (2012). The psychological effects of meditation: a meta-analysis. *Psychological Bulletin, 138*(6), 1139–1171. https://doi.org/10.1037/a0028168.

*Semple, R. J. (2010). Does mindfulness meditation enhance attention? A randomized controlled trial. *Mindfulness*, *1*(2), 121–130. https://doi.org/10.1007/s12671-010-0017-2.

*Srinivasan, N., & Singh, A. (2017). Concentrative meditation influences visual awareness: a study with color afterimages. *Mindfulness, 8*(1), 17–26. https://doi.org/10.1007/s12671-015-0428-1.

Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Catesm, C. J., Cheng, H.-Y., Corbett, M. S., Eldridge, S. M., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T., McAleenan, A., Reeves, B. C., Shepperd, S., Shrier, I., Stewart, L. A., Tilling, K., White, I. R., Whiting, P. F., & Higgins, J. P. T. (2019). RoB 2: a revised tool for assessing risk of bias in randomised trials. *British Medical Journal, 366*, l4898. https://doi.org/10.1136/bmj.l4898.

*Taraban, O., Heide, F., Woollacott, M., & Chan, D. (2017). The effects of a mindful listening task on mind-wandering. *Mindfulness*, *8*(2), 433–443. https://doi.org/10.1007/s12671-016-0615-8.

*Teng, S. C., & Lien, Y. W. (2016). What Confucius practiced is good for your mind: examining the effect of a contemplative practice in Confucian tradition on executive functions. *Consciousness and Cognition, 42*(1), 204–215. https://doi.org/10.1016/j.concog.2016.03.016.

*Teper, R., & Inzlicht, M. (2013). Meditation, mindfulness and executive control: the importance of emotional acceptance and brain-based performance monitoring. *Social Cognitive and Affective Neuroscience*, *8*(1), 85–92. https://doi.org/10.1093/scan/nss045.

Tickell, A., Ball, S., Bernard, P., Kuyken, W., Marx, R., Pack, S., Strauss, C., Sweeney, T., & Crane, C. (2019). The effectiveness of mindfulness-based cognitive therapy (MBCT) in real-world healthcare services. *Mindfulness, 11*, 279–290. https://doi.org/10.1007/s12671-018-1087-9.

*Tsai, M. H., & Chou, W. L. (2016). Attentional orienting and executive control are affected by different types of meditation practice. *Consciousness and Cognition*, *46*, 110–126. https://doi.org/10.1016/j.concog.2016.09.020.

*Valentine, E. R., & Sweet, P. L. G. (1999). Meditation and attention: a comparison of the effects of concentrative and mindfulness meditation on sustained attention. *Mental Health, Religion and Culture*, *2*(1), 59–70. https://doi.org/10.1080/13674679908406332.

Van Dam, N. T., van Vugt, M. K., Vago, D. R., Schmalzl, L., Saron, C. D., Olendzki, A., et al. (2018). Mind the hype: a critical evaluation and prescriptive agenda for research on mindfulness and meditation. *Perspectives on Psychological Science, 13*(1), 36–61. https://doi.org/10.1177/1745691617709589.

*van den Hurk, P. A. M., Giommi, F., Gielen, S. C., Speckens, A. E. M., & Barendregt, H. P. (2010a). Greater efficiency in attentional processing related to mindfulness meditation. *Quarterly Journal of Experimental Psychology*, *63*(6), 1168–1180. https://doi.org/10.1080/17470210903249365.

*van den Hurk, P. A. M., Janssen, B. H., Giommi, F., Barendregt, H. P., & Gielen, S. C. (2010b). Mindfulness meditation associated with alterations in bottom-up processing: psychophysiological evidence for reduced reactivity. *International Journal of Psychophysiology, 78*(2), 151–157. https://doi.org/10.1016/j.ijpsycho.2010.07.002.

*Verhoeven, J. E., Vrijsen, J. N., van Oostrom, I., Speckens, A. E. M., & Rinck, M. (2014). Attention effects of mindfulness-based cognitive therapy in formerly depressed patients. *Journal of Experimental Psychopathology*, *5*(4), jep.037513. https://doi.org/10.5127/jep.037513.

Viechtbauer, W. (2010). Conducting meta-analyses in R with the *metafor* package. *Journal of Statistical Software, 36*(3), 1–48. https://doi.org/10.18637/jss.v036.i03.

Wallace, A. B. (2007). *Contemplative science: where Buddhism and neuroscience converge*. Columbia University Press.

*Walsh, K. M., Saab, B. J., & Farb, N. A. S. (2019). Effects of a mindfulness meditation app on subjective well-being: active randomized controlled trial and experience sampling study. *Journal of Medical Internet Research, 21*(1). https://doi.org/10.2196/10844.

*Wang, Y., Xin, T.-T., Liu, X.-H., Zhang, Y., Lu, H.-H., & Zhai, Y.-B. (2012). Mindfulness can reduce automatic responding: evidences from Stroop task and prospective memory task. *Acta Psychologica Sinica*, *44*(9), 1180–1188. https://doi.org/10.3724/SP.J.1041.2012.01180.

*Watier, N., & Dubois, M. (2016). The effects of a brief mindfulness exercise on executive attention and recognition memory. *Mindfulness*, *7*(3), 745–753. https://doi.org/10.1007/s12671-016-0514-z.

*Wenk, H. E. (1997). *The effect of concentrative attention on habitual cognition* (Unpublished doctoral dissertation). Yale University, New Haven.

Westfall, J. (2016). Five different "Cohen's d" statistics for within-subject designs. [Blog post]. http://jakewestfall.org/blog/index.php/category/effect-size/.

*Wong, K. F., Teng, J., Chee, M. W. L., Doshi, K., & Lim, J. (2018). Positive effects of mindfulness-based training on energy maintenance and the EEG correlates of sustained attention in a cohort of nurses. *Frontiers in Human Neuroscience, 12*(March), 1–12. https://doi.org/10.3389/fnhum.2018.00080.

*Yosai, E. R. (2017). *Further investigating the underlying attentional processes of brief mindfulness-based interventions* (unpublished doctoral dissertation). Baker University, Baldwin City.

*Zhang, Q., Wang, Z., Wang, X., Liu, L., Zhang, J., & Zhou, R. (2019). The effects of different stages of mindfulness meditation training on emotion regulation. *Frontiers in Human Neuroscience, 13*(June), 1–8. https://doi.org/10.3389/fnhum.2019.00208.

*Zhu, T., Xue, J., Montuclard, A., Jiang, Y., Weng, W., & Chen, S. (2019). Can mindfulness-based training improve positive emotion and cognitive ability in chinese non-clinical population? A pilot study. *Frontiers in Psychology, 10*(July), 1–12. https://doi.org/10.3389/fpsyg.2019.01549.

*Ziegler, D. A., Simon, A. J., Gallen, C. L., Skinner, S., Janowich, J. R., Volponi, J. J., Rolle, C. E., Mishra, J., Kornfield, J., Anguera, J. A., & Gazzaley, A. (2019). Closed-loop digital meditation improves sustained attention in young adults. *Nature Human Behaviour, 3*(7), 746–757. https://doi.org/10.1038/s41562-019-0611-9