Mindfulness and Attention: Current State-of-Affairs and Future Considerations

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Abstract

This review examines longitudinal studies of changes in attentional control following mindfulness training. A total of 56 retreat studies, feasibility studies, and randomized controlled trials were identified. Outcome measures were broadly categorized based on whether they operated primarily via top-down mechanisms, involving goal-directed modulation of attention via endogenous information, or bottom-up mechanisms, involving attentional capture via exogenous cues. Although many feasibility and retreat studies provide promising evidence supporting gains in both top-down and bottom-up attention following mindfulness training, evidence from randomized controlled trials, especially those involving active control comparison groups, is more mixed. This review calls attention to the urgent need in our field of contemplative sciences for adopting the methodological rigor necessary for establishing the efficacy of mindfulness meditation as a cognitive rehabilitation tool. Although studies including wait-list control comparisons were fruitful in providing initial feasibility data and pre-post effect sizes, there is a pressing need to employ standards that have been heavily advocated in the broader cognitive and physical training literatures. Critically, inclusion of active comparison groups and explicit attention to reduction of demand characteristics are needed to disentangle the effects of placebo from treatment. Further, detailed protocols for mindfulness and control groups and examination of theoretically guided outcome variables with established metrics for reliability and validity are key ingredients in the systematic study of mindfulness meditation. Adoption of such methodological rigor will allow for causal claims supporting mindfulness training as an efficacious treatment modality for cognitive rehabilitation and enhancement.

Keywords: rigorous randomized controlled trials; mindfulness meditation; attentional control; threats to internal validity

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Introduction

“Mindfulness means paying attention in a particular way: on purpose, in the present moment, and non-judgmentally.”

Jon Kabat-Zinn (1983)

“Mindfulness is an innate human capacity to deliberately pay full attention to where we are, to our actual experience, and to learn from it.”

Jack Kornfield (2005)

“Mindfulness is an open attentiveness to whatever arises.”

Pema Chödrön (2000)

“Mindfulness is a receptive attention to and awareness of present events and experiences.”

Brown & Ryan (2003)

Attention is considered central to the construct of mindfulness. The lessons of leading mindfulness teachers frequently note the use of attentional processes to alter information processing and influence emotional experiences, thought processes, and sensations (Chödrön, 2001; Hanh, 1999; Kabat-Zinn, 1990; Rosenberg, 2004). The key practices taught in longitudinal mindfulness programs, such as breath awareness practices, body scan practices, walking meditation, and choiceless awareness, rely upon attentional processes to focus on either a specific anchor, such as the breath, or various other phenomena, such as thoughts, emotions, and sensations, as they arise. Additionally, although trait mindfulness measures differ with regard to the facets of mindfulness included, the ability to sustain attention is common to the majority of measures, particularly those garnering the most empirical support (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Brown & Ryan, 2003).

Despite the great interest in examining the impact of mindfulness on facets of attentional control, evidence for a beneficial impact of mindfulness-based training on attentional processes is currently mixed. In this narrative review, our aim is to appraise the longitudinal training literature in which mindfulness practices are taught for the purpose of facilitating gains in attentional control. We synthesize the results of these studies with the goal of clarifying the extent to which training in mindfulness meditation offers prophylaxis for the various facets of attentional control. To review preliminary evidence of attentional benefits following mindfulness training, we included feasibility and retreat studies - those examining performance after mindfulness training without a comparison group or those that allowed for self-selection of training groups. In order to examine whether mindfulness training causally impacts attentional control, we included studies that randomized participants to a mindfulness group and to at least one other comparison group.

Although reviews synthesizing the impact of mindfulness training on attentional control exist (Chiesa & Serretti, 2010; Chiesa et al., 2011; Keng et al. 2011), there has been a growing interest in the scientific community as well as the broader public, in leveraging mindfulness meditation as a tool for fostering sustained attention. As a result, there is an impressive body of literature that has emerged since these reviews were published that would contribute to our understanding of whether and how mindfulness impacts attentional control. Additionally, only one existing review of the mindfulness and attention literature has employed an organizing schema for the outcome variables of attentional control (Chiesa et al., 2011), separating findings into alerting, orienting, and conflict monitoring domains (Posner et al., 1990). The other two reviews do not provide exhaustive summaries of the impact of mindfulness on attention, but instead include attention as a secondary or tertiary area of interest within the wider domains of “neurobiological evidence” for mindfulness meditation’s effects (Chiesa & Serretti, 2010) and the impact of mindfulness on “psychological health” (Keng et al., 2011).

The current review expands upon these previous reviews by organizing and discussing measures of attentional control using the well-established theoretical framework of goal-directed, top-down attention and stimulus-driven, bottom-up attention (Posner et al., 1980; Corbetta & Shulman, 2002).

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Although attention has been the focus of studies in cognitive science for many decades, it has been considered a rather elusive construct, underlying multiple perceptual and cognitive systems (Chun, Golomb, Turke-Browne, 2011). It plays a key role in operations ranging from simple sensory processing to higher-order decision-making and long-term encoding and retrieval (Chun & Turke-Browne, 2007). Given this versatility, it is no surprise that a myriad of attention measures have been employed in the mindfulness training literature. As such, categorizing the outcomes of these studies based on the well-established taxonomy of top-down vs. bottom-up attention will help provide a framework for synthesizing the current literature and understanding the neurobiological mechanisms mediating the effects of mindfulness training on attentional control, subsequently aiding in future directions.

Another aim of this review, which sets it apart from the existing reviews, is to highlight key methodological differences in study design that may help to explain the discrepant findings and provide suggestions for future mindfulness training studies. This discussion offers an expansion upon previous reviews examining the impact of mindfulness on attention, which have placed a much smaller emphasis on study design issues (Chiesa, Calati, & Serretti, 2011; Chiesa & Serretti, 2010; Keng, Smoski, & Robins, 2011). In addition, all existing reviews have synthesized findings across both longitudinal training studies and cross-sectional comparisons of experienced meditators and naïve controls, thereby introducing heterogeneity in sample characteristics and combining findings across studies that can and cannot infer causality. By narrowing the focus to longitudinal training studies, this review speaks directly to whether mindfulness training causally improves attentional functioning.

Given the increasing public interest in the employment of mindfulness meditation to enhance cognition in both healthy and clinical populations, it is imperative that the field of contemplative sciences adopts rigorous study designs that will provide unequivocal evidence of attentional benefits following mindfulness training. In this review, we synthesize the results of existing studies to clarify the extent to which mindfulness training improves multiple aspects of attentional control. We also draw upon the broader training literature, which has been plagued by similar threats to internal validity, to critically evaluate existing studies and provide concrete suggestions for addressing such concerns in future studies.

Method

Literature search

We conducted an electronic search in *PubMed*, *PsycINFO*, and *Web of Science* using the keywords *mindfulness*, *meditation*, *training*, *cognition*, *attention*, and *attentional control*. We then inspected the references sections of all retrieved articles for a cross-reference. We included peer-reviewed articles written in English and published prior to October, 2017.

Selection of trials

This review includes feasibility studies, retreat studies, and randomized controlled trials (RCTs) of mindfulness training. The term “mindfulness training” can refer to training in a number of fairly distinct practices, but for the purposes of this review, we included studies in which training involved practices requiring sustained or selective attention to a particular object (i.e., focused attention) or receptive attention to the transient occurrence of sensations, thoughts, or emotions (i.e., open monitoring). The majority of studies employed standardized or adapted versions of Mindfulness Based Stress Reduction, or described training as “mindfulness training,” “mindfulness awareness practices,” “open monitoring,” or “focused attention meditation.” Other training included Mindfulness Based Cognitive Therapy, Attentional Control Training, Integrative Body-Mind Training, Breathworks mindfulness training, Benson mindfulness technique, Open and Calm, the school-based MindUp program, and Mindfulness-based Mind Fitness Training (see Table 1A-C).

Feasibility and retreat studies—those examining performance after mindfulness training without a comparison group or those that allowed for self-selection of training groups— were included to review preliminary evidence of attentional benefits following mindfulness training. Of primary interest, we

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included studies that randomized participants to a mindfulness group and at least one other control comparison group in order to examine whether mindfulness training causally impacts attentional control. We excluded studies that were: 1) case studies, 2) qualitative reports, 3) reviews, 4) meta-analyses, or 5) commentaries/editorials. Of the remaining studies, we included studies that: 1) involved more than one session of in-person mindfulness training, 2) assessed at least one measure of attentional control, and 3) investigated intervention effects by analyzing pre- and post-intervention attentional control data within subjects.

Data extraction and synthesis

Attentional outcomes of interest were classified into two domains: top-down and bottom-up attentional control. Tasks capturing top-down attention included sustained attention, inhibitory control, set-switching, and working memory tasks. Tasks capturing bottom-up attention included visual search and discrimination, spatial and temporal selection, and attentional blink tasks. For each study, we coded the presence or absence of five design characteristics: (1) randomization of participants to groups; 2) inclusion of an active control group; 3) explicit attention to reduction of demand characteristics; 4) detailed discussion of the content of the intervention and control groups; and 5) following of study reporting guidelines (such as CONSORT). We also reported sample characteristics, including the number of participants, mean age, and any clinical features; frequency and duration of intervention and control groups; presence and length of at-home practice; dependent variables of interest, including task name and outcome metrics; and the main longitudinal findings (Tables 1A-C).

Search results

The original search yielded 1,012 papers; 353 were removed based on the above exclusionary criteria. From the remaining studies, 603 did not meet the above inclusionary criteria and 56 were selected for inclusion. We identified 32 longitudinal studies examining the effect of multi-session mindfulness training compared with a control group (see Table 1A for study details), nine retreat studies examining attentional performance before and after an intensive multi-day mindfulness retreat (see Table 1B for study details), and 15 feasibility studies that did not employ randomization of participants to groups (see Table 1C for study details).

Mindfulness and attentional control: A review of the current literature

According to the classical taxonomy proposed by Posner and colleagues (Posner, 1980; Posner & Petersen, 1990), attention is classified as top-down if it is guided by internal sets generated from knowledge, expectation, and current goals, whereas attention is classified as bottom-up if it is driven by sensory and perceptual inputs. For example, whereas noticing an acute sensory pain in your back muscles during a meditative practice involves information selection through bottom-up processes, allowing oneself to consciously let go of the thoughts and emotions associated with the sensory experience and returning to the meditative practice, is representative of top-down control of attention. Although these two types of attention are not mutually exclusive, as stimulus perception is required for any task of attention, they provide a broad schema within which attentional measures can be classified based on the predominant cognitive processes that they require. Moreover, this distinction can also be conceptually mapped onto the primary mechanisms by which mindfulness is hypothesized to confer benefits (Hölzel et al., 2011; Shapiro, Carlson, Astin, & Freedman, 2006). Specifically, bottom-up attention allows for the open perception of sensations, and top-down attention is needed to direct attentional focus and practice non-reactivity as well as to regulate emotions through engaging in acceptance and non-judgment.

Mindfulness training and measures of top-down attention

Given the vast amount of information available to us in both our external and internal environments, attention operates to selectively limit that information, biasing competition either through internally-generated goals (top-down attention) or via perceptual capture of information (bottom-up attention). Top-down attention, often subserved by the operations of the prefrontal cortices, can be

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assessed via measures of response inhibition, such as the Stroop task, that require overriding of habitual responses in favor of task-relevant responses; tasks of set-shifting, such as the Trail Making Test (Part B), that require switching between different attentional sets; and working memory tasks, such as the Digit Span and N-Back tasks, that require maintenance and manipulation of information sans sensory input. Figure 1 (top panel) provides a graphical representation of exemplar tasks. Many measures of top-down attention have been examined as outcome variables in mindfulness training studies, as mindfulness practices promote cultivation of sustained attention requiring maintenance of task sets, although evidence of benefits is rather mixed across the literature.

Measures of response inhibition, such as the Stroop task or the Sustained Attention to Response Task (SART), are often employed to examine cognitive processes associated with inhibiting prepotent responses to facilitate responding based on task goals. Improvements on the Stroop task, requiring inhibition of reflexive word reading in favor of color naming, have been consistently observed in feasibility training studies. These studies found that 8-week mindfulness interventions resulted in reduced accuracy interference in adults and adolescents with ADHD (Zylowska et al., 2008) and older adults with clinically significant anxiety (Lenze et al., 2014), as well as reduced total errors in medical residents (Rodriguez Vega et al., 2014).

By contrast, more rigorous RCTs have produced conflicting evidence, with benefits on the Stroop task observed in some RCTs, but not others. Those that noted improved post-training performance in the mindfulness, but not the comparison group, demonstrated evidence of faster reaction time (RT; Bhayee et al., 2016; Fan et al., 2014; Malinowski et al., 2017) and lower accuracy and RT interference (Allen et al., 2012; Fan et al., 2014; Johns et al., 2016; Kiani, Hadianfard, & Mitchell, 2016). One particularly well-designed RCT examined affective Stroop interference in participants completing a 6-week mindfulness intervention compared with participants engaged in a group-based reading and listening group that was carefully designed to match the training group for non-specific factors (Allen et al., 2012). Compared to this active control group, mindfulness training resulted in decreased RT interference, such that participants engaged with mindfulness practices showed improved response inhibition following training. One of the strengths of this study was the explicit attention to reduction of demand characteristics; the study was advertised as a wellness study in which participants would be randomized to one of two free wellness courses. Although this study did not measure expectancy effects, these recruitment strategies and the construction of an active control intervention that was well-matched with the training group, were laudable attempts at addressing expectancy biases. Another RCT provided evidence of long-term maintenance of mindfulness-related benefits for patients with breast cancer (Johns et al., 2016). Compared to a Fatigue Education and Support Group, 8-week Mindfulness Based Stress Reduction (MBSR) training yielded greater improvements in Stroop accuracy interference, and these gains were maintained at a 6-month follow-up. Importantly, these RCTs (with the exception of Kiani et al., 2016) limited the influence of non-specific factors by comparing mindfulness training to active control groups that included psychoeducation and support (Johns et al., 2016), reading groups (Allen et al., 2012), brain training (Malinowski et al., 2017), math training (Bhayee et al., 2016), and progressive muscle relaxation (Fan et al., 2014). Thus, these studies provide confidence that the observed gains in Stroop performance can indeed be attributable to engagement with mindfulness practices rather than non-specific factors including social support, engagement with stimulating materials, or facilitation of an intervention by experts.

In contrast to these positive reports, mindfulness training failed to yield improvements in a number of other RCTs using measures of Stroop RT (Jensen, Vangkilde, Frokjaer, & Hasselbalch, 2012; Josefsson, Lindwall, & Broberg, 2014; Moore, Gruber, Derosé, & Malinowski, 2012), errors (Anderson et al., 2007a; Josefsson et al., 2014), or interference (Josefsson et al., 2014; Oken et al., 2017; Semple, 2010). In one of the earlier studies in this literature, Anderson et al. (2007) conducted an RCT comparing 8-week MBSR to a wait-list control group. They found that mindfulness training produced no improvements on Stroop errors or RT. Notably, despite having participants engage in meditative practices immediately prior to completing the cognitive assessment, there was no evidence of benefits on several

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other measures of attentional control. However, the authors acknowledge that their healthy sample and ceiling effects on performance likely contributed to the lack of observed improvements.

Another RCT failing to find mindfulness-specific Stroop improvements provided a critical test for the role of participant effort/motivation in explaining variance in cognitive gains following such behavioral interventions (Jensen et al., 2012). This study compared 8-week MBSR to an active control stress reduction group and a wait-list control group. At post-training assessment, the authors manipulated attentional effort for half of the wait-listed participants by randomizing them further into monetary incentive and non-incentive groups, such that wait-listed participants in the monetary incentive group were offered compensation to enhance their performance on measures of cognitive functioning. Interestingly, although the mindfulness group improved on Stroop accuracy compared to the non-incentivized control participants at post-training, these improvements were not greater than those observed in the incentivized control participants, highlighting the role of participant effort on task outcomes. In fact, there is much discussion in the broader cognitive training literature of the role of participant expectancy in performance on measures of attentional control (Boot, Blakely, & Simons, 2011; Boot, Simons, Stothart, & Stutts, 2013), and the results from Jensen et al. (2012) lend credence to such considerations in the mindfulness literature. However, it is important to note that in some RCTs that found positive effects of mindfulness training on Stroop performance (such as Allen et al., 2012 and Johns et al., 2016), careful attention was paid to the reduction of demand characteristics and matching of non-specific factors across groups. Thus, even though these studies did not include an incentivized control group, a difference in attentional effort likely did not explain all of the variance in the observed improvements.

One potential contributor to the discrepant findings across studies using the Stroop task is variation in task characteristics. First, the modality of administration may impact the quality and type of outcome measures. Whereas the paper-and-pencil Stroop task is limited to an assessment of errors and total RT, computerized assessment allows for an assessment of more fine-grained accuracy and RT variables with increased precision. Second, the context in which participants are asked to resolve Stroop interference may impact their performance. For example, some studies employed an affective variant of the Stroop task to examine attentional control performance in the context of emotional interference (Allen et al., 2012; Anderson et al., 2007; Malinowski et al., 2017). Compared to the traditional Stroop, these measures may be differentially impacted by mindfulness training given that it has been hypothesized to influence the inter-related facets of emotion regulation and attentional control (Prakash, De Leon, Patterson, Schirda, & Janssen, 2014). Similar affective variants of attentional control measures have been employed in other studies (Ainsworth, Eddershaw, Meron, Baldwin, & Garner, 2013; Menezes, Bizarro, Menezes, & Bizarro, 2015) and provide further support that mindfulness training improves conflict resolution in the presence of distracting emotional information. These variations in task design, or even simple differences, such as the number of trials or the ordering of tasks within a session, should be taken into consideration as they are likely potent sources of variance in observed outcomes.

Another measure of response inhibition that is frequently employed in the mindfulness training literature is the Go/No-Go task, or the SART, in which participants are asked to respond to frequently presented distractor stimuli and withhold responses to rare targets (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Calculation of a sensitivity index allows for an examination of the ability to discriminate signal from noise by taking both hits and false alarms into account. Given the long duration of these tasks (averaging around 20 minutes across studies), sustained attention can also be indexed by calculating vigilance decrements, or declines in discriminability over time. Similar to the Stroop task literature, there is mixed evidence for improvements following mindfulness training on these tasks. Non-randomized studies have yielded evidence for increased accuracy and RT on the SART following 7 weeks of mindfulness training (Morrison, Goolsarran, Rogers, & Jha, 2013) and MBSR (Meland et al., 2015) compared to wait-list controls. In pre-deployment military personnel, those who engaged in high amounts of mindfulness practice time exhibited greater sensitivity on this task and reduced self-reported mind-wandering than those with low practice time (Jha et al., 2017). Retreat studies have found evidence of increased discriminability following 1-month and 3-month retreats (Sahdra, 2011; Zanesco, King,

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MacLean, & Saron, 2013), and reduced RT variability during sustained attention to auditory tones following a 3-month live-in Vipassana retreat compared to matched controls (Lutz et al., 2009). However, the study by Lutz et al. (2009), along with two feasibility studies (Cusens, Duggan, Thorne, & Burch, 2010; Rodriguez Vega et al., 2014), found no differential improvements in discriminability across groups. Additionally, no differential improvements on a visual oddball task were observed in non-randomized participants of a mindfulness school-based program compared to wait-listed controls (Sanger & Dorjee, 2016).

Building upon these feasibility and retreat studies, eight RCTs have examined the impact of mindfulness training on sustained attention. Comparing a 4-week mindfulness intervention with a progressive muscle relaxation group and a wait-listed control group, Semple et al., (2010) provided evidence of enhanced discrimination in the mindfulness group. However, differential gains in the mindfulness group were observed only on the discriminability index, not other measures of attentional control, and this effect was larger for older than younger participants (note, $max_{age} = 56$ years). In another study, improved discrimination was observed in participants who engaged in combined attention monitoring and acceptance compared to attention monitoring alone, relaxation training, and an active control reading group (Rahl, Lindsay, Pacilio, Brown, & Creswell, 2017). On tasks of sustained attention requiring participants to scan a visual array of distractors for target stimuli, no benefits were found for neurofeedback-assisted, technology-supported mindfulness training (Bhayee et al., 2016), but improvements were observed following five days of focused meditation training compared to wait-list (Menezes et al., 2015) as well as MBSR compared to non-mindfulness stress reduction, incentivized controls, and non-incentivized controls (Jensen et al., 2012). The other three RCTs failed to find benefits on measures of errors, discrimination, or vigilance (Anderson, Lau, Segal, & Bishop, 2007b; Kiani et al., 2016; MacCoon, MacLean, Davidson, Saron, & Lutz, 2014). It is possible that the benefits observed in Semple et al. (2010) were inflated by the additive effects of four weeks of training plus engagement in the practices at the post-assessment sessions, particularly given that even one session of mindfulness training has been found to affect cognitive control (Dickenson, Berkman, Arch, & Lieberman, 2013; Lee & Orsillo, 2014). There is marked discrepancy between these effects and the null findings of MacCoon et al. (2014), one of the more rigorous RCTs that employed a well-defined comparison group and failed to find incremental benefits of mindfulness training for measures of vigilance and discrimination. The lack of observed effects following such a rigorous test highlights the need for future investigations to attend closely to the study design issues outlined below.

Other executive components of attentional control, such as conflict resolution and set-shifting, have been measured in a myriad of ways. Employing the Attention Network Test (ANT; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) that differentiates between alerting, orienting, and conflict monitoring attention networks, several studies have provided support for mindfulness training, especially in novices, to enhance performance on the conflict monitoring network. In this component of the task, participants must respond to the direction of a central arrow flanked on each side by two arrows pointing either in the same direction as the central arrow (congruent condition) or in the opposite direction (incongruent condition). RT interference is calculated as the slowing in RT during the incongruent trials relative to the congruent trials. In what is now considered to be a seminal study, Jha, Krompinger, & Baime (2007) employed the ANT in a comparison of an 8-week MBSR program and a 1-month retreat. Although this study was a non-randomized feasibility trial, it provided evidence of enhanced alerting or “attentional readiness” to exogenous stimuli post 1-month retreat and reduced conflict effects post-MBSR training, which was replicated in another feasibility trial (Zylowska et al., 2008). Building upon these findings, four RCTs also reported benefits for the conflict component of the ANT following mindfulness training (Ainsworth et al., 2013; Becerra, Dandrade, & Harms, 2017; Felver, Tipsord, Morris, Racer, & Dishion, 2017; Tang et al., 2007). All of these RCTs showed a greater decrease in RT on incongruent trials in the mindfulness group in comparison to either wait-listed or active control groups. Notably, some of these interventions were relatively brief. For example, undergraduate participants in Tang et al. (2007) engaged in just 20 minutes of practice for five days in an integrative body-mind technique, described as an integration of mindfulness and meditation components to achieve a “balanced state of relaxation while

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focusing attention” (Tang et al., 2007, *p.* 17152). Similarly, Ainsworth et al. (2013) found improvements after just three, one-hour sessions over an 8-day period of either focused attention or open monitoring practices. Although one feasibility study (Spadaro & Hunker, 2006) and one RCT (Oken et al., 2017) examining the conflict component of the ANT found no improvements, the positive results of the other four RCTs combined with the seminal feasibility study by Jha et al. (2007) offer promise for the potential malleability of conflict monitoring as a function of mindfulness training. Some RCTs have also observed improved orienting on the ANT following mindfulness training, although no active control comparisons have been conducted (Becerra et al., 2017; Felver et al., 2017). Thus, future research would benefit from a thorough assessment of changes in all components of the ANT following longer-term training programs, such as MBSR, with adequate controls for placebo effects.

Additional measures of higher-order conflict resolution that require top-down attentional control include tasks that involve set-shifting or multi-tasking. For example, the classic Trail Making Test (TMT; Reitan, 1955) can assess simple attention when maintaining one attentional set (e.g., TMT A), higher-order switching between two or more task goals simultaneously (e.g., TMT B), as well as the efficiency of maneuvering between attentional sets (e.g., TMT B/A ratio). A lack of set-shifting improvements has been found in feasibility studies of MBCT (Heeren, Van Broeck, & Philippot, 2009), 8-week MBSR (Mallya & Fiocco, 2016), and a 1-week Vipassana retreat (Cohen, Jensen, Stange, Neuburger, & Heimberg, 2017), as well as an RCT of MBSR (Anderson et al., 2007). In contrast with these findings, several other studies that assessed higher-order executive operations of conflict resolution and task-switching found benefits of mindfulness training. First, a feasibility study in adolescents and adults with ADHD found improved performance on TMT A and B following an 8-week mindfulness training program (Zylowska et al., 2007). Second, an RCT conducted in fourth and fifth graders employed the hearts and flowers dot task (Diamond, Barnett, Thomas, & Munro, 2007), a measure of task-switching that requires participants to press a button on the same side if shown a heart or the opposite side if shown a flower (Schonert-Reichl et al., 2015). Students randomized to a 4-month mindfulness-based education program exhibited increased switching abilities compared to those in a social responsibility program designed to enhance social and emotional learning. Third, a randomized comparison of older adults with Mild Cognitive Impairment found improved TMT A and TMT B performance in those who received 8 weeks of MBSR vs. usual care (Wells et al., 2013). Fourth, older adults in an MBSR program showed improved TMT B/A ratio compared to the wait-listed control group immediately post-training; however, these benefits were not maintained at 6-month follow-up (Moynihan et al., 2013). These results critically underscore the importance of collecting follow-up data, particularly since only a handful of studies have assessed the effects of training after an extended follow-up period (Johns et al., 2016; MacCoon et al., 2014; Moynihan et al., 2013). It is possible that a combination of long-term training with booster sessions administered throughout the follow-up period might enhance the efficacy of mindfulness interventions and promote long-term gains. Alternatively, at a minimum, an assessment of continued engagement with practices throughout the follow-up period would help determine the association between practice and maintained benefit. Establishing the long-term efficacy of mindfulness training programs will be instrumental in their broader adoption and appreciation.

Finally, tasks of working memory assess the temporary storage, maintenance, and manipulation of information, relying on both endogenous and exogenous attentional processes (Chun et al., 2011; Smith & Jonides, 1999). Since top-down processes are thought to impact future perceptual selection of external information, working memory capacities allow for a facilitative interaction between endogenous sets and exogenous attention (Kiyonaga & Egner, 2013). Promising results have been observed on the operation span task (O-Span; Unsworth, Heitz, Schrock, & Engle, 2005), which involves maintaining a set of letters in working memory while performing an unrelated arithmetic task. Of the four studies employing the O-Span (Banks, Welhaf, & Srour, 2015; Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010; Morrison, Goolsarran, Rogers, & Jha, 2014; Mrazek, Franklin, Phillips, Baird, & Schooler, 2013), two found benefits following mindfulness training (Jha et al., 2010; Mrazek et al., 2013). A feasibility trial conducted by Jha et al. (2010) investigated the effects of an 8-week mindfulness program in a cohort of pre-deployment military personnel compared to wait-listed military and civilian controls. This study

provided evidence for greater improvements in working memory capacity compared to controls, but only in participants with high amounts of home practice. Importantly, among studies employing randomized designs, only Mrazek et al. (2013) found benefits of mindfulness training. This study found that after two weeks of training, undergraduate participants in the mindfulness group, but not the nutrition education control group, showed better O-Span performance and reduced mind-wandering, which mediated the effect of training on working memory capacity.

Other studies have evaluated working memory performance using Digit Span, Letter-Number Sequencing, and N-back tasks. In the Digit Span task, participants must repeat a series of numbers in the order they heard them (forward), in reverse order (backward), or from smallest to largest (sequencing). The Letter-Number Sequencing task requires participants to repeat a series of letters and numbers in numerical and alphabetical order. In the N-back task, participants are asked to report whether the currently presented number matches the previous number (one-back) or the number presented two trials before (two-back). Three non-randomized studies provided preliminary evidence of improvements on these working memory tasks following mindfulness training. First, a sample of older adults with symptoms of worry, depression, and cognitive dysfunction ($M_{age} = 70.8$) engaged in either an 8-week or 12-week MBSR program (Lenze et al., 2014). The 8-week MBSR group exhibited improved Digit Span forward performance, with no additional benefits from the extended 12-week program. Second, a sample of bereaved older adults ($M_{age} = 77.5$) who completed an 8-week MBCT program exhibited improved Letter-Number Sequencing performance when compared to wait-listed controls (O'Connor, Piet, & Hougaard, 2014). Third, improvements on Digit Span backward were observed in novice meditators following a 10-day intensive retreat (Chambers, Lo, & Allen, 2008). However, a feasibility study of adults and adolescents with ADHD who participated in an 8-week mindfulness meditation program did not find improvements on any component of the Digit Span task (Zylowska et al., 2007). Further, several RCTs have failed to find mindfulness-related improvements on this type of task. Studies employing wait-list comparisons found no change in Digit Span forward or backward or Letter-Number Sequencing in adolescents with ADHD (Kiani et al., 2016) or Letter-Number Sequencing in older adults (Oken et al., 2017), although one study found that participants in a 1-month retreat showed faster and less variable RT, characterized by improved information quality and reduced response conservativeness on a visual working memory task (van Vugt & Jha, 2011). Others found no differential improvement in N-back or Digit Span performance following four days of mindfulness training compared to a reading group (Zeidan, Johnson, Diamond, David, & Goolkasian, 2010), no significant improvement in Digit Span forward or backward following neurofeedback-assisted, technology-supported mindfulness training compared to online math training (Bhayee et al., 2016), and no improvement in a change detection task following mindfulness training compared to N-back training or combined training (Course-Choi, Saville, & Derakshan, 2017). Thus, in light of these inconsistent results, more RCTs are needed to conclusively determine the effects of mindfulness training on top-down attention processes such as maintaining and manipulating internally represented information.

Mindfulness training and measures of bottom-up attention

The domain of bottom-up, or perceptual, attention is defined by the biasing of information processing via sensory inputs. As such, perceptual attention can involve selectively focusing and modulating the various sensory modalities; attending to the physical attributes of stimuli; and prioritizing spatial and temporal attributes of stimuli. Tasks of bottom-up attention might systematically manipulate salient features of an object, such as tone, color, length, or orientation among an array of objects (Sàenz, Buraças, & Boynton, 2003; Theeuwes, 1992; Treue & Martínez Trujillo, 1999); ask participants to attend to a quadrant on the screen through bottom-up redirection of attention through flashing arrows (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; Posner, 1980); or require that participants attend to and discriminate between a rapid succession of stimuli. These manipulations allow for an examination of how perceptual information captures our attention and a quantification of the limits to perceptual attention (see Figure 1, bottom panel).

In contrast to tasks of top-down attention, fewer studies, especially rigorous RCTs, have examined the impact of mindfulness training on perceptual capture of attention. In a seminal study,

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Brown, Forte, and Dysart (1984) provided the first evidence of improvements in perceptual detection and discrimination following mindfulness training. In this study, the authors examined changes in the ability to detect rapidly presented light flashes and discriminate between successive light flashes as a function of an intensive, 3-month mindfulness retreat. Conscious detection of visual stimuli at lower thresholds is dependent on the ability to activate relevant topographic areas in the visual cortex (Chun et al., 2011; Tootell et al., 1998), and this study found a decrease in both the detection and discrimination thresholds in the mindfulness retreat participants, but not in the control group. These promising results of enhanced perceptual detection were further corroborated by results from Jensen et al. (2012) in which MBSR was compared to an active control group and an incentivized wait-list control group to rule out the effects of attentional effort. Employing the combiTVA paradigm, which provides a computationally derived estimate of four attention parameters (Kyllingsbæk, 2006), the authors found that MBSR resulted in reduced visual perception thresholds. This finding was supported and extended to a 3-month follow-up assessment in another RCT by Jensen et al. (2015), in which they provided both group and individual Open and Calm meditation programs to stressed community members, although this study lacked an active comparison group.

In addition to these findings, there is evidence that participating in a 3-month mindfulness retreat increases the capacity limits of visual attention (Slagter et al., 2007). Using an attentional blink task, which assesses the temporal capacity of attention (Raymond, Shapiro, & Arnell, 1992), retreat participants, in comparison to control participants, demonstrated an increased ability to detect the second target in a rapid stream of distractor letters, with no changes in their ability to detect the first target. Neuroimaging evidence from electroencephalography provided further support for a decrease in allocation of neural resources to the first target in the retreat group. Taken together, these studies provide preliminary evidence that mindfulness training enhances perceptual attention. However, given the lack of randomization in two of these studies (Slagter et al., 2007; Raymond, Shapiro, & Arnell, 1992), there is a critical need to replicate these promising results on tasks of bottom-up attention through rigorous RCTs.

In contrast to these favorable results, there is also evidence that mindfulness training fails to impact other facets of bottom-up attention. One feasibility study found no differential improvements on a stimulus-driven attentional capture task following MBSR compared to a wait-list group (Meland et al., 2015). An RCT examining performance on an anti-saccade task, requiring participants to inhibit a reflexive saccade towards a peripheral stimulus and instead execute a voluntary saccade in the opposite direction, found no differential impact of mindfulness training compared to N-back training or combined training (Course-Choi et al., 2017). In the Jensen et al. (2012) study discussed above, the authors also examined the impact of MBSR on temporal attention and spatial attention (Figure 1c) as measures of perceptual selection to time-points and locations that are prioritized by either exogenous or endogenous cueing. Their results provide evidence for greater improvements in the spatial attention measure in the incentivized control participants compared with the MBSR participants, highlighting the necessity of matching groups based on attentional effort. That is, control participants who were paid to perform better at post-test did better on these measures of spatial attention, calling into question the validity of improvements following mindfulness training in non-randomized, non-blinded feasibility studies.

Taken together, the literature examining attentional gains following mindfulness training, although offering promising support for some facets of attentional control, is mired with conflicting evidence. In addition to the differences in task characteristics, administration of measures, and populations of interest, there are a number of key study design issues that likely impact the observed results. One of the primary goals of this review is to highlight the necessity of rigorous RCTs in this literature and provide suggestions for future research. In the next section, we outline and detail five criteria that we believe will help strengthen the design of future longitudinal studies in this field.

Study design considerations

We examined the longitudinal training studies reviewed above through the lens of five study design issues that are increasingly being emphasized in the broader training literature as essential elements for enhancing confidence in results (Boot & Simons, 2012; Boot et al., 2013; Stothart, Simons,

Boot, & Kramer, 2014). These criteria included: 1) randomization of participants to groups; 2) inclusion of an active control group; 3) explicit attention to reduction of demand characteristics; 4) detailed discussion of the content of the intervention and control groups; and 5) following of study reporting guidelines (such as CONSORT). Figure 2 is a graphical representation of the degree to which existing longitudinal studies satisfy these criteria, with the concentric spheres representing the first four criteria and the central “pearls of wisdom” representing explicit compliance with CONSORT guidelines. The number of studies employing each criterion varies considerably, with less than half of the studies including an active control group, reducing demand characteristics, or reporting on CONSORT guidelines (Figure 3). Attention to such study design issues, we believe, will allow for reliable and valid causal claims regarding the benefits of mindfulness training for facets of attentional control.

1) Randomization of participants to groups. Of the 56 studies identified and reviewed above, 32 randomized participants to the treatment group or the control group - an important step in establishing the causal influence of mindfulness practices in improving attentional control. As is well known, randomization of participants is essential for attributing changes in outcome variables to the treatment. Randomization also limits self-selection biases that may predispose the group to benefit from the intervention compared to the broader population. An important additional component to randomization is having experimenters who are blind to the participants’ group membership conduct pre-post assessment sessions. As represented in Figure 3, attentional benefits following mindfulness training were observed in a greater proportion of studies that did not randomize participants to groups compared to those that did. This illustrates the potential inflation of estimated benefits arising from a lack of randomization of participants to conditions. The studies that did not employ randomization by design were either feasibility studies of short-term training in mindfulness (15 studies) or retreat studies that examined the effect of either long-term or short-term intensive meditation practice on attentional control (nine studies). Feasibility studies, assessing changes in the outcome variable pre- and post-intervention, are pragmatic and efficient ways of examining programs that are already being implemented in community settings and can provide valuable pilot data. For example, the feasibility study conducted by Jha et al. (2007) suggested improvements in differential components of the ANT following 8-week vs. 1-month retreat training. This type of study design can also be critical for assessing the feasibility and acceptability of an intervention in unique populations with differential sets of strengths, limitations, and needs. For example, Lenze et al. (2014) provided feasibility data for 8-week and 12-week MBSR programs for older adults (ages 65 and older), noting the necessity of modifying yoga poses and shortening retreat days for the aging cohort. However, there is an immediate need to expand upon these initial feasibility studies to conduct trials that randomize participants to the training and control groups so that changes in outcome variables can be attributed to the mindfulness training.

Retreat studies are plagued by similar criticisms. Only one retreat study (MacLean et al., 2010) randomized participants, in this case to either a 3-month intensive retreat or a wait-list control condition. However, even in this study, pre-intervention assessments were conducted after randomization, creating the possibility of differential expectations influencing the obtained results. Inherent to these programs, which involve longer training periods and substantial daily commitments, is a pragmatic obstacle to randomization of participants. Individuals who are interested in such long-term training studies must be willing or able to invest considerable resources to secure time in their lives for such intense retreats. As such, a wait-list control condition that further delays participation might not be an appealing or realistic alternative. Thus, an ideal method for evaluating the effects of such retreat programs on attentional control might be for future research to compare long-term meditation retreats with an active control condition that is designed to match the retreat condition for intensity and duration of training.

2) Inclusion of an active control group. Of the 32 studies that did in fact randomize participants, 19 included an active control group. Two feasibility studies also included an active control comparison. A contentious issue in the design of active control groups within this literature is the successful dissociation between the “active” ingredients of mindfulness training and the non-specific factors that may also be contributing to the success of such training programs. Across these studies, there is consensus on a few of these non-specific factors. For example, given that mindfulness training is offered in a group format,

social support is one non-specific factor that could influence attentional control (Bassuk, Glass, & Berkman, 1999). Inclusion of an active control group that offers training in a group format can be a valid control for this important determinant of cognitive functioning. Similarly, interacting with a group leader with expertise on the content of the intervention could also have an impact on the expectations of benefit. The majority of studies that had a facilitator for the training group also employed a facilitator for the control group who was matched with respect to expertise. A few studies (for example, Mallya & Fiocco, 2016) also included questionnaires that assessed the competence and likeableness of instructors, thus ensuring that the two groups were matched with respect to participants' judgments of their leader's expertise.

The training studies that employed active control groups did, however, differ on some critical non-specific factors that can have implications for observed effects. The three control groups that have been regularly used in the literature include relaxation controls, nutrition education groups, and book reading groups. Although variations of the relaxation control groups exist, most have been designed to control for the stress-reducing effects of physical relaxation on attention. Even though mindfulness programs are designed to cultivate alertness, the practice of paying attention to some specific anchor in a non-judgmental manner often results in a state of relaxation (Baer, 2003; Dunn, Hartigan, & Mikulas, 1999). Thus, a relaxation control group, designed to invoke a physical state of restfulness, can control for the stress-reducing aspects of relaxation on attentional control. However, it is not clear the extent to which these relaxation control groups involve collaborative discussions, which allow participants to engage with the intervention content with similarly experienced peers and discuss methods for incorporating these practices into their daily lives. Such discussions often act as a critical source of social support in group settings and are an important ingredient likely influencing attentional control. As such, nutrition education control groups and book reading groups that facilitate such social engagement offer a tighter control for the non-specific factor of social support. Interestingly, Figure 3 shows that the percentage of studies observing benefits for mindfulness over control groups drops from 83% in studies with wait list or no control group to 57% in those including an active control group. This pattern highlights the need for effective active control arms to most accurately capture mindfulness-specific benefits.

3) Explicit attention to reduction of demand characteristics. When designing active control groups, it is also important to pay explicit attention to reduction of demand characteristics that may predispose participants in the experimental group to perform better on tasks of attentional control (Boot et al., 2011, 2013). That is, even though active control groups may control for the effects of non-specific factors, such as social support and physical relaxation, it is likely that participants in the two groups have differential expectations of improvements as a function of the intervention. These differential expectations could be the result of their prior exposure to the assigned training, recruitment efforts, or experimenter bias during assessment sessions, and may collectively have a significant impact on training outcomes. In fact, one study directly assessed the impact of motivation on improvements in cognitive outcomes by randomizing participants in the wait-list control group to an incentive or a no-incentive group, where the incentive group was given a monetary enticement to improve their performance at post-test (Jensen et al., 2012). Although increased attentional effort in the incentive group did not fully account for all positive results of MBSR, some of the improvements observed in the MBSR group were also observed in the incentivized control group, thus providing critical evidence for the role of attentional effort and motivation in observed effects. Unfortunately, the majority of studies (44 out of 56) did not explicitly report attempts to equate demand characteristics across groups (Figure 3). Although this does not necessarily mean that efforts were not made, this trend suggests that there is room for growth in this domain.

Several strategies have been utilized in the broader training literature to successfully reduce the differential expectation of benefits between training and control groups (Boot et al., 2013). First, recruitment plays a critical role in the creation of such differential expectations and thus, close attention needs to be paid to recruitment strategies when conducting RCTs. The content of recruitment advertisements should be explicitly stated in published manuscripts to provide information regarding the potential motivations of participants who volunteered for the study. Indeed, the majority of training

studies with active control groups have paid explicit attention to reducing demand characteristics by using advertising materials that promote common aspects of both groups and that emphasize the potential for both groups to enhance cognitive functioning. It is less common, however, for studies to explicitly assess these expectations pre- and post-intervention despite recent commentary in the training literature on the importance of systematically assessing expectancy effects (Boot et al., 2013). An early study of two forms of meditation training by Alexander et al. (1989) methodically assessed for these differential expectancy effects in their various training groups two weeks into the training program. Critically, there were no significant differences in expectation of benefits between the groups, successfully providing quantitative data on the matching of placebo effects across the groups. Thus, although mindfulness training studies have been careful in the design of recruitment strategies, and many address matching of demand characteristics, it is equally important to collect data on such pre- and post-training expectations in order to examine their associations with changes in outcomes.

4) Detailed discussion of content of intervention and control groups. Roughly 50% of included studies discuss the content of the mindfulness-based and active control interventions employed (Figure 3), and there is a great deal of variability in the level of detail provided. In addition to more standardized protocols that have been administered, such as MBSR and MBCT, many studies have employed adapted protocols varying in duration, frequency, and content, with little information on the types of meditative practices engaged in by the participants. Standardized MBSR and MBCT protocols typically involve two different types of meditative practices. First, focused attention (FA) meditation involves the maintenance of selective attention on a chosen object. This regulatory process involves monitoring, or being vigilant of distractions without compromising the intended focus; disengaging from the distractors without further processing; and promptly redirecting attention to the chosen object (Lutz, Slagter, Dunne, & Davidson, 2008). Lutz et al. (2008) suggest that as one's practice progresses, there is a trait-level change whereby one's ability to maintain such focus without the use of regulative skills increases. Second, open monitoring (OM) meditation is achieved by moving from the use of regulative skills to attending to transient occurrences without directed focus on one object. This process involves the development of reflexive awareness of the detailed features of each experience. The types of training that have been provided in the reviewed studies range from focused attention practices and open monitoring practices, to a combination of these components with other elements. Importantly, given that there is preliminary evidence from studies of expert meditators suggesting unique cognitive advantages on the Stroop task, Counting task, and the Continuous Performance Test in practitioners of OM, FA, and loving-kindness meditation (Josefsson & Broberg, 2011; Lee et al., 2012; Valentine & Sweet, 1999), it is critical that future studies provide details regarding the contents of their unique protocols in order to clarify the degree to which there are meaningful differences that might impact results on attentional control measures. This is applicable both for the mindfulness groups as well as any control groups in order to establish the non-specific elements that are being controlled for. Within the reviewed literature, a higher percentage of studies providing detailed intervention descriptions found mindfulness-related benefits (82%) than those with little or no description (64%, Figure 3). One potential reason for this might be that studies were more likely to include descriptions if they employed more extensive or higher fidelity training, which resulted in greater benefits for attention. Relatedly, although existing investigations of the dose-response relationship between attentional outcomes and practice metrics, such as amount of experience, practice time during an intervention, or number of training sessions attended have yielded inconsistent evidence (Allen et al., 2012; Eberth & Sedlmeier, 2012; Jensen et al., 2012; Jha et al., 2010; Menezes et al., 2013; Sedlmeier et al., 2012), it would be important for future studies to systematically measure engagement in homework practices and associated changes in outcome variables.

5) Following of study reporting guidelines (such as CONSORT). Finally, there has been increasing emphasis placed on following a standard pipeline for reporting results that can be instrumental in guiding future research. The CONSORT guidelines (CONsolidated Standards of Reporting Trials) provide an evidence-based framework for researchers to report results of RCTs (Moher, Schulz, & Altman, 2001). Although the majority of existing studies (80%) have not reported following such guidelines, the percentage of studies finding mindfulness-related benefits is similar across those that have

and have not (Figure 3). Nonetheless, we strongly encourage future RCTs in this literature to follow these or similar guidelines as systematic and thorough reporting of RCT results can help clarify the nuances of the study's design and results as well as aid in future research design. Studies that report the results of their RCT while following CONSORT or similar reporting guidelines are denoted by the "pearls of wisdom," represented as the central spheres, in Figure 2.

Overall, the mindfulness training literature boasts a handful of rigorous RCTs that have paid attention to the various study design issues highlighted above. Setting aside the CONSORT criterion that has only recently been emphasized in the literature, six studies meet all of the remaining four criteria (see Column 4 in Table 1A).

Summary and Final Thoughts

There is great interest in both the scientific community and the broader public in using mindfulness meditation as a cognitive rehabilitation tool, particularly to enhance attentional control. Given the widespread prevalence of off-task thoughts in our everyday lives, and the functional consequences of mind-wandering for happiness, cognitive functioning, and overall quality of life (Killingsworth & Gilbert, 2010; Schooler & Smallwood, 2015; Fountain-Zaragoza et al., 2016), mindfulness training presents a promising tool with which to enhance on-task behavior through improved attention. Further, from a cognitive science perspective, attention underlies multiple perceptual and cognitive systems, and deficiencies in such attentional control processes heavily impact individuals with neurological and psychiatric diagnoses. As such, mindfulness training is increasingly being employed to enhance cognitive function in a variety of populations with the promise of improving cognition and overall quality of life.

Given the extensive interest in this training technique, it is our collective responsibility to ensure the methodological rigor of studies either supporting or refuting claims of mindfulness's benefits. This review highlights several key methodological issues currently plaguing this literature -- problems that need to be addressed for us to have confidence in the efficacy of mindfulness meditation training. In this review of training studies, we stress the critical need for going beyond randomized assignment to inclusion of active control groups as well as explicit attention to reduction of demand characteristics. Given the well-known and powerful effects of placebos on not only self-report data, but also behavioral and neuroimaging data, it is likely that these effects explain some of the variance in improved attention following mindfulness training, particularly in feasibility and retreat studies. Thus, explicit attention to either the reduction of those placebo effects, or at the very least, a disentanglement from treatment effects, will improve our understanding of the mechanisms through which mindfulness interventions are having an impact. Additionally, further clarification of the nature of interventions and the fidelity with which they are implemented is needed. Variants of traditional mindfulness-based approaches are not problematic; in fact, tailoring these interventions to accommodate needs, challenges, and priorities of different clinical populations will be paramount. What is needed, however, are more documented details on the content of the training programs and how they may or may not differ from more traditional, manualized approaches.

Finally, it is important to consider whether the variables selected in existing studies fully capture the effects of mindfulness-based interventions on attentional control. Taken from the well-established fields of neuropsychology and cognitive/vision sciences, these computerized or paper-and-pencil tasks are designed to capture basic attentional control processes in isolation, which is a necessary step in the scientific investigation of mindfulness's effects. However, given that attention does not function in isolation in our daily lives, the field would further benefit from the use of more integrative research strategies to investigate attention in context and as one component of a complex causal pathway. Thus, future studies might employ more idiographic or naturalistic outcome measures and explore the effects of mindfulness training on multiple, inter-related components such as attention, emotion regulation, social support, inflammation, etc. Further, consideration of individual difference variables, such as baseline cognitive resources, age, personality, motivation, or clinical features, will further elucidate who benefits

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from mindfulness training and in what ways. Active consideration of these key methodological issues along with theoretically-motivated outcome variables can significantly advance the field.

Mindfulness meditation continues to be a promising tool for enhancing cognitive vitality with some methodologically rigorous studies providing support for its impact on selected facets of attention. However, there is also evidence from other studies that refute such claims. Thus, going forward, it is paramount that we ensure that evidence is based on sound, rigorous studies that address alternative interpretations to avoid making unsubstantiated claims. We must conduct systematic, incremental research that will allow us to examine whether this technique is effective, to understand the mechanisms through which it is effective, and finally, to identify for whom the effects are stronger or weaker.

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Figure 1. Examples of tasks of top-down attention (top panel) and bottom-up attention (bottom panel).

Figure 2. Study design characteristics of longitudinal studies of mindfulness training. Spheres represent existing longitudinal training studies examining the impact of mindfulness training on facets of attentional control. Concentric layers are used to denote the presence of the first four study design issues discussed in the manuscript. The central “pearls of wisdom” denote studies that followed CONSORT guidelines.

Figure 3. Results of mindfulness training studies on attention separated by study design characteristic. For each characteristic, separate bars represent studies that did (Yes, opaque colors) and did not (No, faded colors) employ each characteristic. Studies finding benefits on one or more measures of attention for mindfulness training compared to a control group are shown in green, those finding no difference between groups are shown in blue, and those finding a benefit for the control group over mindfulness training are shown in red. The percent of studies with each result are indicated within the bars, calculated separately for studies that did and did not employ each design characteristic.

Appendix

Tables 1 (A-C). Brief summaries of studies that involved (A) randomized controlled trials examining the effects of training on attention; (B) longitudinal, retreat studies examining the effects of intensive mindfulness practices on attention; and (C) feasibility studies assessing the training effects of mindfulness programs on attention, but lacking the rigor of RCTs.

Table 1 (A). Design characteristics refer to: 1) randomization of participants to groups; 2) inclusion of an active control group; 3) explicit attention to reduction of demand characteristics; 4) detailed discussion of content of the intervention and control groups; and 5) following of study reporting guidelines (such as CONSORT).

	Authors	Year	Design					Sample	Intervention Group(s)	Control Group(s)	Home Practice	Dependent Variables		Main Findings: Group Differences?
			1	2	3	4	5					Task	Metric	
1	Linden	1973	✓		✓	✓		Third grade students ▪ N = 90	Meditation ▪ 20-25 min. twice/week for 18 weeks ▪ n = 26 2) No intervention ▪ n = 30	1) Study skills guidance ▪ 45 min. once/week for 18 weeks ▪ n = 30 2) No intervention ▪ n = 30	None	CEFT	Field Independence: ▪ Metric not specified	Meditation group had higher field independence scores compared with both the active control group and the no intervention group.
2	McMillan, Robertson, Brock, & Chorlton	2002	✓	✓				Traumatic brain injury patients ▪ N = 130 ▪ Mean age = 34	ACT ▪ 45 min. once/week for 4 weeks ▪ n = 44 ▪ Mean age = 35 2) No intervention ▪ n = 48 ▪ Mean age = 36	1) Physical exercise ▪ 45 min. once/week for 4 weeks ▪ n = 38 ▪ Mean age = 31 2) No intervention ▪ n = 48 ▪ Mean age = 36	Daily (audiotape)	Cognitive Failures Questionnaire	Self-report responses	ACT and Physical exercise groups reported fewer cognitive failures than control groups.
												TEA (all subtests)	Scaled scores	NS
												TMT	TMT A & B ▪ Metrics not specified	NS
												PASAT (2 sec)	Working memory: ▪ Metric not specified	NS
												AMIPB	List learning, immediate recall, delayed recall	NS
3	Tang, Ma, Wang, Fan, Feng, Lu, Yu, Sui, Rothbart, Fan, & Posner	2007	✓	✓				Undergraduates at a Chinese University ▪ N = 80 ▪ Mean age = 22	IBMT ▪ 20 min. once/day for 5 days ▪ n = 40	PMR ▪ 20 min. once/day for 5 days ▪ n = 40	None	ANT	Alerting, Orienting, Conflict ▪ Mean RT	IBMT showed greater improvement on conflict trials compared to PMR.
												Raven's Progressive Matrices	Fluid intelligence	NS
4	Anderson, Lau, Segal, & Bishop	2007	✓					Healthy adults ▪ N = 86 ▪ Mean age = 39.5	MBSR ▪ 2 hr. once/week for 8 weeks	Wait-list ▪ n = 33 ▪ Mean age = 42	None: MBSR group encouraged	Vigil CPT	Sustained attention: ▪ Target discrimination	NS

						<ul style="list-style-type: none">▪ n = 39▪ Mean age = 37		to engage in at-home practice		(hits – false alarms) <ul style="list-style-type: none">▪ Mean RT		
								Attention Switching Task	<ul style="list-style-type: none">▪ Mean accuracy▪ Mean RT▪ Switch cost RT	NS		
								Emotional Stroop Task	Affective response inhibition: <ul style="list-style-type: none">▪ True errors (reading word, naming incorrect color)▪ False errors (non-word response)▪ Mean RT	NS		
								Object Detection Task	Non-directed attention: <ul style="list-style-type: none">▪ Mean accuracy▪ Mean RT	NS		
5	MacLean, Ferrer, Aichele, Bridwell, Zanesco, Jacobs, King, Rosenberg, Sahdra, Shaver, Wallace, Mangun, & Saron	2010	✓		Healthy adults familiar with mindfulness practice <ul style="list-style-type: none">▪ N = 60	Focused attention meditation retreat <ul style="list-style-type: none">▪ 3 months▪ Mean = 5 hr./day▪ Mean = 45 min./day▪ complementary practices▪ n = 30	Wait-list <ul style="list-style-type: none">▪ n = 30		Sustained Attention Task	Perceptual discrimination: <ul style="list-style-type: none">▪ $A' = \text{hits} - \text{false alarms}$ Vigilance: <ul style="list-style-type: none">▪ Slope of A'	Mindfulness training produced improvements in discrimination, but not vigilance.	
6	Semple	2010	✓	✓	✓	✓	Healthy adults <ul style="list-style-type: none">▪ N = 53▪ Mean age = 42	Benson Mindfulness Technique <ul style="list-style-type: none">▪ Pretest 90 min. individual training session▪ Posttest 20 min. individual training session <ul style="list-style-type: none">▪ Posttest 20 min. individual training session <ul style="list-style-type: none">▪ n = 14 2) Wait-list <ul style="list-style-type: none">▪ n = 16	20 min. twice/day for 4 weeks (audiotape)	CPT	Sustained attention: <ul style="list-style-type: none">▪ Discriminability (log d)	Mindfulness group demonstrated greater discriminability than controls.
								Stroop Color-Word Task	Response inhibition: <ul style="list-style-type: none">▪ Accuracy interference	NS		
								Digit Symbol Substitution Test	Processing speed: <ul style="list-style-type: none">▪ Number of accurate written	NS		

						▪ n = 15					substitutions in 90 sec.	
7	Zeidan, Johnson, Diamond, David, & Goolkasian	2010	✓	✓	✓	Undergraduates at an American University ▪ N = 63 ▪ Mean age = 22.5	Mindfulness meditation ▪ 20 min. once/day for 4 days ▪ n = 24 ▪ Mean age = 22	Book reading ▪ 20 min. once/day for 4 days ▪ n = 25 ▪ Mean age = 23	None	SDMT	Processing speed: ▪ Number of symbols coded - errors	Mindfulness group improved more than the control group.
										COWAT	Verbal fluency: ▪ Total number of words	NS
										Adaptive N-Back Task (2-back)	Working memory: ▪ Speed of processing ▪ Extended hit rate ▪ Mean accuracy	Mindfulness group exhibited more hit runs than the control group.
										Digit Span Task	Working memory: ▪ Number of trials correctly recalled (forward & backward)	NS
8	Greenberg, Reiner, & Meiran	2012	✓	✓	✓	Students at an Israeli University ▪ N = 76 ▪ Mean age = 26	Adapted MBCT ▪ 7 2-hr. group sessions plus a half-day retreat over 6 weeks ▪ n = 38 ▪ Mean age = 25	Wait-list ▪ n = 38 ▪ Mean age = 26	20 min./day	Water Jug Task	Cognitive rigidity: ▪ Rigidity score = perseverance on learned formula	MBCT group had significantly lower cognitive rigidity than controls.
9	Allen, Dietz, Blair, Beek, Rees, Vestergaard-Poulsen, Lutz, & Roepstorff	2012	✓	✓	✓	Students in Denmark ▪ N = 56 ▪ Mean age = 26.5	Focused awareness and open monitoring practices ▪ 2 hr. once/week for 6 weeks ▪ n = 30 ▪ Mean age = 27	Shared reading and listening ▪ 2 hr. once/week for 6 weeks ▪ n = 31 ▪ Mean age = 26	20 min./day	Error Awareness Task Go/No-Go	Response inhibition: ▪ Stop accuracy (commission errors) Error awareness: ▪ Percent error awareness (aware/total errors)	NS
										Affective Number Counting Stroop Task	Stroop interference: ▪ Incongruent trial RT-	Greater reduction in Stroop interference RT for the mindfulness group.

												<ul style="list-style-type: none">▪ Threshold of conscious perception (t_0)▪ Maximum capacity of visual working memory (K)▪ Speed of visual processing (C)▪ Top-down controlled selectivity (α)	controls. MBSR increased capacity of working memory more than inactive controls. NMSR and incentivized controls had larger improvements on selectivity than MBSR.	
11	Moore, Gruber, Derosé, & Malinowski	2012	✓			✓	✓	Healthy adults <ul style="list-style-type: none">▪ N = 32	Meditation training <ul style="list-style-type: none">▪ 2 hr. training prior to T1 assessment▪ 1 hr. training prior to T2 assessment▪ n = 14▪ Mean age = 36.9	Wait-list <ul style="list-style-type: none">▪ n = 18▪ Mean age = 34.6	10 min./day at least 5 days/week for 16 weeks prior to T3 assessment	Stroop Color-Word Task	Response inhibition: <ul style="list-style-type: none">▪ Mean RT▪ Variability (SD) of RT▪ Inverse efficiency score (mean RT/proportion correct responses)	NS
12	Mrazek, Franklin, Phillips, Baird, & Schooler	2013	✓	✓	✓			Students at an American University <ul style="list-style-type: none">▪ N = 48▪ Mean age = 21	Focused attention mindfulness meditation <ul style="list-style-type: none">▪ 45 min. 4 days/week for 2 weeks▪ n = 26	Nutrition education <ul style="list-style-type: none">▪ 45 min. 4 days/week for 2 weeks▪ n = 22	10 min./day Mindfulness: <ul style="list-style-type: none">▪ Formal practice Nutrition education: Daily food log	O-Span	Working memory capacity: <ul style="list-style-type: none">▪ Proportion of total letters recalled across trials	Mindfulness group improved more on working memory capacity and exhibited reduced mind-wandering, which mediated working memory improvements.
												GRE: Verbal Reasoning Section	Reading comprehension: Accuracy (proportion of total questions answered correctly)	Mindfulness group improved more than the nutrition education group on GRE scores.
13	Ainsworth, Eddershaw, Meron, Baldwin, & Garner	2013	✓	✓				Healthy young adults <ul style="list-style-type: none">▪ N = 76▪ Mean age = 20	1) Focused attention meditation <ul style="list-style-type: none">▪ Three 60-min. sessions over 8 days▪ n = 24	Wait-list <ul style="list-style-type: none">▪ n = 27	10 min./day	ANT	Alerting, Orienting, Conflict <ul style="list-style-type: none">▪ Mean RT	Both active groups demonstrated improved performance on conflict trials (executive control) compared with the no intervention group.

						2) Open monitoring meditation <ul style="list-style-type: none">Three 60-min. sessions over 8 daysn = 25						
14	Wells, Kerr, Wolkin, Dossett, Davis, Walsh, Wall, Kong, & Kaptchuk	2013	✓			Older adults with mild cognitive impairment <ul style="list-style-type: none">N = 14	MBSR <ul style="list-style-type: none">2 hr./week for 8 weeks plus day-long retreatn = 9Mean age = 73	Usual care <ul style="list-style-type: none">n = 5Mean age = 75	30 min./day	TMT	TMT A TMT B <ul style="list-style-type: none">Metrics not specified	Control group performed better than MBSR on TMT A and B.
										RAVLT	Verbal Learning: <ul style="list-style-type: none">Total score	NS
										COWAT	Verbal fluency: <ul style="list-style-type: none">Metric not specified	NS
										Animal Naming	Semantic fluency: <ul style="list-style-type: none">Metric not specified	NS
										Boston Naming	Word-finding: <ul style="list-style-type: none">Metric not specified	NS
										ADAS-cog	Metric not specified	NS
15	Moynihan, Chapman, Klorman, Krasner, Duberstein, Brown, & Talbot	2013	✓			Older adults <ul style="list-style-type: none">N = 201Mean age = 73.4	MBSR <ul style="list-style-type: none">2.5 hr./week for 8 weeks plus 7-hr. retreatn = 101Mean age = 73	Wait-list <ul style="list-style-type: none">n = 100Mean age = 74	None	TMT	Executive control: <ul style="list-style-type: none">TMT B/A (RT)	Mindfulness group had lower TMT B/A immediately post-intervention, but these effects were not maintained at follow-up.
16	Menezes, Couto, Buratto, Erthal, Pereira, & Bizarro	2013	✓	✓	✓	Undergraduate students at a Brazilian University <ul style="list-style-type: none">N = 100Mean age = 25	Focused attention meditation <ul style="list-style-type: none">90 min./week for 6 weeksn = 35	1) PMR <ul style="list-style-type: none">90 min./week for 6 weeksn = 37 2) Wait-list <ul style="list-style-type: none">n = 28	Time not specified (audiotape)	Concentrated Attention Test	Focused attention: <ul style="list-style-type: none">Correct answersErrorsOmissionsTotal Score	Only meditation group reduced omission in concentrated attention test .
										Discrimination Task	Emotion interference: <ul style="list-style-type: none">RT Attention regulation: <ul style="list-style-type: none">Response bias (<i>k</i>) (tendency to	Meditation reduced emotion interference in the easy condition, which was associated with practice time. Meditation and

										response is the same, regardless of trial)	relaxation reduced bias during high load.		
17	Fan, Tang, Tang, & Posner	2014	✓	✓			Undergraduates at a Chinese University <ul style="list-style-type: none">N = 43Mean age = 21	IBMT <ul style="list-style-type: none">20-30 min. once/day for 5 daysn = 21	PMR <ul style="list-style-type: none">20-30 min. once/day for 5 daysn = 22	None	Stroop Color-Word Test	Response inhibition: <ul style="list-style-type: none">Stroop interference RT and accuracy (color, word, color-word)	IBMT group showed significantly faster RTs than the control group and less RT interference. There were no group differences in Stroop accuracy.
18	Josefsson, Lindwall, & Broberg	2014	✓	✓			Healthy community adults <ul style="list-style-type: none">N = 104	Mindfulness meditation <ul style="list-style-type: none">45 min. twice/week for 4 weeksn = 38	1) Relaxation training <ul style="list-style-type: none">45 min. twice/week for 4 weeksn = 35 2) Wait-list <ul style="list-style-type: none">n = 31	None	Stroop Color-Word Test	Response inhibition: <ul style="list-style-type: none">Interference RT (incongruent - neutral & incongruent - congruent)Error rate during incongruent blockAverage RT during incongruent block	NS
19	MacCoon, MacLean, Davidson, Saron, & Lutz	2014	✓	✓	✓	✓	Healthy community adults <ul style="list-style-type: none">N = 63Mean age = 46.5	MBSR <ul style="list-style-type: none">2.5 hr./week for 8 weeks plus 7-hr. retreatn = 31Mean age = 45	Health enhancement program <ul style="list-style-type: none">2.5 hr./week for 8 weeks plus 7-hr. retreatn = 32Mean age = 48	45 min./day	CPT	Discrimination: <ul style="list-style-type: none">$A' = \text{hits} - \text{false alarms}$ Vigilance: <ul style="list-style-type: none">Slope of A'	NS
20	Banks, Welhaf, & Srouf	2015	✓	✓	✓		Students at an American University <ul style="list-style-type: none">N = 62Mean age = 20.87	Mindfulness meditation training <ul style="list-style-type: none">15 min. once at baseline and once at follow-up (audiotape)n = 34 Mean age = 21.91	Relaxation training <ul style="list-style-type: none">15 min. once at baseline and once at follow-up (audiotape)n = 28Mean age = 19.82	15 min./day for 1 week (audiotape)	Automated O-Span	Working memory: <ul style="list-style-type: none">Number of letters recalled in correct serial position	NS

21	Jensen, Lansner, Petersen, Vangkilde, Frokjaer, Adamsen, Knudsen, Denninger, Hasselbalch	2015	✓		✓	✓	Stressed community adults <ul style="list-style-type: none">▪ N = 72▪ Mean age = 42 Open and Calm individual meditation course <ul style="list-style-type: none">▪ 1.5 hr./week for 9 weeks▪ n = 24▪ Mean age = 42.5 Open and Calm group meditation course <ul style="list-style-type: none">▪ 2.5 hr./week group for 9 weeks, plus two 1.5-hr. optional individual sessions▪ n = 24▪ Mean age = 41.7	Treatment as usual <ul style="list-style-type: none">▪ n = 24▪ Mean age = 42.6	10-20 min. once or twice/day (audiotape) and frequent 1-2-min. mini-meditations	TVA	▪ Threshold of conscious perception (t_0)	The Open and Calm group improved more on t_0 than controls adjusting for baseline performance. Greater t_0 was associated with increased intervention compliance.	
22	Johns, Ah, Brown, Beck-Coon, Talib, Alyea, Monahan, Tong, Wilhelm, Giesler	2016	✓	✓	✓	✓	Breast and colorectal cancer survivors with clinically significant fatigue <ul style="list-style-type: none">▪ N = 71▪ Mean age = 57	MBSR <ul style="list-style-type: none">▪ 2 hr./week for 8 weeks▪ n = 35▪ Mean age = 56.9	Fatigue education and support group <ul style="list-style-type: none">▪ 2 hr. once weekly for 8 weeks▪ n = 36▪ Mean age = 56.4	20 min./day	Stroop Color-Word Test	Response inhibition: <ul style="list-style-type: none">▪ Accuracy rate▪ Average block RT	No change in RT, but MBSR group showed higher accuracy on the incongruent relative to congruent trials.
23	Menezes & Bizarro	2015	✓			✓	Students at a Brazilian University <ul style="list-style-type: none">▪ N = 33▪ Mean age = 24.4	Focused meditation <ul style="list-style-type: none">▪ 90 min./day for 5 days▪ n = 14▪ Mean age = 23.9	Wait-list <ul style="list-style-type: none">▪ n = 19▪ Mean age = 24.9	None	The Concentrated Attention Task	Concentrated attention: <ul style="list-style-type: none">▪ Number of correct responses▪ Number of errors▪ Omission errors▪ Total score	Meditation group showed increased correct responses relative to controls.
24	Schonert-Reichl, Oberle, Lawlor, Abbott,	2015	✓			✓	4th and 5th grade classrooms <ul style="list-style-type: none">▪ N = 99▪ Mean age = 10.2	MindUP program <ul style="list-style-type: none">▪ 40-50 min. 12 times over 4 months	Social responsibility program <ul style="list-style-type: none">▪ n = 51	None	Flanker Task	Switch trials & reverse trials: <ul style="list-style-type: none">▪ Percent accuracy (correct	MindUP program showed faster RT on Flanker switch trials compared to control.

	Thomson, Oberlander, & Diamond						<ul style="list-style-type: none">n = 48Mean age = 10.16	<ul style="list-style-type: none">Mean age = 10.31			responses/total responses) <ul style="list-style-type: none">Average RT		
									Hearts and Flowers Dots Task	Incongruent trials: <ul style="list-style-type: none">Percent accuracy (correct responses/total responses)Average RT	MindUP program showed faster RT on the Dots incongruent condition compared to control.		
25	Bhayee, Tomaszewski , Lee, Moffat, Pino, Moreno, Norman, & Farb	2016	✓	✓	✓	✓	Stressed community dwelling adults <ul style="list-style-type: none">N = 26Mean age = 32.65	N-tsMT <ul style="list-style-type: none">10 min. once at baseline and once at follow-up (audiotape)n = 13Mean age = 33.3	Khan Academy math training <ul style="list-style-type: none">15 min. once at baseline and once at follow-up (audiotape)n = 13Mean age = 32.0	10 min./day (audiotape) N-tsMT <ul style="list-style-type: none">Meditation (audiotape) Math: <ul style="list-style-type: none">Algebra practice problems	Stroop Color-Word Task	Response inhibition: <ul style="list-style-type: none">Mean RTTrial interference (incongruent RT – congruent RT)	The mindfulness group showed more improvement in Stroop RT than controls. The mindfulness group initially exhibited greater self-reported effort during practice than controls, but these became equivalent by the end of training.
										Digit Span Task	Working memory: <ul style="list-style-type: none">Number of trials correctly recalled (forward & backward)	NS	
										d2 Test of Attention	<ul style="list-style-type: none">Commission errorsOmission errors	NS	
26	Kiani, Hadianfard, & Mitchell	2016	✓			✓	Female adolescents with elevated ADHD symptoms <ul style="list-style-type: none">N = 30Mean age = 13.30	Mindfulness training <ul style="list-style-type: none">1.5 hr./week for 8 weeksn = 15Mean age = 13.17	Wait-list <ul style="list-style-type: none">n = 15Mean age = 13.42	Time not specified	CPT	Sustained attention: <ul style="list-style-type: none">Number correctOmission errors Response inhibition: <ul style="list-style-type: none">Commission errors	NS
										Digit Span Task	Working Memory: <ul style="list-style-type: none">Number of trials correctly	Although the mindfulness group showed within-group improvement, there	

										recalled (forward & backward)	were no significant between-group differences post-training.	
									Letter-Number Sequencing	Working memory: ▪ Number of correct items		
									Stroop Color-Word Test	Response inhibition: ▪ Color-word interference	Mindfulness group exhibited better inhibition post-training than wait-list, but no significant within-group change.	
									Tower of London Test	Planning: ▪ Number of correct trials	Mindfulness group exhibited better planning post-training than wait-list, but no significant within-group change.	
27	Becerra, Dandrade, & Harms	2017	✓		✓	Students at an Australian University ▪ N = 46 ▪ Mean age = 33.9	Mindfulness training ▪ Once every 2 weeks for 8 weeks ▪ n = 23	Wait-list ▪ n = 23	24 min./day (audiotape)	ANT	Alerting, Orienting, Conflict ▪ Mean RT	Mindfulness training group showed improved orienting and executive attention (conflict), but not alerting.
28	Course-Choi, Saville, & Derakshan	2017	✓	✓	✓	Adults with high worry ▪ N = 60 ▪ Mean age = 28.67	Mindfulness training ▪ 21 min. once at baseline (audiotape); at home daily for 1 week ▪ n = 15 ▪ Mean age = 30.67	Adaptive N-back working memory training ▪ Practice trials at baseline (online); at home daily for 1 week ▪ n = 15 ▪ Mean age = 27.93 Combined mindfulness and adaptive working memory training ▪ Completed both trainings at baseline; at	Mindfulness ▪ 21 min./day N-back ▪ Adaptive duration (online) Combined ▪ Adaptive duration (online & audiotape)	Anti-saccade and Pro-saccade Tasks	▪ Mean latency of correct anti-saccades ▪ Error rate (percent incorrect anti-saccades)	NS
										Change Detection Task	Working memory capacity ▪ WMC = array size (hits – false alarms)	NS

							home daily for 1 week ▪ n = 15 ▪ Mean age = 28.73 Control 1-back training ▪ n = 15 ▪ Mean age = 27.33					
29	Felver, Tipsord, Morris, Racer, & Dishion	2017	✓		✓	School-age youth ▪ N = 47 ▪ Mean age = 11.08	MFSR ▪ 90 min. once/week for 8 weeks ▪ n = 24 ▪ Mean age = 11.08	Wait-list ▪ n = 23 ▪ Mean age = 11.08	15-20 min./day	ANT	Alerting, Orienting, Conflict ▪ Mean RT	Mindfulness training improved conflict and orienting scores, but not alerting scores.
30	Malinowski, Moore, Mead, & Gruber	2017	✓	✓		Older adults ▪ N = 56 ▪ Mean age = 64.5	Mindfulness training ▪ 90 min. four times over 8 weeks ▪ n = 25	Brain training ▪ 90 min. four times over 8 weeks ▪ n = 25	10 min./day at least 5 days/week	Emotional-Counting Stroop Test	Response inhibition: ▪ Mean RT ▪ Hit rate	Mindfulness group, but not brain training, exhibited improved RTs.
31	Oken, Wahbeh, Goodrich, Klee, Memmott, Miller, & Fu	2017	✓	✓	✓	Older adults ▪ N = 134 ▪ Mean age = 60.2	Mindfulness meditation training ▪ 60-90 min. once/week for 6 weeks ▪ n = 66 ▪ Mean age = 60.2	Wait-list ▪ n = 68 ▪ Mean age = 59.4	30-45 min./day (audiotape)	Stroop Color-Word Test	Response inhibition: ▪ Condition (color-word) ▪ Interference (color-word)	NS
										Flanker Task	Switch trials & reverse trials: ▪ Metric not specified	NS
										COWAT	Verbal fluency: ▪ Number correct (letter & category)	NS
										Letter-Number Sequencing	Working memory: ▪ Number of correct items	NS

								Choice & Simple RT task	Metric not specified	NS			
32	Rahl, Lindsay, Pacilio, Brown, & Creswell	2017	✓	✓	✓		Healthy adults <ul style="list-style-type: none">▪ N = 142▪ Mean age = 21	1) Attention monitoring mindfulness training <ul style="list-style-type: none">▪ 20 min. once/day for 4 days▪ n = 41 2) Attention monitoring & acceptance mindfulness training <ul style="list-style-type: none">▪ 20 min. once/day for 4 days▪ n = 41	1) Relaxation training <ul style="list-style-type: none">▪ 20 min. once/day for 4 days▪ n = 38 2) Reading group <ul style="list-style-type: none">▪ 20 min. once/day for 4 days▪ n = 22	None	SART	Sustained attention: <ul style="list-style-type: none">▪ Discrimination (hit rate – error rate)	The attention monitoring plus acceptance group showed the greatest discrimination compared to other conditions.

Table 1 (B)

	Authors	Year	Design					Sample	Intervention Group(s)	Control Group(s)	Home Practice	Dependent Variables		Main Findings
			1	2	3	4	5					Task	Metric	
33	Brown, Forte, & Dysart	1984						Practitioners of Buddhist meditation <ul style="list-style-type: none"> ▪ N = 31 	3-month live-in retreat <ul style="list-style-type: none"> ▪ 16 hr./day ▪ n = 21 	Staff at the retreat center served <ul style="list-style-type: none"> ▪ n = 11 	--	Visual Detection and Discrimination	Detection threshold: <ul style="list-style-type: none"> ▪ Shortest stimulus duration for which 70% correct detection over at least 10 trials Discrimination threshold: <ul style="list-style-type: none"> ▪ Shortest interval for which 70% correct discrimination of two flashes over at least 10 trials 	Decreases in detection and discrimination threshold were observed for the participants in the retreat group at post-test but not in the control participants.
34 *	Slagter, Lutz, Greischar, Francis, Nieuwenhuis, Davis, & Davidson	2007						Meditation practitioners and matched novice controls <ul style="list-style-type: none"> ▪ N = 40 ▪ Mean age = 41 	3-month live-in Vipassana retreat <ul style="list-style-type: none"> ▪ 10-12 hr./day ▪ n = 17 ▪ Median age = 41 	Matched novice controls <ul style="list-style-type: none"> ▪ 1-hr. meditation class ▪ n = 23 ▪ Median age = 41 	For controls: <ul style="list-style-type: none"> ▪ 20 min./day for 1 week prior to the 	Attentional Blink Task	Attentional blink: <ul style="list-style-type: none"> ▪ Target 2 accuracy for trials in which target 1 was correctly reported 	Retreat participants showed significantly reduced attentional blink (increased accuracy) at post-assessment compared with controls.

							assessment				
35	Chambers, Lo, & Allen	2008		✓	Healthy Australian adults <ul style="list-style-type: none">▪ N = 40▪ Mean age = 33	10-day Vipassana retreat <ul style="list-style-type: none">▪ Up to 110 hr.▪ n = 20▪ Mean age = 34	Wait-list <ul style="list-style-type: none">▪ n = 20▪ Mean age = 32	--	Digit Span Task	DS backward: <ul style="list-style-type: none">▪ Number of trials correctly recalled	Retreat participants showed significant improvements on working memory compared to controls.
36*	Lutz, Slagter, Rawlings, Francis, Greischar, & Davidson	2009		✓	Meditation practitioners and matched novice controls <ul style="list-style-type: none">▪ N = 40▪ Mean age = 41	3-month live-in Vipassana retreat <ul style="list-style-type: none">▪ 10-12 hr./day▪ n = 17▪ Median age = 41	Matched novice controls <ul style="list-style-type: none">▪ 1-hr. meditation class▪ n = 23▪ Median age = 41	For controls: 20 min./day for 1 week prior to the assessment	Dichotic Listening Task	<ul style="list-style-type: none">▪ Mean RT▪ SD of RT▪ Sensitivity index (d')	The retreat group demonstrated improved ability to sustain attention as indicated by reduced RT variability (SD). No differences in overall RT or sensitivity.
37	Sahdra, MacLean, Ferrer, Shaver, Rosenberg, Jacobs, Zanesco, King, Aichele, Bridwell, Mangun, Lavy, Wallace, & Saron	2011		✓	Meditation practitioners and matched controls <ul style="list-style-type: none">▪ N = 60▪ Mean age = 48	3-month retreat <ul style="list-style-type: none">▪ 6-10 hr./day▪ n = 30	Wait-list, matched controls <ul style="list-style-type: none">▪ n = 30	Not quantified	Response Inhibition Task	<ul style="list-style-type: none">▪ Threshold▪ Average A' = hits – false alarms▪ Slope of A' across blocks	Mindfulness retreat training yielded increases in average response inhibition accuracy.
38	van Vugt & Jha	2011			Meditation practitioners and matched controls <ul style="list-style-type: none">▪ N = 58▪ Age range = 21-70	1-month mindfulness training retreat <ul style="list-style-type: none">▪ 10-12 hr./day▪ n = 29	Wait-list matched controls <ul style="list-style-type: none">▪ n = 29	--	Visual Working Memory Paradigm	<ul style="list-style-type: none">▪ Accuracy▪ Median RT▪ RT variability	The mindfulness retreat group showed faster and less variable RT than controls characterized by improved information quality and reduced response conservativeness.

39	van Leeuwen, Singer, Melloni	2012					Meditation practitioners and matched novice controls ▪ N = 12 ▪ Mean age = 50	4-day open monitoring retreat ▪ n = 6 ▪ Mean age = 50	Matched novice controls ▪ n = 6 ▪ Mean age = 50	Not quantified	Global to Local Task	▪ Average RT for correct responses	Meditators demonstrated faster RTs, and also reduced local precedence.
40	Zanesco, King, MacLean, & Saron	2013					Meditation practitioners and matched novice controls ▪ N = 55 ▪ Mean age = 52	1-month live-in Vipassana retreat ▪ 10 hr./day ▪ n = 28 ▪ Mean age = 50	Wait-list, matched controls ▪ n = 27 ▪ Mean age = 55	--	Response Inhibition Task	▪ A' = hits – false alarms ▪ RT_CV	The retreat group exhibited increased sensitivity and decreased RT variability compared controls.
41	Cohen, Jensen, Stange, Neuburger, & Heimberg	2017					Meditation practitioners ▪ N = 195 ▪ Mean age = 47.63	1-week live-in Vipassana retreat ▪ 8-10 hr./day	Baseline control period ▪ 1 week	--	Set-Shifting Task	▪ Switch cost RT and accuracy	NS

Note. * Same study but reported different outcomes in the two papers.

Table 1 (C)

	Authors	Year	Design					Sample	Intervention Group	Control Group(s)	Home Practice	Dependent Variables		Main Findings
			1	2	3	4	5					Task	Metric	
42	Jha, Krompinger, & Baime	2007				✓		Graduate students at an American University ▪ N = 34 ▪ Mean age = 23	MBSR ▪ 3 hr. once/week for 8 weeks ▪ n = 17 ▪ Mean age = 24	No intervention ▪ n = 17 ▪ Mean age = 22	30 min./day	ANT	Alerting, Orienting, Conflict ▪ Mean accuracy ▪ Mean RT	MBSR participants showed improved orienting RT compared to control group.
43	Zylowska, Ackerman, Yang, Futrell, Horton, & Hale	2007				✓	Adolescents and adults with ADHD ▪ Adolescent N = 8 ▪ Mean age = 15.6 ▪ Adult N = 24 ▪ Mean age = 49	Mindful awareness practices ▪ 2.5 hr. once/week for 8 weeks ▪ N = 32	None	Daily (duration not specified)		ANT	Alerting, Orienting, Conflict ▪ Mean RT	Mindfulness training improved conflict, but not alerting or orienting scores.
												TMT	TMT A TMT B ▪ Metrics not specified	Mindfulness training improved TMT A and B scores.
												Stroop Color-Word Test	Response inhibition: ▪ Metrics not specified (color, word, color-word)	Mindfulness training improved Stroop color and color-word interference, but not word scores.
												Digit Span Task	Working Memory:	NS

									<ul style="list-style-type: none"> Number of trials correctly recalled (total, forward, & backward) 	
44	Heeren, Broeck, & Philippot	2009		✓	American adults <ul style="list-style-type: none"> N = 36 Mean age = 54.5 	MBCT <ul style="list-style-type: none"> 2.5 hr. once/week for 8 weeks n = 18 Mean age = 54 	Matched controls <ul style="list-style-type: none"> n = 18 Mean age = 55 	Not specified; followed MBCT protocol that presumably included home practices	Hayling Task <ul style="list-style-type: none"> Response inhibition: <ul style="list-style-type: none"> Total error rate Number of correct responses One- and three-point error score Mean RT 	MBCT participants reported fewer total errors than matched controls.
									GoStop Task <ul style="list-style-type: none"> Motor inhibition: <ul style="list-style-type: none"> Proportion of inhibited responses/total stop trials 	NS
									TMT <ul style="list-style-type: none"> TMT B <ul style="list-style-type: none"> Error rate TMT B/A ratio 	NS
									Word Fluency Task <ul style="list-style-type: none"> Semantic, phonemic, verb: <ul style="list-style-type: none"> Number correct Number of errors 	MBCT participants reported more correct items than controls.
									AMT <ul style="list-style-type: none"> Total number of specific, categorical, and extended memories Number of omissions 	MBCT participants recalled more specific memories, and less categorical and extended memories than controls.
45	Cusens, Duggan, Thorne, & Burch	2010	✓	✓	British adults <ul style="list-style-type: none"> N = 33 Mean age = 46.7 	Breathworks Mindfulness Training program <ul style="list-style-type: none"> 6-10 2.5 hr. once/week n = 12 Mean age = 46.7 	Treatment as usual <ul style="list-style-type: none"> n = 18 Mean age = 48.4 	30-45 min./day	CPT <ul style="list-style-type: none"> Sustained attention: <ul style="list-style-type: none"> Mean d' 	NS
46	Jha, Stanley, Kiyonaga, Womg, & Gelfand	2010		✓	American military personnel and civilians <ul style="list-style-type: none"> N = 60 Mean age = 29.6 	MMFT <ul style="list-style-type: none"> 2 hr. once/week for 8 weeks plus a full day retreat n = 31 Mean age = 30 	1) Military control group <ul style="list-style-type: none"> n = 17 Mean age = 25 2) Civilian control <ul style="list-style-type: none"> n = 12 Mean age = 34 	30 min./day	O-Span <ul style="list-style-type: none"> Working memory capacity: <ul style="list-style-type: none"> Sum of all recalled letters from correct sets 	Working memory capacity degraded in the military control group. In the mindfulness training group, working memory capacity degraded in those with low practice times, but

										increased in those with high practice times.		
47	Rodriguez Vega, Melero-Llorente, Perez, Cebolla, Mira, Valverde, & Fernández-Liria	2014			Spanish psychiatry and clinical psychology residents <ul style="list-style-type: none">N = 103	MBSR <ul style="list-style-type: none">2.5 hr. once/week for 8 weeks plus 7-hr. retreatn = 58Mean age = 30	Wait-list <ul style="list-style-type: none">n = 43Mean age = 28	Not specified; followed MBSR protocol that presumably included home practices	CPT	Sustained attention: <ul style="list-style-type: none">Percent omissionsPercent commissionsMean RTMean <i>d'</i>Beta RT consistency: <ul style="list-style-type: none">SE of predicted RT by sub-blockSE of predicted RT by ISI	NS	
									Stroop Color-Word Test	Response inhibition: <ul style="list-style-type: none">Word & color RTCongruent, incongruent, neutral RTErrorsPerseverations	MBSR group had reduced word, congruent, and neutral RT, as well as fewer errors and perseverations compared to controls.	
48	Morrison, Goolsarran, Rogers, & Jha	2014		✓	✓	American undergraduate students <ul style="list-style-type: none">N = 58Mean age = 18	Mindfulness training <ul style="list-style-type: none">20 min. once/week for 7 weeksn = 38	Wait-list <ul style="list-style-type: none">n = 20	20 min. twice/week proctored in-lab (audiotape)	SART	Sustained attention: <ul style="list-style-type: none">Mean accuracyMean target accuracyMean non-target accuracyMean RT on correct non-target responses	Group X time effects on accuracy driven by decreased non-target performance in controls. Mindfulness decreased RT variability compared to controls.
										O-Span	Working memory capacity: <ul style="list-style-type: none">Sum of correctly recalled items from correct setsSum of correctly recalled items regardless of set performance	NS
										Delayed-Recognition with Distractors Task		NS

49	Lenze, Hickman, Hershey, Wendleton, Ly, Dixon, Dore, Wetherell	2014				Older adults with symptoms of anxiety, depression, and cognitive dysfunction ▪ N = 34 ▪ Mean age = 70.8	1) MBSR 8-week ▪ 2.5 hr. once/week for 8 weeks plus one day retreat ▪ n = 16 ▪ Mean age = 70.9 2) MBSR 12-week ▪ 2.5 hr. once/week for 12 weeks plus one day retreat ▪ n = 18 ▪ Mean age = 70.7	None	Not specified; followed MBSR protocol that presumably included home practices	RBANS or CVLT	List and paragraph learning, immediate and delayed ▪ Total number of correct words recalled	MBSR improved delayed recall on list learning and improved immediate and delayed recall on paragraph learning.
										DKEFS-FAS	Verbal fluency: ▪ Number of correct words	MBSR improved verbal fluency.
										Computerized Color-Word Interference Test	▪ Color-word interference RT	MBSR reduced interference.
										Digit Span Task	Working memory: ▪ Number of trials correctly recalled (forward)	NS
50	O'Connor, Piet, Hougaard	2014			✓	Bereaved older adults ▪ N = 65 ▪ Mean age = 77.5	MBCT ▪ 2 hr. once/week for 8 weeks ▪ n = 32 ▪ Mean age = 78	Wait-list ▪ n = 33 ▪ Mean age = 77	40 min./day	WAIS-III Letter-Number Sequencing (administered via telephone)	Working memory: ▪ Number of correct items	Mindfulness group showed improvements in working memory compared to wait-list controls.
51	Tabak & Granholm	2014				Veterans with psychotic disorders ▪ N = 10	Mindfulness training ▪ 60 min. once/week for 6 weeks	None	5-15 min./day	MATRICES Consensus Cognitive Battery	Metrics not specified: ▪ Processing speed ▪ Attention/vigilance ▪ Working memory ▪ Verbal learning ▪ Visual learning ▪ Reasoning/problem solving	Mindfulness training improved working memory scores, but no others.
52	Meland, Ishimatsu, Pensgaard, Wagstaff, Fonne, Garde, & Harris	2015				Military personnel preparing for redeployment ▪ N = 40 ▪ Mean age = 37.5	MBSR ▪ 10-hr. introductory course plus 3 hr. once/week ▪ n = 25 ▪ Mean age = 35	Wait-list ▪ n = 15 ▪ Mean age = 40	20 min. twice/week (personal sessions)	SART	Sustained attention: ▪ Errors of commission ▪ Mean RT	Mindfulness group showed improved SART RT compared to wait-list controls.
										Attentional Capture Task	Discrimination: ▪ Sensitivity (d') ▪ Mean RT	NS
53	Mallya & Fiocco	2016	✓	✓	✓	Older adults ▪ N = 97	MBSR	Reading and relaxation group	30 min./day	TMT	TMT A & B ▪ RT	NS
										COWAT	Verbal fluency:	NS

					<ul style="list-style-type: none">▪ Mean age = 69.3	<ul style="list-style-type: none">▪ 2.5 hr. once/week for 8 weeks▪ n = 57▪ Mean age = 68.8	<ul style="list-style-type: none">▪ 2.5 hr. once/week for 8 weeks▪ n = 40▪ Mean age = 69.7			<ul style="list-style-type: none">▪ Total number of words	
								CVLT	<ul style="list-style-type: none">▪ List learning, immediate and delayed▪ Number of correct words	NS	
54	Sanger & Dorjee	2016			Healthy adolescents <ul style="list-style-type: none">▪ N = 45	.b Foundations Programme <ul style="list-style-type: none">▪ 50 min. once/week for 8 weeks▪ n = 20▪ Mean age = 16.6	Wait-list controls <ul style="list-style-type: none">▪ n = 25▪ Mean age = 17.1	None	Oddball Task	Attention: <ul style="list-style-type: none">▪ RT, accuracy, omissions, false-alarms (pre-target, post-target)	NS
55	Spadaro & Hunker	2016			Nursing students <ul style="list-style-type: none">▪ N = 26	Online adapted MBSR <ul style="list-style-type: none">▪ 8 weeks▪ N = 26	None	Encouraged to practice once/week	ANT	Alerting, Orienting, Conflict <ul style="list-style-type: none">▪ Mean RT▪ Mean accuracy	NS
56	Jha, Morrison, Parker, & Stanley	2017		✓	High-stress predeployment American military personnel <ul style="list-style-type: none">▪ N = 55▪ Mean age = 27.5	MMFT <ul style="list-style-type: none">▪ 2 hr. once/week for 8 weeks plus a full day retreat▪ n = 31▪ Mean age = 30	Military control group <ul style="list-style-type: none">▪ n = 24▪ Mean age = 25	30 min./day	SART	Sustained attention: <ul style="list-style-type: none">▪ Mean RT▪ Mean accuracy Intraindividual coefficient of variability: <ul style="list-style-type: none">▪ SD RT/Mean RT Sensitivity: <ul style="list-style-type: none">▪ $A' = \text{hits} - \text{false alarms}$	Those with high mindfulness practice times exhibited greater sensitivity and reduced self-reported mind-wandering than those with low practice time. Whereas sensitivity declined from T1 to T2 for controls and low practice individuals, those with high practice maintained performance.

Notes. NS = no significant difference.

Interventions: ACT: Attentional Control Training; IBMT: Integrative Body-Mind Training; MBCT: Mindfulness-Based Cognitive Therapy; MBSR: Mindfulness-Based Stress Reduction; MMFT: Mindfulness-Based Mind Fitness Training; MFSR: Mindful Family Stress Reduction; NMSR: Non-Mindfulness Stress Reduction; N-tsMT: Neurofeedback-Assisted, Technology-Supported Mindfulness Training; PMR: Progressive Muscle Relaxation.

Tasks: ADAS-Cog: Alzheimer's Disease Assessment Scale-Cognitive sub-scale; AMIPB: Adult Memory and Information Processing Battery; AMT: Autobiographical Memory Test; ANT: Attention Network Task; CEFT: Children's Embedded Figures Test; CombiTVA: Combination Theory of Visual Attention Task; COWAT: Controlled Oral Word Association Test; CPT: Continuous Performance Task; CVLT: California Verbal Learning Test; DART: Dual Attention to Response Task; DKEFS: Delis-Kaplan Executive Function Scale; GRE: Graduate Record Examination; O-Span: Operation Span Task; PASAT: Paced Auditory Serial Addition Task; RAVLT: Rey Auditory Verbal Learning Test; RBANS: Repeatable Battery for the Assessment of Neuropsychological Status; SART: Sustained Attention to Response Task; SDMT: Symbol Digit Modalities Test; STAN: Spatial and Temporal Attention Network; TEA: Test of Everyday Attention; TMT: Trail Making Test.

Metrics: RT: Reaction Time; RT_CV: Reaction Time Coefficient of Variability