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REVIEW

Mindfulness, Attentional Networks, and Executive Functioning: a Review of Interventions and Long-Term Meditation Practice

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Abstract
The booming research into mindfulness and associated practices have facilitated our understanding of its components, mechanisms, and outcomes. This review re-examines the current evidence regarding the effects of mindfulness on cognitive functions, especially attention and executive functions, in healthy individuals. Forty-three intervention studies and twelve studies of long-term meditation practice of mindfulness that measured the three attentional networks (alerting, orienting, executive control) and three executive functions (inhibition, updating, and shifting) were included. According to the findings, mindfulness interventions and long-term meditation practices lead to substantial improvements in the inhibition facet of executive functioning. The findings for the three attentional networks and other executive functions are limited and inconsistent. Long-term experience in meditation does not offer additional gains in any function than the relatively shorter mindfulness interventions. The review assisted in establishing the specific effects of mindfulness on the attentional networks and executive functioning and determining the impact of duration of training and practice in mindfulness on these functions. Based on the findings, the implications of mindfulness for non-clinical populations are discussed, and recommendations for future research in this domain of active investigation are provided.

Keywords Mindfulness · Interventions · Long-term meditation practice · Attentional networks · Executive functioning

Introduction

Contemporary mindfulness practices have gained substantial popularity among the mainstream population as a means to well-being. Rooted in eastern meditation traditions (Gunaratana, 1993), the current literature describes mindfulness as a process of paying purposeful, moment-to-moment, non-judgmental attention to thoughts, feelings, and body sensations (Kabat-Zinn, 1990). The infusion of mindfulness practices in non-clinical settings is receiving priority presently, and mounting evidence suggests enhanced cognitive and emotional functioning as a result of these practices (Brown & Ryan, 2003; Brown et al., 2007; Chiesa et al., 2013; Eberth & Sedlmeier, 2012; Guendelman et al., 2017; Lodha & Gupta, 2020; Tang et al., 2015).

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Traditionally considered a lifelong practice with a spiritual orientation, mindfulness meditation includes meditation styles like Tibetan, Vipassana, and Zen, which individuals have regularly practiced for several years. Unlike the traditional meditation styles, contemporary mindfulness practices like mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) and mindfulness-based cognitive therapy (MBCT; Teasdale et al., 2000) are shorter, usually delivered in group settings, and have therapeutic goals revolving around mental health concerns, symptom relief, and promoting relaxation and well-being (Creswell, 2017). The two categories of practices may therefore have different cognitive and affective outcomes. However, presently, a substantial amount of understanding and empirical evidence about the effects of mindfulness has been derived from mindfulness interventions. In the ongoing quest for gaining a more nuanced understanding of mindfulness, the following questions, for instance, remain to be answered: what are the differences in cognitive performance in short-term and long-term mindfulness practices? Are the observed effects in cognitive functions transitory, or do they sustain over time? Which cognitive function needs to be trained or emphasized initially, and which needs training for a longer duration? This review intends to explore how the refined mindfulness intervention studies, compared to the longer traditional meditation styles, shape different aspects of cognitive functions.

Mindfulness Interventions and Long-Term Meditation Practice

The studies of mindfulness with long-term meditation practices (> 1 year) include practitioners from diverse meditation backgrounds, ranging from traditional Buddhist Vipassana practice to Shambhala to contemporary mindfulness-based techniques (Isbel & Mahar, 2015). These studies employ a between-group (matched or unmatched) cross-sectional design, which, unfortunately, does not allow for drawing of causal inferences regarding whether the observed differences in mindfulness and control groups were the actual result of particular mindfulness practice or due to the pre-existing between- and within-groups differences (Davidson & Kaszniak, 2015).

In an attempt to establish causality, the turn of the century has witnessed an exponential increase in mindfulness interventions involving novice participants (Creswell, 2017). The precursor to most mindfulness interventions used today in the scientific literature is the secular MBSR (Kabat-Zinn, 1990). The 8-week MBSR program, delivered by a trained instructor, entails weekly 2–2.5-h group meetings, a day-long mindfulness retreat during the sixth week (7 h of mindfulness practice), and daily audio-guided homework of around 45 min. The program focuses on developing awareness of bodily sensations through mindful breathing, body scans, simple stretching, yoga exercises, and applying mindfulness to daily activities. Other treatment- and population-specific group-based mindfulness interventions like MBCT for depression (Teasdale et al., 2000) and mindfulness-based relapse prevention for drug addiction (Bowen et al., 2014) evolved from MBSR and followed the same foundational program structure. The modified versions of the usual 8-week mindfulness-based programs might vary from 4 to 16 weeks (e.g., mindfulness-based attention training or MBAT; Whitmoyer et al., 2020). MBAT includes all the formal practices from traditional MBSR but is shorter and emphasizes focused attention more than open monitoring. Moreover, brief mindfulness interventions have also emerged, which include short training of 2–3 weeks (Mrazek et al., 2013) and even shorter training of 3–5 days (e.g., Integrative body-mind training or IBMT; Esch et al., 2017; Prätzlich et al., 2016; Tang et al., 2007; Zeidan et al., 2010). IBMT, or integrative meditation, which incorporates different components of mindfulness and meditation (relaxation, breathing adjustment, mental imagery), is a short training focused on achieving "a balanced state of mind" (Tang et al., 2007). Additionally, residential meditation retreats with intensive mindfulness practice spanning from 3 days to 3 months deliver carefully regulated doses for deepening the mindfulness skills (Chambers et al., 2008; Jha et al., 2007; Sahdra et al., 2011; van Vugt & Jha, 2011; Zanesco et al., 2013).

Of late, researchers have also started relying on brief experimental mindful inductions (a few minutes) that use a single-session intervention followed immediately by a post-test (e.g., Broderick, 2005; Jankowski & Holas, 2020; Norris et al., 2018; Schofield et al., 2015; Westbrook et al., 2013) for their experimental robustness, but the inductions generate temporary cognitive states (Colzato et al., 2015). Serving current needs, smartphone- and internet-based mindfulness programs (e.g., mobile apps like Headspace, UCLA Mindful, Healthy Minds program) offer a great deal of flexibility and customization in delivery (Bhayee et al., 2016; Ziegler et al., 2019), although their effectiveness is still under investigation.

Mindfulness interventions and long-term meditation practice often begin with focused attention (FA) meditation style, followed by open monitoring (OM), either in a single practice session or several practice sessions (Isbel & Summers, 2017; Lutz et al., 2008; Lutz et al., 2015). In focused attention, the practitioner concentrates on a single chosen object, detects mind wandering, disengages from the object of distraction, and quickly reorients the attention to the primary object of meditation. On the other hand, open monitoring requires progressive reduction of an explicit focus on any object and distributing attention to a broad field of experience (Lutz et al., 2008). Mindfulness interventions involve inculcating either focused attention or open monitoring or both styles of varying durations (Hölzel et al., 2011; Lutz et al., 2007). However, the distinction between focused attention and open monitoring is usually blurred, and these practices often overlap.

Mechanisms of Mindfulness: Attention as the Core Component

To simplify the construct of mindfulness and understand the psychological processes involved in mindfulness, Bishop et al. (2004) proposed two core components of mindfulness: first, self-regulation of attention or maintaining awareness in the present moment and second, assuming a particular orientation towards all experiences marked by curiosity, openness, and acceptance. Treating this model as the foundation, Isbel and Summers (2017) has described mindfulness as a "cognitive faculty" of non-judgmental attention to the present moment that needs to be evoked and sustained during the mindfulness practice. Two sub-components characterize this faculty—an attentional component, which maintains sustained attention on an object (like breath, body sensations, thoughts, emotions) without getting distracted, and a non-judgmental acceptance component, defined by an even-minded orientation to all experiences regardless of their origin or affective valence (Isbel & Summers, 2017).

Besides the two-component models, Shapiro et al. (2006) proposed three potential mechanisms underlying mindfulness represented by intention (or the purpose), attention (attending to the "here and now"), and attitude (of patience, compassion, and non-striving). Hölzel et al. (2011) attempted to bring more precision in elucidating mindfulness and proposed four operating mechanisms: (1) attention regulation, or sustaining uninterrupted focus on the object of attention; (2) body awareness, or recognition and distinction of subtle physical sensations; (3) emotion regulation, or non-judgmental acceptance of ongoing emotional reactions and modulation of emotional responses; and (4) a change in perspective on the self, or disidentification from a permanent sense of self and viewing the mental processes as temporary. Since attention constitutes a common and essential ingredient across the theoretical models of mindfulness, it is vital to investigate the particular functions of attention being altered by mindfulness practices.

The Attentional Networks and Executive Functioning

"Attention" is a dynamic and complex cognitive process which guides the brain to prioritize and select relevant information from the less relevant information. According to the seminal model of attention by Posner and Petersen (1990), attention consists of three distinct and independent functional networks: alerting (preparatory and vigilant state for an incoming stimulus), orienting (directing attention to a subset from multiple sensory stimuli), and executive control (or executive attention or conflict monitoring; resolving a conflict between competing tasks, inhibition of pre-planned responses, and execution of correct response). The alerting network, associated with goal-directed, bottom-up attention (Katsuki & Constantinidis, 2014), detects sudden changes in sensory stimuli, identifies salient targets located outside the focus of attention, and infrequently occurs (Corbetta & Shulman, 2002). On the other hand, the orienting and executive control networks are involved in high-order information processing or stimulus-driven, top-down attention (Katsuki & Constantinidis, 2014). The orienting network analyzes the early input-level sensory-perceptual information, and the executive control network guides the later response-level decision-making and response processes. Although these systems interact to a certain extent, they are mainly independent concerning controlling behavior and brain regions (Corbetta & Shulman, 2002). The Attention Network Test (ANT) devised by Fan et al. (2002) offers evidence for the relative dissociation between the three systems (Gupta & Kar, 2009; Gupta et al., 2011; Gupta et al., 2006).

Note that the "inhibitory" component of the conflict monitoring or the executive control network also acts as an attentional control mechanism underlying other executive functions (Gupta, 2011; Gupta & Singh, 2021; Miyake & Friedman, 2012; Pandey & Gupta, 2022). Executive functions usually comprise several higher-order processes such as problem-solving, planning, rule acquisition, decision-making, and other goal-directed behaviors (Ardila, 2008; Diamond, 2013). In their tripartite model of executive functioning, Miyake et al. (2000) proposed three distinct but moderately interrelated core capacities—response inhibition or inhibitory control: active suppression of irrelevant stimuli and prepotent responses; (2) updating and monitoring: constantly refreshing the contents of the working memory; and (3) shifting or cognitive flexibility: the ability to shift attention from one stimulus to another quickly. The three facets of executive function work to respond to new and unprecedented circumstances where appropriate cognitive control and flexible adaptation are required (Miyake et al., 2000). Specifically, the updating and monitoring facet corresponds to the executive component of working memory, responsible for holding information in the brain while performing complex tasks (Baddeley, 2010; Gupta & Srinivasan, 2009). The updating facet is closely related to the shifting facet. For example, one has to update the internal settings while switching from one task to another. Theoretically, while updating and shifting facets do not befit the ANT framework, the inhibition facet partially overlaps with the executive control network (Miyake & Friedman, 2012). Inhibition, in this context, refers to the maintenance of task goals, instructions, and procedures for managing attention and resisting distractions (Diamond, 2013).

The existing literature on attentional networks and executive functions identifies separable sub-functions that are also moderately correlated. Each function needs to be examined individually to parse out the specific effects of mindfulness on cognitive performance.

Association Between Mindfulness, Attention, and Executive Functions

Multiple reviews and meta-analyses have investigated the impact of mindfulness on attention and executive functions (Chiesa et al., 2011; Eberth & Sedlmeier, 2012; Gallant, 2016; Prakash et al., 2020; Sumantry & Stewart, 2021; Yakobi et al., 2021). Chiesa et al. (2011) systematically reviewed fifteen controlled or randomized controlled studies and eight case–control studies to examine the neuropsychological consequences of mindfulness meditation practices on attention and executive functions. The authors concluded that focused attention or concentrative style of meditation may be associated with changes in selective and executive attention abilities and would come first in the early phases of mindfulness training. The later phases are marked by the emergence of the open-monitoring style and may increase unfocused sustained attention (Chiesa et al., 2011). Gallant (2016) examined the effects of mindfulness meditation on executive functioning based on Miyake et al.'s (2000) tripartite model. This comprehensive systematic review of twelve experimental or quasi-experimental studies revealed that mindfulness meditators performed better on inhibition tasks than controls. Results for shifting and updating facets were inconsistent.

In a narrative review, Prakash et al. (2020) investigated fifty-six retreat studies, feasibility studies, and randomized controlled trials for changes in attentional control following mindfulness training. The authors systematically classified the outcome measures of meditation studies into a dual framework of top-down and bottom-up attention. Many feasibility and retreat studies supported benefits in both types of attention following mindfulness training. However, randomized controlled trials showed heterogeneous evidence, especially those involving active control comparison groups. A meta-analysis and systematic review of randomized controlled trials in adults (Cásedas et al., 2020) revealed that mindfulness meditation exerts a small-to-medium effect in enhancing executive control. Another meta-analytic study (Sumantry & Stewart, 2021) found that mindfulness meditation improved generalized attention, alerting, and executive control networks, but there was no effect on the orienting network. Studies that taught both focused attention and open monitoring techniques did not show attentional improvements over those that taught only a single technique. Meditation led to more significant improvements in accuracy-based tasks than reaction time tasks. Although the above findings are encouraging, these reviews do not study the link between the length of mindfulness practices and attentional and executive functions.

In conclusion, the current review re-examines the effects of mindfulness interventions and long-term meditation practice on cognitive functions, focusing on attentional networks and executive functioning. Based on the findings, we discuss the effects of mindfulness on six functions: alerting, orienting, executive control, inhibition, updating, and shifting. The current review would help (1) clarify the role of mindfulness in improving discrete aspects of attentional networks and executive functioning and (2) establish the potential for improving cognitive functions through mindfulness practices for non-clinical populations. However, the evident interconnections and non-orthogonality between the functions warrant caution to the reader in evaluating the findings.

Methods

Literature Search

Studies were obtained via online search using PsychInfo and Google Scholar. Keywords associated with mindfulness, "mindfulness," "mindfulness meditation," "mindfulness training," "mindfulness-based stress reduction," and "mindfulness-based cognitive therapy," were combined with terms relevant to the attentional networks and executive functions, including "attention," "attention control," "attention subsystems," "attention network test," "cognition," "executive attention," "executive control," "inhibitory control," and "executive functioning," "working memory," "cognitive flexibility." The reference section of all relevant papers was scrutinized to obtain additional papers. The search was concluded in November 2019.

Inclusion and Exclusion Criteria of Studies

We included the following studies: an empirical study that investigated the effects of either mindfulness intervention or long-term meditation practices on objective measures of attentional networks and executive functioning in a sample of healthy adults ($K = 55$). Intervention studies that assigned participants to or recruited participants to a meditation group were included to examine the causal involvement of mindfulness training on attentional outcomes. We included pre-test and post-test studies involving at least one control group (active or passive), with or without random allocation ($K_S = 43$), and studies in which participants with previous experience in meditation were compared with a control group ($K_L = 12$). Brief mindfulness inductions were excluded as their transient effects might not provide evidence of long-term outcomes. The studies that employed the techniques of focused attention, open monitoring, or both were included. This criterion excluded studies of mantra meditation, transcendental meditation, Gurdjieff meditation, and movement-based practices like tai chi and Body-Mind Axial Awareness. Objective attentional outcomes were alerting, orienting, and executive control measures. The facets of executive functioning were further divided into inhibition, shifting, and updating. We excluded studies associated with tasks that primarily measure sustained attention, such as the sustained attention to response task, the continuous performance test, and a sustained counting task. Only peer-reviewed articles published in English were included while excluding systematic and narrative reviews, meta-analyses, case studies, commentaries/editorials, and qualitative reports.

Outcome Measures, Data Extraction, and Synthesis

The outcomes were categorized into six functions: alerting, orienting, executive control, inhibition, updating, and shifting. After scrutiny, the behavioral tasks included in each study were sorted based on the cognitive function they primarily measured (see Table 1). Findings for each function are nearly ordered along a dose–response dimension in terms of weeks of intervention and amount of long-term experience to interpret the effects that emerge after interventions and those that require longer practice or even extensive expertise (see Figs. 1 and 2). Other details related to sample characteristics, intervention, and control group are provided in Supplementary Material 1. We have separated the studies on the sub-components of the attentional networks into different sub-sections. The studies of inhibition, updating, and shifting are grouped under a single sub-section, *"Executive functioning,"* as the organization of studies along the dose–response curve and the interconnections between outcome measures limited explicit section-wise segregation of each facet. However, the findings for each facet are discussed and interpreted separately.

Note that the effects of the amount of daily practice, duration of mindfulness sessions, or the total hours of meditation practice to date (see Supplementary Material 1 for details) are not reviewed. Although these variables are an integral part of mindfulness, studies do not consistently measure and report them, which restricts us from including these variables in the paper.

Effects of Mindfulness Interventions and Long-Term Meditation Practice

Alerting Eight mindfulness intervention studies assessing the alerting network were reviewed (Ainsworth et al., 2013, Exp.1 & Exp.2; Becerra et al., 2017; Burger & Lockhart, 2017; Esch et al., 2017; Felver et al., 2017; Jha et al., 2007; Quan et al., 2018; Tang et al., 2007). The duration of interventions ranged from 5 days to 8 weeks, and all of these studies used the ANT. A standard ANT combines the Posner cueing task (Posner, 2008) with a flanker task (Eriksen & Eriksen, 1974) to index the efficiency of the three networks using reaction time and accuracy scores. In one study (Jha et al., 2007), participants were randomized to mindfulness and control groups, and two studies included active comparison groups (Jha et al., 2007; Quan et al., 2018). None of the observations reported improvements in the alerting component. Esch et al. (2017) found non-significant differences in alerting RTs between the focused attention and control groups. However, the focused attention meditators successfully reduced overall error, especially in the trials with short RTs, following the 5-day intervention. The findings might reflect that mindfulness increases both speed and accuracy instead of using a simple speed-accuracy trade-off strategy.

In examining the effects of long-term meditation practice on alerting, Jha et al. (2007) recruited participants with previous experience in focused attention meditation (mean experience 5 years) who underwent an intensive 1-month retreat training in focused attention (concentrative) technique. The retreat group was compared with an MBSR group that received an 8-week training in focused attention and open monitoring techniques and a waitlist control group. At post-test, the retreat group demonstrated improved alerting performance on ANT compared to the waitlist control + MBSR participants. Moreover, the reduced alerting scores were associated with greater experience. The findings indicate that the retreat participants with long-term meditation experience were in a "state of readiness," even when a warning signal about target onset was absent.

In contrast, Isbel and Mahar (2015), who compared experienced meditators (mean experience of 10 years) with the non-meditators, found no significant difference between groups on the alerting component of ANT. Similarly, van den Hurk et al. (2010) failed to find improved alerting performance on ANT in long-term mindfulness practitioners (mean experience 14.5 years) compared to age and gender-matched controls. Meditators in both studies had experience in focused attention and open monitoring techniques (Isbel & Mahar, 2015; van den Hurk et al., 2010), but the participants in the meditation group in these studies did not undergo additional mindfulness training, unlike the retreat group in Jha et al. (2007). Jha et al. (2007) argue that previous experience with focused attention meditation followed by mindfulness training might result in the development of receptive attention (a hypothesized outcome of open-monitoring meditation), leading to attentional readiness (i.e., alertness) in the retreat group. However, if that were the case, Isbel and Mahar (2015) and van den Hurk et al. (2010) would find similar improvements in the more experienced meditators who practiced both focused attention and open monitoring techniques.

Orienting The intervention studies that measured alerting also measured orienting and executive control using the ANT. Among studies employing an active control group, only Quan et al. (2018) found improvements in the orienting network in the mindfulness group. The 1-week training involved 100-min sessions daily. Becerra et al. (2017) randomly assigned participants to mindfulness and waitlist groups. The mindfulness group was introduced to the focused breath awareness practice and was instructed to engage in 24-min mindfulness practice daily using an audiotape for 8 weeks. All subjects completed a minimum daily practice of 80%. Four in-person group sessions were conducted during the 8-week intervention. At the post-test, the

Table 1 Description of the main tasks used in the reviewed studies

Functions	Task	Task description
Attention network		
Alerting	ANT	Attention task involving the presentation of an array of five arrows. The central or the target arrow might be in the same (congruent) or opposite (incongruent) direction as the other four arrows. Participants respond to the direction of the target, pointing to either left or right. Performance on three functions is determined by subtracting reaction times (RTs) in different cue conditions (for alerting and orienting) and target congruency (for executive control)
Orienting	ANT	Described above
Executive control	ANT	Described above
Executive functioning		
Inhibition	Stroop test	Participants respond to the color of the word while ignoring its meaning. The Stroop (interference) effect occurs when responses are faster or more accurate in the congruent condition (the word color matches the meaning, e.g., the word "blue" in blue ink color) compared to the incongruent condition (the word color differs from the meaning, e.g., the word "blue" in red ink color). Affective Stroop often uses emotional words to evoke emotional interference
	Go-nogo	Participants respond to frequently occurring stimuli by identifying the target (Go trials) and withhold the response when the infrequent auditory or visual stimulus is presented either simultaneously (No-Go trials) or after some delay from the onset of target stimuli (Stop trials)
	Hayling task	The task consists of two sets, with fifteen sentences being read aloud in each set. The participant quickly completes a sentence with the befitting word in the first condition. In the second condition, the participant quickly completes the sentence with a nonsensical word. RTs and error rates are compared to measure response initiation and inhibition ability in the first and second conditions, respectively
	Response inhibition task	Participants respond to frequently occurring trials with long lines and withhold responses to infrequent trials with short lines
	Anti-saccade	Participants inhibit a reflexive, involuntary saccade towards a peripheral stimulus and execute a conscious, voluntary saccade in the opposite direction
	Attention capture task	Participants must ignore the infrequent task-irrelevant stimulus while responding to the target stimulus as quickly and accurately as possible
Updating	N-back	Participants must identify if the current letter is the same or different from the letter presented N (1, 2…n) items back in a sequence of letters
	Digit span (forwards and backwards)	Participants are asked to recall the digits in the order of appearance either in a forward manner (forward-span; DSF) or a reverse manner (backwards-span; DSB) by typing them via key press. The number of digits presented increases by one on a successful attempt for each subsequent trial or remains the same on each failed attempt on the current trial. The digit span is the maximum number of digits correctly recalled
	Operation span (OSpan)	On a computer, participants are given an equation–word string and asked to verify aloud if the math equation is correct. Participants then read the word aloud. At the end of the series, they write down the sequence of words. OSpan is the total number of words correctly recalled
	Reading span task	Participants are presented with a sentence–letter string on a computer and asked to verify aloud if the sentence makes sense. Participants then read the letter aloud. At the end of the series, they write down the sequence of letters. RSPAN is the total number of letters correctly recalled
Shifting	Attention switching task	Participants respond to task A and task B by different keypresses. They carry out two trials of task A (A-A), followed by two trials of task B (B-B) (repeat trials), and then back to task A (B-A or A-B; switch trials). Shifting performance is indexed by comparing RTs during blocks of repeat trials relative to switch trials
	Internal switching task	Participants keep an internal mental count of words presented one by one from two different semantic categories and report the total number of words from each category at the end
	Trail making tests (TMT)	The TMT-A requires participants to draw a line between circles marked 1–25 in increasing order (base speed). In contrast, the TMT-B requires the participants to switch between numbers and letters in consecutive order, like 1-A-2-B-3-C (shifting speed). TMT-A is compared with TMT-B to provide an index of shifting ability
	Wisconsin card sorting task	According to different criteria, participants figure out the classification rule to sort the card from the four other cards on screen—the rule changes after every 10th card. Thus, the participant must determine the changed rule based on the feedback

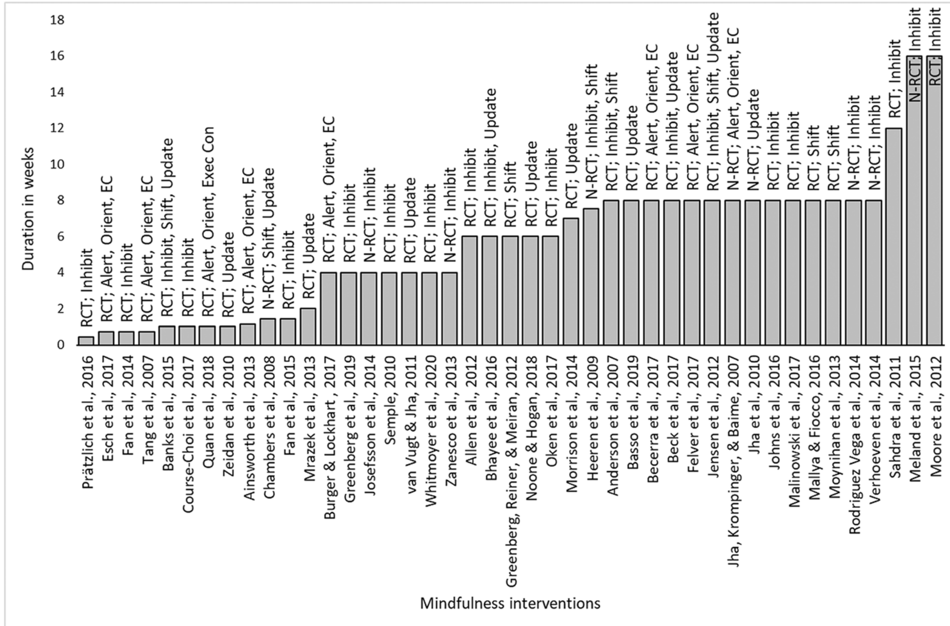

Fig. 1 The main characteristics of intervention studies as reviewed in the paper. Separate bars represent the duration of the intervention in weeks. Data labels specify whether the study randomized the participants into groups or not and the function(s) measured. RCT, randomized controlled trials; N-RCT, non-randomized controlled trials; Alert, alerting; Orient, orienting; EC, executive control; Inhibit, inhibiting; Shift, shifting; Update, updating

mindfulness group showed improved orienting RTs compared to the waitlist group. Another 8-week randomized controlled trial (RCT; Felver et al., 2017) with a mindfulness training group (FA and OM) and a waitlist control group demonstrated enhanced orienting RTs; they employed eight training sessions of 90 min each. Jha et al. (2007) also showed that the participants in the MBSR course trained in the focused attention technique demonstrated significantly improved orienting compared to the waitlist controls after 8 weeks (eight 180-min sessions). All other RCTs for 5 days to 4 weeks found null effects on the orienting network after mindfulness intervention (Ainsworth et al., 2013, Exp.1 & Exp.2; Burger & Lockhart, 2017; Esch et al., 2017; Tang et al., 2007).

Out of the limited studies examining the impact of mindfulness on the orienting network, only one study with long-term meditation practitioners (van den Hurk et al., 2010) demonstrated significant enhancements in orienting RTs compared to the age and gender-matched controls. However, the accuracy scores were non-significant. The improved orienting performance might be explained by more experienced meditators (mean experience of 14.5 years) and a better match between meditators and control participants than in other studies (Isbel & Mahar, 2015; Jha et al., 2007).

Executive Control Esch et al. (2017) compared a focused attention group and a waitlist control group in a brief mindfulness intervention of 5 days but failed to find significant improvement in the mindfulness group on executive control. Tang et al. (2007) found that training in IBMT followed by 5 days of 20-min group sessions showed more significant improvement in incongruent trials as measured by ANT than in a relaxation group. Similar performance-related improvements in the ANT executive network were reported (Quan et al., 2018) in the MBCT group post-intervention, concluding after a week (100-min sessions for seven consecutive days).

Ainsworth et al. (2013) demonstrated enhancements in the executive control network (reflected by decreased RTs on incongruent trials measured by an affective variant of ANT) in the focused attention and open monitoring groups compared to the waitlist group. Notably, the training in focused attention and open monitoring involved only three 1-h sessions spanning 8 days. In a 4-week intervention, Burger and Lockhart (2017) randomly assigned the nursing students to a mindfulness group (instructions in FA) and a waitlist group. Although the mindfulness group exhibited higher executive control efficiency on the ANT than controls in the pre-test, statistical adjustments revealed that mindfulness participants had more improvement in executive attention than those in the control group in the post-test. Studies also found enhancements in conflict scores on the ANT when an 8-week mindfulness intervention group was compared to a waitlist group (Becerra et al., 2017; Felver et al., 2017), but Jha et al. (2007) observed no differences between the MBSR, retreat, and control groups post the 8-week intervention.

For Jha et al. (2007), the pre-test scores on ANT showed that the retreat group with previous experience in meditation had better executive control capacity than the MBSR and control groups. Neither of the two studies (Isbel & Mahar, 2015; van den Hurk et al., 2010) involving participants with even longer meditation experiences showed significant improvement in executive control in the meditation group relative to the control group.

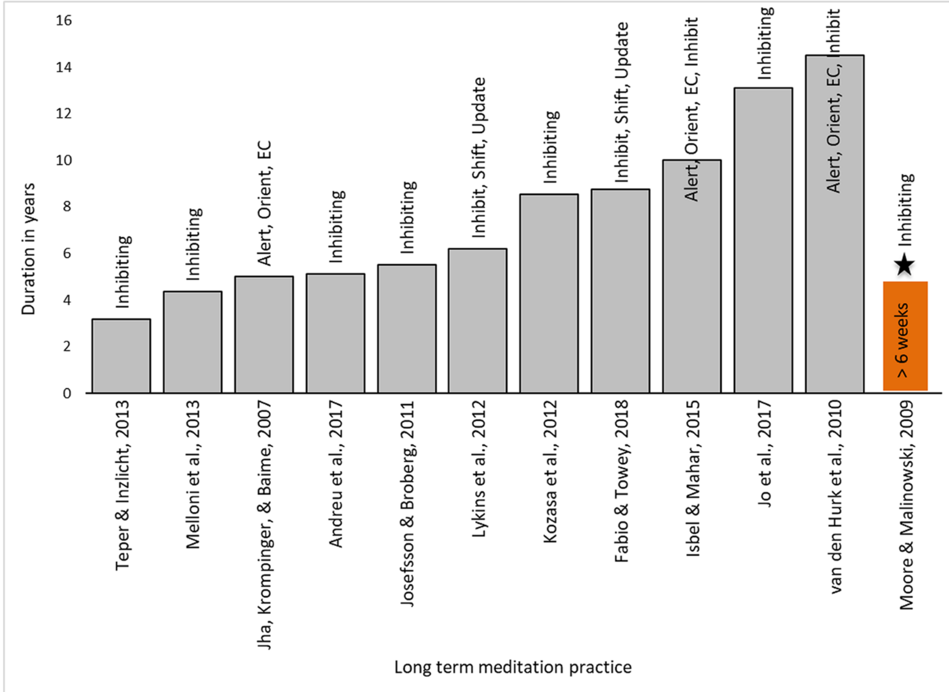

Fig. 2 The main characteristics of long-term meditation practice studies as reviewed in the paper. Separate bars represent the duration of the practice in years. Data labels specify the function(s) measured. Alert, alerting; Orient, orienting; EC, executive control; Inhibit, inhibiting; Shift, shifting; Update, updating. *Missing data on the mean meditation experience of the participants

The limited studies measuring the attentional networks yield no substantial effects of mindfulness. The null findings obtained for the alerting network from mindfulness interventions of mere weeks are similar to those from experienced meditation practitioners of several years. Evidence for enhancement in the orienting network with long-term practice and mindfulness interventions is inconsistent. The executive control network showed consistent improvements following interventions but not with the long-term meditation practice.

Executive Functioning The training duration of the intervention studies assessing executive functioning varied from 3 days to 16 weeks. In one RCT (Prätzlich et al., 2016) with a focused attention group and a waitlist control group, brief mindfulness interventions of 3 days did not significantly affect inhibition measured using the Stroop Color and Word Task. Furthermore, Fan et al., (2014, 2015) compared IBMT and relaxation groups on a Stroop task during brief interventions varying from 5 to 10 days. The IBMT group had significantly faster RTs, but the groups did not differ on Stroop accuracy. The reasonably consistent results from the brief IBMT interventions in inhibition and executive control (Tang et al., 2007) might be attributed to the "augmented practices," which possibly offer superior attentional benefits over only one of these practices, regardless of the duration. However, other RCTs with a 1-week intervention period and active control groups reported null effects on different facets of executive functioning. Course-Choi et al. (2017) employed an anti-saccade task associated with inhibition. After a single session, they found non-significant RTs and accuracy differences between a mindfulness training group and N-back training or N-back and mindfulness training groups. Of the two studies measuring updating associated with the working memory capacity, none found differential benefits on Automated Operation Span Task accuracy (Banks et al., 2015) or N-back and Digit Span accuracy (Zeidan et al., 2010) following almost a week-long mindfulness training.

Brief interventions ranging from more than a week to 2 weeks (Chambers et al., 2008; Mrazek et al., 2013) suggested improvements in executive functioning following mindfulness training. Contrary to Zeidan et al. (2010), Chambers et al. (2008) found improvements in Digit Span-backward performance in meditation-naive participants after a 10-day intensive mindfulness retreat compared to control. Additionally, the mindfulness group's overall RTs improved over time on the Internal Switching Task measuring shifting, although no change was observed in the task-switching ability. One RCT (Mrazek et al., 2013) compared a group receiving a modified MBSR program, specifically focused attention, to an active control group receiving a nutrition course of a 2-week duration using the Operation Span task (OSpan). There was a significant increase in the OSpan performance in the MBSR group at post-test. Notably, the improved task performance on the measure of working memory was mediated by reduced mind-wandering as assessed by self-reports. The findings indicate that training in focused attention may have increased the ability to stay in the present moment while ignoring distractions, which benefits the working memory capacity (Diamond, 2013; Isbel & Summers, 2017; Vago & Silbersweig, 2012).

Mindfulness intervention studies of slightly longer durations (4–6 weeks) have used more diverse tasks and measures to examine executive functioning. Greenberg et al. (2019) compared a mindfulness group (FA + OM + loving-kindness meditation) with a creative writing group on a Recent Probes Task. This behavioral task evaluates the extent of inhibition to proactive interference from recently encountered but no longer-useful information (Atkins et al., 2011). Following the 4-week training, the mindfulness group presented lower proactive interference error rates than the control group. As opposed to the positive finding, two studies found that a 4-week mindfulness intervention did not improve Stroop RTs (Josefsson et al., 2014; Semple, 2010) or Stroop accuracy (Josefsson et al., 2014) compared to a progressive muscle relaxation group and a waitlist control group. In a markedly well-designed RCT (Whitmoyer et al., 2020), a mindfulness group that received training in MBAT was compared with a lifestyle education group on the Go-nogo task and Working Memory Index from the Wechsler Adult Intelligence Scale (WAIS-IV). Although the participants in the MBAT with higher working memory showed more remarkable improvement in executive control, there were no group differences on the Go-nogo task. Comparisons between a mindfulness retreat group and a waitlist control group exhibited encouraging results for executive function (van Vugt & Jha, 2011; Zanesco et al., 2013). Following a 4-week intensive mindfulness training, the retreat group showed a higher discriminability index, less variable RTs on a response inhibition task (Zanesco et al., 2013), and shorter and less variable RTs on a visual working memory task (van Vugt & Jha, 2011) than controls.

In a mindfulness intervention of 6 weeks with six training sessions, Allen et al. (2012) found a more significant reduction in Stroop interference RTs in the mindfulness group than in a shared reading and listening group. However, there were no differential effects between the two groups on the metrics of the Go-nogo task (stop accuracy and percent error awareness; Allen et al., 2012). A neurofeedback technology-supported mindfulness training (abbreviated to N-tsMT) in which the mindfulness group practiced 10-min daily audio-guided calming meditation for 6 weeks (Bhayee et al., 2016) found faster Stroop RTs in the mindfulness group than in active controls. However, the authors found insignificant results on the Digit Span Forwards and Digit Span Backwards tasks that measured updating. A strength of this study was the proper control for expectancy effects. Instead of explicitly advertising mindfulness, participants in both groups were told that the study aimed to compare the effects of two different technology-supported training.

Contrary to some favorable results, there is evidence of 6-week mindfulness training failing to impact executive functions (shifting: Greenberg et al., 2012; updating: Noone & Hogan, 2018; inhibiting: Oken et al., 2017). Noone and Hogan (2018) adapted rigorous methods like pre-registration of the study, publication of a study protocol, and double-blinding procedure to control potential biases. Moreover, the study included a closely matched active control group (sham meditation) with adequate sample size. Still, the lack of improvements in updating in the mindfulness group compared to the control group could result from the online mode of delivery of mindfulness intervention via the Headspace app or the employment of the cognitive test, the Sternberg memory task, which failed to tap the "control" component adequately.

In standard 7- to 8-week studies, Anderson et al. (2007) and Beck et al. (2017) found no differential effects on inhibition, switching or updating task performance in the MBSR group compared to controls. Similarly, no improvements were reported between mindfulness and podcast listening groups (Basso et al., 2019) on measures of executive functioning (Reading Span Task, Wisconsin Card Sorting Task, Eriksen Flanker Task) except for the N-back and Stroop (accuracy) tasks. However, the intervention involved a single introductory training session, following which the participants were asked to listen to a 13-min audio guide every day for 8 weeks. Concerning these three studies, the authors recognize that the inclusion of a healthy sample (Anderson et al., 2007), small sample size (Basso et al., 2019; Beck et al., 2017), self-selection to the meditation group (Basso et al., 2019), shorter meditation period (Basso et al., 2019), and ceiling effects on performance (Anderson et al., 2007; Basso et al., 2019) might limit the hypothesized improvements.

More studies that observed post-intervention inhibitory improvement in mindfulness, but not the comparison group, evidenced faster RTs (Malinowski et al., 2017; Rodriguez Vega et al., 2014; Verhoeven et al., 2014) and fewer errors (Johns et al., 2016; Rodriguez Vega et al., 2014) on the Stroop task. Jensen et al. (2012) employed an MBSR group and three comparison groups: an incentivized waitlist group, a non-incentivized waitlist group, and an active stress reduction group. MBSR had significantly fewer errors than non-incentivized controls but was comparable to incentivized controls on the Stroop task. The study also employed a particular version of Dual Attention to Response Task which measured shifting. Participants were required to monitor the color of the digits, 1 to 9, presented sequentially, and pressed 1 after white digits, 2 after gray digits but inhibited the response after the digit 3. The MBSR group exhibited no improvement on DART compared to the three control groups (Jensen et al., 2012). Of the two studies that measured updating using the OSpan (Jha et al., 2010; Morrison et al., 2014), only one study (Jha et al., 2010) reported positive increments in the working memory performance at post-test in the mindfulness group compared to wait-listed military and civilian controls. Notably, the increments were only found in participants with higher amounts of home practice. Studies found null effects on shifting after eight weekly sessions of a mindfulness intervention, including FA + OM + loving kindness meditation (Heeren et al., 2009; Mallya & Fiocco, 2016). One study reported improvements in the MBSR group on TMT B/A task performance compared to a control group at post-test (Moynihan et al., 2013). An outstanding feature of Moynihan et al. (2013) was a huge sample size ($N = 208$) which, along with a passive comparison group, might have contributed to the observed differences. However, the beneficial effects were not sustained at the 6-month follow-up. Notably, the participants in this study were older adults (mean age > 73 years) who are prone to executive function decline (Kirova et al., 2015). The authors are skeptical about how the participants continued to practice mindfulness after the intervention. The executive function capabilities ameliorated through mindfulness might have diminished without persistent practice. Heeren et al. (2009) found that the mindfulness group reported better performance than passive controls at post-test on the Hayling Task, but they found no improvement on the Go-nogo task.

Two studies with a longer duration of interventions (16 weeks) failed to find improvements in inhibition after the mindfulness training (Meland et al., 2015; Moore et al., 2012). Moore et al. (2012) acknowledge that the administration of a verbal paper–pencil version of the Stroop task, trial repetition, and associated ceiling effects or the duration of meditation training (only a single session in 16 weeks of intervention) could potentially contribute to the null effects observed following the mindfulness intervention. In a 12-week retreat study involving intensive guided mindfulness meditation practices, Sahdra et al. (2011) compared the mindfulness group to a control group. The crucial findings were that only the mindfulness exhibited group improved accuracy on the response inhibition task, and improved inhibitory performance was found when the control group received the same intervention later. The groups showed these effects in the follow-up session 5 months after the intervention.

In studies of long-term meditation practice where participants had a mean meditation experience of shorter than 10 years, the mindfulness group exhibited enhancements in inhibition compared to controls, measured using the Stroop task (Fabio & Towey, 2018; Moore & Malinowski, 2009; Teper & Inzlicht, 2013). In addition, Fabio and Towey (2018) reported that the meditators were effective in updating the working memory during the N-back task, even when the task difficulty increased. Moreover, they were more frequent at target identification and performed better on trials requiring no response. Andreu et al. (2017) noted that the mindfulness meditation practitioners (mean experience 5.1 years) made fewer errors on incongruent trials on a flanker task than an athlete control group. Still, the RTs did not improve.

However, studies also found null effects on inhibition (Josefsson & Broberg, 2011; Kozasa et al., 2012; Lykins et al., 2012; Melloni et al., 2013) as well as shifting and updating (Lykins et al., 2012). Lykins et al. (2012) note that the insignificant group differences in their study may result from a poor match between meditators and non-meditators. When the meditation experience increased, one study using the Stroop task (Jo et al., 2017) observed improvements in inhibition in the meditation group relative to the control group.

Inhibition appears to be the most frequently measured facet of executive functioning. The bulk of experimental studies used the Stroop task to measure inhibition. Of those studies that examined inhibition, improvements associated with faster RTs, higher accuracy scores, or lower interference RTs were reported in almost half of the observations. These improvements were not limited to any particular duration of intervention or years of meditation experience. Few studies exhibited enhancements in the updating facet, and like inhibition, the effects were not confined to any specific training duration. The interventions (all RCTs) with training duration from 6 to 8 weeks and those with long-term meditators (only two) failed to impact the updating facet positively. Lastly, mindfulness interventions yielded beneficial effects on the shifting facet in studies with an intervention duration of 8 weeks (Jensen et al., 2012; Moynihan et al., 2013) and a 10-day retreat study (Chambers et al., 2008). A single study associated with long-term meditation practice found insignificant effects on shifting (Lykins et al., 2012). Based on the above evidence, it is wise to infer that inhibition is the only facet of executive functioning consistently associated with benefits from interventions and long-term mindfulness meditation practice. People who were either assigned to meditate or those with prior meditation experience were more skilled at inhibiting distracting stimuli than were non-meditating individuals.

Discussion

The scientific inquiry into mindfulness-based practices has witnessed significant progress in recent years owing to their potential to positively impact psychological well-being and cognition (Chiesa et al., 2011; Creswell, 2017). The current review aimed to re-examine the effects of mindfulness on attentional networks and executive functioning. Intervention studies and studies of long-term meditation practice reporting the effects of mindfulness in healthy individuals on outcomes that measured functions of alerting, orienting, executive control, inhibition, updating, and shifting were evaluated (see Figs. 1 and 2 for function-wise characterization of studies). Reviewing the empirical studies in this manner assisted in establishing the specific (i.e., improvement in a particular function) and non-specific (i.e., improvements in all functions) effects of mindfulness and determining the impact of duration of training and practice in mindfulness on attentional and executive effects.

Although there are fewer studies investigating the effect of mindfulness on the attentional networks compared to executive functioning, overall—the review suggests that mindfulness—interventions and long-term meditation practice enriched cognitive capabilities across the studies. The findings from interventions uphold the causal involvement of mindfulness in bringing attentional and executive benefits exhibited by the long-term meditators compared to non-meditating, novice individuals. The review offers a persuasive case: if brief doses of mindfulness can lead to perceptible improvements in cognitive capacities, it is worthwhile for individuals to incorporate prolonged mindfulness practices in day-to-day lives to not only broaden attention and executive skills but other related processes (e.g., emotion, memory; Chun & Turk-Browne, 2007; Taylor & Fragopanagos, 2005). It could be argued that mindfulness might benefit all three attentional networks and three facets of executive functioning. However, the present review found that mindfulness confers specific rather than general cognitive benefits.

A meta-analysis (Sumantry & Stewart, 2021) found that the length of meditation intervention was inversely associated with alerting. The improvement in alerting diminished for every 10-h increase in intervention length. Additionally, the alerting network showed benefits in people with prior meditation experience. Also, typically, mindfulness training involves implicit instructions to stay in the present moment and maintain attention on an object for a prolonged duration (Lutz et al., 2008). It is prudent to assume that mindfulness would then improve alerting. Surprisingly, the present review found that neither the length of training nor years of experience in meditation had any noticeable impact on the alerting network. Mindfulness involves detecting subtle internal and external changes with no comprehensible onset, or a clear presentation of cues, as appearing in the ANT. Thus, ANT may not likely be an appropriate tool to capture the nature of monitoring practiced in mindfulness. An alternative possibility is somewhat counterintuitive. Failure to enhance alertness might be advantageous for the attentional system. Enhanced alerting corresponds to becoming increasingly responsive to frequent distractions occurring in the environment, which might unnecessarily burden the attentional system (Kahneman, 1973). One might avoid the "excessive alertness" and conserve cognitive resources with continued mindfulness practice.

In half of the reviewed studies concerning the orienting network, interventions led to improvements in the mindfulness group compared to the meditation-naive individuals. Conceivably, mindfulness meditators, in general, might develop flexible orienting; a crucial instruction during mindfulness meditation is to continuously detach attention from all objects appearing in the field of experience and redirect the attention to the primary object of attention (e.g., breath). The detach-attach-detach exercise might improve flexibility in directing attention—an essential characteristic of the orienting network. However, on the whole, studies provide mixed evidence to support the improvement in the orienting network with mindfulness training interventions. Perhaps, the development of orienting requires more extended practice, and the improvements would be observed with a sample of more experienced meditators (van den Hurk et al., 2010). However, although the beneficial effects on the orienting network were observed in interventions with a training duration of just 7 days (Quan et al., 2018), other longer practices were ineffective (Isbel & Mahar, 2015; Jha et al., 2007). Mindfulness practices might nurture a flexible re-orientation of attention to novel stimuli without getting immersed in them. However, the practice does not emphasize attaining speed and accuracy of re-orientation. In that case, the ANT employed to tap the outcomes of orienting, which essentially require externally directed visual attention to execute quick and accurate responses, does not gauge mindfulness-induced attentional changes precisely.

The intervention studies provide more robust evidence for the positive effects of mindfulness on the executive control (or conflict monitoring) network compared to the long-term meditation practice. Similar findings were reported by Chiesa et al. (2011). If mindfulness interventions enhance the executive control network, why are not similar attentional benefits found across studies of long-term meditation practice? Citing the lack of adequate empirical evidence, the authors had only speculated that executive control (of attention) is closely associated with the focused or concentrative attentional style. Hence, it develops almost entirely during the initial phases of training and practice. There is no marked improvement in this aspect in the later phases of practice when open monitoring becomes dominant, requiring paying attention to each stimulus (Lutz et al., 2008). Moreover, hypothetically, even if mindfulness leads to improved executive control across a longer duration of practice, the ANT might not index the refined changes in the attention system scrupulously. Even after a decade of the seminal review (Chiesa et al., 2011), the executive network similar to alerting and orienting remains less extensively investigated. The assumptions need careful consideration and warrant further examination.

In their capacity model of mindfulness, Isbel and Summers (2017) describe the repetitive engagement of executive functions—inhibition, updating, and shifting, in mindfulness training. They, therefore, predict that mindfulness training will improve performance in these facets (Isbel & Summers, 2017). The prediction is validated by studies reporting improvements in the executive functions following mindfulness interventions (Chambers et al., 2008; Greenberg et al., 2019; Jensen et al., 2012; Jha et al., 2010; Moynihan et al., 2013; Mrazek et al., 2013; Rodriguez Vega et al., 2014). Of the fifty-five studies reviewed in the paper, the inhibition facet not only emerged as the most frequent outcome measure in intervention studies and long-term meditation practice but also exhibited maximum advantages regardless of training duration or meditation experience. The current findings are supported by a systematic review which reports steady improvements in the inhibition facet after mindfulness training (Gallant, 2016). That inhibition is a core executive skill developed during mindfulness training comprehensible given its association with control of attention (Miyake & Friedman, 2012). During the early phases of mindfulness practice, there is frequent mind-wandering, and executive attention becomes predominant in attempts to detect distraction. With increased mindfulness training, one seeks to improve the ability to inhibit automatic responses towards external stimuli or internal thoughts and remain focused on the desired object or task (Isbel & Summers, 2017; Lutz et al., 2015). Such practice-related changes are evident in mindfulness intervention studies and those of long-term meditation practice reviewed here.

Interestingly, none of the studies that measured the inhibition facet using the Go-nogo task has reported improvements following mindfulness training (Allen et al., 2012; Heeren et al., 2009; Whitmoyer et al., 2020). The Go-nogo task mainly assesses "motor inhibition" related to suppressing preplanned motor responses, while the Hayling task primarily measures "cognitive inhibition" linked with inhibition of attention, although the two inhibitory aspects are strongly associated with each other (Diamond, 2013; Friedman & Miyake, 2004). Mindfulness training possibly only helps to regulate thoughts and feelings and limits distractor interference. Therefore, it may not benefit motor inhibition as much as cognitive inhibition. Altogether, variations in the tasks and task characteristics, utilization of diverse mindfulness techniques and their mode of delivery, passive, and non-matched control groups, and different interventions in the active comparison groups are potential contributors to the discrepancies in studies that found significant effects reporting null findings on the inhibition facet.

The effects of mindfulness on the updating facet are variable compared to inhibition. Intervention studies, to some extent, reported improvements in updating following mindfulness training. Although not restricted to specific durations, these studies involved the focused attention technique. The findings are not surprising, given the role of focused attention in monitoring the precise moment when attention is distracted and quickly updating the working memory to execute control processes to bring back the attention to the object of focus. However, why did the long-term meditation practitioners fail to show similar improvements in the updating facet? It is possible that as experience grows, the practitioners are no longer required to frequently monitor distractions as they become receptive to all contents of experiences and let them pass by. In fact, "repetitive updating" might have a deleterious effect on the executive system and, in turn, on the mindfulness practice.

Mindfulness interventions and long-term meditation practice were not associated with incremental benefits in the shifting facet. We offer the following explanation for the null effects. Mindfulness practitioners are trained to focus on an object, notice mind-wandering, and gently re-align their attention to the object (Lutz et al., 2008). The practice of gentle re-alignment contrasts with speed-based task measures of shifting. Heeren et al. (2009) pointed out that the aspects of visual and motor shifting tapped by the set-shifting tasks might not accurately measure the mental set shifting trained through mindfulness. More empirical studies of updating and shifting, specifically with long-term meditators, are required as the meager studies restrict a clear interpretation of mindfulness-induced effects on these facets. Furthermore, in light of the mixed results regarding executive functioning at follow-ups (Moynihan et al., 2013; Sahdra et al., 2011), research is required to examine if the effects sustain over time.

Considering the inadequate number of studies involving participants with long meditation experience, a direct comparison of long-term meditation practices and interventions on attentional and executive functions seems unreasonable, and no conclusion can be drawn. Nevertheless, the current evidence suggests that long-term meditation practices likely manifest a similar impact on all cognitive functions reviewed here, except executive control. Presumably, the effects of mindfulness meditation on attentional and executive skills are maximized through certain hours of practice, beyond which the effects are only sustained with practice and do not grow. As several authors have pointed out, the increased duration of meditation practice is accompanied by a qualitative shift in attention and awareness (Lutz et al., 2015; Vago & Silbersweig, 2012; Zanesco et al., 2013). At advanced stages, attention becomes finer and is characterized by "vivid clarity and a high degree of perceptual acuity" (Isbel & Summers, 2017), which cannot be measured by tasks that quantify attention and executive skill functions. There is a likelihood that the attentional and executive effects of mindfulness on the outcomes evaluated in these studies might be a function of the amount of current practice; i.e., they are neither determined by the duration of training nor the cumulative years of experience (Teper & Inzlicht, 2013). Within interventions, the impact of duration of training on attention and executive functions was unsteady as increasing the number of weeks, and even the duration of the sessions did not show uniform effects. In the long-term meditators, the number of years of meditation practice was not associated with the observed effects. Perhaps, the effects reach a ceiling effect earlier in practice, beyond which only qualitative changes occur. The speculations might find evidence in phenomenological studies, which is out of the scope of the current review.

The cognitive effects were not significantly different between focused attention and open monitoring techniques. However, when we look closely, focused attention was predominant in studies in which significant differences between groups were observed, especially on the inhibition facet. Focused attention, the starting point of mindfulness practices, is included in almost every training ranging from brief interventions to long-term meditation (see Supplementary Material). The attention monitoring learned during focused attention (Isbel & Summers, 2017; Lutz et al., 2008) is also a primary exercise in inhibitory control (staying focused on one object without getting distracted), which might explain the findings. However, given the qualitative changes in attention, it is not easy to account for the transition from focused attention to open monitoring. Moreover, in the absence of personal reports and practice feedback, it is not easy to guarantee that the participants practice the technique being taught. Hence, future studies should integrate cognitive-behavioral studies, experiential reports, and neuroscientific studies to parse out the technique-specific effects of mindfulness.

The control groups—active and passive—generated similar results in interventions and long-term meditation practice. The finding validates "mindfulness" as the driving force behind the observed attentional and executive effects in the participants and no other non-specific factors (e.g., group membership; Eberth & Sedlmeier, 2012). The interventions given to active control groups within the reviewed studies were quite diverse, like podcast listening, fatigue education and support groups, creative writing, nutrition class, and relaxation training. Despite controlling for artificial inflation effects resulting from between-group differences, group diversity makes it impossible to determine a common factor driving the group effects. While three studies that incorporated active control groups attempted to reduce demand characteristics (Bhayee et al., 2016; Jensen et al., 2012; Noone & Hogan, 2018), most of them did not, which might produce expectations of improvements from a particular intervention. Prakash et al. (2020) suggested that it would be helpful to document participants' expectations from the intervention and compare the pre-post changes in outcomes.

The task metrics corresponding to speed and accuracy improved with mindfulness training and long-term practice. The findings indicate that mindfulness practices do not involve prioritizing a single performance strategy but rather enable the individuals to shift to a more effective speed-accuracy function. The strategy reflects a more efficient utilization of resources by the meditators because they perform accurately even during shorter RTs (Esch et al., 2017; Jo et al., 2017; Tang et al., 2007; van den Hurk et al., 2010).

Non-clinical Implications

Following from above, it is clear that mindfulness practices can extend potential aid for enhancing inhibitory control. Mindfulness is appraised as a non-pharmacological treatment for impaired inhibition in eating disorders (Katterman et al., 2014), attention deficit hyperactivity disorder (Baijal & Gupta, 2008), obsessive–compulsive disorders (Külz et al., 2019; Strauss et al., 2018), addiction, and substance abuse (Garland & Howard, 2018; Sancho et al., 2018). The strengthening of top-down cognitive control through mindfulness interventions that improve response inhibition, and control automatic habits, might assist in reducing non-clinical "executive deficits" in healthy populations. Notably, some contextually modified mindfulness interventions have been efficacious in improving executive functioning (Felver et al., 2017; Jha et al., 2010) in a specific, healthy population. It is expected that longer mindfulness practices will benefit behaviors like internet and computer overuse, workplace and academic distractions, unwarranted shopping, and snack overconsumption before reaching the threshold of clinical disorders. In a workplace, for example, people often engage in activities that keep them from focusing on their work, such as constantly checking their phones, conversing with fellow workers, or frequently going to the cafeteria to get coffee. Employees who regularly practice mindfulness may be able to recognize their counterproductive behaviors, stop engaging in them, and then redistribute their attentional resources to more balanced and productive tasks. Additionally, people who tend to dwell on negative thoughts and spend excessive time worrying about personal matters also lack adequate inhibitory control. Mindfulness might enable people to garner control and "turn-off" these negative thoughts (Lee & Chao, 2012).

Summary, Limitations, and Future Directions

Attention and executive functioning are considered fundamental cognitive processes indispensable for higher-order information processing and everyday activities. In a world with increasing deficits in cognitive control, mindfulness practices are attracting immense interest because of their capacity to enhance cognitive functioning. The present review partially supports the idea that one can train attention and executive skills through mindfulness meditation. Mindfulness consistently improves inhibitory function, while the findings for the attentional networks and other executive functions are limited and inconsistent. The extended meditation experience does not confer additional benefits to the mindfulness interventions. Additionally, both focused attention and open monitoring techniques enhance cognitive functions, but the effects of focused attention are predominant. Mindfulness makes individuals faster and more accurate, thus, not representing a simple speed-accuracy trade-off. Indistinct differences across control groups, meditation techniques, and types of tasks verify that mindfulness is the crucial variable that generates the cognitive effects.

There are limitations to the current review that need careful consideration before arriving at conclusions regarding the efficacy of mindfulness on attentional and executive functions. First, findings cannot be generalized to clinical populations. The present review found evidence of the beneficial effects of mindfulness in a healthy population. Future reviews should examine how mindfulness might impact attentional networks in clinical populations. Second, different mindfulness interventions and practices might place different degrees of emphasis on certain mindfulness principles and techniques. For example, MBSR, a stress reduction program, also includes yoga exercises. MBAT explicitly focuses on attention components, IBMT emphasizes several components to achieve "mind–body" balance, and Vipassana programs teach ethical and moral principles and basic mindfulness practices. The variabilities across mindfulness practices cause difficulty teasing out the specific factor responsible for producing beneficial outcomes. Hence, future investigations must employ a similar technique to determine if mindfulness is the key to producing cognitive improvements.

Finally, we found several methodological shortcomings in studies, including underpowered sample sizes, lack of an active control group, non-randomization of participants, self-selection biases, and missing data. For example, Moore and Malinowski (2009) reported the minimum meditation experience of the participants in the mindfulness group but not the mean meditation experience. In another study (Chan & Woollacott, 2007; not included in the current review), authors found that the number of minutes participants meditated each day was associated with improved inhibitory control. While the study was well-designed, the authors did not report their years of experience. Besides, the review also discovered certain inconsistencies across studies. The differences in task characteristics, inconsistent sorting of behavioral tasks to the function they assess, variable administration of tasks, different sample populations, and missing critical intervention-related details might affect the findings. Furthermore, in addition to the existing review of the dose–response relationship between mindfulness and attentional outcomes in terms of duration of training in weeks and years of meditation experience, the mindfulness research would also benefit from systematically integrating variables like the number of training sessions, minutes of daily practice, and the total hours of practice to date, or homework practices into scientific investigations. As noted by Vago et al. (2019), the effects of mindfulness on cognition remain divergent and contextual but offer promising avenues for future research.

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Declarations

Competing Interests The authors declare no competing interests.

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