Consciousness and Cognition 40 (2016) 116–130

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Review article

Mindfulness meditation practice and executive functioning: Breaking down the benefit

Sara N. Gallant *

Department of Psychology, Ryerson University, Toronto, Ontario, Canada

ARTICLE INFO

Article history:
Received 10 February 2015
Revised 16 September 2015
Accepted 9 January 2016
Available online 16 January 2016

Keywords:
Mindfulness meditation
Cognition
Executive function
Shifting
Updating
Inhibition

ABSTRACT

This paper focuses on evidence for mindfulness meditation-related benefits to executive functioning, processes important for much of human volitional behaviour. Miyake et al. (2000) have shown that executive functions can be fractionated into three distinct domains including inhibition, working memory updating, and mental set shifting. Considering these separable domains, it is important to determine whether the effects of mindfulness can generalize to all three sub-functions or are specific to certain domains. To address this, the current review applied Miyake et al.'s (2000) fractionated model of executive functioning to the mindfulness literature. Empirical studies assessing the benefits of mindfulness to measures tapping the inhibition, updating, and shifting components of executive functioning were examined. Results suggest a relatively specific as opposed to general benefit resulting from mindfulness, with consistent inhibitory improvement, but more variable advantages to the updating and shifting domains. Recommendations surrounding application of mindfulness practice and future research are discussed.

Contents

* Address: Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada.
E-mail address: s7gallan@psych.ryerson.ca

http://dx.doi.org/10.1016/j.concog.2016.01.005
1053-8100/

1. Introduction

Common amongst human nature is our consciousness, comprised of an awareness and attention to internal and external environments (Brown & Ryan, 2003). Whether we are *mindful* of our consciousness, however, is another story. Compared to those who are mindless, the mindful individual is oriented in the present, open to novelty, sensitive to changes in context, and aware of multiple perspectives (Langer & Moldoveanu, 2000; Sternberg, 2000). The cultivation of mindfulness is rooted in Eastern Buddhist tradition, where it is perceived as a state of mind that can be achieved through various forms of meditation. These practices are generally based on two foundational principles including awareness and attention to the present moment and mindful, nonjudgmental acceptance of emotional states (Baer & Krietemeyer, 2006; Brown & Ryan, 2003; Hick, 2008; Kabat-Zinn, 1990, 2003; Teper, Segal, & Inzlicht, 2013). Mindfulness is therefore trained by practicing moment-to-moment monitoring of attention with an emphasis placed on always bringing focus back to the present. When the mind wanders or distractions arise, trainees are taught to acknowledge these mental shifts and bring attention back to the present without judgment. As a result, mindfulness meditation fosters alertness to changes in environment and emotion and as well as the ability to react without rumination (Langer & Moldoveanu, 2000; Sternberg, 2000; Teper et al., 2013).

Mindfulness can be practiced through formal intervention-style meditation practices or informally on an individual basis. Formal practices such as Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1982), Mindfulness-Based Cognitive Therapy (MBCT; Segal, Williams, & Teasdale, 2013), or Integrative Mind–Body Training (IMBT; Tang, Yang, Leve, & Harold, 2012; also see Baer & Krietemeyer, 2006; Hick, 2008) are generally led by a trained instructor that guides participants in sustaining attention to the present moment according to the aforementioned principles. Recently, scientific interest in the beneficial effects of such practices has increased in contexts such as medicine, mental health, and education. Evidence from these studies have identified positive effects including stress management (Chiesa & Serretti, 2009; Nyklíček & Kuijpers, 2008), symptom reduction in depression (Coffman, Dimidjian, & Baer, 2006; Hoffman, Sawyer, Witt, & Oh, 2010; Ma & Teasdale, 2004; Piet & Hougaard, 2011) and anxiety (Hoffman et al., 2010; Roemer, Salters-Pedneault, & Orsillo, 2006), decreased substance abuse (Bowen et al., 2006), and reduced binge eating (Tapper et al., 2009). In addition to these more clinically-based findings, mindfulness practices have been found elicit a positive impact on objective measures of mood and cognition, including executive functioning (e.g., Chambers, Lo, & Allen, 2008; Chiesa, Calatti, & Serretti, 2011; Fiocco & Mallya, 2015; Heeren, Van Broeck, & Philippot, 2009; Jha, Krompinger, & Baime, 2007; Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010; MacLean et al., 2010; Moore & Malinowski, 2009; Zeidan, Johnson, Diamond, Zhanna, & Goolkasian, 2010).

Executive functions make up the system that controls and directs higher-order cognitive processes such as planning, decision making, disinhibition, self-regulation, and many other goal-directed behaviours (Alvarez & Emory, 2006; Ardila, 2008; Black, Semple, Pokhrel, & Grenard, 2011; Chan, Shum, Toulopoulou, & Chen, 2008). The work of Miyake et al. (2000) fractionates executive functioning into three distinct domains including *inhibition* of irrelevant information, *updating* of working memory contents, and mental set *shifting* (also see Miyake & Friedman, 2012). The fact that the system can be fractionated in this manner points to the importance of considering each separable process in executive functioning research. As an example, Bueno et al. (2014) recently examined cognitive performance of an attention deficit hyperactivity disorder (ADHD) population according to Miyake et al.'s (2000) fractionated model of executive functioning. Whilst the existing literature was unclear on whether executive dysfunction in ADHD was selective or general, their results demonstrated *selective* impairment to the shifting domain. This reinforces the argument in favour of considering each constituent process when executive functioning performance is the primary outcome measure. Applying this to the scope of the current paper, before it can be stated that mindfulness meditation practice benefits executive functioning in general, it must be determined how such practices impact each sub-function. Accordingly, the goal of this review is to evaluate the effects of mindfulness meditation practice on each domain of executive functioning so as to determine if effects are specific (i.e., extend to only specific sub-functions) or general (i.e., extends to all sub-functions).

This is a critical question to address as efficient executive functioning has been linked to several positive developmental outcomes including greater attentional control, successful relationships, enhanced emotion regulation, and many other activities of daily living (Alvarez & Emory, 2006). The current review therefore used Miyake et al.'s (2000) model as a framework for addressing the primary research question, in which studies were reviewed based on whether they objectively measured the effects of mindfulness meditation practice on the inhibition, updating, or shifting sub-functions. Prior to this systematic review of the literature, however, an operational definition of mindfulness meditation practice and an understanding of the complex nature of executive functions are required.

1.1. Scientific operationalization of mindfulness

Although mindfulness practice is often characterized by "bare attention" to the present-moment with a nonjudgmental acceptance of the environment (Bishop et al., 2004; Brown & Ryan, 2003; Moore & Malinowski, 2009), its scientific operationalization varies from study to study. Some authors address the effects of mindfulness meditation resulting from facilitated intervention, each of which vary in some respect including their length and the setting in which they are conducted. For instance, MBSR and MBCT generally involve eight weeks of twice weekly meetings and one full day of intensive mindfulness training. Both are led by an instructor in a group setting and involve a range of class-based and independent exercises such as body awareness, sitting meditation, and hatha yoga that emphasize the cultivation of mindfulness. An example instruction for attentional exercises might look like the following: "Focus your entire attention on your incoming and outgoing breath. Try to sustain your attention there without distraction. If you get distracted, calmly return your attention to the breath and start again" (Hölzel et al., 2011). MBCT, however, diverges as it weaves in components of cognitive behavioural therapy that help participants acknowledge the negative automatic cognitive processes that can trigger relapses in formerly depressed individuals (e.g., rumination). In this way, participants learn to accept and deal with negative thoughts instead of reacting to them. IBMT similarly seeks to develop a heightened awareness of mental states although its format is less structured than the formerly mentioned. For example, some IBMT programs last as little as five days (e.g., Fan, Tang, Ma, & Posner, 2010) whilst others last up to six weeks (Tang et al., 2012). Despite these variations, each method of practice attempts to engage and reinforce the top-down processes that direct and sustain attention to the present.

In addition, mindfulness has been operationalized as a dispositional trait to describe those who are aware of their overt behaviours whilst "in tune" and receptive of internal states and emotions (Brown & Ryan, 2003; also see Langer & Moldoveanu, 2000). For instance, Lyvers, Makin, Toms, Thorberg, and Samios (2013) examined trait mindfulness in participants with no prior mindfulness meditation exposure using the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), which measures the degree of present-moment focus and frequency of attention and awareness in daily life. Thus, it is clear that mindfulness is a multifaceted construct that can be cultivated or measured with a variety of approaches. However, such operational variations present a challenge for forming a strong theoretical foundation on which to study the effects of mindfulness (for a review on such issues see Tang & Posner, 2013). As this review focuses on the facilitative effects of mindfulness practice on executive functioning, only studies that concern the impact of mindfulness achieved through interventions or prior meditation experience are considered whilst studies measuring the influence of trait mindfulness are excluded.

1.2. The complex nature of executive functioning

The executive functioning system is dominated primarily by frontal and prefrontal brain regions and is responsible for much of human volitional behaviour. Dysfunction in this system caused by ADHD, traumatic brain injury, stroke, or aging, thus has potential to impair regulatory behaviour crucial to maintaining an independent life (Chan et al., 2008; Goel, Grafman, Tajik, Gana, & Danto, 1997). Determining methods that can strengthen or preserve executive functioning in its entirety therefore has great societal relevance.

As previously described, Miyake et al. (2000) fractionate executive functioning into three sub-domains including: (1) *inhibition* or active suppression of stimuli and automatic responses that are irrelevant to the task at hand; (2) *updating* and monitoring of information in working memory to include only the most relevant material; and (3) *shifting* or switching attention between multiple mental representations or operations. Using confirmatory factor analysis, the authors showed that these three sub-functions are clearly separable domains that also moderately correlate with one another, highlighting the "unity and diversity" of this higher-order system. Moreover, across a series of structural equation models, each sub-domain of executive functioning was shown to play a differential role in performance on a range of executive outcome measures used in cognitive research, emphasizing the need to recognize the diversity of these sub-processes.

The potential for mindfulness meditation practice to improve executive functioning has been examined. For example, Moore and Malinowski (2009) found that the ability to deliberately suppress an automatic response was stronger in experienced mindful meditators relative to non-meditators as indexed by performance on the Stroop task (Stroop, 1935). However, the literature has yet to consider the fractionation of executive functioning and so it is unknown whether this benefit selectively improves certain sub-functions or could generalize across the executive system. Addressing this gap in the literature is important, as many basic daily tasks rely on all three sub-functions of the executive system, such as the ability to drive a car. A driver must be able to efficiently *shift* their attention between the mirrors and road in front of them, *inhibit* distracting conversations between passengers, and *update* their working memory with new directions should their current route become irrelevant. Not only are these processes significant for driving, but for many other instrumental activities of daily living (IADLs) such as financial management, medication use, meal preparation, and caring for one's home (Vaughan & Giovanello, 2010). As one can then imagine, deficits in these processes can significantly compromise the ability to lead an active and independent lifestyle.

1.3. Objective and hypotheses

To reiterate, the current review seeks to determine whether mindfulness meditation practice can elicit improvement to executive functions in general (i.e., across all constituent processes) or on specific sub-functions, using Miyake et al.'s (2000) three-factor model as a theoretical framework. Hypotheses were based on the link between the underlying processes trained in mindfulness meditation practices and those activated in each of the executive functioning domains. The work of Lutz, Slagter, Dunne, and Davidson (2008) provides a theoretical framework of focused attention meditation describing the processes engaged during mindfulness practice. These include (1) sustaining attention in the moment or on a specific object; (2) detection of mind wandering or distraction (i.e., attention monitoring); (3) withdrawing attention from distractors and shifting focus back to the moment or object of attention; and (4) nonjudgmental appraisal of the distractor. Linking this to the sub-domains of executive functioning, the maintenance of attention on a specific object and active *withdrawal* of attention from distracting stimuli would require engagement of the executive inhibitory processes responsible for tuning out irrelevant information (Hasher, Lustig, & Zacks, 2007; Miyake et al., 2000). Moreover, during mindfulness practice, when attention wanders to distraction and a *shift* in focus is required to move back to the present, the shifting sub-function would be executed to fulfill this task (Miyake et al., 2000). Thus, it is hypothesized that mindfulness meditation practice will have the most benefit to these two sub-functions and less or perhaps more variable benefit to the updating domain.

2. Method

2.1. Literature search

In order to address the primary research question, a review of literature on mindfulness meditation practice effects on executive functioning was performed, whilst applying Miyake et al.'s (2000) three-factor model of executive functioning. Studies were obtained via literature search using PsychINFO and Google Scholar. Mindfulness related search terms included "mindfulness meditation", "mindfulness training", "mindfulness based stress reduction", "mindfulness based cognitive therapy" combined with search terms relevant to the target outcome functions including "executive functions", "updating" and/or "working memory updating", "shifting" and/or "task switching", and "inhibition". Additional papers were selected from the reference section of relevant articles.

2.2. Selection of relevant investigations

Selected papers were written in English and were published up until January 2015. To be included in the review, studies had to meet the following inclusion criteria: (1) involve an investigation of mindfulness either through examination of mindfulness-based interventions (e.g., MBSR or MBCT) or prior experience with mindfulness meditation; (2) include objective outcome measures that assessed one or more of the inhibition, updating, or shifting sub-functions of executive functioning (e.g., comparison of non-meditators to meditators on an executive function task or comparison of performance on a task prior to and following a mindfulness intervention); and (3) test healthy participants (i.e., a non-clinical sample, free of mental or health disorders). Thus, studies assessing the impact of trait mindfulness without exposure to mindfulness meditation practice were not included.

2.3. Executive function outcome measures

The goal of this review was to assess the effects of mindfulness meditation based on the fractionation of the executive system as outlined by Miyake et al. (2000). Selected studies were required to include outcome measures that directly targeted at least one sub-function in order to directly evaluate effects within these constituent processes. Studies were included if their outcome measures targeted one of the sub-functions according to the following criteria:

2.3.1. Inhibition

Studies were included in the review if they examined the effect of mindfulness meditation on outcome measures that required execution of processes required to resolve interference or tune out irrelevant or distracting information (Hasher et al., 2007; Miyake et al., 2000).

2.3.2. Updating

Studies were reviewed if they examined the effect of mindfulness meditation on outcome measures that required processes to monitor existing representations in working memory and update them with incoming stimuli to determine which information is most relevant to the task at hand (Miyake et al., 2000).

2.3.3. Shifting

Studies were reviewed for shifting improvements if they included outcome measures that required processes responsible for switching between internal or external sets or information.

Table 1 provides a description of the outcome measures used in the reviewed papers.

2.4. Synthesis and evaluation of the literature

Using the selected papers, studies were reviewed and grouped based on the sub-function they assessed. This organization largely depended on the outcome measures included in the reviewed papers and which executive function it directly tapped

Table 1
Description of outcome measures included in reviewed studies.

Sub-function	Task	Description
Inhibition	Stroop test	Requires deliberate inhibition of an automatic response. In the classic test, participants' responses to indicate the colour of words that are *congruent* with the meaning of the word (e.g., the word "red" in red ink) are compared to responses when the colour of the word is *incongruent* to its meaning (e.g., the word "red" in blue ink). The stoop effect is the finding that participants are faster at the congruent condition than the incongruent
	Go–Stop	Used to assess ability to inhibit a motor response. Random five-digit numbers are presented and participants respond when a signal to 'go' appears and withhold their response when a 'stop' signal appears. Half of the five-digit numbers match and the other half are random non-matches. Participants respond when the five numbers are matching and withhold that response when the colour of that word turns red
	Hayling task	Assesses ability to inhibit cognitive prepotent responses. In two conditions, participants are read a series of sentences. In the automatic condition, the participant has to complete a sentence with the appropriate word as quickly as possible. In the inhibition condition, the participant inhibits the appropriate word and completes the sentence with a nonsensical word as quickly as possible. Reaction times and error rates are compared across conditions
	Response Inhibition Task	Single grey vertical lines that vary in length appear one at a time in the centre of a computer screen. Participants respond as quickly and accurately as possible to long lines, which appear at a frequency of 70% and inhibit responses to rare short lines that appear with a frequency of 30% of all trials. Response inhibition performance is indexed as number of errors
Updating	*N*-Back	A sequence of letters is presented and participants must indicate whether or not the current letter is the "same" or "different" than the letter presented *N* number of items back. Participants must therefore continuously update existing working memory representations with incoming information
	Operation Span	An equation–word pair is presented at each trial. Participants must read aloud and verify the correctness of the math equation, then read aloud the word. At the end of all trials, participants recall all words. The maximum number of words recalled is the participant's operation span
Shifting	Switching Task	A four-by-four grid is presented and on each trial a circle appears in one of the grids. On each trial a question appears below the grid reading either "upper or lower?" or "left or right?". The participant must indicate the location of the circle by responding to this question. Shifting performance is indexed by comparing reaction times during blocks of trials where participants only respond to "upper or lower?" or "left or right?"relative to blocks where they must switch between the two response options
	Internal Switching Task	A series of words are individually presented from two semantic categories (e.g., types of food and household objects). Participants are asked to keep an internal mental tally of how many words from each of the categories they have seen, therefore requiring a shift between mental sets upon presentation of each word. Total number of words from each category is reported at the end
	Trail Making Tests	Trail Making Test (TMT) part A involves drawing a line between circles numbered 1–25 in ascending order. In TMT part B, circles contain numbers 1–13 and letters A to L; a line must be drawn connecting numbers and letters in an alternating sequence (i.e., 1-A-2-B-3-C, etc.). TMT part A provides baseline performance for speed while TMT part B performance provides a measure of set shifting. Comparing TMT B against TMT A corrects for speed
	Dual-Attention Response Task	Numbers ranging from 1 to 9 are presented in white or grey. Participants monitor the colour of the number by pressing '1' on the keyboard after white numbers and pressing '2' after grey numbers, but are asked not to respond when the number '3' is presented on the screen. Participants therefore need to shift between different cognitive sets (i.e., instructions)

into according to the above descriptions (i.e., inhibition, updating, or shifting). For example, studies examining mindfulness effects on objective measures of inhibition (e.g., the Stroop task; Stroop, 1935; see Table 1) were evaluated for their ability to improve this sub-function of the executive system. The same was done for the remaining two sub-functions. If a selected paper included multiple objective measures that tapped into more than one sub-function, they were included in the review and improvement was assessed for both sub-functions.

3. Results

The initial literature search returned 1604 papers and 1592 of these were excluded from the review, as they did not meet the inclusion criteria. This resulted in 12 eligible studies for inclusion in the review. Characteristics of included studies can be seen in Tables 2–4.

3.1. Inhibition

Six studies were reviewed that assessed improvements to inhibition resulting from mindfulness meditation practice. Four observations were intervention based using a pretest-training-posttest protocol and the remaining two explored the effects of self-reported mindfulness practice on inhibition (see Table 2 for characteristics of the studies); all but one of observation reported improvements to the inhibition-related outcome measure.

Table 2
Characteristics of inhibition studies reviewed.

Study	Subjects	Age (*M*)	MF group (*N*)	Control (*N*)	Training duration	Daily homework	Prior MF experience	Outcome measure	Main findings
Allen et al. (2012)	Healthy adults	MT: 27 Control: 26	MT (30)	Active: reading (31)	6 weeks of weekly 2 h meetings	Yes: 20 min/day	No	Affective Stroop, BOLD activity	Relative to controls, the MT group showed reduced Stroop conflict and greater DLPFC responses
Anderson et al. (2007)	Healthy adults	MBSR: 37 Control: 41.7	MBSR (39)	No-contact: Wait-list (33)	8 weeks of weekly 2 h sessions	Yes, time not specified	No	Elaborative Stroop Task	No effects of group or time on performance on the modified Stroop task
Heeren et al. (2009)	Healthy adults	MBCT: 54.28 Control: 54.67	MBCT (18)	No-contact (18)	8 weeks of weekly 2 h sessions	Yes: 20 min/day	No	Hayling task (behavioural) Go Stop (motor)	Relative to controls, MBCT group improved Hayling task performance at posttest. No changes were observed to Go Stop performance
Moore and Malinowski (2009)	Healthy adults	MF: 28 Control: 27.5	MF mediators (25)	Non-meditators (25)	N/A	N/A	Yes, at least 6 weeks	Stroop	Relative to non-meditators, meditators showed enhanced Stroop performance, which was positively correlated with levels of MF
Sahdra et al. (2011)	Healthy adults	MF: 48 Control: 48	Intensive meditation retreat (30)	No-contact (30)	3 months of 6–10 h practice/day	Yes: 6 h per day (average)	Yes, with meditation retreats	Response Inhibition Task	Relative to controls, the MF group improved inhibition performance over time
Teper and Inzlicht (2013)	Healthy adults	MF: 33 Control: 37.47	MF meditators (20)	Non-meditators (18)	N/A	N/A	Yes, at least 1 year	Stroop, ERP activity in ACC	Relative to controls, the MF group showed greater Stroop performance and ACC activity

Note: ACC = Anterior Cingulate Cortex; BOLD = Blood-Oxygen-Level Dependent; DLPFC = Dorsolateral Prefrontal Cortex; ERP = Event-Related Potential; MBCT = Mindfulness Based Cognitive Therapy; MBSR = Mindfulness Based Stress Reduction; MF = Mindfulness; MT = Mindfulness Training; N/A = not applicable.

Table 3
Characteristics of updating studies reviewed.

Study	Subjects	Age (*M*)	MF group (*N*)	Control (*N*)	Training duration	Daily homework	Prior MF experience	Outcome measure	Main findings
Jha et al. (2010)	Healthy adults	MMFT: 30 MC: 25 CC: 34	MMFT (31)[a]	No-contact military (MC; 17)[a] No-contact civilian (CC; 12)[a]	8 weeks of weekly 2 h sessions, 1 full day silent retreat	Yes: 30 min/day	No	Operation span	Relative to controls, the MMFT group with high levels of practice improved operation span performance. Degraded performance was observed in MC
Mrazek et al. (2013)	Students	MBSR & Control: 20.38[b]	Modified MBSR (26)	Active: nutrition class (22)	45 min MBSR or nutrition class 4 times a week for 2 weeks	Yes: 10 min/day	Not specified	Operation span	Relative to controls, operation span performance improved overtime in MBSR group
Zeidan et al. (2010)	Healthy adults	MT: 22 Control: 23	MT (24)	Active: listening to audio books	4 sessions in 1 week for 20 min/day	No	No	*N*-Back	Relative to controls, the MT group showed improved sustained *N*-Back accuracy at posttest

Note: CC = Civilian Control; MBCT = Mindfulness Based Cognitive Therapy; MBSR = Mindfulness Based Stress Reduction; MC = Military Control; MF = Mindfulness; MT = Mindfulness Training.
[a] Completely male sample.
[b] separate group mean ages were not provided.

Table 4
Characteristics of shifting studies reviewed.

Study	Subjects	Age (*M*)	MF group (*N*)	Control (*N*)	Training duration	Daily homework	Prior MF experience	Outcome measure	Main findings
Anderson et al. (2007)	Healthy adults	MBSR: 37 Control: 41.7	MBSR (39)	No-contact (33)	8 weeks of weekly 2 h sessions	Yes, time not specified	No	Switching task	No effects of group or time on switching performance. RTs significantly decreased in both groups over time
Chambers et al. (2008)	Healthy adults	MT: 33.70 Control: 31.9	MT (20)	No-contact (20)	10-day intensive MF retreat	Not specified	No	Internal Switching Task	Relative to controls, the MT group improved on overall RTs over time but not actual task switching ability
Heeren et al. (2009)	Healthy adults	MBCT: 54.28 Control: 54.67	MBCT (18)	No-contact (18)	8 weeks of weekly 2 h sessions	Yes: 20 min/day	No	Trail Making Test, Parts A and B	No effects of group or time on Trails B/A ratio scores
Jensen et al. (2011)	Healthy adults	20–39 years[a]	MBSR (16)	Active: NMSR (16) No-contact, incentive (8) No-contact, incentive (8)	MBSR and NMSR: 8 weeks of weekly 2.5 h sessions	Yes, 45 min/day (both MBSR and NMSR)	No	Dual attention response task	The no-contact incentive improved on the relevant outcome over time. No improvement was seen in the MBSR group
Moynihan et al. (2013)	Healthy older adults	MBSR: 73.3 Control: 73.6	MBSR (100)	No-contact (100)	8 weeks of weekly 2 h sessions, 1 full day intensive session	Not specified	No	Trail Making Test, Parts A and B	Relative to the control, the MBSR group improved their Trails B/A ratio over time

Note: MBCT = Mindfulness Based Cognitive Therapy; MBSR = Mindfulness Based Stress Reduction; MF = Mindfulness; MT = Mindfulness Training; N/A = Not applicable; NMSR = Nonmindfulness Based Stress Reduction.

[a] Average ages not provided, only a range for overall sample.

In the first of these studies, Heeren et al. (2009) found a main effect of time (i.e., pre vs. post intervention) that was modulated by condition (i.e., mindfulness vs. control) on Hayling Task performance. Specifically, relative to controls, those practicing mindfulness showed significantly fewer errors and an increase in correct responding from pre to post intervention, an effect that could not be explained by changes in reaction time. Motor inhibition was also measured using the Go–Stop task, although no differences were observed across time points on this task.

A later study by Sahdra et al. (2011) compared a control group to a group receiving a three-month mindfulness retreat that involved six to ten hours of guided mindfulness meditation a day. An interaction of group and assessment time (i.e., pre-, mid-, and post-retreat) was found, such that only meditating participants improved accuracy on a sustained response inhibition task. These findings were replicated when the control group later underwent an identical three-month mindfulness retreat, showing similar training-related inhibitory improvement. Both groups also sustained their benefits five-months following training.

In an fMRI investigation, Allen et al. (2012) compared an active control condition (i.e., a reading group for six-weeks) to a group completing six-weeks of mindfulness training on an affective Stroop task. Behaviourally, an interaction between group (active control vs. mindfulness) and time (pre vs. post intervention) in Stroop performance emerged such that only the mindfulness group showed reduced interference over time. fMRI analyses further showed significant mindfulness effects over time in blood-oxygen-level dependent (BOLD) activation levels in the dorsolateral prefrontal cortex (DLPFC). Specifically, the experimental group showed greater recruitment of DLPFC mechanisms – important for executive-based processes – during conflict resolution performance.

Similar mindfulness-related improvement on a Stroop task was also observed in two studies that examined the association between experienced mindfulness meditators relative to groups of non-meditators (Moore & Malinowski, 2009; Teper & Inzlicht, 2013). In addition to finding inhibitory advantages in the meditators, these authors found an association between the magnitude of trait mindfulness and Stroop performance suggesting that higher levels of mindfulness are associated with greater inhibitory processing (e.g., Moore & Malinowski, 2009). As well, compared to their non-experienced counterparts, meditators showed greater amplification of the error-related negativity (ERN) event-related potential (ERP) component thought to reflect conflict-monitoring behaviour whilst completing the Stroop task (Teper & Inzlicht, 2013).

Although the above studies show consistent improvement, Anderson, Lau, Segal, and Bishop (2007) found null effects when comparing a no-contact control (i.e., wait-list) to a group completing an MBSR program on pre to posttest performance on a modified Stroop task. A potential reason this study failed to find improvements may be related to the Stroop paradigm that was used, which assessed inhibition of elaborative processing, diverging from its more traditional format.

3.2. Updating

Three intervention-based studies were reviewed (see Table 3). In the first of these, Jha et al. (2010) compared a military cohort receiving mindfulness training, a no-contact military control, and a no-contact civilian control on operation span performance prior to and following the intervention. Post-intervention improvement on the operation span task was found in the mindfulness trained military cohort but only at high levels of practice. Those with low amounts of practice as well as the military control group showed degraded operation span performance over time. The civilian control group showed no change in performance across sessions.

In a later study, Mrazek et al. (2013) compared a group receiving a modified two-week MBSR program to an active control group completing a two-week nutrition course on operation span performance. An interaction between group and time (pre vs. post intervention) was observed with an increase in operation span performance seen in the experimental group only. Moreover, this effect was mediated by reductions in mind wandering, as indexed by a self-report assessment during and following the operation span task, suggesting that benefits to working memory updating may have been driven by increased ability to focus attention in the present moment whilst ignoring distraction.

Zeidan et al. (2010) also examined the effects of brief mindfulness training on *N*-back task performance relative to an active control group (i.e., audio book listening). After four sessions, no group differences on *N*-back accuracy (i.e., number of correct responses) were observed but the groups did differ in sustained *N*-back performance. Specifically, overtime, the mindfulness group showed improvements in the number of correct responses in a row relative to the control group. This may suggest that the brief mindfulness intervention may not have necessarily improved working memory updating, but facilitated sustained accuracy over time.

3.3. Shifting

Five intervention-based studies that investigated set shifting performance were reviewed (see Table 4). In the first, Anderson et al. (2007) compared participants in an MBSR program to a no-contact control group on the switching task. No group differences in performance were observed at either time point or across time points. Different from this study, Chambers et al. (2008) compared a group receiving a 10-day intensive mindfulness intervention to a control group on an Internal Switching Task. There was no evidence for pre to post intervention improvement on actual task switching ability; however, the meditating participants did show a reduction in overall reaction times on the task over time relative to controls.

Heeren et al. (2009) examined improvement to shifting ability using the Trail Making Test (TMT) in participants receiving an MBCT intervention relative to wait-list controls; no group differences were observed from baseline to follow-up on the shifting related TMT part B or the TMT B/A ratio (see Table 1). Jensen, Vangkilde, Frokjaer, and Hasselbalch (2011) also found null effects of an MBSR intervention on another measure of shifting, the dual attention to response task (DART). This was relative to three control groups: a no-contact control group receiving extra incentive, a no-contact control group not receiving extra incentive, and a non-mindfulness stress reduction group (NMSR).

Diverging from this pattern of results, Moynihan et al. (2013) found pre to post intervention improvement in shifting performance resulting from participation in MBSR in older adults. Specifically, older adults completing MBSR showed enhanced shifting ability as indexed by a posttest improvement in TMT B/A ratio scores relative to a wait-list control group. This difference in findings may suggest that the potential for mindfulness to improve shifting may be specific to certain populations.

4. Discussion

Mindfulness meditation practices continue to gain attention in the scientific community, particularly for their potential beneficial effect on psychological well-being and cognition (e.g., Chiesa et al., 2011). The goal of this review was to further elucidate the benefits to executive functioning resulting from mindfulness meditation practice by fitting Miyake et al.'s (2000) fractionated model of executive processes to the mindfulness literature. Studies looking at the effects of mindfulness meditation practice on outcome measures that tapped the inhibition, updating, and shifting sub components of executive functioning were assessed. Examination of the literature in this way allowed for determination of whether the mindfulness benefit to executive functions is *general* (i.e., enhances all three sub-functions) or *specific* (i.e., benefits only specific sub-functions).

As previously described, mindfulness interventions such as MBSR or MBCT train participants in present moment awareness through repeated *inhibition* of internal and external distractions, and through *shifting* of attention back to the current moment when attention wanders (Baer, 2010; Baer & Krietemeyer, 2006; Bishop et al., 2004; also see Lutz et al., 2008). Following from this, it was hypothesized that mindfulness meditation benefits would be specific as opposed to general, with expected increases to inhibitory and shifting processes. Since the exercises practiced during mindfulness do not necessarily tap the updating function (i.e., updating and monitoring the contents of working memory), benefits to this subcomponent were expected to be absent or reduced relative to the other two components. Only partial support for this hypothesis was obtained.

As predicted, the majority of studies involving an inhibitory outcome measure showed enhanced performance at both a behavioural (Allen et al., 2012; Heeren et al., 2009; Moore & Malinowski, 2009; Sahdra et al., 2011; Teper & Inzlicht, 2013) and neural level (Allen et al., 2012; Teper & Inzlicht, 2013) following mindfulness meditation practice or through comparison of meditators to non-meditators. These studies further showed that beneficial effects may be sustainable up to five months following cessation of training (Sahdra et al., 2011) and may be mediated by the amount of practice, with a positive association observed between practice and inhibitory efficiency (Moore & Malinowski, 2009; Teper & Inzlicht, 2013). However, more research is needed to replicate the sustainability of these beneficial effects over time.

A particularly interesting finding came out of Heeren et al. (2009) showing improvement on a *cognitive* inhibition task (Hayling task) but not a *motor* inhibition task (Go–Stop task). This implies that mindfulness practice may specifically benefit the cognitive component of inhibition associated with suppression of thoughts or feelings as opposed to more motor-based inhibitory processes that work to suppress prepotent motor responses. This falls in line with Lutz et al.'s (2008) theoretical framework of focused attention meditation, which emphasizes consistent detection of distractors (e.g., thoughts) during meditation followed by the cognitive appraisal of and attentional withdrawal from these distractors.

One exception to these findings is that of Anderson et al. (2007), who found no change in performance on a modified Stroop task after a mindfulness intervention. It is important to note, however, that this Stroop task diverged from that used in other studies reported here. In this task, participants were required to name the colour of negative words that were self-relevant positive or negative adjectives. The use of emotional self-relevant adjectives was meant to induce interference thus requiring inhibition of elaborative processes associated with viewing such words. However, as reported by the authors, reliable Stroop effects were not observed for these conditions. As such, the more complex and varied nature of this task relative to its standard format could be contributing to why post intervention improvement was not observed here. Despite the findings of this study, the fact that inhibitory advantages were observed in the majority of instances as a result of both experimenter-facilitated programs and in self-reported mindfulness meditators suggests that such benefits can be attained on both an individual basis as well as during intervention.

Consistent with Lutz et al.'s (2008) focused attention meditation framework, it was predicted that improvements to the updating domain would be reduced relative to the observed inhibitory benefits. Improvement was seen in some capacity across the reviewed studies, although the findings also suggest that these benefits may not necessarily have been indicative of enhanced updating performance per se but other underlying mechanisms. For instance, Zeidan et al. (2010) had null group effects in overall *N*-back accuracy from pre to posttest, but found increases in *sustained* accuracy on the task in the mindfulness group. As well, Mrazek et al. (2013) found that mindfulness practice could increase operation span performance relative to a control, but this was mediated by reductions in mind wandering (i.e., enhanced attentional focus). Taken together, these two findings may imply that mindfulness is not necessarily training the updating domain, but the attentional processes that allow participants to dampen distraction, focus on the present moment and sustain focus over time, which transfers to improvement on measures of updating. Reductions in mind wandering as a result of mindfulness meditation practice (Lutz et al., 2008) may therefore be the mechanism driving improvement in updating performance.

Jha et al. (2010) also add some interesting points to consider in their investigation of mindfulness-related improvement in updating performance in a military population. The authors' took a different perspective in that they were concerned with the *protective* benefits of mindfulness for working memory updating during periods of high stress (e.g., military deployment). In a military control group, updating performance was found to deplete over time (relative to a civilian control) thought to be the result of exposure to high levels of stress but increases in performance were found in the military group that completed mindfulness training. Importantly, this effect was observed only in those that completed high amounts of practice. These findings therefore emphasize (1) the moderating role of practice time, (2) the protective potential of mindfulness practice against the deleterious effects of stress on updating, and (3) the importance of considering stress levels during experimental investigation of mindfulness effects on cognitive performance.

Finally, as a result of practice with shifting attention to and from distractors during mindfulness meditation (Lutz et al., 2008), it was predicted that a specific benefit to shifting-related outcome measures would be observed; partial support for this hypothesis was obtained. Specifically, only one out of five studies showed direct improvement to shifting performance following a mindfulness meditation intervention and this was specific to an older adult sample (Moynihan et al., 2013). Recent evidence from Fiocco and Mallya (2015) lends further support to this finding demonstrating a positive association between the level of *trait* mindfulness (i.e., dispositional mindfulness) and set shifting performance in older adults, an effect that was partially mediated by perceived stress levels. It is important to note that what these two studies have in common is the population of interest – older adults over the age of 65 – which is substantially older than those in the studies showing null effects (see Table 4). It has been well documented that this population faces declines in cognitive performance particularly to the executive functions (i.e., frontal lobe degeneration) that begin to appear around the age of 65 (Hedden & Gabrieli, 2004) and include difficulties with set shifting behaviour (Verhaeghen & Cerella, 2002; Verhaeghen, 2011). However, further evidence suggests that despite such decline, these processes may remain malleable and susceptible to improvement via cognitive training (Yang, 2011). The fact that only mindfulness-related improvements to shifting were observed in older adults might therefore suggest that such practices are beneficial to populations experiencing deficits in task-switching ability where there is room for these processes to improve. This may help to explain why younger or middle-aged adults in the other reviewed studies showed no improvements as their shifting ability may have yet to degrade. It should also be noted that Moynihan et al. (2013) had a significantly larger sample ($N = 100$) than the other studies, which may have enhanced their ability to detect significant effects.

In addition, two studies proposed differences in the types of set shifting behaviour being trained by mindfulness practice. Heeren et al. (2009) suggested that, according to the principles of mindfulness, such practice should train measures of mental set shifting and not motor-related shifting. Similarly, Chambers et al. (2008) theorized that mindfulness should enhance internal (or mental) as opposed to external shifting behaviour. Heeren et al. (2009) failed to find improvements to Trail Making performance (thought to assess motor-related shifting behaviour), supporting their argument, while Chambers et al. (2008) did not observe increases in internal (cognitive) switching, which fails to support both authors' arguments. Although speculative, this might lend support to the above argument of mindfulness-related benefits being specific to populations experiencing deficits to shifting ability (e.g., older adults). To confirm this speculation, future research should aim to compare mindfulness-related improvements across young and older populations on various measures of task switching.

Taken together, findings from this systematic review suggest a more specific as opposed to general benefit to executive functioning resulting from mindfulness meditation practice. The nature of these effects, however, is complex and appears to be most specific to the inhibitory component of Miyake et al.'s (2000) fractionated executive function model, whilst more variable benefits are found to updating and shifting performance. Moreover, there is evidence to suggest that benefits observed to some of these sub-domains seem to depend on other factors such as the amount of practice time or the targeted population. This raises an important question that deserves more attention: what other mechanisms could be driving these benefits? Although the processes engaged during mindfulness undoubtedly tap into some of these executive functions, it could also be possible that reductions in stress – often a main goal of these interventions – are related to improvements in executive function. This seems plausible considering that high levels of stress have often been associated with poor cognitive performance (Lupien, Maheu, Tu, Fiocco, & Schramek, 2007). The findings of Fiocco and Mallya (2015) provide support for this speculation by showing that perceived stress partially mediates the relationship between trait mindfulness and performance on a measure of set shifting in older adults. As well, Jha et al. (2010) document improvements to updating in a high stress sample receiving mindfulness training, whilst the matched control group showed degraded performance. This finding suggests that mindfulness practice may help to buffer against impairments associated with exposure to stress. Future studies assessing the effects of mindfulness practice on cognitive function should therefore measure pre to posttest changes in stress to further confirm this mediating relationship.

Linking behaviour to brain activity, the observed changes in executive functioning resulting from mindfulness could also be linked to neuroplasticity – or changes in the structure and function of the brain – resulting from mindfulness meditation (e.g., Allen et al., 2012; Hölzel et al., 2007, 2011; Luders, Toga, Lepore, & Gaser, 2009; Tang & Posner, 2013; Treadway & Lazar, 2010). Many studies within the mindfulness meditation literature have documented changes to regions that are important for executive functions, such as regions associated with the frontal lobe. For instance, increased activation of the anterior cingulate cortex (ACC) has frequently been identified in mindfulness meditators relative to controls (e.g., Hölzel et al., 2007).[1] Activation of this region may be specifically related to the constant engagement and sustaining of attention during mindfulness practice, as the ACC is often implicated in directing attention and detecting conflicting information (Treadway & Lazar, 2010). Although increased activation of the ACC has been identified in novice meditators, the opposite has been observed in long-term meditators. These reduced activation patterns might therefore suggest that more efficient processing is developed overtime, with fewer resources required to sustain attention during practice (Brefcyznski-Lewis et al., 2007).

In addition to the ACC, research has shown that the prefrontal cortex, important for complex cognitive behaviour, may be influenced by mindfulness practice. For example, Hölzel et al. (2007) demonstrated stronger activation of the medial prefrontal cortex in participants engaging in a form of mindfulness meditation relative to a control condition completing mental arithmetic. Moreover, when comparing meditators to non-meditators using voxel-based morphometry, significant volumetric differences have been detected, with meditators showing increased grey matter volume in the frontal cortex and hippocampus (Luders et al., 2009). However, a caveat to this research is that its cross-sectional design limits the ability to determine whether those that seek mindfulness meditation are more likely to have higher volume to begin with or if it is a direct result of engaging in such practices. Interestingly though, Lazar et al. (2005) suggest that mindfulness meditation may ward off some of the age-related neural degradation typically observed in the frontal lobe. Specifically, they found that older experienced meditators did not show the usual decline in grey matter volume of frontal regions generally observed with aging, whereas older control comparisons did. In addition to these relatively consistent findings, changes to regions such as the hippocampus (Luders et al., 2009) and insula (Allen et al., 2012) have been observed. Taken together, these results suggest that brain regions important for executive functioning are engaged during mindfulness meditation and perhaps experience change as a function of consistent practice. Considering the ties between these brain regions and executive functioning, mindfulness induced neuroplasticity may very well be linked to the observed behavioural changes reported here. Future research should work to further uncover the relationship between the brain, executive functioning, and mindfulness.

4.1. Future directions

The findings of this review provide several avenues for future research. First, it offers potential support for the application of mindfulness-based interventions as a means for improving certain aspects of executive function. In particular, it seems the most effective implementation of these programs would be to populations experiencing deficits in inhibitory processing, such as older adults. According to the inhibitory deficit hypothesis of aging (Hasher & Zacks, 1988), older adults' reduced ability to ignore or inhibit distracting information is proposed to underlie much of the cognitive decline observed in aging. Considering the mindfulness-related benefits observed to inhibitory functioning in this review, future research should determine if such interventions could lead not only to increased inhibitory efficiency, but transfer to improvements in the cognitive domains thought to be mediated by inhibition. This is an important question to address as the older adult population is increasing at a rapid pace (Statistics Canada, 2010). Identifying ways in which we can enhance this population's ability to live an active and independent lifestyle for as long as possible is thus of great relevance. Mindfulness meditation practice could be an accessible and affordable means of doing so.

Furthermore, the influence of certain factors on outcomes following a mindfulness intervention requires further exploration. In particular, the optimal amount of mindfulness practice required to elicit benefits to executive functioning (or other outcomes of interest) should be identified as, currently, the majority of investigations vary considerably in intervention length. Such investigations could use neuroimaging techniques to determine the spatial and temporal effects (e.g., functional connectivity, volumetric changes, or processing efficiency) of mindfulness on the brain at various intervals throughout the intervention. To determine functional significance, these neural changes could then be associated with behavioural outcomes at each interval so as to pinpoint when changes begin to occur and the amount of practice required to elicit these changes.

Finally, the literature on mindfulness-related benefits to cognition would benefit from use of outcome measures more representative of everyday functioning. Currently, the majority of studies use lab-based tasks (e.g., *N*-back, Stroop, Trail Making Test) that have little ecological validity. Use of self-report and performance based outcome measures of instrumental activities of daily living that rely on efficient executive functioning (e.g., Vaughan & Giovanello, 2010) would therefore help to bolster real-world applicability of mindfulness practice as a means for improving executive functioning in everyday life.

4.2. Limitations of the current review

Although the number of investigations concerning the effects of mindfulness on executive functioning will undoubtedly continue to grow, the field is still in its infancy. It is evident that more research is necessary given the lack of standardization, which limits interpretation of the literature. This became apparent in this review with little consistency across reviewed studies. For instance, studies differed on the length of training, level of pre-intervention exposure to mindfulness, degree and type of control (i.e., active vs. no-contact control groups), overall amount of practice or homework completion, and

[1] However, these findings are limited due to a lack of comparison to other forms of meditation.

measures used to tap the targeted outcome functions. These methodological variations make it challenging to draw conclusions regarding the most optimal mindfulness technique or time requirement for eliciting beneficial effects. Moreover, as different intervention approaches may place more of an emphasis on certain mindfulness principles relative to others, the ability to pinpoint what exactly it is about mindfulness training that is producing a benefit becomes difficult. The use of no-contact controls in several investigations also does not help in solving this issue. Future studies need to incorporate active control groups that use similar techniques as the mindfulness interventions, whilst removing the mindfulness component to determine if it is the key to eliciting improvement, as perhaps it is stress reduction and not mindfulness per se that is improving executive functioning. A good illustration of this is the study of Jensen et al. (2011) who compared their MBSR intervention group to a *non-mindfulness* stress reduction group, allowing them to isolate the effects of mindfulness on their outcome measures. Although limitations to the literature, the fact that benefits can still be consistently observed to processes such as inhibition despite great variation in technique suggests these effects may be reliable.

Given the varied nature of these studies and the fact that the number of observations this review was based upon is quite small, the conclusions drawn should be interpreted with caution. Further research is thus warranted to better understand the complex nature of the relationship between mindfulness and the sub-domains of executive functioning.

4.3. Conclusions

In conclusion, although evidence supports a mindfulness-related benefit to executive functioning, the findings of the current review suggest this benefit may be most specific to the inhibitory subcomponent of Miyake et al.'s (2000) three-factor model. This may represent a promising finding for populations experiencing inhibition deficits (e.g., older adults and individuals with ADHD), as mindfulness practice may represent a possible treatment option for improving such abilities. However, further research is recommended in order to replicate existing findings and enhance the standardization of the literature, the establishment of which is necessary prior to real-word application.

Acknowledgments

Special thank you to Dr. Maureen Reed, Dr. Julia Spaniol, and Dr. Lixia Yang for their constructive comments and feedback on this review.

References

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

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*, 17–42. http://dx.doi.org/10.1007/s11065-006-9002-x.

Anderson, N. D., Lau, M. A., Segal, Z. V., & Bishop, S. R. (2007). Mindfulness-based stress reduction and attentional control. *Clinical Psychology and Psychotherapy, 14*, 449–463. http://dx.doi.org/10.1002/cpp.544.

Ardila, A. (2008). On the evolutionary origins of executive functions. *Brain and Cognition, 68*, 92–99. http://dx.doi.org/10.1016/j.bandc.2008.03.003.

Baer, R. A. (2010). Mindfulness- and acceptance-based interventions and processes of change. In R. A. Baer (Ed.), *Assessing mindfulness & acceptance processes in clients* (pp. 1–24). Oakland, CA: New Harbinger Publications.

Baer, R. A., & Krietemeyer, J. (2006). Overview of mindfulness- and acceptance-based treatment approaches. In R. A. Baer (Ed.), *Mindfulness-based treatment approaches: Clinician's guide to evidence base and applications* (pp. 3–27). London, UK: Elsevier.

Bishop, S. R., Lau, M., Shapiro, S., Carson, L., Anderson, N. D., Carmody, J., ... Devins, G. (2004). Mindfulness: A proposed operational definition. *Clinical Psychology: Science and Practice, 11*, 230–241. http://dx.doi.org/10.1093/clipsy/bph077.

Black, D. S., Semple, R. J., Pokhrel, P., & Grenard, J. L. (2011). Component processes of executive function—Mindfulness, self-control, and working memory—And their relationships with mental and behavioural health. *Mindfulness, 2*, 179–185. http://dx.doi.org/10.1007/s12671-011-0057-2.

Bowen, S., Witkiewitz, K., Dillworth, T. M., Chawla, N., Simpson, T. L., Ostafin, B. D., ... Marlatt, G. A. (2006). Mindfulness meditation and substance use in an incarcerated population. *Psychology of Addictive Behaviours, 20*, 343–347. http://dx.doi.org/10.1037/0893-164X.20.3.343.

Brefczynski-Lewis, J. A., Lutz, A., Schaefer, H. S., Levinson, D. B., & Davidson, R. J. (2007). Neural correlates of attentional expertise in long-term meditation practitioners. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 11483–11488. http://dx.doi.org/10.1073/pnas.0606552104.

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality & Social Psychology, 84*, 822–848. http://dx.doi.org/10.1037/0022-3514.84.4.822.

Bueno, V. F., da Silva, M. A., Alves, T. M., Louza, M. R., & Pompéia, S. (2014). Fractionating executive functions of adults with ADHD. *Journal of Attention Disorders*, 1–12. http://dx.doi.org/10.1177/1087054714545537.

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

Chan, R., Shum, D., Toulopoulou, T., & Chen, E. (2008). Assessment of executive functions: Review of instruments and identification of critical issues. *Archives of Clinical Neuropsychology, 23*, 201–216. http://dx.doi.org/10.1016/j.acn.2007.08.010.

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

Chiesa, A., & Serretti, A. (2009). Mindfulness-based stress reduction for stress management in healthy people: A review and meta-analysis. *The Journal of Alternative and Complementary Medicine, 15*, 593–600. http://dx.doi.org/10.1089/acm.2008.0495.

Coffman, S. J., Dimidjian, S., & Baer, R. A. (2006). Mindfulness-based cognitive therapy for prevention of depressive relapse. In R. A. Baer (Ed.), *Mindfulness-based treatment approaches: Clinician's guide to evidence base and applications* (pp. 31–50). London, UK: Elsevier.

Fan, J., Tang, Y. Y., Ma, Y., & Posner, M. I. (2010). Mucosal immunity modulated by integrative meditation in a dose dependent fashion. *Journal of Cognitive Neuroscience, 14*, 340–347. http://dx.doi.org/10.1162/089892902317361886.

Fiocco, A. J., & Mallya, S. (2015). The importance of cultivating mindfulness for cognitive and emotional well-being in late life. *Journal of Evidence-Based Complementary & Alternative Medicine, 20*, 35–40. http://dx.doi.org/10.1177/2156587214553940.

Goel, V., Grafmann, J., Tajik, J., Gana, S., & Danto, D. (1997). A study of the performance of patients with frontal lobe lesions in a financial planning task. *Brain, 120*, 1805–1822. http://dx.doi.org/10.1093/brain/120.10.1805.

Hasher, L., Lustig, C., & Zacks, R. (2007). Inhibitory mechanisms and the control of attention. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 227–249). New York, NY: Oxford University Press.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 193–225). San Diego, CA: Academic Press.

Hedden, T., & Gabrieli, J. D. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5*, 87–96. http://dx.doi.org/10.1038/nrn1323.

Heeren, A., Van Broeck, N., & Philippot, P. (2009). The effects of mindfulness on executive processes and autobiographical memory specificity. *Behaviour Research and Therapy, 47*, 403–409. http://dx.doi.org/10.1016/j.brat.2009.01.017.

Hick, S. F. (2008). Cultivating therapeutic relationships: The role of mindfulness. In S. F. Hick & T. Bien (Eds.), *Mindfulness and the therapeutic relationship*. New York, NY: The Guilford Press.

Hoffman, S. G., Sawyer, A. T., Witt, A. A., & Oh, D. (2010). The effect of mindfulness-based therapy on anxiety and depression: A meta-analytic review. *Journal of Consulting and Clinical Psychology, 78*, 168–183.

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

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters, 421*, 16–21. http://dx.doi.org/10.1016/j.neulet.2007.04.074.

Jensen, C. G., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2011). Mindfulness training affects attention—Or is it attentional effort? *Journal of Experimental Psychology: General, 14*, 106–123.

Jha, A. P., Krompinger, J., & Baime, M. I. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective, & Behavioural Neuroscience, 7*, 109–119. http://dx.doi.org/10.3758/CABN.7.2.109.

Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. *Emotion, 10*, 54–64. http://dx.doi.org/10.1037/a0018438.

Kabat-Zinn, J. (1982). An outpatient program in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: Theoretical considerations and preliminary results. *General Hospital Psychiatry, 4*, 33–47. http://dx.doi.org/10.1016/0163-8343(82)90026-3.

Kabat-Zinn, J. (1990). *Full catastrophe living: Using the wisdom of your body and mind to face stress, pain and illness*. New York: Delacorte.

Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice, 10*, 144–156. http://dx.doi.org/10.1093/clipsy.bpg016.

Langer, E. J., & Moldoveanu, M. (2000). The construct of mindfulness. *Journal of Social Issues, 56*, 1–9. http://dx.doi.org/10.1111/0022-4537.00148.

Lazar, S. W., Kerr, C. E., Wasserman, R. H., Gray, J. R., Greve, D. N., Treadway, M. T., ... Rauch, S. L. (2005). Meditation experience is associated with increased cortical thickness. *NeuroReport, 16*, 1893–1897. http://dx.doi.org/10.1097/01.wnr.0000186598.66243.19.

Luders, E., Toga, A. W., Lepore, N., & Gaser, C. (2009). The underlying anatomical correlates of long-term meditation: Larger hippocampal and frontal volumes of gray matter. *NeuroImage, 45*, 672–678. http://dx.doi.org/10.1016/j.neuroimage.2008.12.061.

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

Lupien, S. J., Maheu, F., Tu, M., Fiocco, A., & Schramek, T. E. (2007). The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. *Brain and Cognition, 65*, 209–237. http://dx.doi.org/10.1016/j.bandc.2007.02.007.

Lyvers, M., Makin, C., Toms, E., Thorberg, F. A., & Samios, C. (2013). Trait mindfulness in relation to emotional self-regulation and executive function. *Mindfulness, 5*, 1–7. http://dx.doi.org/10.1007/s12671-013-0213-y.

Ma, S. H., & Teasdale, J. D. (2004). Mindfulness-based cognitive therapy for depression: Replication and exploration of differential relapse prevention effects. *Journal of Consulting and Clinical Psychology, 72*, 31–40. http://dx.doi.org/10.1037/0022-006X.72.1.31.

MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., ... Wallace, B. A. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science, 21*, 829–839. http://dx.doi.org/10.1177/095679761371339.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21*, 8–14. http://dx.doi.org/10.1177/0963721411429458.

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

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

Moynihan, J. A., Chapman, B. P., Klorman, R., Krasner, M. S., Duberstein, P. R., Brown, K. W., & Talbot, N. L. (2013). Mindfulness-based stress reduction for older adults: Effects on executive function, frontal alpha asymmetry and immune function. *Neuropsychobiology, 68*, 34–43. http://dx.doi.org/10.1159/000350949.

Mrazek, M. D., Franklin, M. S., Tarchin, D., Baird, B., & Schooler, J. W. (2013). Mindfulness training improves working memory capacity and GRE performance while reducing mind wandering. *Psychological Science, 24*, 776–781. http://dx.doi.org/10.1177/0956797612459659.

Nyklíček, I., & Kuijpers, K. F. (2008). Effects of mindfulness-based stress reduction intervention on psychological well-being and quality of life: Is increased mindfulness indeed the mechanism? *Annals of Behavioral Medicine, 3*, 331–340. http://dx.doi.org/10.1007/s12160-008-9030-2.

Piet, J., & Hougaard, E. (2011). The effect of mindfulness-based cognitive therapy for prevention of relapse in recurrent major depressive disorder: A systematic review and meta-analysis. *Clinical Psychology Review, 31*, 1032–1040. http://dx.doi.org/10.1016/j.cpr.2011.05.002.

Roemer, L., Salters-Pedneault, K., & Orsillo, S. M. (2006). Incorporating mindfulness and acceptance-based strategies in the treatment of generalized anxiety disorder. In R. A. Baer (Ed.), *Mindfulness-based treatment approaches: Clinician's guide to evidence base and applications* (pp. 52–74). London, UK: Elsevier.

Sahdra, B. K., MacLean, K. A., Ferrer, E., Shaver, P. R., Rosenberg, E. L., Jacobs, T., ... Saron, C. (2011). Enhanced response inhibition during intensive meditation training predicts improvements in self-reported adaptive socioemotional functioning. *Emotion, 11*, 299–312. http://dx.doi.org/10.1037/a0022764.

Segal, Z. J., Williams, M. G., & Teasdale, J. D. (2013). *Mindfulness based cognitive therapy for depression: A new approach to preventing relapses*. New York, NY: Guilford Press.

Statistics Canada (2010). *Population projections: Canada, the provinces and territories*. <http://www.statcan.gc.ca/daily-quotidien/100526/dq100526b-eng.htm>.

Sternberg, R. J. (2000). Images of mindfulness. *Journal of Social Issues, 56*, 11–26. http://dx.doi.org/10.1111/0022-4537.00149.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662. http://dx.doi.org/10.1037/h0054651.

Tang, Y.-Y., & Posner, M. I. (2013). Tools of the trade: Theory and method in mindfulness neuroscience. *Social, Cognitive, and Affective Neuroscience, 8*, 118–120. http://dx.doi.org/10.1093/scan/nss112.

Tang, Y.-Y., Yang, L., Leve, L. D., & Harold, G. T. (2012). Improving executive function and its neurobiological mechanisms through a mindfulness-based intervention: Advances within the field of developmental neuroscience. *Child Development Perspectives, 6*, 361–366. http://dx.doi.org/10.1111/j.1750-8606.2012.00250.x.

Tapper, K., Shaw, C., Ilsley, J., Hill, A. J., Bond, F. W., & Moore, L. (2009). Exploratory randomized controlled trial of a mindfulness-based weight loss intervention for women. *Appetite, 52*, 396–404. http://dx.doi.org/10.1016/j.appet.2008.11.012.

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

Teper, R., Segal, Z. V., & Inzlicht, M. (2013). Inside the mindful mind: How mindfulness enhances emotion regulation through improvements in executive control. *Current Directions in Psychological Science, 22*, 449–554. http://dx.doi.org/10.1177/0963721413495869.

Treadway, M. T., & Lazar, S. W. (2010). Meditation and neuroplasticity: Using mindfulness to change the brain. In R. A. Baer (Ed.), *Assessing mindfulness & acceptance processes in clients: Illuminating the theory & practice of change* (pp. 185–206). Oakland, California: New Harbinger Publications Inc.

Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging, 25*, 343–355. http://dx.doi.org/10.1037/a0017729.

Verhaeghen, P. (2011). Aging and executive control: Reports of a demise greatly exaggerated. *Current Directions in Psychological Science, 20*, 174–180. http://dx.doi.org/10.1177/0963721411408772.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience & Biobehavioural Reviews, 26*, 849–857. http://dx.doi.org/10.1016/S0149-7634(02)00071-4.

Yang, L. (2011). Practice-oriented retest learning as the basic form of cognitive plasticity of the aging brain. *Journal of Aging Research*. 8 pages 407074.

Zeidan, F., Johnson, S. K., Diamond, B. J., Zhanna, D., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: Evidence of brief mental training. *Consciousness and Cognition, 19*, 597–605. http://dx.doi.org/10.1016/j.concog.2010.03.014.