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Does mindfulness training help working memory 'work' better?

Amishi P Jha[1], Ekaterina Denkova[1], Anthony P Zanesco[1], Joanna E Witkin[1], Joshua Rooks[1] and Scott L Rogers[2]

There has been a proliferation of mindfulness training (MT) programs offered across a multitude of settings, including military, business, sports, education, and medicine. As such, ascertaining training effectiveness and determining best practices for program delivery are of the utmost importance. MT is often introduced to promote an array of desired effects from better mood, better leadership and management skills, to improved workplace or academic performance. Despite the diversity of factors motivating adoption of MTs, it can be argued from a cognitive training perspective that there should be uniformity in the core cognitive processes strengthened via repeated and systematic engagement in MT exercises. Herein, we explore the hypothesis that MT promotes salutary changes in the brain's working memory (WM) system. We review prior research and highlight aspects of MT programs that may be critical for achieving beneficial WM effects. Further, we suggest that given the centrality of WM in core processes such as emotion regulation, problem solving, and learning, MT programs capable of achieving WM benefits may be best positioned to promote other desired outcomes (e.g. reductions in negative mood). For these reasons, we recommend that more studies include WM metrics in their evaluation of MT programs.

Addresses
[1] Department of Psychology, University of Miami, FL, USA
[2] School of Law, University of Miami, FL, USA

Corresponding author: Jha, Amishi P (a.jha@miami.edu)

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Introduction

Over 1,500 years ago, the Indian Buddhist sage, Master Asanga, offered this description of mindfulness: "Notforgetfulness of the mind, having the function of nondistraction" ([1], p. 157). In his English translations, Ñ yāṇamoli Bhikkhu, a Western monk who spoke the Buddha's own language of Pali said of *sati* (the Pali word for mindfulness; *smriti* in Sanskrit), "Its characteristic is not wobbling; its function is not to forget. It is manifested as guarding or the state of being face to face with an object" ([2], p. 45).

As will be explored herein, this historical characterization of mindfulness is strikingly resonant with the cognitive neuroscience construct of working memory (WM). We begin by providing an overview of the cognitive and neural underpinnings of WM and discuss how MT might entrain and strengthen WM processes. Next, we review prior MT research and describe training contexts and MT program features which best promote salutary WM effects. We end by considering the broader utility of improving WM with MT, given WM's centrality in the regulation of emotion and behavior.

Working memory and mindfulness training

Working memory refers to the brain's capacity to selectively maintain and manipulate goal-relevant information over short intervals (from a few seconds to minutes), without becoming distracted by irrelevant information. WM is limited in capacity and necessary for complex thought and fluid behavior. There have been many models of WM since this construct entered the cognitive neuroscience literature over 50 years ago [3–5]. The most prominent of these is the multicomponent model of WM by Baddeley and Hitch [6], which proposed a domain-general central executive component that acts upon the contents of subordinate domain-specific components, which are parsed as a function of the type of information to be maintained (e.g. visuospatial or verbal) [6], or as integrated unified episodic representations [7].

There is growing evidence that attentional processes play a significant role in supporting successful WM [8,9]. Encoding of memoranda requires selective attention to foreground domain-specific, task-relevant information represented within sensory/perceptual or long-term memory networks. Successful maintenance of encoded information requires reflective attentional resources to 'refresh' memory traces over the maintenance interval [10,11]. Refreshing involves boosting, prolonging, and strengthening the representations of task-relevant items being maintained in WM. Without refreshing, memory traces are vulnerable to becoming unstable, leading to WM failures. WM maintenance also relies on attentional disengagement to ensure that distracting or outdated information that is no longer task-relevant is removed from capacity-limited WM storage [12,13]. Thus, selective and reflective attention support the foregrounding of task-relevant memoranda, and attentional disengagement minimizes the processing of distracting information.

How might these processes be related to classical descriptions of mindfulness? During encoding and maintenance, selective and reflective attention promote 'nonforgetfulness' [1] by biasing neural activity in favor of mental content most pertinent to the task-at-hand. Specifically, neural activity within perceptual regions (e.g. face-specific perceptual cortex during WM for faces) is greater for task-relevant memoranda versus distracting information [14]. The absence of biased neural activity in favor of memoranda corresponds with performance failures, which are indicative of forgetting [15]. A connection between WM processes and 'guarding' [2] can be drawn as well. Disengagement, monitoring, and updating are processes proposed to *guard* against interference so that task-relevant information is able to exert greater influence over information processing and behavior guided by WM [13].

While parallels can certainly be drawn between WM and classical descriptions of mindfulness, WM should not be equated with mindfulness [see Ref. [16] for a discussion on this point]. Instead, classical descriptions of mindfulness may have been pointing to those mental capacities that are strengthened by repeatedly engaging in MT practices in support of *clear comprehension* [2]. As classically described, clear comprehension is the capacity to understand, with meta-awareness, what is happening in one's conscious experience in any given moment [1]. Relatedly, contemporary descriptions of mindfulness, characterized as attention to present moment experience without judgment or elaboration [17••], may also be related to WM. Attention to present-moment experience involves, at least in part, awareness of information that is actively being maintained and manipulated in WM. To probe the mind in this way requires access to stable representations in WM.

How might MT exercises entrain WM processes? A cognitive training perspective suggests that cognitive processes which are engaged by a particular activity may be amenable to being strengthened by repeated engagement in that activity [18]. Below we propose how MT exercises may engage and putatively strengthen core WM processes.

Two categories of formal exercises typically comprise MT programs. These are focused attention (FA) and open monitoring (OM) [19]. During formal engagement in either FA or OM exercises, the practitioner must willfully decide that for some period of uninterrupted time, they will follow the specific instructions for each form of exercise, with an aspiration to follow these instructions well (e.g. resist falling asleep, or engaging in some other activity during the practice period). As such, *both* FA and OM require maintaining the task set in WM, as practitioners hold in mind the specific instructions they are to engage in for the practice period. There may be additional information maintained as part of the task set as well, such as holding in mind the larger contextual motivation behind why one practices [19].

In FA, the practitioner is instructed to select a particular object of focus for the practice period (e.g. breath-related sensations), and sustain selective attention, moment-by-moment, on the selected object with a fairly narrow focus (e.g. the specific sensations caused by the breath at the nostrils or abdomen). As practitioners notice the occurrence of distractions, they are to disengage attention from them and reorient attention to the selected object for the duration of formal practice. In addition, certain sensory input, such as the coolness of air during exhalation, or certain mental content such as thoughts or images, may prompt engagement of reflective attention to 'refresh' maintenance of the task set. Thus, FA instructions emphasize attentional engagement on the selected object and disengagement from task-irrelevant distraction [19,20].

During OM, the practitioner is to remain in a receptive and open monitoring state, attending moment-by-moment to anything that arises in one's conscious experience, without focusing and elaborating on the content of any particular object. In OM, if attention becomes overly engaged in a particular thought, memory, or sensation (such that the occurrence of newly arising phenomena is obscured), the practitioner is to disengage his/her attention from this mental content. While monitoring is more prominent in the task set for OM compared to FA, monitoring is, nonetheless, required during both forms of MT exercises to ensure that the task set is being appropriately engaged. Thus, collectively, FA and OM practices may repeatedly require selective and reflective attentional engagement, disengagement, maintenance, and monitoring. Since these processes are also necessary to successfully maintain and manipulate information in WM, a strong prediction from a cognitive training perspective is that their repeated engagement during MT exercises will strengthen WM. Many studies have been conducted to investigate this hypothesis [see Ref. [21] for review].

MT studies examining WM

As discussed above, FA and OM engage processes central to WM. From a cognitive training perspective, this leads to the strong prediction that MT strengthens WM. In accordance with this prediction, we suggest that a key question regarding MT and WM should not be *if* WM is impacted by MT, but instead what features of MT programs are necessary to bring about salutary WM effects in a manner that is tractable. Below, we review prior studies to highlight the training context and program features of MT programs found to result in such WM effects. Specifically, we discuss: 1) MT offered during high-demand intervals (e.g. predeployment military training) versus typical civilian life, 2) program features such as in-person training versus recordings, requirements for out-of-class MT practice between training sessions, and training program duration (number of total instruction hours as well as days/weeks over which the program is delivered), and 3) differences in how WM was indexed (e.g. span tasks, delayed-recognition tasks, or *N*-back tasks).

The bulk of studies conducted by our group have been aimed at determining vulnerabilities in WM over high-demand intervals, and whether MT may protect against degradation in WM over such intervals. Over multiple studies, we have observed degradation in WM over high-stress intervals such as predeployment military training in active duty military cohorts [see Ref. [22••] for review]. One of the first studies conducted on MT in military cohorts involved delivery of a 24-hour, 8-week program modeled on mindfulness-based stress reduction (MBSR [23) but contextualized for military personnel [17••]. MT course meetings were offered via in-person instruction, and 30 min of daily out-of-class MT exercises were assigned to participants between group meetings. The study was conducted during troops' predeployment training, which is a high-demand interval known to degrade WM and mood [24,25]. Indeed, no-training control participants who did not receive MT during this interval significantly declined in their performance on a WM operational span task (OSPAN). Those in the MT group also declined, but the degree of decline was commensurate with the amount of daily MT practice (i.e. time spent engaging in out-of-class MT exercises) in which they engaged. Those with high MT practice (12 or more minutes a day) demonstrated stability in WM over time, whereas those with low practice declined in their scores over time. Based on the basis of these results, we concluded that MT was protective against WM decline when offered in-person, and when participants engaged in sufficient daily out-of-class MT practice.

Given the importance of MT practice in promoting salutary outcomes, and the time-pressured setting of offering MT to predeployment military cohorts, we conducted a follow-up study, which compared two shorter-form, 8-hour MT course variants [22••]. One of these course variants primarily involved practice-focused instruction and the other involved didactic instruction (e.g. discussion of conceptual information about mindfulness, stress, and resilience). The same instructor taught both 8-hour variants of the course, and both courses were equated for out-of-class practice requirements. While the no-training control group, once-again, declined in WM performance over the 8-week interval, those in the MT group who received the practice-focused instruction maintained WM performance over time. The MT group with didactic-focused course instruction performed worse than the practice-focused group. Thus, we concluded that MT was protective against WM decline when the in-person MT program was practice-focused, and when participants were required to engage in sufficient daily out-of-class MT exercises.

There have been several studies with similar training parameters of delivery over multiple consecutive days or weeks, live-instruction, and requirements for daily out-of-class practice in which salutary WM benefits have been found. These benefits are not simply protective against decline but correspond to an enhancement above baseline. In elite military cohorts, for example, enhanced performance on a delayed-recognition WM task was found after a 4-week but not 2-week MT program delivered in-person with assigned daily out-of-class practice [26••].

In civilian contexts, improved performance on WM span tasks has been reported in studies with in-person MT programs requiring out-of-class practice [27••,28]. For example, Roeser *et al.* [28] found increases in OSPAN scores in teachers receiving an 8-week MT program compared to those receiving no-training, and Mrazek *et al.* [27••] found higher OSPAN scores in undergraduates receiving a 2-week MT program compared to an active-comparison nutrition education program. In contrast, reliable improvements on WM span tasks have not been found when MT is offered via recordings alone [29–33], or when training does not require independent daily out-of-class practice [34]. Together these findings suggest that when MT programs are offered in-person and emphasize consistent practice (e.g. out-of-class engagement in MT exercises between course meetings), salutary effects either as protection from decline or as enhancement above baseline may be observed on the span and delayed-recognition WM tasks.

When MT is offered via recordings or does not involve out-of-class practice, WM benefits are not consistently observed across WM tasks or task-specific outcomes [31,33,34]. For example, two studies in which MT was offered via recording-based delivery of MT instruction found beneficial effects for *N*-back tasks but not for span tasks [31,33]. MT-related *N*-back performance improvements in one of the studies were observed when the testing session was immediately preceded by an MT practice session [33]. As such, it is possible that MT-related benefits on the *N*-back reflected temporary effects versus lasting changes due to cognitive training and strengthening of WM with MT. Thus, while there are many WM tasks available to index component WM processes such as maintenance, distraction, manipulation, and updating, more research is necessary to determine if some WM tasks are susceptible to task-practice or immediate MT-practice effects moreso than others. In addition, future studies should explore if and how recording-based MT could be supplemented in its delivery to achieve reliable across-task WM benefits.

It is also important to note that while the review above is specifically for MT-related WM results, there is growing support that attention and WM are highly inter-related and many studies have similarly investigated MT's influence on attention. Consistent with WM results, MT-related salutary effects have been observed on tasks of attention with MT programs emphasizing in-person training, significant daily out-of-class MT practice, and offered over protracted time intervals [26••,35–40]. Thus, these MT program features may be key to supporting cognitive training of both WM and attention.

Why does improving WM with MT matter?

It is important to note that MT program characteristics which best promote salutary WM effects are also those reported to be critical for other MT-related benefits, including self-reported well-being [41]. As such, it is possible that these are generalizable MT program features necessary to achieve a variety of beneficial outcomes. Alternatively, perhaps MT-related WM changes are driving other salutary effects. Indeed, in the study described above in military service members [17••], the high-demand predeployment interval degraded not only WM but also mood. Negative mood increased and positive mood decreased over time in the no-training control group. Yet, those in the MT group were protected against mood decline in a manner commensurate with the amount of MT practice in which they engaged. Higher practice resulted in better protection against mood decline. Since MT practice time significantly corresponded with both WM and mood benefits, a series of formal analyses were conducted to determine if these cognitive and affective measures were inter-related. Indeed, WM changes corresponded with negative (but not positive) mood changes in the MT group. A formal mediation analysis also concluded that the MT's salutary effects on negative mood were mediated by MT-related changes in WM. With more practice, WM was better protected, which resulted in better protection from the worsening of negative mood over the 8-week predeployment interval investigated.

Indeed, in line with these results, it is well established that the integrity of WM is closely related to emotion regulation [42•], decision making [43,44], perspective taking [45,46], learning, and academic performance [47,48]. From our perspective, the numerous processes with which WM is closely related, represent the 'work' that working memory can do. That is, WM provides a mental 'scratchspace' [7] in which high-integrity, task-relevant information is maintained in an easily accessible form and protected from interference. A variety of computations can be performed on this information. For example, in the context of learning, the stable presence of task-relevant information provides opportunities for elaboration and binding of this information with long-term memory representations, which aids in the integration of newly learned material. Indeed, higher levels of WM are associated with a number of desirable outcomes, including greater mathematics performance [49] and even higher levels of general academic achievement [47].

While WM is powerful and trainable, it is fragile and vulnerable. A recent meta-analysis identified 21 factors such as stress, stereotyped threat, poor mood, craving, and lack of sleep that corresponded with compromised WM [50]. In addition, mind wandering, or having off-task thoughts during ongoing tasks or activities, is also known to correspond with lower WM [51]. In clinical contexts, rumination and worry are characterized as 'sticky' mental content that can clutter the mental 'scratchspace' of WM, compromising attentional disengagement, inhibition, and updating [52–54]. Thus, given the centrality and criticality of WM for a host of complex operations, as well as the multitude of vulnerabilities that compromise its functioning, routes by which to strengthen WM are warranted. While there is promising evidence that MT strengthens WM and attention-related processes [17••,22••,36,37,39,55], more research is needed. Interestingly, many studies of MT have reported salutary effects for outcomes known to correspond with individual differences in WM (e.g. emotion regulation and mood [56,57], decision making [58], and academic achievement [59]).

Conclusions

We employed a cognitive training perspective to suggest that MT protects and strengthens WM. When WM 'works' better, the multitide of processes that critically rely on access to a high-integrity mental 'scratchspace' (e.g. processes such as emotion regulation, problem-solving, and learning) will also, in turn, benefit. As such, future studies should investigate if MT-related improvements in WM may be a requisite step for bringing about desired outcomes in applied and clinical settings. In addition, since processes such as meta-awareness and dereification [19], as well as decentering [60], have been proposed to be strengthened via repeated engagement in MT exercises, future studies should examine inter-relationships between MT-related changes in these processes and WM. In sum, we encourage researchers to consider adding WM metrics (specifically, span and delayed-recognition tasks) in MT program evaluation research. Doing so could help shed light on the mechanisms of action by which MT results in a myriad of desired outcomes motivating its broad adoption.

Conflict of interest statement

Nothing declared.

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Papers of particular interest, published within the period of review, have been highlighted as:

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