Research Report

Mindfulness Training Improves Working Memory Capacity and GRE Performance While Reducing Mind Wandering

Psychological Science
XX(X) 1–6

DOI: 10.1177/0956797612459659
pss.sagepub.com

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Abstract

Given that the ability to attend to a task without distraction underlies performance in a wide variety of contexts, training one's ability to stay on task should result in a similarly broad enhancement of performance. In a randomized controlled investigation, we examined whether a 2-week mindfulness-training course would decrease mind wandering and improve cognitive performance. Mindfulness training improved both GRE reading-comprehension scores and working memory capacity while simultaneously reducing the occurrence of distracting thoughts during completion of the GRE and the measure of working memory. Improvements in performance following mindfulness training were mediated by reduced mind wandering among participants who were prone to distraction at pretesting. Our results suggest that cultivating mindfulness is an effective and efficient technique for improving cognitive function, with wide-reaching consequences.

Keywords

mindfulness, mind wandering, working memory capacity, reading comprehension, attention, cognitive ability, reading, memory

Received 4/4/12; Revision accepted 7/16/12

Millions of college and graduate-school applicants take standardized tests of academic ability such as the SAT and GRE each year on the premise that these tests capture variability in a stable cognitive capacity that is predictive of educational and professional success. Although these tests are designed to be minimally coachable (Powers & Rock, 1999), their role in gating access to competitive schools has generated a multibillion-dollar test-prep industry. In a similar fashion, although on a smaller scale, broadly predictive psychological measures such as working memory capacity (WMC) have traditionally been thought to capture fixed abilities but have recently become the focus of training studies aimed at testing plasticity in fundamental cognitive capacities (Klingberg, 2010).

As research into enhancing cognitive function proceeds, it is important to address not only which specific capacities can be improved, but also which mechanisms underlie observed changes in cognitive capacities. Although it is unsurprising that practicing for the GRE or a WMC task could improve performance on these tests, rigorous demonstrations of enhanced capacity require mechanistic accounts of improvements that cannot be explained by task-specific learning or strategies (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008).

Training studies frequently target a single ability (Klingberg, 2010), yet performance might be enhanced more generally by interventions that target a cognitive process underlying performance in a variety of contexts (Slagter, Davidson, & Lutz, 2011). The ability to attend to a task without distraction constitutes one such ability. Indeed, mind wandering—defined as a shift of attention from a task to unrelated concerns—is associated with impaired performance on a wide variety of measures, including WMC, fluid intelligence, and SAT performance (Mrazek, Smallwood, Franklin, et al., 2012). Unfortunately, little progress has been made in establishing empirically validated strategies that dampen mind wandering's disruptive influence. A notable exception is the recent finding that mind wandering during a vigilance task can be

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reduced by brief mindfulness exercises (Mrazek, Smallwood, & Schooler, 2012), which suggests that mindfulness training may be a promising strategy for improving task focus and performance.

Sages have long advocated the value of cultivating an ability to mindfully focus on the here and now, and converging scientific evidence has begun to corroborate this view. Mindfulness training prevents the deterioration of WMC during periods of high stress (Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010), enhances attention (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; MacLean et al., 2010; Slagter et al., 2007), improves visuospatial processing efficiency (Kozhevnikov, Louchakova, Josipovic, & Motes, 2009), increases backward digit memory span (Chambers, Lo, & Allen, 2008), and serves as a useful treatment for a large and growing list of medical conditions (Ludwig & Kabat-Zinn, 2008). In this randomized controlled investigation, we examined whether mindfulness training was more effective than a control program (nutrition training) in (a) improving reading comprehension, which is among the most important skills in modern society; (b) enhancing performance on the WMC measure most highly predictive of performance across a range of contexts; and (c) reducing distracting thoughts during the completion of both a reading-comprehension measure (based on the GRE) and the WMC measure. We also hypothesized that improvements in WMC and GRE performance would be mediated by a reduction in mind wandering.

Method

Forty-eight undergraduate students (14 male, 34 female; mean age = 20.83 years, *SD* = 2.05) were randomly assigned to either a mindfulness class (n = 26) or a nutrition class (n = 22) using a mixed factorial pretest-posttest design. Classes met for 45 min four times a week for 2 weeks and were taught by professionals with extensive teaching experience in their respective fields.

The mindfulness class emphasized the physical posture and mental strategies of focused-attention meditation (Dorje, 2009; Lutz, Slagter, Dunne, & Davidson, 2008). It required participants to integrate mindfulness into their daily activities and to complete 10 min of daily meditation outside of class. During class, participants sat on cushions in a circle. Each class included 10 to 20 min of mindfulness exercises requiring focused attention to some aspect of sensory experience (e.g., sensations of breathing, tastes of a piece of fruit, or sounds of an audio recording). Participants shared their experiences with the class and received personalized feedback from the instructor. Class content was designed to provide a clear set of strategies for and a conceptual understanding of how to practice mindfulness. Classes focused on (a) sitting in an upright posture with legs crossed and gaze lowered, (b) distinguishing between naturally arising thoughts and elaborated thinking, (c) minimizing the distracting quality of past and future concerns by reframing them as mental projections occurring in the present, (d) using the breath as an anchor for attention during meditation, (e) repeatedly counting up to 21 consecutive exhalations, and (f) allowing the mind to rest naturally rather than trying to suppress the occurrence of thoughts.

This training has many similarities to, but also some key differences from, the widely researched Mindfulness Based Stress Reduction (MBSR) program (Grossman, Niemann, Schmidt, & Walach, 2004). For instance, both programs introduce a secular version of mindfulness over the course of eight small-group sessions, require participants to practice mindfulness outside of class, and cultivate mindfulness of multiple sensory modalities. However, the mindfulness training used in this study differed from MBSR in that it occurred over 2 weeks rather than 8, required considerably less time spent in formal daily practice outside of class, and involved a slightly different presentation of techniques for developing mindfulness.

The nutrition program covered fundamental topics in nutrition science and applied strategies for healthy eating. To match the time commitment of the daily meditation requirement, we required participants assigned to the nutrition program to log their daily food intake, but they were not required to make any specific dietary changes.

Within a week before and within a week after classes, participants completed in a counterbalanced order a WMC task and a verbal-reasoning section from the GRE (20 min allotted for completion), which we modified by excluding vocabulary-focused questions. Given this modification, the GRE measure is best interpreted as an assessment of reading comprehension. Accuracy on the GRE was calculated as the proportion of total questions answered correctly. We used two versions of the verbal GRE measure that were matched for difficulty and counterbalanced within each condition. There was no significant difference in accuracy on the two versions at pretesting, $F(1, 46) = 0.114$, $p = .737$, which indicated that the two versions were well-matched for difficulty.

WMC was assessed via the widely used operation span task (OSPAN). Relative to other measures of WMC, complex span tasks such as the OSPAN are highly predictive of an individual's performance across a range of contexts (Unsworth, Heitz, Schrock, & Engle, 2005). In this complex span task, presentations of to-be-remembered stimuli were alternated with an unrelated processing task (i.e., participants had to verify the accuracy of presented equations). In each of 15 trials, the to-be-remembered items were sets of 3 to 7 letters chosen from a pool of 12 letters and presented for 250 ms each. At the end of each trial, participants selected the presented items in the order in which they had appeared. Stimuli for the OSPAN were chosen randomly from a list of letters and equations, which ensured that participants would not encounter the same pattern of stimuli across the two testing sessions. Following standard procedures, we defined accuracy rates less than 85% on the unrelated processing task as an exclusion criterion (counting as errors any responses that exceeded the mean latency for 15 practice items by more than 2.5 standard deviations; Unsworth et al., 2005); however, no participants met this criterion and had to be excluded. WMC was calculated as the proportion of total letters recalled across all trials.

Mind wandering during the OSPAN was measured with a widely used retrospective measure of task-unrelated thought administered after the OSPAN (Matthews et al., 1999). During the GRE, mind wandering was measured with both thought sampling and participants' self-reports of instances of mind wandering. Eight thought-sampling probes were presented at unpredictable quasirandom intervals and asked participants to indicate the extent to which their attention was focused on the task or on task-unrelated concerns, using a 5-point Likert scale (1 = *completely on task*; 2 = *mostly on task*; 3 = *both on the task and on unrelated concerns*; 4 = *mostly on unrelated concerns*; 5 = *completely on unrelated concerns*). Participants also used a written form to count instances in which they caught their minds wandering independently of thought probes. Detailed descriptions of these methodologies are available in prior work (Mrazek et al., 2011; Schooler et al., 2011).

Several aspects of the methodological design, particularly the control group, allow for confidence that any observed improvements in task focus and performance were a direct result of the mindfulness training rather than a confounding element of the mindfulness program or the research design. All participants understood that they would be randomly assigned to a training program, which eliminated any self-selection effects between conditions. Both classes were taught by expert instructors, were composed of similar numbers of students, were held in comparable classrooms during the late afternoon, and used a similar class format, including both lectures and group discussions. Furthermore, all participants were recruited under the pretense that the study was a direct comparison of two equally viable programs for improving cognitive performance, which minimized motivation and placebo effects. Finally, we minimized experimenter expectancy effects by testing participants in mixed-condition groups in which nearly all task instructions were provided by computers.

Results

Accuracy on the verbal GRE measure at pretesting was correlated with participants' SAT reading-comprehension scores from when they had applied to college ($r = .446$, $p = .003$), which provided support for the ecological validity of this laboratory measure. For each performance and mind-wandering variable, a mixed-model analysis of variance (ANOVA) was conducted with condition (mindfulness training vs. nutrition training) entered as a between-subjects factor and testing session (before training vs. after training) entered as a within-subjects factor. Prior to training, there were no significant differences in GRE accuracy ($p = .98$), in WMC ($p = .48$), or in probe-caught ($p = .41$), self-caught ($p = .34$), or retrospectively self-reported ($p = .07$) mind wandering. We found a significant main effect of session only for WMC, $F(1, 46) = 17.102$, $p < .001$ (all other ps $> .05$).

More important, the condition-by-session interaction was significant for each of the performance and mind-wandering variables. Relative to the nutrition program, mindfulness training led to improved accuracy on the GRE, $F(1, 46) = 5.609$, $p = .02$, higher WMC, $F(1, 46) = 3.954$, $p = .05$, and less probe-caught mind wandering, $F(1, 46) = 8.241$, $p = .006$, self-caught mind wandering, $F(1, 46) = 3.956$, $p = .05$, and retrospectively self-reported mind wandering during testing, $F(1, 46) = 5.337$, $p = .03$. Follow-up t tests indicated that the mindfulness training led to significant improvements in performance and reductions in mind wandering across all variables (ps $<$ .05; Fig. 1). Using standardized score conversion procedures for the GRE test, the change in GRE accuracy from mindfulness training led to an average improvement analogous to 16 percentile points.

Given that only participants whose minds had wandered at pretesting could measurably improve their focus, we next examined whether improvement in WMC and GRE performance following mindfulness training was mediated by reduced mind wandering specifically among participants who were prone to mind wandering at pretesting. Following Preacher, Rucker, and Hayes (2007), we ran a test of moderated mediation examining whether the effect of condition on change in performance (an average of changes in the proportion of correct responses on the WMC and GRE measures) was mediated by change in mind wandering (an average of z-score-standardized changes in probe-caught and retrospectively self-reported mind wandering) specifically for participants with high levels of baseline mind wandering (an average of z-score-standardized probe-caught and retrospectively self-reported mind wandering at pretesting; see Table 1).

Following standard procedures, we examined the indirect effect of condition on change in performance through change in mind wandering at three conditional values of baseline mind wandering (corresponding to the mean, 1 *SD* above the mean, and 1 *SD* below the mean). The indirect effect was significant only at 1 standard deviation above the mean (Table 2). Change in mind wandering therefore significantly mediated the effect of mindfulness training on change in performance among participants who exhibited a tendency to mind-wander at pretesting.

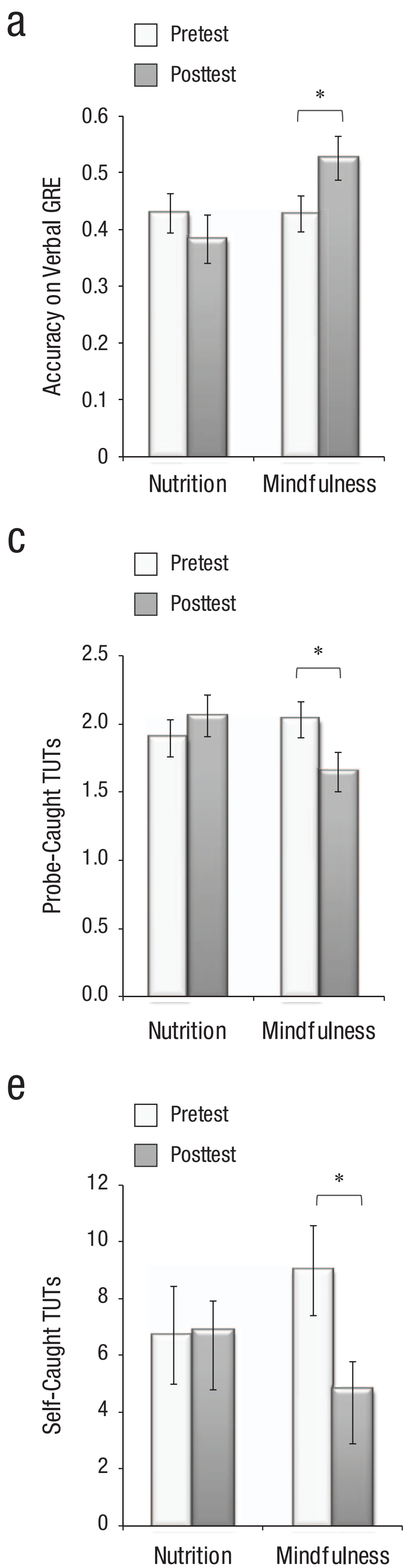

Fig. 1. Results. The graphs show results for each of the following study variables as a function of condition and testing session: (a) accuracy (proportion of correct responses) on the GRE, (b) working memory capacity (WMC), (c) probe-caught TUTs (task-unrelated thoughts), (d) retrospectively self-reported TUTs during performance of the WMC measure, and (e) self-caught TUTs during performance of the GRE. Error bars represent standard errors of the mean. Asterisks indicate significant differences between the two testing sessions ($p < .05$).

Table 1. Moderated-Mediation Results

Predictor	β	*SE*	Statistical test	*p*
Predicting the mediator				
Constant	1.124	0.363	$t(46) = 3.097$	.003
Condition	−0.734	0.225	$t(46) = -3.257$	.002
Predicting the outcome variable				
Constant	−0.177	0.196	$z = -0.899$	.374
Condition	0.183	0.123	$z = 1.490$	.144
TUT change	−0.126	0.080	$z = 1.566$	.125
TUT baseline	0.027	0.077	$z = 0.352$	.727
TUT Change × TUT Baseline	−0.178	0.058	$z = -3.079$	.004

Note: In the moderated-mediation model, change in mind wandering (task-unrelated thought, or TUT) was the mediator variable, baseline mind wandering was the moderator variable, and change in performance was the outcome variable.

This finding demonstrates that, relative to nutrition training, which did not cause changes in performance or mind wandering, the mindfulness training led to an enhancement of performance that was mediated by reduced mind wandering among participants who had been prone to mind wandering at pretesting.

Discussion

The present study demonstrates that a 2-week mindfulness training program can elicit increased WMC and superior reading comprehension on the GRE. The practice of mindfulness encouraged in our intervention entailed promoting a persistent effort to maintain focus on a single aspect of experience, particularly sensations of breathing, despite the frequent interruptions of unrelated perceptions or personal concerns. The present findings suggest that when this ability to concentrate is redirected to a challenging task, it can prevent the displacement of crucial task-relevant information by distractions. At least for people who struggle to maintain focus, our results suggest that the enhanced performance derived from mindfulness training results from a dampening of distracting thoughts.

Our findings of reduced mind wandering are consistent with recent accounts that mindfulness training leads to reduced activation of the default network, a collection of brain regions that typically show greater activation at rest than during externally directed cognitive tasks. Both long-term meditators and individuals who have completed 2 weeks of mindfulness training show reduced activation of the default network (Brefczynski-Lewis et al., 2007; Brewer et al., 2011; Tang et al., 2009). Given that the default network has been repeatedly associated with markers of mind wandering (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Mason et al., 2007), future research should directly test whether mindfulness training reduces mind wandering by dampening activation of the default network.

Table 2. Mediation Effects According to Baseline Levels of Mind Wandering

TUT baseline	Indirect effect	*SE*	*z*	*p*
–0.820 (1*SD* below the mean)	–0.015	0.071	–0.208	.8356
.000 (mean)	0.092	0.068	1.360	.1740
0.820 (1 *SE* above the mean)	0.200	0.095	2.108	.0351

Note: The table presents results from the model of the effect of condition on performance as mediated by mind wandering (task-unrelated thought, or TUT).

Training studies typically involve extensive practice of a task that targets a specific cognitive ability. Often, the goal of these studies is to demonstrate a transfer of improvement beyond the trained task to an unpracticed task measuring the same ability, thereby ruling out explanations based on task-specific learning or strategies (Klingberg, 2010). In principle, the strongest evidence for enhanced cognitive ability is therefore derived from studies that use a training task with little resemblance to the outcome measure. From this perspective, our use of mindfulness-training in the present investigation allowed us to provide a rigorous demonstration of cognitive enhancement that cannot be attributed to overlap between training and testing contexts.

Counter to the longstanding assumption that mental aptitude is largely fixed across the life span, recent work has indicated that extensive practice on tests of WMC can generalize to improvements in IQ (Jaeggi et al., 2008) and that IQ can either improve or deteriorate throughout adolescence (Ramsden et al., 2011). Although it is likely that a variety of mechanisms contribute to these changes, the present demonstration that mindfulness training improves cognitive function and minimizes mind wandering suggests that enhanced attentional focus may be key to unlocking skills that were, until recently, viewed as immutable.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

M. D. M., M. S. F., D. T. P., and J. W. S. are supported through U.S. Department of Education Grant R305A110277 awarded to J. W. S. B. B. is supported by a National Science Foundation Graduate Research Fellowship under Grant DGE-0707430. The content of this article does not necessarily reflect the position or policy of the U.S. government, and no official endorsement should be inferred.

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