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Meditation Training Influences Mind Wandering and Mindless Reading

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It is challenging for individuals to maintain their attention on ongoing cognitive tasks without being distracted by task-unrelated thought. The wandering mind is thus a considerable obstacle when attention must be maintained over time. Mental training through meditation has been proposed as an effective method of attenuating the ebb and flow of attention to thoughts and feelings that distract from one's foremost present goals. We provide evidence from 2 longitudinal studies that intensive meditation training in focused attention and monitoring meditation is associated with attenuated lapses of attention while reading. Across 2 studies, participants completed a reading task requiring ongoing error monitoring to detect episodes of semantic inconsistency. In a preliminary study, training participants were assessed at the beginning and end of a 3-month *shamatha* meditation retreat and again 7 years later. In a second study, training and experience-matched control participants were assessed at the beginning and end of a 1-month *insight* meditation retreat. Across both studies, training participants engaged in less mind wandering and less mindless reading following meditation training. Intensive meditation training may promote reductions in mind wandering among practitioners when required to maintain attention during a complex cognitive task.

Keywords: attention, meditation, mind wandering, reading

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Thought often arises and unfolds with little regard to the ongoing circumstances of the external environment. Task-unrelated thought may accompany almost half of all waking experience (Kane et al., 2007; Killingsworth & Gilbert, 2010), occupying a profound portion of our mental lives. Given the propensity for discursive thought to occupy awareness, it is perhaps unsurprising that mind wandering can have a substantial influence on our performance when attention must be maintained over time. Task-unrelated thought can dominate awareness at the expense of attending to one's current task or goal, resulting in significant performance impairments (Kam & Handy, 2013; Smallwood & Schooler, 2006, 2015). In situations in which attention is necessary for success or safety, such as in the workplace or when navigating traffic, consequential performance errors can occur when attention is decoupled from the current task and instead becomes occupied with the contents of thought (He, Becic, Lee, & McCarley, 2011; Yanko & Spalek, 2014). The wandering mind can thus be a considerable hindrance in daily life.

The maladaptive consequences of task-unrelated thought are a central focus of many traditional Buddhist contemplative models of cognition (Fell, 2012; MacLean & Weber, 2013; Wallace, 1999, 2006). Within this framework, recurring mental distractions are thought to limit an individual's attention from being applied in wholesome and useful ways, which in turn can lead to significant psychological, physical, and soteriological consequences. These accounts suggest that as practitioners gain meditative expertise, the frequency of spontaneous and intrusive thoughts can be reduced, calming the mind and allowing attention to be pliantly directed toward accomplishing one's goals (Wallace, 1999, 2006, 2011). Of central importance to this conception is the notion that attention should be made serviceable to the goals and intentions of the individual and not be held as an involuntary captive of discursive thought. From this perspective, thought itself is not something to be eliminated through meditation training, but rather is an aspect of cognition that requires agency (cf. Metzinger, 2013).

In line with these conceptions, contemplative traditions have developed complex mental training techniques that aim in part at reducing mind wandering and its deleterious consequences (Wallace, 1999, 2006). These meditation techniques are believed to cultivate the capacity to sustain concentration on an object of focus, and to increase the clarity, stability, and duration of an individual's concentration. During a session of focused attention meditation, the practitioner is encouraged to maintain attention on a chosen object (e.g., the tactile sensations of the breath at the aperture of the nostrils) and to monitor ongoing experience for moments when distractions arise. Inevitably, the practitioner's concentration wavers and awareness is drawn off task; remaining vigilant for distractions, the practitioner is encouraged to disengage from the source of distraction and to reorient attention back to the chosen object of focus. In addition, practitioners often engage in practices aimed at the maintenance of present-centered attention to the circumstances, sensations, and mental events that intermittently occupy awareness during meditation practice. These techniques are practiced not only with the aim of reducing lapses of attention during formal sessions of meditation, but also to reduce such lapses during daily life as well. Thus, practitioners are encouraged both to maintain their attention on their present circumstances and to monitor their mental state for distracting rumination.

Training in these meditation techniques is believed to improve a practitioner's capacity to avoid distraction and to notice and reorient attention back to the object of focus when concentration is detrimentally disrupted by a thought, sensation, or event in the environment. For example, training with focused attention meditation should reduce mind wandering as practitioners become more efficient at monitoring their internal mental state for distraction and at redirecting cognitive resources away from task-unrelated thoughts and back to the task at hand. This repeated cycle—noticing that one's attention has wandered from the intended object, noting the new object of attention (noting the distractor), and redirecting attention back to the intended object—constitutes a central practice component of focused attention meditation (Jha, Krompinger, & Baime, 2007). Another important component of practice involves the ongoing assessment of the quality of attention, whether applied to the intended meditative object or during moments of distraction, with the iterative goal of cultivating a calm, wakeful observational stance that suffers neither from felt cognitive sluggishness nor from excitement and over arousal (Wallace, 2006). These techniques familiarize the practitioner with the phenomenological qualities of mind wandering and provide strategies for reorienting attention away from task-unrelated thought when necessary. Engaging with these techniques over time presumably facilitates the development of domain-general cognitive capacities to direct attention and regulate the contents of awareness (Lutz, Jha, Dunne, & Saron, 2015; Malinowski, 2013; Slagter, Davidson, & Lutz, 2011).

Despite the acknowledged importance of mind wandering to both contemplative and psychological models of cognition (Kuan, 2012; Schooler et al., 2014; Wallace, 1999, 2006), studies have provided mixed empirical evidence that mind wandering may be reduced by brief meditation exercises in subsequent moments (Mrazek, Smallwood, & Schooler, 2012) as well as following nonintensive practice over several weeks (Jazaieri et al., 2016; Morrison, Goolsarran, Rogers, & Jha, 2014; Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). One study reported no changes in mind wandering in either training or active control participants following 1 week of nonintensive meditation practice (Banks, Welhaf, & Srour, 2015). Furthermore, a growing body of evidence has suggested that patterns of activity and functional connectivity of brain regions associated with the default-mode network may contribute to changes in the generation and regulation of spontaneous thought during the practice of various forms of concentrative meditation (Brewer et al., 2011; Garrison, Zeffiro, Scheinost, Constable, & Brewer, 2015; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; see Raichle, 2015, for review of the default-mode network and its potential role in self-generated thought). Thus, some evidence supports the notion that meditation practice may reduce the occurrence of mind wandering and increase the ability to regulate the consequences of mind wandering when it occurs. Finally, although several studies have provided support for the notion that intensive meditation training may improve practitioners' capacity to sustain their attentional focus over time during cognitively demanding tasks (Jha et al., 2007; Lutz et al., 2009; MacLean et al., 2010; Sahdra et al., 2011; Zanesco, King, MacLean, & Saron, 2013), the extent to which intensive training also influences mind wandering remains unclear.

In the present studies, we utilized a computer-based reading paradigm (Zedelius, Broadway, & Schooler, 2015) to examine the effects of intensive meditation training on participants' capacity to resist disruption by task-unrelated thought and maintain attention in an ongoing manner. Mindless reading is one of the most salient examples of the consequences of mind wandering in daily life (Smallwood, 2011), and a number of studies have provided evidence that task-unrelated thought can be detrimental to reading comprehension (Broadway, Franklin, & Schooler, 2015; Feng, D'Mello, & Graesser, 2013; Smallwood, McSpadden, & Schooler, 2008; Unsworth & McMillan, 2013) and learning in educational environments (Farley, Risko, & Kingstone, 2013; Lindquist & McLean, 2011; Smallwood, Fishman, & Schooler, 2007; Unsworth, McMillan, Brewer, & Spillers, 2012). Participants in our study read a simple text (i.e., a children's story) displayed through serial single word presentation, and were asked to monitor the text for infrequent semantic irregularities that rendered the meaning nonsensical. Participants' capacity to detect these gross semantic violations served as a behavioral measure of error monitoring and mindless reading (cf. Schad, Nuthmann, & Engbert, 2012).

In addition, this paradigm incorporated experience sampling probes in order to assess the frequency of mind wandering independent of monitoring for errors in the text. Given that mind wandering can occur in the absence of awareness, experience sampling probes may be effective in capturing the occurrence of task-unrelated thought during task performance (Smallwood & Schooler, 2015). We hypothesized that meditation training would increase an individual's capacity to resist disruption by task-unrelated thought and reduce instances of mindless reading and mind wandering. In particular, we predicted that practitioners would be quicker at detecting episodes of gibberish (operationalized as the number of words presented before detection of textual gibberish) and should report fewer instances of mind wandering following training.

Here we present the results of two separate longitudinal studies of intensive meditation training. Our aim across these studies was to utilize measures of mind wandering and mindless reading to explore whether intensive mental training is associated with reductions in task-unrelated thought. In both studies, participants completed a gibberish detection task (Zedelius et al., 2015) before (*preassessment*) and after (*postassessment*) a long-term residential meditation retreat. In the first study, participants were assessed before and after completing 3 months of training primarily in concentration (shamatha) meditation techniques (Wallace, 1999, 2006), then again approximately seven years following the conclusion of training. In the second study, a separate cohort of training participants was assessed at the beginning and end of a month-long meditation intervention during which they practiced concentration, monitoring, and deconstructive techniques (Dahl, Lutz, & Davidson, 2015; Lutz, Slagter, Dunne, & Davidson, 2008), commonly known as *insight* meditation (Goldstein, 1976; Goldstein & Kornfield, 2001). This second study included a group of demographic- and meditation-experience-matched control participants who completed identical longitudinal assessments but did not undergo training. These studies were conducted in the context of broader investigations of the effects of intensive meditation practice on attention and emotional responding, and served as initial exploratory assessments of the sensitivity of measures of mind wandering to intensive meditation practice.

Study 1

Method

Participants. Sixty participants were recruited through online and printed media and randomly assigned to either an initial training ($n = 30$) or wait-list control ($n = 30$) group through stratified matched assignment (see Table 1 for demographic and meditation experience information; see Sahdra et al., 2011, for full demographic matching criteria). Training participants underwent a 3-month-long intensive residential meditation retreat located at Shambhala Mountain Center (SMC) in Red Feather Lakes, Colorado. Approximately three months following this initial retreat, wait-list control group participants ($n = 29$) underwent formally identical training during a second 3-month retreat held at SMC. All participants were assessed at the beginning, middle, and end of each retreat using a comprehensive collection of cognitive, affective, and physiological measures (several of which are reported elsewhere, e.g., MacLean et al., 2010; Rosenberg et al., 2015; Saggar et al., 2015; Sahdra et al., 2011). The gibberish detection task was administered at the beginning and end of this second retreat. Thus, the training data reported here are from wait-list control participants as they underwent

Table 1
Demographic and Experience Variables

Measure	Study 1 Training group	Study 2 Training group	Study 2 Control group	*t* value (*df*)	*p* value
Age (years)	46 (22–65)	50.41 (25–70)	54.35 (23–72)	1.07 (51)	.29
Sex	14 male, 16 female	9 male, 19 female	6 male, 21 female	—	—
Education	4.90 (3–6)	5.07 (3–6)	4.88 (2–6)	.60 (50)	.55
Income	6.45 (1–11)	8.00 (1–11)	7.30 (1–11)	.75 (53)	.46
Mean meditation (min/day)	54 (12.8–155)	40.17 (0–320)	30.58 (6–120)	.76 (50)	.45
Lifetime meditation (hours)	2470.61 (200–15000)	3205.62 (165–15000)	1742.36 (76–9265)	1.80 (47)	.08
Years of experience	13.11 (2–40)	13.33 (3–39)	10.32 (1–30)	1.16 (49)	.25

Note. Mean values and ranges (in parentheses) are provided for demographic and meditation experience variables for the full participant sample for Study 1 (training, $N = 29$) and Study 2 (training, $N = 28$; control, $N = 27$). Independent samples *t* tests between groups in Study 2 revealed no significant differences on reported variables (all $ps > .05$) at initial assessment. Education was scored on the following scale: 1 = less than high school diploma; 2 = high school diploma; 3 = some college; 4 = college degree; 5 = some graduate study; 6 = graduate degree. Total annual household income was reported on the following scale: 1 = $10,000 or less; 2 = $10,001 to $20,000; 3 = $20,001 to $30,000; 4 = $30,001 to $40,000; 5 = $40,001 to $50,000; 6 = $50,001 to $60,000; 7 = $60,001 to $70,000; 8 = $70,001 to $80,000; 9 = $80,001 to $90,000; 10 = $90,001 to $100,000; 11 = More than $100,000. Estimated meditation experience variables included average daily minutes of formal meditation practice during the past month, total number of lifetime hours of formal meditation practice, and number of years practicing meditation. *df* = degrees of freedom.

training in the second 3-month meditation retreat.

Additionally, participants from both the initial and wait-list training groups were invited to participate in a long-term follow-up conducted approximately seven years (M = 6.73 years, range = 6.02–7.71 years) following the completion of their respective training. These follow-up data thus comprise two groups of participants that differ in their assessment waves of the gibberish detection task: wait-list training participants from the second retreat (referred to as the *training group*) who completed the task both during retreat (pre- and postassessment) and again at the long-term follow-up, and participants who received training in the initial retreat but who did not complete the gibberish task during retreat (referred to as the *follow-up comparison group*). This later group completed the task for the first time at the follow-up assessment and serve here as a comparison group to examine effects of task-repetition and compare performance in another cross-sectional sample. Complete longitudinal follow-up data were available for 23 participants from the Retreat 2 training group, and cross-sectional data are available using 21 participants from the initial retreat who completed the task only at the follow-up testing. All study procedures were approved by the institutional review board of the University of California, Davis. Participants gave informed consent and were debriefed following training. All participants paid for their room and board during their retreat (~$5,300), but were compensated $20 for each hour of data collection during retreat and during follow-up.

Meditation practice. During the first retreat, wait-list control participants continued their regular meditation practice routine while living their daily lives at home. Participants later received training in meditation during the second retreat under the guidance and instruction of an experienced Buddhist contemplative, meditation teacher, translator, and scholar (Dr. B. A. Wallace). Training employed two general classes of techniques drawn from the Buddhist contemplative tradition: shamatha techniques that involve sustaining attention on a chosen object (e.g., the breath), and ancillary techniques aimed at generating benevolent aspirations for the well-being of self and others (e.g., loving-kindness, compassion; Wallace, 2006). Throughout their day, participants were encouraged to maintain mindful, present-centered awareness on whatever task or activity in which they were engaged. Details of the specific practices employed in this training are outlined in Sahdra et al. (2011). At the end of each day, participants recorded the amount and type of each practice over the course of the second retreat in daily journals. Participants met twice daily for group meditation practice and discussion guided by Dr. Wallace, and devoted about six hours (M = 6.0, SD = 1.5) of their remaining daily time to formal solitary meditation practice. Participants were free to determine the amount of their solitary meditation dedicated to each type of practice in consultation with Dr. Wallace, with the preponderance of their practice time devoted to shamatha practices. Participants also met with Dr. Wallace privately once a week for individual advice and guidance.

Procedure. Participants completed the gibberish detection task at pre- and postassessment as part of a battery of cognitive–behavioral tasks. Testing occurred in a behavioral testing room in a lodge at SMC where participants lived and practiced meditation. The task was implemented using E-Prime software (Neurobehavioral Systems; http://www.neurobs.com), and stimuli were presented on a Viewsonic VX-922 LCD monitor in a dimly lit room. The gibberish detection task was also administered on laptops roughly seven years following completion of the training. Participants were contacted and a box containing an IBM T-40 ThinkPad laptop equipped with E-Prime software was sent to their place of residence, as well as materials and detailed instructions for assembling an in-home testing station and completing the task. Participants were asked to set up a dimly lit testing environment free of distractions for the testing period.

Gibberish detection task. Participants read a simple children's story in a self-paced reading format using the spacebar on the keyboard to present text (black text on white background) one word at a time at the center of the screen. During the second retreat, each participant was assigned to read one of two possible children's stories, with one story viewed at preassessment and the second presented at postassessment. Stories were counterbalanced across pre- and postassessments. At the follow-up assessment, all participants read the same narrative, which was one of the two stories presented during Retreat 2. Thus, participants in the training group had previously viewed the story at either their pre- or postassessment. At follow-up, the comparison group completed the task for the first time and viewed the same story as the training group.

Participants were instructed to read the text while monitoring for instances of gibberish (i.e., to notice when the text turned to "gibberish") and to respond as soon as they were aware of gibberish by pressing the "G" key on the keyboard. Once a gibberish episode began, the text continued as gibberish until the participant detected the episode. To construct gibberish episodes, sentences were modified so that text-relevant words were used in a grammatical manner, but the ordering of words was manipulated in such a way as to render the string of text nonsensical. For example, the sentence "We must make some money for the circus" might instead appear as "We must make some circus for the money." Gibberish episodes were presented pseudorandomly throughout the story. Consequently, the number of episodes differed slightly at each testing session and occurred at different points in the story for participants. Approximately 18 episodes of gibberish (preassessment, $M = 17.9$ gibberish episodes, $SD = 1.9$; postassessment, $M = 18.1$ gibberish episodes, $SD = 1.8$; longitudinal follow-up, $M = 18.6$ gibberish episodes, $SD = 2.2$; comparison follow-up, $M = 18.7$ gibberish episodes, $SD = 2.1$) occurred at pseudorandom intervals ($\sim$1.5 min between episodes) throughout the story for each participant. After a gibberish episode was correctly detected, the story (i.e., nongibberish) text continued normally, beginning with the sentence where the text had previously turned into gibberish. Participants generally reported detecting gibberish episodes only when they were actually present (preassessment false alarm rate, $M = 0.27$, $SD = 0.12$; postassessment false alarm rate, $M = 0.17$, $SD = 0.12$; longitudinal follow-up false alarm rate, $M = 0.22$, $SD = 0.14$; comparison follow-up false alarm rate, $M = 0.21$, $SD = 0.18$).

Throughout the task, participants were presented with thought probes asking whether they were on-task or off-task at that moment. Approximately nine probes (preassessment, $M = 8.8$ probes, $SD = 2.5$; postassessment, $M = 9.7$ probes, $SD = 2.4$; longitudinal follow-up, $M = 9.6$ probes, $SD = 2.5$; comparison follow-up, $M = 9.3$ probes, $SD = 2.1$) were delivered at pseudorandom intervals ($\sim$2.5 min between probes) throughout the story. In response to each probe, participants could report that they were either on-task or off-task. For off-task responses, participants were asked to indicate one of two types of mind wandering: *tuning out* or *zoning out*. Participants were instructed to report tuning out if they were already aware that their attention had drifted from the task at the time the probe was presented. In contrast, participants were instructed to indicate that they were zoning out if they noticed that they were off task only after they were alerted by the mind wandering probe. Zoning out therefore reflects instances of mind wandering in which participants are unaware that their attention has drifted from the task and are "lost" in task-unrelated thought. Finally, participants were instructed to freely report self-caught episodes of mind wandering (using the "M" key) whenever they noticed that they were thinking about something unrelated to the current story. For these self-caught episodes, participants were also asked to report whether they were tuning out or zoning out. Instances of mind wandering were therefore identified using both probe-caught and self-caught methods in this task.

Each story ended after approximately 30 min ($M = 30.2$ min, $SD = 1.7$), even if the participant had not fully completed the story. Participants then completed a series of comprehension questions assessing knowledge of specific events and characters from the text they had just read. Approximately 25 four-option multiple-choice questions were presented following each story (preassessment, $M = 24.9$ questions, $SD = 7.5$; postassessment, $M = 25.4$ questions, $SD = 6.9$; longitudinal follow-up, $M = 23.7$ questions, $SD = 6.0$; comparison follow-up, $M = 23.2$ questions, $SD = 5.3$).

Analysis. We analyzed longitudinal changes in four dependent measures derived from the gibberish detection task. *Gibberish detection* was quantified as the number of words that a participant read in a gibberish sentence before detection of a gibberish episode. This was defined as the number of times a participant pressed the space bar to continue reading from the instance the text had changed to gibberish. *Probe-caught mind wandering* was quantified by coding whether a participant reported being on-task (coded 0) or off-task (coded 1) for each randomly presented mind wandering probe. Additional analyses explored whether differences in off-task states reflected changes in aware (i.e., tuning out) or unaware (i.e., zoning out) mind wandering. *Self-caught mind wandering* was the total number of self-reported mind wandering episodes for each individual. Finally, *comprehension accuracy* was quantified as proportion accuracy of correct answers to the post-story comprehension questions.

Dependent measures from the gibberish detection task were analyzed using multilevel mixed effects models with PROC MIXED and PROC GLIMMIX in SAS version 9.4. We employed multilevel Poisson regression models to analyze count data for both gibberish detection and self-caught mind wandering. These models assume a Poisson distribution and utilize a logarithmic link function. For analysis of gibberish detection, the gibberish word count corresponding to each gibberish episode was entered as a separate observation. We employed multilevel logistic regression models (Guo & Zhao, 2000) to analyze the binomial responses (off-task or on-task) of probe-caught mind wandering and results are reported as odds ratios (*OR*s). Each random probe occurrence was included as a separate observation in the analysis. Parameters were estimated using maximum likelihood estimation based on adaptive quadrature. Random effects were included for the intercept in all multilevel analyses. Chi-square Type III tests of fixed effects are reported alongside parameter estimates, *OR*s, 95% confidence intervals (CIs), and mean comparisons across groups and assessments.

Results

Summary descriptive statistics for measures of mind wandering while reading from Study 1 are reported in Table 2. One participant was missing data at postassessment but was included in multilevel analyses.

Measures of mind wandering. The parameter estimates from analyses of gibberish detection task measures for Study 1 are reported in Table 3.

Gibberish detection. A multilevel Poisson model was used to examine changes in the number of gibberish words that participants continued to read before indicating the text had turned to nonsense. We observed a significant effect of assessment, $\chi^2(1) = 54.83$, $p < .001$. The parameter estimate for this effect, $\beta = -0.230$, $p < .001$, 95% CI [−0.29, −0.17], reflects the difference in the log of counts from pre- to postassessment.[1] Thus, the significant effect of assessment represents a reduction in the frequency of words that training group participants read before detecting incongruities in the text following 3 months of meditation training. Model-estimated frequencies indicate that training group participants were estimated to read 4.3 words at preassessment before detecting that the text had turned into gibberish compared with 3.4 words at postassessment.

Probe-caught mind wandering. Overall, participants reported being off-task on 21 of 265 total probes (8%) at preassessment and 10 of 281 probes (4%) at postassessment. Multilevel logistic models were used to examine changes in the probability of being on-task (coded 0) or off-task (coded 1) across assessments for these random probes. We observed a significant effect of assessment, $\chi^2(1) = 3.85$, $p = .050$. Training group participants were more than 2 times less likely to report being off-task in response to probes at the postassessment than they were at the preassessment, $OR = 0.446$, $p = .050$, 95% CI [0.20, 1.00]. The model-estimated odds of probes classified as off-task was .060 at the preassessment and .026 at the postassessment.

For each indicated off-task probe, participants were asked to report whether they were tuning out versus zoning out. We therefore conducted separate analyses on each of the off-task categories. Separate multilevel logistic models were used to compare occurrences of on-task responses to zoning-out and tuning-out responses, respectively. First, we tested whether the probability of zoning out changed across assessments. The effect of assessment approached, but did not achieve, significance, $\chi^2(1) = 3.81$, $p = .051$, suggesting that a probe was almost 5 times less likely to be classified as zoning out following training, $OR = 0.206$, $p = .051$, 95% CI [0.04, 1.01]. The model-estimated odds of probes classified as zoning out was .012 at the preassessment and .003 at the postassessment. Next, we tested instances of tuning out. We found no significant effect of assessment, $\chi^2(1) = 0.83$, $p = .362$. The model-estimated

[1] Three participants were Spanish-English bilinguals with potential deficits in English reading proficiency. The effect of assessment, $\beta = -0.141$, $p < .001$, 95% CI [−0.21, −0.08], remained significant after removing these individuals from the analysis.

Table 2
Descriptive Statistics for Dependent Measures of Mind Wandering

	Study 1				Study 2			
	Training group			Comparison group	Training group		Control group	
Measure	Pre	Post	Follow-up	Follow-up	Pre	Post	Pre	Post
N	29	28	23	21	25	26	24	23
Gibberish detection	4.83 (3.33)	3.69 (2.09)	3.59 (2.99)	3.74 (2.32)	3.62 (2.70)	3.15 (2.50)	5.05 (3.56)	5.29 (4.00)
Probe-caught TUT	.07 (.11)	.04 (.06)	.06 (.11)	.03 (.07)	.15 (.25)	.06 (.11)	.14 (.24)	.12 (.20)
Self-caught TUT	.52 (1.38)	.39 (1.26)	.61 (1.31)	.14 (.34)	1.24 (2.11)	1.27 (2.05)	1.59 (3.53)	.87 (1.84)
Comprehension	.82 (.09)	.84 (.05)	.78 (.11)	.80 (.08)	.87 (.07)	.89 (.06)	.81 (.09)	.86 (.11)

Note. Means and standard deviations (in parentheses) are reported for dependent variables derived from the gibberish detection paradigm for training participants and 7-year follow-up comparison participants included in Study 1, and both training and control participants in Study 2. Summary statistics were calculated for each individual then averaged to obtain the values reported here. The number of participants with complete summary data is indicated as *N*. Gibberish detection indicates the average frequency of trials until detecting gibberish. Probe-caught task-unrelated thought (TUT) indicates the average proportion of off-task probes. Self-caught TUT indicates the average frequency of self-caught mind wandering. Comprehension indicates the average proportion of correct comprehension questions. Pre = preassessment; Post = postassessment.

odds of probes classified as tuning out was .032 at the preassessment and .020 at the postassessment. Overall, these findings suggest that instances of zoning out may be more sensitive to effects of training than those of tuning out. Participants generally reported being more on-task following the meditation intervention.

Self-caught mind wandering. The frequency of self-caught mind wandering did not change following training, $\chi^2(1) = 0.57$, $p = .450$. It is possible, however, that the frequency of self-caught mind wandering was influenced by an overall reduction in mind wandering across assessments. Participants were about 2 times less likely to report being off-task at the postassessment than at preassessment, potentially constraining the number of mind wandering episodes that were accessible to participants for self-report. Following previous work (Sayette, Reichle, & Schooler, 2009; Sayette, Schooler, & Reichle, 2010), we adjusted the frequency of self-caught mind wandering to account for the change in likelihood of mind wandering between pre- and postassessments. To account for lower levels of mind wandering after training, we multiplied each participant's frequency of self-caught mind wandering at postassessment by the *OR* (0.446), reflecting the relative reduction in probe-caught mind wandering at postassessment. Following this adjustment, we observed a significant effect of assessment, $\chi^2(1) = 4.53$, $p = .033$, suggesting that participants tended to report a greater number of self-caught mind wandering episodes at postassessment, after accounting for reductions in the odds of probe-caught mind wandering across assessments.

Comprehension accuracy. We examined changes in text comprehension accuracy across assessments. We observed no significant effect of assessment, $\chi^2(1) = 2.30$, $p = .130$. Comprehension accuracy did not change following training.

Long-term follow-up. Participants completed an assessment of their performance on the gibberish detection task approximately seven years after the completion of their training intervention. We first investigated levels of mind wandering in participants who had previously completed the task during their meditation retreat.[2] Next we compared these estimates from training group participants with comparison participants who did not complete the gibberish detection task during their training but were assessed at the long-term follow-up.

Gibberish detection. Training participants demonstrated similar levels of gibberish detection at the long-term follow-up assessment compared with their posttraining assessment, $\beta = -0.064$, $p = .07$, 95% CI [−0.13, 0.01].

[2] Effects of story presentation order were examined for all follow-up analyses. For training group participants, performance on measures of mind wandering and comprehension was not influenced by when an individual previously read the designated follow-up story.

Table 3
Parameter Estimates From Analyses of Mind Wandering in Study 1

	Gibberish detection		Probe-caught TUT		Self-caught TUT		Comprehension	
Model Parameter	Estimate (*SE*)	*p*	Estimate (*SE*)	*p*	Estimate (*SE*)	*p*	Estimate (*SE*)	*p*
Fixed effects								
Intercept	1.45 (.10)	<.001	−2.82 (.36)	<.001	−2.40 (.84)	.008	.82 (.01)	<.001
Assessment	−.23 (.03)	<.001	−.81 (.41)	.050	−.30 (.40)	.457	.02 (.02)	.141
Random effects								
$\sigma2_0$ (intercept)	.25 (.07)		.85 (.59)		4.20 (2.73)		.01 (.01)	
$\sigma2_e$ (residual)							.01 (.01)	
N	1,021		528		57		57	
BIC	7,926		229.9		103.9		−129.2	

Note. Maximum likelihood estimates are reported across the fixed effects of assessment (preassessment = 0, postassessment = 1) in the gibberish detection task. Standard errors (*SE*s) are reported in parentheses. Estimates are reported in log counts for gibberish detection and self-caught task-unrelated thought (TUT), and log-odds for probe-caught TUT. For the fixed effects estimates, *p* values are reported from *t* statistics. The number of observations in each analysis is reported as *N*. The Bayesian information criterion (BIC) is provided as an indicator of model fit.

Their performance roughly seven years later was significantly better than their preassessment performance, $\beta = -0.289$, $p < .001$, 95% CI [−0.35, −0.22]. Furthermore, participants mean gibberish detection at postassessment was correlated with their follow-up levels, $\rho(21) = .591$, $p = .003$, suggesting that performance was generally stable within individuals. Model-estimated frequencies suggest that training group participants were estimated to read 3.4 words at postassessment and 3.2 words at the long-term follow-up. At the long-term follow-up, these participants were no different than follow-up comparison participants, $\chi^2(1) = 0.19$, $p = .667$.

Probe-caught mind wandering. Participants in the training group had similar levels of probe-caught mind wandering at the long-term follow-up compared with postassessment, *OR* = 1.677, $p = .26$, 95% CI [0.69, 4.11]. However, although postassessment levels significantly differed from those at preassessment, their performance approximately seven years later was no different than pre- assessment levels, *OR* = 0.755, $p = .49$, 95% CI [0.60, 2.93]. At the long-term follow-up, these participants were no different than those individuals who had not completed the gibberish task while on retreat, $\chi^2(1) = 1.42$, $p = .233$.

Self-caught mind wandering. Training participants reported similar levels of self-caught mind wandering at the long-term follow-up compared with both their postassessment, $\beta = .351$, $p = .393$, 95% CI [−0.47, 1.17], and preassessment estimates, $\beta = .055$, $p = .884$, 95% CI [−0.70, 0.81]. At the long-term follow-up, these participants were no different than those individuals who had not completed the gibberish task while on retreat, $\chi^2(1) = 1.89$, $p = .170$.

Comprehension accuracy. At the long-term follow-up, training participants had worse comprehension accuracy compared with their postassessment, $\beta = -.067$, $p < .001$, 95% CI [−0.10, −0.03], and preassessment, $\beta = -0.043$, $p = .026$, 95% CI [−0.08, −0.01]. Accuracy for training group participants was .84 at postassessment and .77 at the long-term follow-up. At the long-term follow-up, these participants were no different than comparison group participants, $\chi^2(1) = 0.55$, $p = .459$.

Correlations among measures of mind wandering. Nonparametric Spearman correlations were computed between summary measures of gibberish detection, probe-caught mind wandering, self-caught mind wandering, and comprehension accuracy, separately for each assessment. These correlations are reported in Table 4. At the preassessment, mean gibberish was significantly correlated with an individual's comprehension accuracy, $\rho(27) = -.47$, $p = .010$. Individuals who advanced the text longer before detecting gibberish had poorer text comprehension. There were no significant correlations between summary measures at postassessment. At the long-term follow-up, we computed correlations across all individuals who completed the follow-up assessment to examine relations between depen-

Table 4
Correlations Among Dependent Measures of Mind Wandering

Measure	Preassessment			Postassessment		
	1	2	3	1	2	3
Study 1						
1. Gibberish detection	—			—		
2. Probe TUT	.20	—		.03	—	
3. Self TUT	.16	.01	—	−.05	−.25	—
4. Comprehension	−.47*	−.06	−.07	−.33	−.07	−.15
Study 2						
Training group						
1. Gibberish detection	—			—		
2. Probe TUT	.13	—		.45*	—	
3. Self TUT	−.22	−.03	—	.11	.30	—
4. Comprehension	−.18	−.32	−.20	−.28	−.22	−.07
Control group						
1. Gibberish detection	—			—		
2. Probe TUT	.22	—		.42*	—	
3. Self TUT	.09	.46*	—	.43*	.40	—
4. Comprehension	−.12	−.35	−.30	−.46*	−.15	−.01

Note. TUT = task-unrelated thought.
* $p < .05$.

dent measures. There were no significant correlations between summary measures at follow-up.

Meditation practice hours. We examined whether accumulated practice hours over the course of training predicted reductions in mindless reading and mind wandering beyond changes predicted by assessment alone. Participants' accumulated meditation hours from both wait-list and training periods were entered into the previous models of gibberish detection and probe-caught mind wandering. Pre- and postassessment values represented participants' individually-varying practice hours recorded since entering the study. At preassessment, hours represented their total reported practice over the initial 3-month wait-list period ($M = 39.25$ hr of total practice, $SD = 31.06$). At postassessment, hours represented an individual's cumulative total of meditation practice across *both* the wait-list period and the 3-month training period ($M = 432.39$ hr of total practice, $SD = 107.20$). Thus, for both gibberish detection and probe-caught mind wandering, we estimated a continuous slope across cumulative hours of practice while controlling for effects of assessment.

The number of words participants read before detecting gibberish in the text decreased with accumulated practice hours, $\chi^2(1) = 8.28$, $p = .004$. After accounting for accumulated practice hours across the training, the effect of assessment was no longer significant, $\chi^2(1) = 0.38$, $p = .539$. For every hundred hours of practice, log counts of gibberish were reduced by −0.09 (95% CI [−0.15, −0.03]). This indicates that the training-related reduction in the amount of gibberish read by participants can be predicted by accumulated practice hours. When practice hours were entered into the model for probe-caught mind wandering, neither practice hours, $\chi^2(1) = 0.12$, $p = .731$, nor assessment $\chi^2(1) = 0.08$, $p = .784$, were significant.

Discussion

The present findings provide initial support for the notion that reductions in mind wandering and mindless reading are associated with intensive meditation training in a retreat setting. After 3 months of training, participants read fewer words before identifying semantic inconsistencies in the text (gibberish) and, when randomly probed, were less likely to report being off-task. Importantly, these training-related reductions over time were predicted by the cumulative amount of meditation practice participants engaged in during their training. As cumulative hours of practice increased, participants read fewer gibberish words before detection, after accounting for effects of assessments. However, we observed no significant changes in self-caught mind wandering following training. Thus, this longitudinal study provides initial exploratory evidence suggesting that measures of mindless reading and mind wandering may be sensitive to an intensive meditation training intervention.

Participants were experienced and dedicated meditation practitioners who underwent intensive 3-month meditation training and continued to engage in meditation practice in the time following their 3-month meditation retreat. We administered the gibberish detection task again approximately seven years following the retreat in order to examine their levels of mind wandering since they were previously assessed. Participants who completed the task during training demonstrated similar levels of improved gibberish detection about seven years later compared with their preassessment. Levels of probe-caught mind wandering, however, did not continue to differ from preassessment levels at follow-up. The maintenance of these improvements presumably reflects participants' continued commitment to meditation practice and should not be attributed directly to the study intervention without further investigation. These effects may therefore be related to individual differences in participants continued meditation practice. Future studies should collect information following periods of intensive practice in order to examine the longevity of training-related improvements and examine whether continued meditation practice facilitates this maintenance.

Although comprehension accuracy did not change with training, it is unclear why comprehension accuracy was lower at this long-term follow-up. One possibility is that this difference may reflect domain-specific changes in reading comprehension in our aging sample. Participant age at follow-up, however, did not significantly predict any of our reported findings. Another possibility is that there were motivational differences between specific components of the task, such that participants may have devoted limited cognitive resources toward maintaining high levels of error monitoring at the expense of overall narrative comprehension. Finally, the testing environment at participants' homes may have adversely influenced performance at the follow-up. Both reading comprehension and reports of being on-task may have suffered because of unknown environmental distractors that could have reduced performance on the task.

Participants completed the mind wandering paradigm as part of a large battery of cognitive and behavioral tasks in this study. The inclusion of this mind wandering paradigm was intended as an exploratory investigation into the consequences of mental training on task-unrelated thought. Consequently, this mind wandering task was only completed by wait-list training participants during the second of two scheduled meditation retreats. Thus, without a control group, we are unable to rule out the possibility that these findings resulted largely from effects of task repetition. This may be unlikely, however, as participants from the initial retreat, who had never completed the task but engaged in identical training, demonstrated similar performance on measures of mind wandering at the long-term follow-up compared with participants who received training in the second retreat who had previously completed the task. This suggests that task repetition was not a major factor influencing the observed reductions in mind wandering and mindless reading. We attempted to address the limitations of this study in a second investigation, which incorporated an experience-matched comparison group drawn from meditation practitioners not currently undergoing intensive meditation training.

Study 2

In Study 1, we observed reductions in mindless reading as well as reductions in probe-caught mind wandering following 3 months of intensive shamatha meditation training. In Study 2, we examined the effects of 1 month of intensive insight meditation training on identical measures of mind wandering. The gibberish detection task was administered to experienced meditation practitioners before and after 1 month of intensive meditation training and to demographic and meditation-experienced matched control participants. We utilized this comparison group in an attempt to account for biases related to self-selection, expectation, motivation, other preexisting demographic or psychological factors unique to cohorts of meditation practitioners, and any effects of retest that may account for reductions in mind wandering. We predicted that meditation training would improve gibberish detection and reduce mind wandering relative to demographic and meditation-experienced matched control participants.

Method

Participants. Twenty-eight self-selected volunteers were recruited from a pool of individuals undergoing 1 month of intensive training at a residential retreat center at Spirit Rock Meditation Center (SRMC) in Woodacre, California. Training participants were assessed at the beginning and end of a retreat on several computer-based cognitive and affective measures (some of which are reported elsewhere; Zanesco et al., 2013). A comparison group of 27 control participants (matched on demographic variables and meditation experience; see Table 1) were recruited from SRMC community meditation classes and day-long retreats, and were tested onsite at SRMC before and after an interval of approximately one month (M = 27.7 days, SD = 3.5 days). Control participants were experienced with meditation but did not undergo intensive training between study assessments and had not completed any retreats up to 4 weeks prior to beginning the study. Study details were approved by the institutional review board of the University of California, Davis. Participants gave informed consent at the first assessment and were debriefed at the end of the second assessment. Training participants paid for their room and board during their retreat (~$3,700), and all participants were compensated $15 for each hour of study participation.

Meditation training. Training involved practice with several meditation techniques known collectively as *vipassana* or *insight* meditation, drawn primarily from the Theravada Buddhist tradition (Goldstein, 1976; Goldstein & Kornfield, 2001). Meditation instruction was provided by multiple experienced SRMC teachers. Meditation techniques involved the application of focused attention to the physical sensations of the breath and body; the observation and identification of sensations, thoughts, desires, intentions, and emotions; and the metacognitive monitoring of the quality of attention and the diversity of mental states as they arise. Participants also engaged in a number of ancillary aspirational meditation practices emphasizing the cultivation of compassion and loving kindness (e.g., Salzberg, 2002) to supplement the primary training. They were encouraged to maintain mindful present-centered awareness throughout their day on whatever task or activity in which they were engaged. Participants maintained silence for the duration of the retreat and typically attended 13 45-min group meditation sessions each day (seven sessions of sitting meditation and six sessions of slow walking meditation). In this regard, many features of training employed in Study 2 were similar to those of Study 1. In both studies, the training involved focused-attention meditation techniques, ancillary exercises for the generation of compassion, and the maintenance of present-centered awareness on the circumstances, sensations, and mental events that accompany experiences throughout the day.

Procedure. Training group participants were tested on the morning of the first and last day of silence, before the formal conclusion of the retreat. Testing sessions took place in participants' individual dormitory rooms. Each participant was provided with a laptop box containing an IBM T-40 ThinkPad laptop equipped with E-Prime software (http://www.pstnet.com) to control stimulus delivery and record behavioral responses, as well as materials and instructions for assembling a testing environment in their individual dormitory room. Participants maintained dim ambient lighting (i.e., blocking window light and using a low-wattage lamp) and a set viewing distance of 57 cm from the computer screen. Control group participants underwent identical testing procedures and were assessed in small cohorts in the same dormitories at SRMC. At each testing session, participants completed the gibberish-detection task, which was the fourth of six behavioral tasks completed at each assessment. Although this novel testing procedure allowed us to simultaneously collect data from all study participants and to minimize the invasiveness of the testing procedures, it may have contributed to a number of potential data collection issues (see Results).

Gibberish detection task. The gibberish detection paradigm and stories were identical to those used in Study 1. Participants were assigned one of two possible stories at the preassessment and the second story at postassessment. Story presentation was counterbalanced across participants. The stories ended approximately 27 min (M = 27.2 min, SD = 2.3) after they began. Participants were asked to detect when the text turned into "gibberish," using the "G" key on the keyboard to indicate that gibberish was present (precontrol, M = 17.2 gibberish episodes, SD = 2.7; postcontrol, M = 17.5 gibberish episodes, SD = 1.9; pretraining, M = 17.3 gibberish episodes, SD = 2.8; posttraining, M = 18.2 gibberish episodes, SD = 3.3) at pseudorandom intervals (M = 81.42 s between episodes, SD = 14.53) throughout the story. Participants generally responded only when gibberish was present (precontrol false alarm rate, M = 0.27, SD = 0.19; postcontrol false alarm rate, M = 0.21, SD = 0.13; pretraining false alarm rate, M = 0.28, SD = 0.14; posttraining false alarm rate, M = 0.20, SD = 0.14). Thought probes were presented randomly throughout the experiment (M = 157.93 s between probes, SD = 52.46) to track instances of task-unrelated thought (precontrol, M = 8.4 probes, SD = 2.8; postcontrol, M = 9.9 probes, SD = 2.4; pretraining, M = 8.7 probes, SD = 2.4; posttraining, M = 9.5 probes, SD = 3.4). A series of comprehension questions were administered at the end of the story, each with four possible answers (precontrol, M = 25.4 questions, SD = 8.0; postcontrol, M = 28.5 questions, SD = 7.8; pretraining, M = 24.5 questions, SD = 7.4; posttraining, M = 26.1 questions, SD = 7.3).

Analysis. All analyses followed the same analytic strategy described in the Method section of Study 1 using PROC MIXED and PROC GLIMMIX in SAS Version 9.4. For Study 2 analyses, in addition to fixed effects of assessment, the effect of group (control = 0, training = 1) was included in all models, as was the interaction between assessment and group. Random effects were included on the intercept to allow for individual differences. Chi-square Type III tests of fixed effects are reported for all multilevel analyses.

Results

There were no significant differences between groups on demographic or meditation-experience variables at preassessment (see Table 1), though differences in hours of estimated lifetime meditation experience approached significance. Two control participants were excluded from analyses because of excessive failure to detect ongoing gibberish (M = 97.6 words per episode, SD = 274.9), suggesting that these participants advanced the text without regard to content. Two training participants were excluded because they did not follow task instructions. One additional control participant was excluded because of an interruption of the testing session and failure to complete the task. Data were lost for two individuals (one control) across dependent variables at one of the two assessments, but were included in multilevel analyses. Thus, the final behavioral sample included 26 training and 24 comparison group participants. Descriptive summary statistics for these participants in Study 2 are reported in Table 2.

Measures of mind wandering. Parameter estimates from analyses of dependent measures derived from the gibberish detection task for Study 2 are reported in Table 5.

Gibberish detection. Multilevel Poisson models were used to examine changes in the frequency of words read by participants before recognizing the text as nonsense. We observed a significant effect of group, $\chi^2(1) = 5.37$, p = .021, but no significant effect of assessment, $\chi^2(1) = 3.13$, p = .077. Importantly, we observed a significant interaction between group and assessment, $\chi^2(1) = 11.26$, $p < .001$. The parameter estimate for this interaction, β = −0.164, $p < .001$, 95% CI [−0.26, −0.07], reflects a reduction of the number of words that training group participants continued to read before detecting a gibberish episode, over and above that observed for control participants.

Mean comparisons confirmed that training group participants read fewer gibberish words per episode at postassessment compared with preassessment, β = −0.125, $p < .001$, 95% CI [−0.20, −0.05], whereas control group participants did not change across assessments, β = 0.039, p = .222, 95% CI [−0.02, 0.10]. The difference between groups at the preassessment approached, but did not achieve, significance, β = −0.339, p = .064, 95% CI [−0.70, 0.02]. Importantly, we observed a significant difference at postassessment, β = −0.503, p = .006, 95% CI [−0.86, −0.14]. Model-estimated frequencies suggest that training group participants were estimated to read 2.94 words at the preassessment before detecting that the text had

Table 5
Parameter Estimates From Analyses of Mind Wandering in Study 2

Model Parameter	Gibberish detection Estimate (*SE*)	*p*	Probe-caught TUT Estimate (*SE*)	*p*	Self-caught TUT Estimate (*SE*)	*p*	Comprehension Estimate (*SE*)	*p*
Fixed effects								
Intercept	1.42 (.13)	<.001	−3.67 (.58)	<.001	−1.24 (.56)	.030	.81 (.02)	<.001
Assessment	.04 (.03)	.222	.35 (.39)	.370	−.55 (.28)	.055	.05 (.02)	.018
Group	−.34 (.18)	.064	.61 (.71)	.388	.21 (.68)	.756	.06 (.02)	.015
Assessment × Group	−.16 (.05)	<.001	−1.51 (.56)	.008	.61 (.38)	.114	−.03 (.02)	.302
Random effects								
$\sigma2_0$ (intercept)	.40 (.08)		3.59 (1.39)		3.53 (1.36)		.01 (.01)	
$\sigma2_e$ (residual)							.01 (.01)	
N	1,709		894		98		96	
BIC	11,591		488.6		275.4		−191.5	

Note. Maximum likelihood estimates are reported across the fixed effects of assessment (preassessment = 0, postassessment = 1) and group (control group = 0, training group = 1) in the gibberish detection task. Standard errors (*SE*s) are reported in parentheses. Estimates are reported in log counts for gibberish detection and self-caught task-unrelated thought (TUT), and log-odds for probe-caught TUT. For the fixed effects estimates, *p* values are reported from *t* statistics. The number of observations in the analysis is reported as *N*. The Bayesian information criterion (BIC) is provided as an indicator of model fit.

turned into gibberish compared with 2.59 words at the postassessment. Control group participants were estimated to read 4.12 words at the preassessment and 4.28 words at the postassessment.

Probe-caught mind wandering. Training participants reported being off-task on 30 of 218 total probes (13%) at preassessment and 12 of 247 probes (5%) at postassessment. Control participants reported being off-task on 18 of 202 probes (9%) at preassessment and 23 of 227 probes (10%) at postassessment. The logistic model examining changes in the likelihood of being off-task revealed no significant effect of group, $\chi^2(1) = 0.04$, $p = .833$, and no significant effect of assessment, $\chi^2(1) = 2.01$, $p = .156$. There was, however, a significant interaction between group and assessment, $\chi^2(1) = 7.12$, $p = .008$. Specifically, training group participants were less likely to report being off-task at postassessment than at preassessment, *OR* = 0.316, $p = .004$, 95% CI [0.14, 0.70], whereas control group participants did not change over time, *OR* = 1.423, $p = .370$, 95% CI [0.66, 3.08]. Groups, however, did not differ at the preassessment, *OR* = 1.846, $p = .388$, 95% CI [0.46, 7.43], or at the postassessment, *OR* = 0.410, $p = .223$, 95% CI [0.10, 1.72]. For training participants, the model-estimated odds of probes classified as off-task was .063 at the preassessment and .020 at the postassessment. Training group participants were therefore more than 3 times less likely (*OR* = 0.32) to indicate being off-task at the postassessment compared with preassessment.

We conducted additional analyses using multilevel logistic analyses in order to separately compare each off-task category with on-task probes. We first examined changes in the probability of being on-task (coded 0) versus zoning out (coded 1). There was no significant effect of group, $\chi^2(1) = 0.60$, $p = .440$, or assessment, $\chi^2(1) = 0.16$, $p = .685$. The interaction between group and assessment, however, only approached significance, $\chi^2(1) = 3.68$, $p = .056$. Thus, the probability of reporting zoning out was not clearly influenced by the intervention.

Next, we conducted a similar analysis for instances of aware mind wandering (i.e., tuning out). We observed no significant effect of group, $\chi^2(1) = 1.78$, $p = .182$. However, we observed a significant effect of assessment, $\chi^2(1) = 6.54$, $p = .011$, and the interaction between group and assessment, $\chi^2(1) = 6.32$, $p = .014$. Training group participants were about 10 times less likely to report tuning out at the postassessment than preassessment, *OR* = 0.097, $p = .004$, 95% CI [0.02, 0.46], whereas control group participants did not change over time, *OR* = 0.984, $p = .972$, 95% CI [0.40, 2.42]. Groups did not differ at the preassessment, *OR* = 1.243, $p = .754$, 95% CI [0.32, 4.84], but differed at the postassessment, *OR* = 0.123, $p = .030$, 95% CI [0.02, 0.82], indicating that training group participants were about 8 times less likely to report tuning out following training compared with controls. For training participants, the model-estimated odds of probes classified as tuning out was .038 at the preassessment and .004 at the postassessment. Thus, the probability of tuning out was significantly lower for the training group following the meditation intervention and overall reductions in probe-caught mind wandering were largely driven by reductions in tuning out.

Self-caught mind wandering. Multilevel Poisson models were used to examine changes in the number of times that participants self-reported engaging in mind wandering. We observed no significant effect of group, $\chi^2(1) = 0.61$, $p = .435$, assessment, $\chi^2(1) = 1.76$, $p = .185$, or interaction between group and assessment, $\chi^2(1) = 2.59$, $p = .107$. Therefore, the frequency of self-caught mind wandering did not appear to change for either group from pre- to postassessment. As in Study 1, we next adjusted the frequencies of training participants' self-caught mind wandering to account for the reduced likelihood of probe-caught mind wandering across assessments. For training participants, we adjusted the frequency of self-caught mind wandering by multiplying their postassessment frequencies by the *OR* (0.316), reflecting their relative reduction in probe-caught mind wandering at postassessment. Following this adjustment, we observed a significant effect of assessment, $\chi^2(1) = 9.58$, $p = .002$, suggesting that training group participants self-caught more episodes of mind wandering after accounting for their reduction in probe-caught mind wandering.

Comprehension accuracy. Data from two participants (one control) at preassessment were not available because they did not complete the comprehension questions. Postassessment values for these participants were included in these multilevel analyses. We observed a significant effect of assessment, $\chi^2(1) = 6.30$, $p = .012$, a significant effect of group, $\chi^2(1) = 5.61$, $p = .018$, but no interaction between group and assessment, $\chi^2(1) = 1.09$, $p = .296$. These results suggest that levels of text comprehension accuracy were higher at the second assessment for both groups. No effects specific to training were observed for comprehension accuracy.

Correlations among measures of mind wandering. Nonparametric Spearman correlations were computed between summary measures of gibberish detection, probe-caught mind wandering, self-caught mind wandering, and comprehension accuracy, separately for each group and assessment. These correlations are reported in Table 4. At the preassessment, control participants' mean proportion of probe-caught mind wandering was correlated with comprehension accuracy, $\rho(22) = .46$, $p = .024$. At the postassessment, control participants' mean frequency of words read until gibberish detection was significantly correlated with mean proportion of probe-caught mind wandering, $\rho(21) = .42$, $p = .044$, self-caught mind wandering, $\rho(21) = .43$, $p = .041$, and comprehension accuracy, $\rho(21) = -.46$, $p = .027$. For training group participants, mean frequency of words read until gibberish detection was significantly correlated with mean proportion of probe-caught mind wandering, $\rho(24) = .45$, $p = .020$. Thus, at postassessment, control participants who took longer to detect a gibberish episode reported more mind wandering in response to random probes, self-caught more episodes of mind wandering, and had poorer comprehension accuracy. Training group participants who took longer to detect a gibberish episode reported more mind wandering in response to random probes at the postassessment. All other correlations were nonsignificant.

Discussion

This second longitudinal study provides further support that intensive meditation training is associated with reductions in mind wandering and mindless reading. Critically, training group participants demonstrated reductions in the amount of gibberish read and reductions in probe-caught mind wandering across training, whereas control participants did not differ in these measures across assessments. However, we observed no training-related changes in self-caught mind wandering or reading comprehension. Overall, the results of Study 2 replicate the pattern of findings observed in our first study, and suggest that these improvements are not unique to any one retreat environment or teacher, but rather reflect a generalizable pattern of reduced mind wandering following intensive meditation training.

Comparison group participants were members of the same community of meditation practitioners as active training participants, and were well-matched on a number of socioeconomic and demographic characteristics. Furthermore, comparison group participants were experienced meditators who did not differ from training group participants on their overall levels of meditation experience prior to the study. As these comparison group participants were regular meditation practitioners, they were encouraged to continue their ordinary (nonintensive) meditation practice in the time between assessments. Therefore, it is likely that these participants had expectations regarding the benefits of meditation and were equally motivated as those participants who received the intensive intervention. Indeed, when we measured task-related motivation and effort in these same participants following a demanding sustained attention task, the training and control groups did not differ in their amount of self-reported effort and motivation dedicated to task performance (Zanesco et al., 2013).

General Discussion

We provide evidence from two separate longitudinal studies that intensive meditation practice is associated with reductions in mindless reading and probe-caught mind wandering during a word-by-word reading task requiring ongoing error monitoring. In both studies, participants undergoing intensive meditation training were quicker to notice and detect semantic inconsistencies in the text while reading. Participants were also less likely to report being off-task when presented with random thought probes. Together, these findings support the notion that intensive meditation training reduces an individual's tendency to engage in mind wandering and mindless reading.

The reductions in mind wandering reported here are consistent with a growing body of evidence detailing the beneficial consequences of meditative training on attention and executive control (Hölzel et al., 2011; Mrazek et al., 2013; Slagter et al., 2011). In both of the present studies, individuals receiving training were members of a cohort of participants taking part in multimeasure studies examining the potential for intensive meditation practice to improve outcomes of attentional performance and psychological well-being. The same cohorts of participants reported here have demonstrated improved performance accuracy in continuous-performance tasks requiring perceptual discrimination and response inhibition (MacLean et al., 2010; Sahdra et al., 2011; Zanesco et al., 2013). The demonstration of reduced mind wandering in these same individuals further contributes to the literature suggesting that intensive meditation practice may beneficially affect multiple components of vigilant attention (e.g., Lutz et al., 2015). Thus, in intensive meditation training, generalized improvements in the executive control of attentional resources may facilitate the adaptive regulation of task-unrelated thought and the capacity to maintain attention in an ongoing manner.

Meditation practitioners across both studies demonstrated greater levels of error monitoring following training, as measured by their ability to detect gross semantic violations in the text. This suggests that training group participants were more attentive to the story content and ongoing text, allowing them to better detect these salient text discrepancies. In contrast, individuals engaging in mindless reading and task-unrelated thought would presumably be less likely to detect these instances of semantic incongruity. Thus, the increased gibberish detection suggests that training participants demonstrated less mindless reading following the meditation training interventions. Importantly, these reductions in mindless reading were related to meditation practice hours and were maintained almost seven years following a 3-month intervention.

Mind wandering probes revealed that training group participants were less likely to report being off-task following meditation training. As participants need not be aware that they are mind wandering when probes occur, probe-caught mind wandering is thought to reflect the actual frequency of mind wandering episodes that occur for an individual (Smallwood & Schooler, 2006). In Study 1, we observed an overall decrease in the likelihood of participants reporting being off-task when queried after training. Similarly, Study 2 training group participants were less likely to report being off-task at the second assessment, whereas control group participants reported similar levels of probe-caught mind wandering across assessments. Investigation of specific forms of off-task mind wandering revealed that the overall decrease in the likelihood of being off-task when probed was likely the result of a reduction in instances of both unaware (zoning out) and aware (tuning out) mind wandering in Study 1, whereas reductions in Study 2 were primarily a result of tuning out. Overall, these findings corroborate the notion that meditation training facilitates an increased capacity to maintain task-related attention.

The reduction in tuning out observed in Study 2 suggests that training participants experienced fewer instances of mind wandering in which they were aware of their off-task state. One possible explanation is that when training participants were aware of their wandering mind, they were able to quickly redirect their attention back to the task before a probe was able to catch this lapse. When unaware of their mind wandering, practitioners may not be able to engage their capacity to recouple attention in a consistent manner. In this regard, probe-caught measures of mind wandering might be expected to catch more episodes of mind wandering without awareness than episodes with awareness following training. It seems likely that these findings reflect an increase in practitioners' capacity to regulate instances of mind wandering when they occur. Thus, the reduction in tuning out, but not zoning out, observed following training in Study 2 supports the notion that training facilitates the efficient recoupling of attention to the task when participants are aware of their wandering mind.

An important avenue of future research on meditation training will be to understand whether reductions in task-unrelated thought primarily reflect a baseline reduction in spontaneous thought, an improved capacity to maintain an attentional task set that is resistant to attentional lapses, or an increased capacity to regulate mind wandering when it occurs. Although evidence from our study suggests that participants may be better at noticing and regulating mind wandering when it occurs, these alternative explanations are also plausible. Phenomenological accounts suggest that meditation leads to a reduction in the spontaneous occurrence of thought as the mind calms naturally with practice (Wallace, 2006, 2011). This may occur in tandem with increases in a practitioner's ability to disengage from distracting thought and reorient attention when focus must be directed and maintained in the service of task performance. Meditation practice may also strengthen the integrity of attentional processes such that task-unrelated thought is suppressed as attention is maintained over time. Each of these three possible processes may have contributed to the findings observed here. Careful interrogation of moment-to-moment changes in mental states using behavioral, neural, and phenomenological methods with high temporal precision are required to better understand these processes as well as approaches that contrast mind wandering at rest with mind wandering during task performance.

Mind wandering may be a particularly challenging phenomenon to investigate among practitioners of meditation. The present results suggest that, regardless of group membership, participants exhibited relatively low levels of mind wandering on measures of gibberish detection and thought probes at preassessment—levels that were nonetheless reduced following intensive meditation training. The groups in our study read almost 4 times fewer words before detecting gibberish in the text than did non-meditation-trained individuals reported elsewhere (i.e., Smallwood et al., 2007). Similarly, the present participants, on average, detected gibberish within the first sentence of the episode, compared with university students who detected gibberish almost two sentences after it began (Zedelius et al., 2015). Finally, related studies of mind wandering while reading also commonly report participants mind wandering between 30% and 50% of the time when randomly probed (Broadway et al., 2015; Feng et al., 2013; Unsworth & McMillan, 2013; Zedelius et al., 2015) in contrast to the low levels reported by our participants. Practitioners of meditation may be particularly adept at regulating task-unrelated thought when required to sustain their attention in service of task performance.

Episodes of mind wandering may therefore be relatively infrequent in this task performance context, reducing the likelihood that task-unrelated thought contributes to lapses in performance. In the present studies, we observed little evidence that mind wandering was a persistent or substantial contributor to lapses in performance among study participants. In support of this notion, we observed few consistent or significant correlations between dependent measures of gibberish detection, comprehension, and probe-caught mind wandering across studies and the overall frequency of mind wandering was low. The performance consequences of task-unrelated thought may potentially be a more significant and challenging problem in novice practitioners or in populations unfamiliar with these attention regulatory techniques. Future research should address this issue by comparing the performance of experienced meditators with that of other groups and populations.

The frequency of self-caught mind wandering was unchanged following meditation training. In contrast to probe-caught mind wandering, self-caught mind wandering is thought to primarily reflect an individual's awareness of mind wandering, rather than the frequency of mind wandering episodes (Smallwood & Schooler, 2006). Meditation practitioners might be expected to report more instances of self-caught mind wandering follow training, presumably reflecting greater levels of metacognitive monitoring of their internal experience. On the other hand, practitioners may also experience fewer lapses of task-related attention following training, which would provide fewer opportunities for practitioners to catch and report their wandering mind. Thus, changes in probe-caught and self-caught mind wandering should be considered in tandem. After adjusting the frequencies of self-caught mind wandering to account for fewer overall episodes of mind wandering (cf. Sayette et al., 2009, 2010), training group participants reported a greater proportion of self-caught mind wandering episodes following training. These findings suggest that meditation training may increase awareness of attentional lapses when they occur, consistent with the notion that training facilitates greater levels of metacognitive monitoring.

It is important to note that practitioners in both studies were encouraged to maintain mindful present-centered awareness on whatever tasks or activities they were engaged in throughout the day. In the studies reported here, training participants lived in a secluded and scenic residential retreat location while engaging in intensive meditation training. Thus, during this time, training participants' daily lives differed markedly (e.g., diet, environment, sleep) from their normal routines. Practitioners' daily routines are necessarily changed when the majority of their waking hours are spent engaged in meditation practice, and at formal retreat centers, practitioners are explicitly supported by environmental and social changes intended to promote seclusion, quietude, and adherence to the training regimen. In this context, daily activities become opportunities for practicing a continuous application of mindful awareness. Thus, although environmental factors likely contribute to a portion of the beneficial effects of meditation practice when individuals engage in long-term intensive meditation retreats, it is challenging to disentangle the consequences of training exercises from altered lifestyle in retreat contexts. It is possible that the altered routine and environment of retreat may have influenced the observed findings either by facilitating dedication to the techniques and exercises participants engaged in throughout their intervention or by influencing these measures directly, for example, by altering participants' current life concerns (Kopp, D'Mello, & Mills, 2015).

One important limitation of these studies is our inability to definitively rule out motivation and expectation as a potential mediator of improvements in task performance. This is a problem because our active training participants may be highly motivated to confirm the benefits of meditation practice, have different performance goals than comparison participants, or may try harder to achieve these goals. Motivation and effort may account for many of the differences in behavioral performance in short-term studies of novice meditation practitioners (Jensen, Vangkilde, Frokjaer, & Hasselbalch, 2012). Ideally, these potential contributing factors require active or wait-list controlled experimental design structured to rule out these confounds definitively.

Despite these limitations, there are a number of reasons to believe these factors may not have unduly influenced performance on the measures of mind wandering and mindless reading in the studies reported here. First, the demographic and meditation-experience-matched comparison participants utilized here should share similar expectations regarding the beneficial effects of meditation as do active training participants. When we measured task-related motivation in a concurrent experiment, this comparison group did not differ on their self-reported effort or motivation compared with the training group (Zanesco et al., 2013). Second, we observed training-specific improvements across a number of important dependent measures, including gibberish detection and probe-caught mind wandering, whereas other measures did not change (self-caught mind wandering) or were not specific to training (comprehension accuracy). The specificity of these training effects on measures most directly related to mind wandering (gibberish detection and probe-caught mind wandering) suggests that motivation may have indefinite or complicated relations with the dependent measures in question. Third, these reductions in mindless reading were predicted by participants' accumulated practice hours over the course of training, suggesting that time or effort spent on meditation practice was one factor mediating performance outcomes.

These limitations are a consequence of the methodological difficulties inherent in longitudinal investigations of intensive meditation training. Although we replicated the present results across two separate longitudinal studies, these findings should be corroborated using wait-list, incentivized, or active controlled experimental designs in order to more thoroughly account for differences in incidental factors such as the scenic retreat environment, social cohesion, and motivation, which may influence performance or mediate training-related improvements. However, implementing these controls is often impractical in long-term studies of this type, but it is more feasible in studies utilizing less intensive or briefer periods of training (e.g., Banks et al., 2015). Shorter term studies, however, may not implement training of suitable duration or intensity to plausibly affect stable or trait-like cognitive outcomes in a lasting manner. Thus, some of the limitations in our study involve our inability to experimentally identify potential active mechanisms or mediators of training-related changes in mind wandering. As our study is fundamentally an exploratory investigation regarding the potential for intensive meditation practice to reduce mind wandering and increase task-related attention, elucidating the precise mechanisms involved in training-related change is beyond the scope of this current investigation. We hope that our research will lead investigators to explore these questions further.

Conclusion

It has been proposed that spontaneous self-generated thought may serve an adaptive role in human cognition, facilitating spontaneous creative elaboration of problems and mental simulations of the future (Schooler et al., 2014; Smallwood & Andrews-Hanna, 2013). Even so, there can be clear affective and performance consequences of inopportune thought-related distraction in situations in which sustained attention is a requirement. A major aim of contemplative mind training is to develop and support the serviceable application of attention toward the accomplishment of task goals and the maintenance of ethical behavior. Through directed mental training, practitioners are thought to enhance their ability to regulate the contents of awareness so that the deleterious consequences of the wandering mind may be tempered. Across two studies of intensive meditation training, we provide supporting evidence that practitioners may engage in less mind wandering following intensive training. When required to maintain attention during a complex cognitive task, practitioners of meditation may be less susceptible to distraction by task-unrelated thought.

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