Mindfulness (2020) 11:203–218
https://doi.org/10.1007/s12671-019-01218-3

ORIGINAL PAPER

Mindfulness Training and Attentional Control in Older Adults: a Randomized Controlled Trial

Patrick Whitmoyer[1] · Stephanie Fountain-Zaragoza[1] · Rebecca Andridge[2] · Keith Bredemeier[3] · Allison Londeree[1] · Liat Kaye[1] · Ruchika Shaurya Prakash[1]

Published online: 4 September 2019

Abstract

Objectives Mindfulness-based interventions have been found to improve facets of attentional control. However, comparison with active control groups has been scarce, and few studies have examined mindfulness as a means to ameliorate age-related cognitive deficits. This rigorously designed randomized controlled trial investigated the effects of mindfulness-based attention training (MBAT) on attentional control in older adults relative to an active control group.

Methods Seventy-four community-dwelling older adults were randomized to 4 weeks of MBAT or an active lifestyle education control group. Pre- and post-intervention, participants completed two computerized measures of attentional control with intermittent assessments of self-reported mind-wandering, with metrics of attentional control and mind-wandering being the primary outcome variables for the study. Additionally, participants completed trait and state measures of mindfulness, the positive and negative affect scale, and homework logs to assess intervention-related engagement.

Results Although we found some evidence for greater reductions in mind-wandering in the MBAT than the active control group, the MBAT group did not exhibit greater improvements in attentional performance. Exploratory analyses revealed working memory as a significant moderator of the observed effects, such that those in the MBAT group with higher working memory showed greater improvement in attentional control.

Conclusions We found partial evidence that brief mindfulness training improves mind-wandering, but not attentional control in older adults. Our study provides preliminary support for working memory as an important moderator of short-duration mindfulness training; however, given the exploratory nature of these effects, replication is warranted.

Keywords Mindfulness training · Aging · Attentional control · Working memory · Mind-wandering

The USA is an "aging nation" (Ortman et al. 2014). Projections suggest that between the years 2012 and 2050, the population of adults over age 65 will nearly double in size. With age comes significant impairment across a number of cognitive domains (Chao and Knight 1997; Verhaeghen 2011; Verhaeghen and Salthouse 1997) that have shown important linkages with the ability to carry out activities of daily living (Vaughan and Giovanello 2010) and quality of life (Kazazi et al. 2018). Attentional control refers to the ability to optimize information processing via selecting task-relevant information and inhibiting task-irrelevant information to achieve complex behavioral goals (Petersen and Posner 2012). Prominent theories accounting for age-related deficits in cognitive functioning have posited that different facets of attentional control play a role in higher-level cognitive processes and may drive age-related cognitive deficits (Braver 2012; Braver et al. 2008; Hasher and Zacks 1988). Hasher and Zacks' (1988) theoretical account suggested that deficits in inhibitory control primarily explain age-related differences on higher-order tasks of executive control. On the other hand, the dual mechanism of control theory (Braver 2012; Braver et al. 2008) contended that aging is characterized by deficits in goal maintenance rather than a general deficit in inhibitory control. According to this model, there are

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12671-019-01218-3) contains supplementary material, which is available to authorized users.

✉ Ruchika Shaurya Prakash
prakash.30@osu.edu

1 Department of Psychology, The Ohio State University, 1835 Neil Ave, Columbus, OH 43210, USA

2 Department of Biostatistics, The Ohio State University, Columbus, OH 43210, USA

3 Department of Psychological and Brain Sciences, University of Delaware, Newark, DE 19716, USA

two modes of cognitive control that vary in their reliance on attentional processes: proactive control (i.e., active goal maintenance) and reactive control (i.e., late correction). It has been posited that with age, there is a shift away from use of proactive strategies, which place higher demands on sustained attention, toward greater reliance on less-taxing reactive strategies (Paxton et al. 2008).

Much cognitive aging research has focused on examining the efficacy of various cognitive training programs, as well as lifestyle interventions (e.g., physical activity), for the enhancement of cognitive and neural vitality (Lustig et al. 2009; Prakash et al. 2015). Recently, mindfulness training has emerged as a potential means for improving cognitive functioning, particularly attentional control, across development. Mindfulness training involves the purposeful, nonjudgmental directing of attention to specific phenomena as they arise (Kabat-Zinn 1982). Thus, attentional control is a central skill involved in the practice of mindfulness. According to previously proposed models, mindfulness practices involve several key facets of attentional control, including (1) conflict monitoring to continuously detect mind-wandering (i.e., shifts in attention away from the task at hand and toward internal thoughts) as it emerges, (2) attention switching to disengage from distracting stimuli, (3) selective attention/inhibitory control to inhibit distracting stimuli and redirect attention to particular present-moment phenomena, and (4) sustained attention to maintain focus on target phenomena over a prolonged period of time (Chiesa et al. 2011; Lutz et al. 2008). There has also been some speculation that sustained engagement in mindfulness practices could enhance other cognitive functions, such as working memory and executive functions, as a result of this cultivation of attentional control (Chiesa et al. 2011). In support of these theories, variants of mindfulness meditation training in young-adult samples have yielded improvements in working memory (Mrazek et al. 2013), cognitive flexibility (Greenberg et al. 2012; Heeren et al. 2009), and various facets of attentional control including selective attention (Jensen et al. 2012; van Leeuwen et al. 2012), sustained attention (Menezes et al. 2013; Semple 2010), attention switching (Hodgins and Adair 2010), inhibitory control (Semple 2010), and conflict monitoring (Ainsworth et al. 2013). In light of this promising evidence in young adults, mindfulness training is increasingly being investigated as a potential method for reducing age-related cognitive decline.

The few existing studies examining the effects of mindfulness training on cognition in older adults have utilized various versions of the mindfulness-based stress reduction (MBSR) program. The MBSR protocol, developed by Kabat-Zinn (1982), emphasizes cultivation of present-moment awareness through acceptance of thoughts, feelings, and sensations. The protocol incorporates both focused attention (FA) meditation, which consists of sustaining attention on a particular object, and open-monitoring (OM) meditation, which involves nonreactively monitoring moment-to-moment experience (Lutz et al. 2008). In its standard form, MBSR is an 8-week program consisting of weekly 2.5-h classes and 45 min of daily mindfulness practice at home (e.g., breath awareness, sitting meditation) (Kabat-Zinn 2009). Initial studies of MBSR in older adults have produced mixed findings. Moynihan et al. (2013) found that an 8-week MBSR intervention produced small yet significant changes in executive function among healthy older adults. However, MBSR was only compared to a waitlist control in this study, precluding the authors from dissociating mindfulness-specific effects from non-specific factors. Another study, designed as a feasibility trial with no control group comparisons, found that both 8-week and 12-week MBSR improved executive function and memory among older adults with significant anxiety-related distress and self-reported cognitive dysfunction (Lenze et al. 2014).

More recent studies, published after the initiation of the current study, yielded less promising results. Mallya and Fiocco (2015) found that an 8-week MBSR intervention in healthy older adults produced no significant improvements in executive function, episodic memory, or verbal fluency relative to a rest and relaxation active control group. Similarly, Oken et al. (2017) found that a 6-week, one-on-one program based on MBSR and mindfulness-based cognitive therapy (Segal et al. 2002), in cognitively healthy older adults endorsing moderate perceived stress led to reductions in self-reported negative affect and stress but did not produce significant improvements in working memory, verbal fluency, processing speed, or inhibitory control relative to a waitlist control group. Another recent study by Malinowski et al. (2017) reported slightly more promising findings when examining the effects of an 8-week mindful breath awareness intervention relative to a brain training active control group in healthy older adults. Although this study found no significant between-group differences in emotion regulation or Stroop accuracy, the mindfulness group did yield greater improvements in response times and electrophysiological measures during task performance, suggesting that mindfulness training led to improvements in general task-related attentional processing. These improvements occurred with only 10 min of mindful breath awareness practice five times per week, which is significantly less practice time than the typical MBSR course.

Building upon the aging literature on mindfulness training, this randomized controlled trial examined whether a briefer, more targeted mindfulness intervention, referred to as mindfulness-based attention training (MBAT), would improve attentional control in older adults. Our primary outcomes of interest were measures of performance and mind-wandering—a proposed mechanism of mindfulness' attentional benefits—collected during two computerized tasks of attentional control: a go/no-go task and a continuous performance task. Although methodological shortcomings have limited the causal conclusions that may be drawn from many previous studies, we predicted that mindfulness training would lead to greater improvements in performance and reductions in mind-wandering during each task relative to a lifestyle education group. We additionally conducted exploratory analyses to examine WM as a moderator of the effects of mindfulness training. As secondary outcomes, we also collected self-report measures of trait mindfulness, state mindfulness, and positive and negative affect, hypothesizing that those in the MBAT group should exhibit greater increases in trait and state mindfulness, greater increases in positive affect, and greater reductions in negative affect than those in the lifestyle education group. Additionally, the role of engagement with intervention material was examined to ensure that participants in each group were similarly engaged and to explore how changes in primary and secondary outcomes depended upon engagement with intervention-related material.

Method

Participants

This study was approved by The Ohio State University Institutional Review Board, and all methods were performed in accordance with relevant guidelines and regulations. The study registration number in the ClinicalTrials.gov register is NCT03432754. Older adults ($M_{age} = 66.16$) were recruited from the Columbus, Ohio area to participate in a 4-week intervention designed to train health behaviors. Baseline data for this longitudinal dataset have been presented in previous publications (Fountain-Zaragoza et al. 2016, 2018). Advertisements referred to the study as a “Health and Lifestyle Education Study,” described aspects common to both groups, and excluded the phrases “mindfulness,” “meditation,” or “physical activity” to reduce participant bias in favor of either the mindfulness training group or the lifestyle education group. The study was promoted as a 4-week series of workshops designed to promote overall well-being and health in older adults. Participants were only given specific information about their respective groups following randomization during the first day of the intervention. All participants were fully debriefed on the nature of study as well as our goals and hypotheses following study completion.

All participants were required to meet several inclusionary criteria: (1) ages 60–74 years; (2) no prior exposure to mindfulness training, meditation, or yoga; (3) capable of attending all sessions; (4) corrected visual acuity of 20/40 or better; (5) normal color vision; (6) no self-reported history of psychiatric, neurological, or chronic inflammatory conditions; (7) no regular use of psychiatric medication; (8) native English speaker; (9) a score > 23 on the Mini-Mental Status Examination (Folstein et al. 1975); and (10) a score $\leq$ 10 on the Geriatric Depression Scale (Yesavage et al. 1982). Participants were compensated $8 per hour for each assessment session. Participants were not compensated for participation in intervention groups, but training was provided at no cost. All participants provided written, informed consent before participating according to policies set forth by The Ohio State University Institutional Review Board.

Conducting a power calculation for this study was difficult since no other study, at the conception and planning stages of the current study, had examined the effects of mindfulness training on attentional control and mind-wandering in older adults. For this reason, we conducted a priori power analyses using the closest study examining changes in these outcomes as a function of mindfulness training in young adults (Mrazek et al. 2013), which reported a partial eta-square of 0.08 for improvements in WM capacity in the mindfulness group and a partial eta-square of 0.15 for reductions in probe-caught mind-wandering in the mindfulness group. Given that the outcome of mind-wandering was more closely related to the primary outcomes for the current study, we based our sample size of off the latter partial eta-square value. Utilizing an alpha of 0.05, results indicated that a total sample size of 50 participants (25 participants per group) would be required to yield an estimated power equal to 0.80. Additional participants were recruited to account for potential drop-out.

Randomization was conducted by a study author using a computerized random number generator program (randomization.com), applying a varying block size of two and four and stratifying participants by sex. All assessors, at pre- and post-intervention, were blinded to group assignments. To further reduce demand characteristics, participants were unaware of which group was considered the experimental intervention until debriefed by an experimenter after completing the study. Study binders were created to blind group assignment, and participants in each group were asked not to discuss the sessions with members of the other group.

A total of 147 individuals underwent eligibility screening over the phone and in person at an initial assessment session (see Fig. 1 for the CONSORT diagram depicting a complete progression of participants through each phase of the randomized trial). Of those eligible, 75 participants volunteered to participate and were randomly assigned to groups. However, one of these participants did not complete the first assessment session and was randomized in error. Thus, 74 participants who completed the first assessment session and met all eligibility criteria were randomly assigned to either the MBAT group or the active control group (lifestyle education). A total of 37 participants were allocated to the mindfulness group, and 37 participants were allocated to the active control group. Of those, 25 participants in the MBAT group ($M_{age} = 66.52$; 56.00% female) and 32 participants in the active control group ($M_{age} = 66.47$; 53.13% female) completed the entire study. Three participants in the MBAT group and two participants

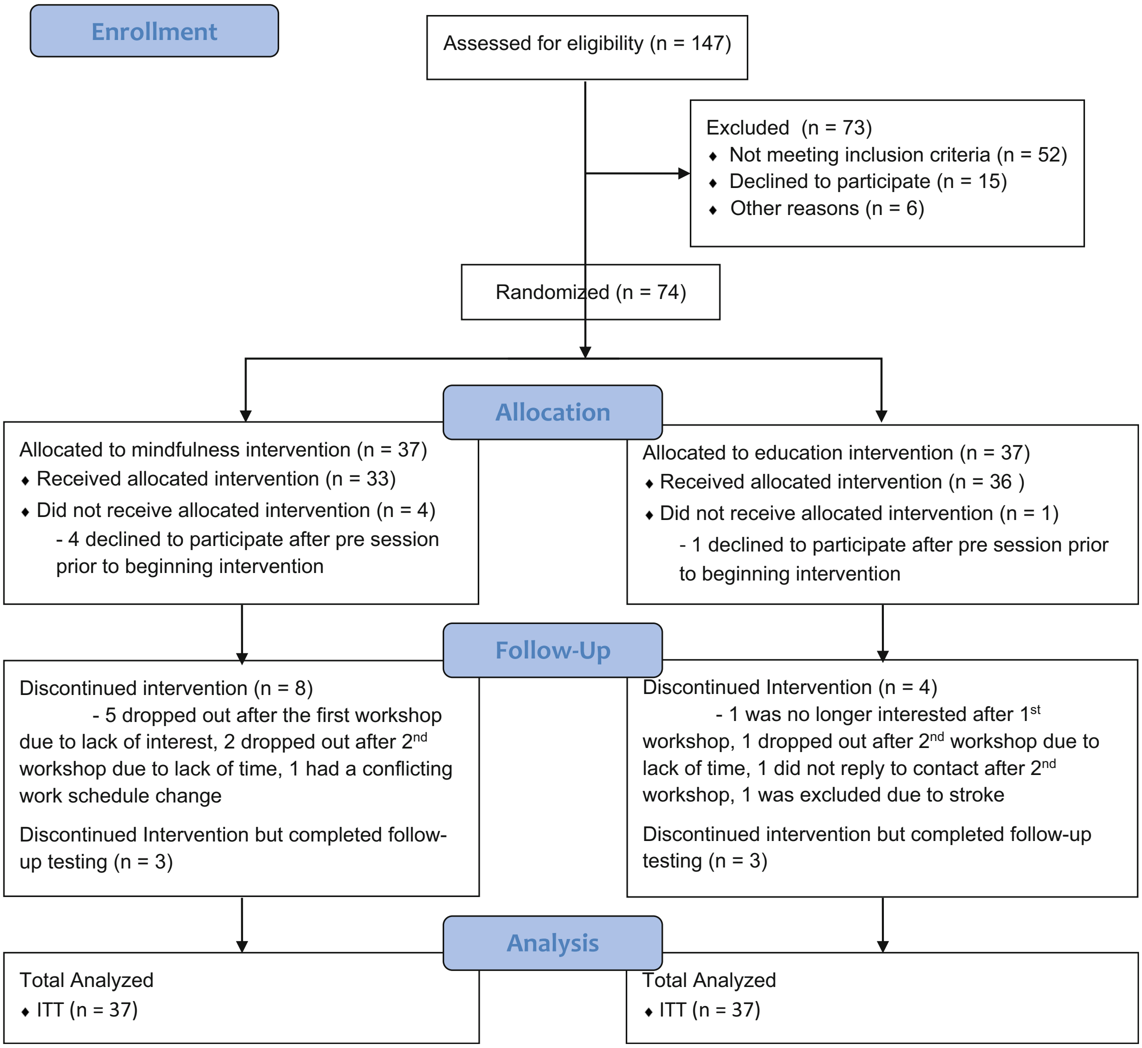

Fig. 1 CONSORT flowchart depicting progression of participants through each phase of the study

in the active control group agreed to complete a post-assessment after withdrawing from the intervention. In the CONSORT figure, "total analyzed" refers to the total number of participants included in the analyses reported in this paper. Of the total number of participants included in analyses, post-training data were imputed for nine participants allocated to the MBAT group and two allocated to the lifestyle education group who did not attend the post-training assessment sessions. For more detailed information on participants included in each analysis, please refer to the "Statistical Analyses" section.

Procedure

This randomized control trial compared an MBAT group with an active control lifestyle education group. Participants completed a 2.5-h assessment session, consisting of questionnaires as well as paper-and-pencil and computerized cognitive tasks, 2 weeks prior to beginning the intervention (T1) and within 2 weeks after the conclusion of the intervention (T2). All data were collected by trained research staff and graduate students at a research laboratory at The Ohio State University. There were 10 different cohorts (five MBAT cohorts and five lifestyle education cohorts) that participated between November 2014 and March 2015. MBAT and lifestyle education cohorts were led by instructors with significant experience in facilitating their respective groups. Both interventions consisted of four weekly 1.5-h meetings. Training duration was justified based on the findings of significant effects of mindfulness training on mind-wandering and cognitive functioning after as few as 6 h of instruction (Mrazek et al. 2013). Meetings for both groups were held at The Ohio State University's Psychological Services Center at the same times, but in different group therapy rooms.

Answering the recent call for more thorough methodology in randomized controlled trials examining cognitive gains in older adults ("A Consensus" 2014), the control group was designed to allow us to rule out the possible confounding effects of non-specific factors and attribute the observed findings to the causal influence of principles and skills specific to mindfulness training. Both groups were offered in a group format in order to control for the possible effects of social support and belonging on cognitive and attentional control (Baumeister et al. 2002; Seeman et al. 2001). Additionally, given that engagement both within- and between-sessions can influence outcomes, we matched both groups on the time allotted for lecture and the completion of intervention-related activities in class meetings as well as the amount of homework assigned (30–45 min per day). Both groups completed the state Mindful Attention Awareness Scale (Brown and Ryan 2003), which was relabeled Awareness Scale to reduce demand characteristics, and the Positive and Negative Affect Schedule—Short Form (PANAS-SF; Watson et al. 1988) at the end of each class. To examine dose-response relationships between engagement in respective exercises and cognitive benefits, participants in both groups were asked to keep a daily homework log throughout the 4 weeks of the intervention. Additionally, we assessed participants' beliefs about the cognitive benefits they expected from their respective interventions to further quantify placebo effects (see Supplemental Materials).

Mindfulness-Based Attention Training Mindfulness training is a form of mental training that emphasizes the regulation of attention toward present-moment experiences, and it is believed to improve attentional control via reducing vulnerability to reactive modes of the mind (Bishop 2002). Our MBAT protocol was modeled after the traditional mindfulness-based stress reduction (MBSR) protocol (Kabat-Zinn 1982), incorporating formal MBSR practices such as breath exercises (directing focus away from free-floating thoughts and emotions and reorienting toward the breath), body scans (directing attention toward the present sensations of the body), and long sitting meditations (practicing sustained nonjudgmental awareness of thoughts and feelings arising moment by moment). However, in addition to being briefer than the traditional MBSR protocol, our MBAT protocol also placed greater emphasis on focused attention (FA) meditational practices than open-monitoring (OM) meditational practices given that the use of selective attention skills to concentrate on thoughts, emotions, and bodily sensations in FA practices more directly trains attentional skills (Lutz et al. 2008). During the first 3 weeks, the program was centered around body scans and breath awareness practices to cultivate sustained attention. Then, in the final week of the program, participants were introduced to open-monitoring practices. A female instructor trained in MBSR with 17 years of experience leading MBSR groups led the MBAT group. Guided group meetings (5–9 members per group) consisted of a didactic component, engagement with mindfulness practices, and review of homework. Additionally, participants were given audio recordings, readings, and homework assignments consisting of various mindfulness practices, as well as homework logs to facilitate reflection and practice of material at home.

Lifestyle Education The active control group was focused on providing scientific health and lifestyle information to participants. Didactic lectures focused on concepts presented in the book "The Culprit and the Cure: Why lifestyle is the culprit behind America's poor health and how transforming that lifestyle can be the cure" (Aldana 2005). The text in this book summarizes research underlying the health information presented by the popular media. This group was led by a female exercise physiologist. Group meetings (6–9 members per group) consisted of a didactic component, discussing how to begin and maintain a more nutritious diet, classifying healthy choices across food groups, completing low-intensity stretching/toning exercises, and reviewing homework. Homework included readings from "The Culprit and the Cure," diet monitoring, identifying new healthy food choices, and completing 20 min of low-intensity stretching and toning exercises per day. Homework logs were also provided to facilitate reflection and engagement with material at home.

Further information about attendance for both groups can be found in the Supplemental Materials. Additional details on the two groups, along with session agendas and workbooks, are available from the corresponding author upon request.

Measures

Word Version of the Continuous Performance Task The continuous performance task (CPT) assesses goal representation, active goal maintenance, and goal updating in response to contextual cues (Paxton et al. 2008). In this task, words were presented to participants one at a time, in cue-probe pairs. Participants were asked to respond "YES" with the index finger of their dominant hand when a target sequence (correct cue, followed by correct probe) was complete and to respond "NO" with their dominant-hand middle finger when it was not complete. Task demand was manipulated by altering cue-probe delay. Each participant was presented with four low-demand blocks (delay = 1000 ms) and four high-demand blocks (delay = 5000 ms). The primary outcome variables of interest for this study were the signal detection sensitivity scores for proactive (d-proactive) and reactive control (d-reactive). Both signal detection sensitivity scores (d_L) were calculated using the formula for logistic distributions ($\ln\{[H(1-FA)]/[(1-H)FA]\}$). The d-proactive score was calculated using hit rates for "AX" (correct cue, correct probe) trials and false alarm rates for "BX" (incorrect cue, correct probe trials). The d-reactive score was calculated using hit rates for AX trials and false alarm rates for "AY" (correct cue, incorrect probe) trials (Stawarczyk et al. 2014). Another variable of interest was reaction time coefficient of variability (RT_CV). RT_CV was calculated for the entire task by dividing the standard deviation of reaction times by mean reaction time, providing a behavioral measure of task engagement, with higher variability indicating lower task engagement, independent of mean differences (Cheyne et al. 2009). This task was administered during assessment sessions at T1 and T2. Further details on this task can be found in the Supplemental Materials.

Modified Go/No-Go Task This task measures sustained attention and inhibitory control (O'Connell et al. 2008). Participants were asked to respond to frequent targets by identifying the presented stimuli (Go trials) and inhibit their responses when infrequent auditory tones were presented simultaneously with stimuli (No-Go trials). Our primary outcome measure during this task was the signal detection sensitivity index (d_L). The d_L provides a measure of task performance and was calculated using the formula for logistic distributions: $d_L = \ln\{[H(1\text{-}FA)]/[(1\text{-}H)FA]\}$, where H refers to hit rates for go trials and FA refers to false alarms on no-go trials. Additionally, we examined RT_CV for go trials. Participants completed this task during assessment sessions at T1 and T2. Further details on this task can be found in the Supplemental Materials.

Mind-Wandering Thought Probes Mind-wandering, a phenomena closely tied to attentional dysregulation (Randall et al. 2014; Smallwood and Schooler 2006) and antithetically related to mindfulness (Epel et al. 2012), can be differentiated into task-unrelated thoughts (TUT) and task-related interference (TRI) (McVay et al. 2013). In young adults, there is evidence that mindfulness training reduces TUTs (Jha et al. 2015; Morrison et al. 2014; Mrazek et al. 2013), and that reduced TUTs mediate the beneficial effects of mindfulness on cognition (Mrazek et al. 2013), but the effects of mindfulness training on mind-wandering in older adults has yet to be studied. To assess mind-wandering in the current study, self-report probes were administered in a quasi-random fashion during both computerized tasks. At various times while performing the tasks, participants were unexpectedly asked to categorize their thoughts as either (1) on-task, (2) evaluating performance (task-related interference), or (3) off-task (task-unrelated thought). Next, participants were asked to summarize the content of their thought, describe how judgmental their thought was on a 5-point Likert scale, and identify the temporal orientation of their thought as past, present, or future. For the current study, the variables of interest were the proportion of task-related interference (TRI; category 2 responses/total responses) and the proportion of task-unrelated thought (TUT; category 3 responses/total responses). Self-report mind-wandering probes have been validated as a measure of mind-wandering and have been used previously during go/no-go tasks and continuous performance tasks (McVay et al. 2013; Smallwood et al. 2008).

Mindful Attention Awareness Scale The Mindful Attention Awareness Scale (MAAS) is a 15-item scale used to assess trait mindfulness that has shown good internal consistency and validity (Brown and Ryan 2003). The MAAS is a widely used measure that has been implemented in older adult samples (Lenze et al. 2014). For each item, participants rate their experience using a six-point Likert scale from 1 (Almost Always) to 6 (Almost Never). Thus, higher scores on this scale indicate greater levels of trait mindfulness. An example item from this scale asserts: "I find myself doing things without paying attention." This scale was administered at T1 and T2. Cronbach's alpha was 0.78 at T1 and 0.85 at T2.

Homework Logs These logs provided a means of assessing within- and between-group differences in time engaging in intervention-related material outside of group meetings. Participants were asked to report the day of the week, the type of activity that the participant was engaging in, and the start and end time for each activity. The variable of interest was the total minutes of homework for each participant for the course of the intervention.

Working Memory Index from the Wechsler Adult Intelligence Scale The Working Memory Index (WMI) from Wechsler Adult Intelligence Scale (WAIS-IV) (Wechsler 2008) assesses the ability to memorize information, retain this information in short-term memory, and perform some manipulation on this information (Baddeley 2003; Baddeley and Hitch 1974). Several previous studies have found that WM moderates the cognitive benefits of different intervention approaches including the teaching of cognitive learning strategies and physical activity (Evers et al. 2011; Naumann et al. 2008). Although the role of WM as a moderator of mindfulness' effects on attention has yet to be assessed, WM has been associated with enhanced attentional control cross-sectionally (Kane et al. 2007; McVay and Kane 2009; Zavagnin et al. 2014) and baseline WM predicted increased engagement in mindfulness practice in one mindfulness training study (Jha et al. 2010). Since the current study sample consisted of older adults, only WMI subtests with age-appropriate norms were administered: digit span and arithmetic. An overall age-normed standardized score was derived from overall performance on the two subtests administered at T1. WMI scores were examined as a continuous variable to assess general moderation effects without eliminating potentially meaningful WM variance. However, for visualization purposes only, the standardized Working Memory Index scores were divided into low-average and high levels. We initially planned to divide the standardized scores into low, average, and high levels.

However, only four participants exhibited low T1 scores (< 1 SD below the mean). Thus, the standardized scores were instead divided into two categories to indicate low-average and high WM corresponding to scores 1 SD below the normative mean (< 115; $n = 54$) and scores 1 SD above the normative mean (≥ 115; $n = 20$) respectively. Although only T1 WMI scores were incorporated in the present analyses, the WMI was administered at both T1 and T2 and demonstrated good test-retest reliability, $r = .81$, $p < .001$.

Additional Measures Additional questionnaire data pertaining to state mindfulness, positive/negative affect, and expectancy questions were collected. Descriptions of these measures and relevant analyses can be found in the Supplemental Materials.

Data Analyses

Data Exclusion and Outlier Correction Analyses were performed according to the intention-to-treat (ITT) principle such that all participants randomized and with valid data at T1 were included in analyses. Nine participants allocated to the MBAT group and two allocated to the lifestyle education group did not attend T2 assessment sessions. Additionally, computerized task data for four participants were excluded from baseline comparison analyses. Go/no-go task data for one participant in the MBAT group were excluded due to a no-go trial accuracy score below chance. Also, CPT data for three participants (MBAT $n = 2$, lifestyle education $n = 1$) were excluded; one participant did not complete the full CPT at T2, one participant completed the CPT with their non-dominant hand at T1, and another participant completed the CPT with their non-dominant hand at T2. As these participants were randomized and had valid initial assessment data, a multiple imputation (MI) approach was used to estimate missing data and T1 and T2 variables were checked for outliers pre-imputation. Outliers were defined as scores greater than 2.5 SD from the mean, which were replaced with values corresponding to 2.5 SD from the mean. Each variable was then checked for normality using the Shapiro-Wilk test of normality.

Imputation Procedures Multiple imputation procedures were used to handle missing data, since these techniques tend to produce unbiased estimates of effects and standard errors even when missing data is not missing completely at random (Dziura et al. 2013). Multiple imputation procedures were performed in SAS version 9.4 using data augmentation assuming multivariate normality. Imputation was conducted separately within the MBAT group and within the lifestyle education group. A ridge prior with two degrees of freedom was applied to stabilize the inference due to high correlations between some T1 and T2 variables and a small sample size relative to the number of variables included in the imputation model. Markov chain Monte Carlo (MCMC) chains were then checked for convergence using trace plots. Thirty imputed datasets were generated. The number of datasets was determined based on the number of incomplete cases within the MBAT group (30% of cases with missing values on at least one variable included in the imputation model) (White et al. 2011). Results were combined across imputed datasets using standard Rubin's rules. The following variables were included in the imputation model: age, sex, education, homework minutes, T1 and T2 WMI scores, T1 and T2 MAAS scores, all T1 and T2 CPT variables (d-proactive, d-reactive, TRI, TUT, and RT_CV), and all T1 and T2 go/no-go variables (d_L, TRI, TUT, and go-trial RT_CV).

Statistical Tests We first conducted independent-samples tests (chi-square tests for categorical data, Hotelling's *t* tests for normally distributed data, and Mann-Whitney *U* tests for non-normally distributed data) to determine if there were any baseline differences between participants who completed the intervention (completers) and participants who dropped out (non-completers).

To assess changes in variables over time within each group, paired-samples *t* tests were conducted. Then, to assess differences in variables by intervention group over time, multiple one-way analyses of covariance (ANCOVAs) were conducted in which T1 scores were included as a covariate, T2 scores were entered as the dependent variable, and group was entered as the independent variable. To examine the potential moderating effects of WM, additional ANCOVAs were conducted with working memory index and group incorporated as independent variables, T1 scores for primary measures included as covariates, and T2 scores for primary measures entered as dependent variables. In all these analyses, WM was treated as a continuous variable, with the index scores being broken down into low-average and high working memory categories (as described above) for the purpose of visually depicting the results in a figure.

To assess the impact of engagement with intervention materials on outcomes, an independent-samples test (Mann-Whitney *U*) was conducted to examine between-group differences in homework minutes. Additionally, within-group bivariate correlations (Pearson correlations for normally distributed data and Spearman rank-order correlations for non-normally distributed data) between homework minutes and residualized gain score variables for mind-wandering, trait mindfulness, and cognitive performance measures were conducted. Residualized gain scores were calculated by regressing the scores for measures at T2 on the scores for measures at T1 and saving the standardized residuals from these analyses for each participant. Since between-group differences in homework minutes were found, follow-up ANCOVAs were conducted with T1 scores for primary outcomes and homework minutes as covariates, T2 scores for primary outcomes as the dependent variable, and group as the independent variable.

Results

Baseline Characteristics

Descriptive statistics for demographic variables and scores on computerized cognitive assessments at T1 are presented in Table 1. Intervention groups did not differ on age, education, sex, mind-wandering frequency, or attentional control at baseline. Although the MBAT group had more non-completers than the lifestyle education group ($\chi_2 = 3.74$, $p = .053$), no significant differences were observed at baseline between completers and non-completers within either intervention group (all p values > .05, see Table 2).

Training Effects

For a complete summary of the results of within-group and between-group analyses of mind-wandering and performance on cognitive measures, please refer to Table 3. Utilizing paired t tests to assess within-group changes in mind-wandering and performance during the continuous performance task, significant within-group changes were noted in RT_CV for both the MBAT group ($t(19.4) = -2.43$, $p = .03$, $d = -0.41$) and the lifestyle education group ($t(26.6) = -2.31$, $p = .03$, $d = -0.39$). A series of ANCOVAs was then conducted to examine intervention group effects on mind-wandering and cognitive performance within the CPT, controlling for T1 differences. There were no effects of group on TRI, TUT, RT_CV, reactive control, or proactive control (all p values > .05).

Within the go/no-go task, paired t tests revealed significant within-group changes in d_L ($t(18.7) = 2.60$, $p = .02$, $d = 0.53$) and RT_CV ($t(18.3) = -3.92$, $p < .01$, $d = -0.66$) for the MBAT group and significant changes in d_L ($t(31.4) = 3.09$, $p < .01$, $d = 0.60$) and RT_CV ($t(32.6) = -2.22$, $p = .03$, $d = -0.31$) for the lifestyle education group. A series of ANCOVAs revealed no significant group effects on TRI or d_L (all p values > .05). However, there was a marginally significant effect of group on TUT ($t(51.8) = -1.98$, $p = .053$, $d = -0.46$) and a significant group effect on RT_CV ($t(41.0) = -2.22$, $p = .03$, $d = -0.45$), suggesting that the

Table 1 Baseline characteristics of participants allocated to mindfulness-based attention training (MBAT) and lifestyle education

	MBAT (n = 37)	Lifestyle Education (n = 37)
Characteristic	Number (%) or *M* (SD)	Number (%) or *M* (SD)
Demographics		
Age	65.92 (3.85)	66.89 (4.09)
Education (Years)	16.85 (2.93)	16.16 (2.50)
% Female	59.46%	56.76%
MAAS	4.43 (.55)	4.47 (.63)
WMI	108.95 (14.58)	103.95 (10.80)
CPT		
TRI	0.13 (.13)[a]	0.14 (.13)[b]
TUT	0.10 (.11)[a]	0.10 (.13)[b]
d-proactive	8.20 (3.16)[a]	7.82 (2.95)[b]
d-reactive	8.25 (2.80)[a]	7.70 (2.85)[b]
RT_CV	0.24 (.03)[a]	0.25 (.03)[b]
Go/No-Go Task		
TRI	0.21 (.21)[b]	0.21 (.17)
TUT	0.13 (.14)[b]	0.13 (.15)
d_L	6.91 (2.46)[b]	6.54 (1.93)
RT_CV	0.20 (.04)[b]	0.21 (.04)

MAAS mindful attention awareness scale, *WMI* working memory index, *CPT* continuous performance task, *TRI* task-related interference, *TUT* task-unrelated thought, *RT_CV* reaction time coefficient of variation, d_L signal detection sensitivity index

[a] $n = 35$

[b] $n = 36$

Table 2 Summary of baseline characteristics (means and standard deviations) and between-group comparisons of means for completers relative to non-completers

Characteristic	MBAT			Lifestyle Education		
	Completer (n = 25)	Noncompleter (n = 12)	Comparison	Completer (n = 32)	Noncompleter (n = 5)	Comparison
Demographics						
Age	66.52 (3.63)	64.67 (4.16)	$t(35) = 1.39$	67.03 (4.10)	66.00 (4.42)	$U = 88.00$
Education	17.28 (3.22)	15.96 (2.05)	$t(35) = 1.30$	16.44 (2.42)	14.40 (2.51)	$t(35) = 1.74$
% Female	56.00	66.67	$\chi^2 = 0.38$	53.13	80.00	$\chi^2 = 1.27$
MAAS	4.36 (.50)	4.59 (.66)	$t(35) = -1.18$	4.47 (.64)	4.52 (.62)	$t(35) = -0.17$
WMI	108.44 (15.57)	110.00 (12.85)	$t(35) = -0.30$	104.16 (11.27)	102.60 (7.89)	$t(35) = 0.30$
CPT						
TRI	0.16 (.15)[a]	0.10 (.08)	$U = 159.50$	0.15 (.14)[c]	0.10 (.10)	$U = 93.50$
TUT	0.11 (.11)[a]	0.09 (.12)	$U = 151.50$	0.08 (.10)[c]	0.23 (.20)	$U = 41.50$
d-proactive	7.88 (3.22)[a]	9.05 (3.01)	$U = 108.50$	7.44 (2.85)[c]	9.85 (3.00)	$t(34) = -1.74$
d-reactive	8.48 (2.63)[a]	7.91 (3.24)	$t(33) = 0.54$	7.39 (2.75)[c]	9.17 (2.75)	$t(34) = -1.31$
RT_CV	0.24 (.04)[a]	0.24 (.03)	$t(33) = -0.19$	0.25 (.03)[c]	0.25 (.03)	$t(34) = -0.31$
Go/No-Go Task						
TRI	0.21 (.21)[b]	0.24 (.21)	$U = 133.00$	0.20 (.17)	0.27 (.18)	$U = 59.00$
TUT	0.14 (.15)[b]	0.09 (.09)	$U = 163.00$	0.12 (.14)	0.21 (.23)	$U = 67.50$
d_L	6.80 (2.32)[b]	7.18 2.80)	$U = 134.50$	6.53 (2.05)	6.63 (.93)	$U = 63.50$
RT_CV	0.20 (.05)[b]	0.19 (.04)	$t(34) = 0.61$	0.21 (.04)	0.20 (.05)	$U = 79.00$

For all analyses reported in the table above, $p > .05$

MBAT mindfulness-based attention training, *MAAS* mindful attention awareness scale, *WMI* working memory index, *CPT* continuous performance task, *TRI* task-related interference, *TUT* task-unrelated thought, *RT_CV* reaction time coefficient of variation, d_L signal detection sensitivity index

[a] $n = 23$

[b] $n = 24$

[c] $n = 31$

MBAT group exhibited greater reductions in TUT and RT_CV than the lifestyle education group (see Fig. 2).

Paired t tests revealed no significant changes in trait mindfulness within the MBAT group ($t(19.7) = -1.04$, $p = .31$, $d = -0.20$) or the lifestyle education group ($t(31.2 = 1.47$, $p = .15$, $d = 0.15$). An ANCOVA revealed no intervention effect on T2 trait mindfulness, controlling for T1 differences in trait mindfulness ($t(38.1) = -1.66$, $p = .10$, $d = -0.36$).

Homework Minutes

On average, those in the lifestyle education group engaged in more minutes of homework than those in the MBAT group ($U = 277$, $p < .01$), possibly indicating a difference in compliance rates or that homework in the lifestyle education group may have required a greater time commitment than initially expected. Additionally, the range of homework minutes was higher in the lifestyle education group (median = 1026, range 0–3060) than in the MBAT group (median = 470, range: 0–1345).

Bivariate correlations between total homework minutes and residualized gain scores for task performance variables were conducted within each group (see Tables 4 and 5). Homework minutes were unrelated to mind-wandering or cognitive performance in either task in the MBAT group or in the lifestyle education group (all p values $> .05$). Additionally, homework minutes were not associated with residualized gain scores for trait mindfulness (MBAT: $r = -0.03$, $p = .89$; lifestyle education: $r = -0.12$, $p = .55$).

Training Effects Controlling for Homework Minutes

Since homework minutes differed between groups, two further ANCOVAs were conducted to determine whether the marginally significant intervention effects on go/no-go, TUT, and RT_CV would remain with homework minutes included as an additional covariate in the original ANCOVA models. Results from these two ANCOVAs revealed that the initially marginally significant group effects remained marginally significant when controlling for group differences in homework minutes, both for go/no-go TUT ($t(53.4) = -2.09$, $p = .04$, $d = -0.55$) and RT_CV ($t(55.3) = -1.96$, $p = .055$, $d = -0.42$).

Working Memory as a Moderator

To evaluate the extent to which intervention effects on cognitive performance and mind-wandering were dependent upon WM, additional ANCOVAs were conducted utilizing working memory index (WMI) scores as a moderator variable.

Table 3 Mean scores and standard errors on primary outcomes, and results of within-group and between-group analyses of change over time per ITT protocol

	MBAT						Lifestyle Education									
	Time 1	Time 2	Within-group Change				Time 1	Time 2	Within-group Change				Between-group Comparison			
Task	*M* (SE)	*M* (SE)	*t*	*df*	*p*	*d*	*M* (SE)	*M* (SE)	*T*	*df*	*p*	*d*	*t*	*df*	*p*	*d*
CPT																
TRI	0.13 (.02)[a]	0.10 (.03)[a]	-1.32	23.2	.20	-0.29	0.14 (.02)[b]	.11 (.02)[b]	-1.07	31.5	.29	-0.20	-0.46	42.9	.65	-0.11
TUT	0.10 (.02)[a]	0.08 (.02)[a]	-1.10	14.2	.29	-0.20	0.10 (.02)[b]	.10 (.02)[b]	-0.22	28.7	.83	-0.02	-0.78	34.1	.44	-0.16
d-pro	8.20 (.53)[a]	8.90 (.63)[a]	0.86	25.8	.40	0.22	7.82 (.50)[b]	7.97 (.59)[b]	0.31	29.7	.76	0.05	0.96	52.4	.34	0.25
d-rea	8.25 (.48)[a]	9.04 (.54)[a]	1.10	22.4	.28	0.28	7.70 (.49)[b]	7.90 (.51)[b]	0.36	29.4	.72	0.07	1.39	47.4	.17	0.35
RT_CV	0.24 (.01)[a]	0.23 (.01)[a]	-2.43	19.4	.03	-0.41	0.25 (.01)[b]	0.24 (.01)[b]	-2.31	26.6	.03	-0.39	-0.63	41.9	.53	-0.14
Go/No-Go																
TRI	0.21 (.03)[b]	0.17 (.04)[b]	-1.12	23.9	.28	-0.20	0.21 (.03)[c]	0.18 (.03)[c]	-0.92	32.8	.37	-0.20	-0.11	53.6	.91	-0.03
TUT	0.13 (.02)[b]	0.08 (.02)[b]	-1.75	23.1	.09	-0.33	0.13 (.03)[c]	0.15 (.03)[c]	-0.68	31.4	.50	0.12	-1.98	51.8	.05	-0.46
d_L	6.91 (.41)[b]	8.21 (.54)[b]	2.60	18.7	.02	0.53	6.54 (.32)[c]	7.70 (.42)[c]	3.09	31.4	<.01	0.60	0.46	41.7	.65	0.13
RT_CV	0.20 (.01)[b]	0.17 (.01)[b]	-3.92	18.3	<.01	-0.66	0.21 (.01)[c]	0.19 (.01)[c]	-2.22	32.6	.03	-0.31	-2.22	41.0	.03	-0.45

All results are based on analyses utilizing 30 imputed datasets

MBAT mindfulness-based attention training, *CPT* continuous performance task, *TRI* task-related interference, *TUT* task-unrelated thought, *d-pro* d-proactive, *d-rea* d-reactive, *RT_CV* reaction time coefficient of variation, d_L signal detection sensitivity index

[a] $n = 35$

[b] $n = 36$

[c] $n = 37$

Assessing WM as a continuous variable, a significant group × WM interaction was found for d_L on the go/no-go task ($t(61.4) = 2.46$, $p = .02$, $\eta_p^2 = 0.09$), such that for those with higher WMI scores, the MBAT group led to greater d_L

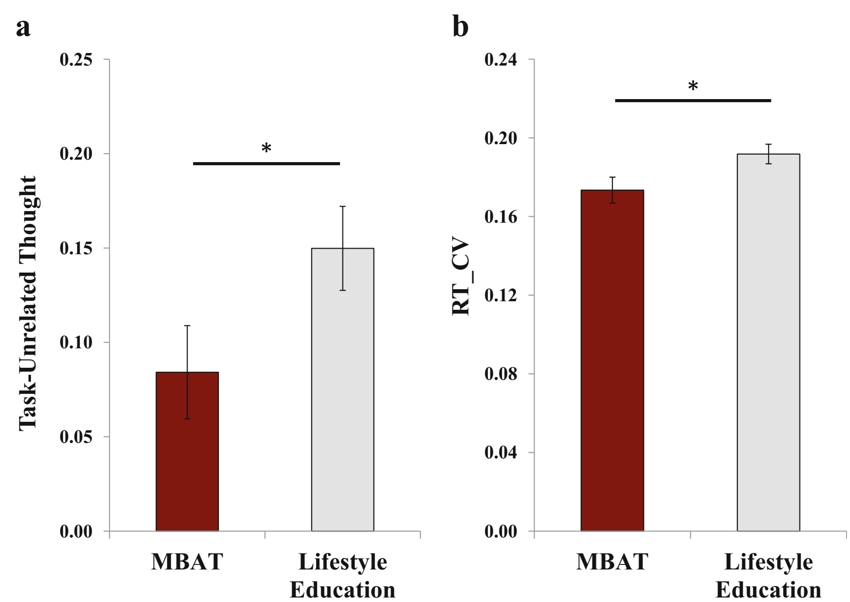

Fig. 2 Estimated marginal means for **a** T2 task-unrelated thought, controlling for T1 task-unrelated thought and **b** T2 RT_CV, controlling for T1 RT_CV during the go/no-go task. Error bars represent standard error of the mean. MBAT mindfulness-based attention training; RT_CV reaction time coefficient of variation

Table 4 Bivariate correlations between total homework minutes and residualized gain in go/no-go performance within those allocated to mindfulness-based attention training (MBAT) and lifestyle education

Homework Minutes	d_L Gain	RT_CV Gain	TRI Gain	TUT Gain
MBAT	0.09	0.15	0.19	-0.04
Lifestyle Education	-0.26	-0.02	0.02	-0.12

For all analyses reported in the table above, $p > .05$

Results based on a multiple imputation analysis with 30 imputed datasets

improvement. For the purposes of visually depicting this moderation effect, participants' WMI scores were broken down into two categories (low-average and high) based on where they fell relative to the normative mean (see Fig. 3).

Discussion

This randomized controlled trial evaluated the impact of a brief mindfulness-based training program, MBAT, on attentional functioning in older adults. Attentional control was examined within the context of two sustained attention tasks, with the go/no-go task offering a general measure of inhibitory control and the CPT offering more nuanced measures of proactive and reactive control. Our primary question was whether a brief, 4-week mindfulness intervention would improve performance and reduce mind-wandering rates on tasks of attentional control when compared with a lifestyle education active control group. We also examined changes in trait mindfulness and whether WM moderated intervention effects.

Although two previous studies without an active control comparison found that mindfulness training lead to improvements in set-shifting in healthy older adults above age 65 (Moynihan et al. 2013) and in executive function and memory in older adults above age 65 with clinically significant worry and self-reported "memory and concentration" deficits (Lenze et al. 2014), findings from the current study were less straightforward. Both the MBAT group and the lifestyle education group exhibited improved performance on the CPT and go/no-go, but these effects were not intervention-specific. Our findings better align with those observed in the two studies in older adults that have examined the effects of mindfulness training in comparison to active control groups (Malinowski et al. 2017; Mallya and Fiocco 2015). In one study, Mallya and Fiocco (2015) found that in a sample of healthy older adults ages 60 and older, 8 weeks of MBSR produced no significant changes in executive function or episodic memory relative to a rest and relaxation active control group. In the other study, an 8-week mindful breathing intervention yielded no significant improvements in executive function for a sample of older adults (ages 55–75) relative to a brain training active control group, despite some significant improvements in general attentional processing (Malinowski et al. 2017). Given that Moynihan et al. (2013) enrolled a significantly greater number of participants than the other studies, and Lenze et al. (2014) was the only study conducted in a clinical population, variation in findings might be attributable to differences in sample characteristics. Additionally, since the only significant effects in older adults so far were observed in studies failing to utilize an active control group, it is plausible that those significant improvements may be attributable to non-specific factors.

One unique feature of the current study was the implementation of a more condensed, 4-week training protocol rather than the typical 8-week MBSR course. Previous evaluations in young adults provided preliminary evidence for cognitive change following condensed trainings even in comparison to active control conditions. For example, one study found improved reading comprehension and WM performance following 2 weeks of focused attention mindfulness training compared to an active nutrition education control (Mrazek et al.

Table 5 Bivariate correlations between total homework minutes and residualized gain in continuous performance task (CPT) performance within those allocated to mindfulness-based attention training (MBAT) and lifestyle education

Homework Minutes	d-proactive Gain	d-reactive Gain	RT_CV Gain	TRI Gain	TUT Gain
MBAT	0.20	0.24	0.01	-0.07	0.12
Lifestyle Education	0.00	0.07	-0.24	-0.25	0.01

For all analyses reported in the table above, $p > .05$

Results based on a multiple imputation analysis with 30 imputed datasets

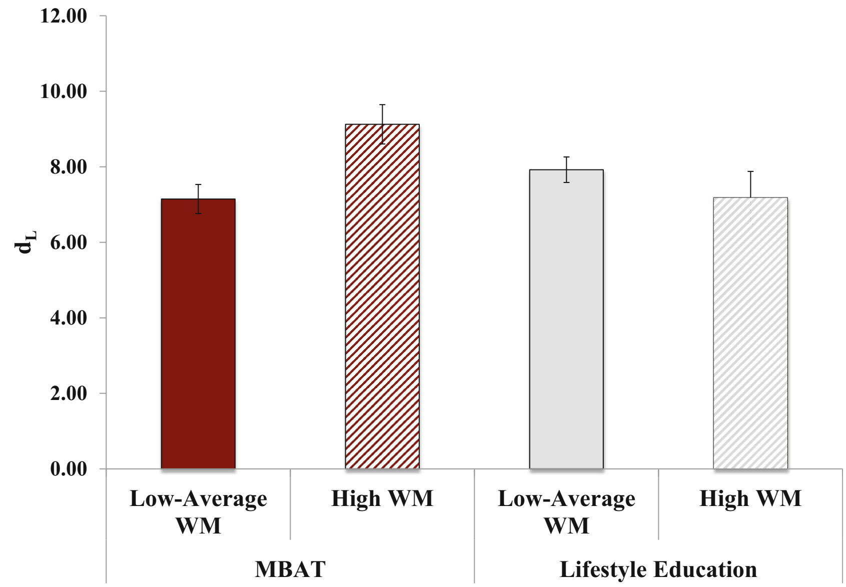

Fig. 3 Estimated marginal means for T2 go/no-go performance, controlling for T1 go/no-go performance. Error bars represent standard error of the mean. Participants have been categorized according to their T1 performance on the Working Memory Index from the Wechsler Adult Intelligence Scale (WAIS-IV). For visualization purposes only, the standardized Working Memory Index scores were divided into low-average and high levels according to their proximity to the normative mean score. WM working memory; MBAT mindfulness-based attention training; d_L signal detection sensitivity index

2013). Another study found improved signal detection following 4 weeks of mindfulness training compared to a relaxation active control group but did not find significant changes in performance on digit symbol substitution or Stroop tasks (Semple 2010). Interestingly, age was positively associated with changes in discriminability, suggesting that mindfulness training impacted cognition more for older participants, although the maximum age in that study was limited to 56. However, our evaluation of a 4-week mindfulness program for adults above the age of 60 did not yield improvements in attentional control beyond that seen in a lifestyle education control condition. Thus, improved cognitive performance within the MBAT group may have been attributable to non-specific factors acting in both groups or due to practice effects. Alternatively, it is also possible that the lifestyle education intervention may have been more effective than initially intended due to specific factors such as the stretching/toning exercises that the participants were invited to engage in over the course of 4 weeks. Future investigations will benefit from comparisons against different types of active control groups in addition to waitlist conditions. It is also important to note that whereas a more condensed, 4-week intervention may have been sufficient in younger adults, 4 weeks of mindfulness training may not have provided sufficient amount of training for older adults to demonstrate meaningful change. Given the results of our exploratory analyses examining WM as a moderator, it seems plausible that this may be particularly the case for older adults with lower WM levels. Perhaps if given more time, individuals with lower WM may begin to exhibit more noticeable changes in attentional control, comparable to those exhibited by individuals with higher WM in our analyses. However, further replication of our WM moderation findings and further comparisons of mindfulness interventions of varying doses (e.g., 4 weeks vs. 6 weeks vs. 8 weeks, etc.) in older adult populations relative to active and waitlist control groups would be necessary to establish the validity of such claims.

Despite a lack of observed improvements in attentional performance specific to MBAT, we found MBAT-specific reductions in TUT and RT_CV, a behavioral indicator of attentional lapses (Cheyne et al. 2009), within the go/no-go task, but not the CPT, and no effects on TRI. These MBAT-specific reductions remained marginally significant even when controlling for homework minutes and expectancy bias. These results suggest that MBAT may promote resilience to task-unrelated distraction, but that this resilience may differ by task. Several previous studies employing a paradigm similar to the go/no-go—the Sustained Attention to Response Task (SART)—found that young adults exhibited fewer attentional lapses (Jha et al. 2015) and less self-reported mind-wandering following mindfulness training compared to waitlist (Morrison et al. 2014), nutrition education (Mrazek et al. 2013), and didactic active control groups (Jha et al. 2015). Two of these studies also found greater reductions in SART RT_CV in mindfulness training groups relative to controls (Jha et al. 2015; Morrison et al. 2014). Therefore, our results are fairly consistent with this literature and expand these effects into a sample of older adults. However, our finding of task-specific modulation of mind-wandering via mindfulness training was unexpected and requires further replication before any definitive claims can be made about the effects of mindfulness being domain-specific or dependent upon task demands. Additionally, the specificity of mindfulness' effects on type of mind-wandering (reduced TUT but not TRI) was also unexpected. It is possible that the ability to regulate task-unrelated thoughts may be more directly impacted by mindfulness training, especially brief mindfulness training programs. Alternatively, these differential effects could have been attributable to differences in ability to accurately report on

TUT vs. TRI. However, the specificity of mindfulness' effects on TUT but not TRI will also need to be replicated prior to drawing any definitive conclusions about the explanations for these observed effects. Although one previous study provided evidence for mind-wandering as a mediator of the effects of mindfulness training on cognition (Mrazek et al. 2013), we did not examine the mechanistic role of mind-wandering due to null attentional improvements between groups.

In addition to not observing improvements in attentional control, we did not find a significant improvement in trait mindfulness within the MBAT group. Recent meta-analytic evidence indicated that over half of mindfulness interventions failed to find significant increases in self-reported mindfulness, raising serious questions about the validity of current measures of mindfulness (Visted et al. 2015). In the present study, our choice to use the MAAS to assess changes in trait mindfulness could have played a role in our null findings. The MAAS is a single-factor scale that indexes a unique type of attention/awareness to the present moment (Brown and Ryan 2003). Although this present-centered attention and awareness is an integral component of mindfulness, the MAAS is less sensitive to other important facets of mindfulness, such as non-reactivity to inner experience and non-judging of experience, which may have been impacted by the intervention (Baer et al. 2006).

Since it is unlikely that mindfulness training's effects are ubiquitous, there is a need to identify moderators of treatment effects in order to inform future selection of target groups. Cognitive training studies, more broadly, have found moderating effects of various neuropsychological, neurobiological, and genetic factors in older adults (Rahe et al. 2015; Stine-Morrow et al. 2014). In the current study, exploratory analyses revealed that WM moderated the effects of mindfulness training on go/no-go performance, such that those with higher WM exhibited better performance following MBAT than those with lower WM. This could suggest that either MBAT is more impactful for individuals with high WM or that those with high WM are better able to glean benefits from training. With the caveat that these results are replicated, this could mean that mindfulness training, and especially brief mindfulness training programs, might be particularly beneficial as a preventative training program for older adults. Such a notion is consistent with previous findings that older adults with better baseline cognitive functioning derive more benefit from both cognitive training and environmental enrichment (Stine-Morrow et al. 2014) and that working memory capacity specifically predicts sustained attention performance (McVay and Kane 2009; Zavagnin et al. 2014). However, given that this was an exploratory analysis within a small, relatively healthy sample of older adults, further replication of these effects will be necessary to draw any firm conclusions about the implications of these findings.

Despite the efforts to equate the intervention groups on time spent with intervention material, we found that the lifestyle education group spent more time on homework than the MBAT group. However, evaluations of homework adherence revealed that time spent on homework was not associated with improvements in performance or mind-wandering in either intervention group. This is inconsistent with previous work demonstrating greater improvements on a CPT task for those who engaged in more at-home mindfulness practice (MacCoon et al. 2014). It is possible that these non-significant homework minute associations were attributable to a lack of power to detect effects for these exploratory analyses. However, it is also important to note that we utilized self-report measures of homework adherence, which may limit the validity of these findings. In future studies, manipulating the duration of mindfulness interventions, in addition to the use of a larger sample, will be helpful in clarifying the dose-response effect of engagement in mindfulness practices on cognitive outcomes.

Limitations and Future Research

There are several notable limitations to the current study that should be considered. One critical limitation is the significantly higher rate of attrition in the MBAT group than the lifestyle education group. To address this issue, we compared demographic and cognitive characteristics of completers and non-completers in both groups. We found no significant differences, suggesting that attrition was not related to demographic variables or cognitive limitations that might have influenced participation in this effortful intervention. Additionally, as can be seen in Fig. 1, three participants in the MBAT group and one participant in the lifestyle education group withdrew after the pre-intervention session. Six of the 10 cohorts for the study were run during the winter months, which could have influenced older adults' decisions to travel to campus. Still, there was differential attrition after the first training session: four participants discontinued in the MBAT group as compared to one participant in the lifestyle education group. Upon follow-up, most of the participants who discontinued in the MBAT group expressed a lack of interest in mindfulness meditation as an intervention for health improvements. Therefore, although our recruitment strategies were designed to communicate a common introduction to the two interventions, it is possible that advertising the study as a "Health and Lifestyle Education Study" may have biased participants in favor of the active control group and reduced motivation to participate particularly for participants assigned to the MBAT group. This is an important point to consider given that motivation appears to play a critical role when working with older adults (e.g., Lockenhoff and Cartensen 2007; Warner et al. 2014). However, it is important to note that there were no significant between-group differences in participants' expectations of improved performance on the cognitive tasks or improved responses on the questionnaires as a result of their assigned intervention (see Supplemental materials). A second limitation of this study was the lack of a waitlist control group, which would have allowed us to determine the extent to which performance improvements may have been due to mere practice effects rather than to either intervention. Third, even though our sample size was based on an a priori power analysis, it is possible that our study was not powered sufficiently to find effects on all of our primary outcome variables given that there were several marginally significant effects that were in the expected direction. Lastly, we employed stringent inclusion criteria that resulted in a relatively young and physically and cognitively healthy sample of older adults, potentially limiting the degree of attainable improvement following training. Larger-scale randomized controlled trials would be beneficial for replicating our findings and increasing generalizability by expanding cohort characteristics.

Despite these limitations, the results of our study help to improve our understanding of the specific effects of mindfulness training on mind-wandering and attentional control in older adults and potential moderators of these effects. Contrary to the observation of improved cognitive function in older adults following mindfulness training in two previous studies in older adults without active control groups (Lenze et al. 2014; Moynihan et al. 2013), we did not find enhancements in attention that were specific to the MBAT group. Although prior studies in young adults have observed significant cognitive improvements following similarly brief trainings (Mrazek et al. 2013; Semple 2010), it is possible that 4 weeks of training is not sufficient to produce similar effects in our sample of older adults. This suggests that the duration of training may be a particularly important factor to consider in future studies implementing mindfulness interventions in older adult populations. However, within the MBAT group, training did result in reductions in mind-wandering in one of the two attentional control tasks, offering some optimism for the benefits of brief mindfulness training for attentional control in the elderly. Additionally, exploratory analyses identified WM as a possible moderator of the effects of this brief mindfulness training program. Specifically, within cognitively intact healthy older adults, mindfulness training yielded attentional benefits primarily for those with higher baseline cognitive capacity.

Author Contributions PW assisted with data collection and data analysis, prepared tables and figures with input from other authors, and wrote the introduction, method, and results. SF collaborated with the design of the study and data analyses and wrote the discussion. RA assisted with data analyses and wrote part of the method. KB assisted with data analysis and collaborated in the writing and editing of the final manuscript. AL collaborated with the design of the study and writing and editing of the final manuscript. LK assisted with data collection and collaborated in the writing and editing of the final manuscript. RSP designed the study, performed randomization procedures, provided materials and resources for the interventions, provided input and guidance on data analysis and the preparation of tables and figures, and collaborated in the writing and editing of the final manuscript.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics All procedures performed in studies involving human participants were in accordance with the ethical standards of The Ohio State University Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

A Consensus on the Brain Training Industry from the Scientific Community. (2014). *Institute for Human Development and Stanford Center on Longevity*, Accessed 1 Oct 2017. http://longevity.stanford.edu/a-consensus-on-the-brain-training-industry-from-the-scientific-community-2/.

Ainsworth, B., Eddershaw, R., Meron, D., Baldwin, D. S., & Garner, M. (2013). The effect of focused attention and open monitoring meditation on attention network function in healthy volunteers. *Psychiatry Research, 210*(3), 1226–1231. https://doi.org/10.1016/j.psychres.2013.09.002.

Aldana, S. (2005). *The culprit and the cure: why lifestyle is the culprit behind America's poor health*. Mapleton: Maple Mountain Press.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience, 4*, 829–839. https://doi.org/10.1038/nrn1201.

Baddeley, A., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation, 8*, 47–89. https://doi.org/10.1016/S0079-7421(08)60452-1.

Baer, R. A., Smith, G. T., Hopkins, J., Krietemeyer, J., & Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. *Assessment, 13*(1), 27–45. https://doi.org/10.1177/1073191105283504.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology, 83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817.

Bishop, S. R. (2002). What do we really know about mindfulness-based stress reduction? *Psychosomatic Medicine, 64*, 71–83.

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2008). Explaining the many varieties of working memory variation: dual mechanisms of cognitive control. In A. Conway, C. Jarrold, M. Kane, A. Miyake, & J. Towse (Eds.), *Variation in working memory* (pp. 76–106). Oxford: Oxford University Press.

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology, 84*(4), 822–848. https://doi.org/10.1037/0022-3514.84.4.822.

Chao, L. L., & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex, 7*(1), 63–69. https://doi.org/10.1093/cercor/7.1.63.

Cheyne, J. A., Solman, G. J. F., Carriere, J. S. A., & Smilek, D. (2009). Anatomy of an error: a bidirectional state model of task engagement/disengagement and attention-related errors. *Cognition, 111*(1), 98–113. https://doi.org/10.1016/j.cognition.2008.12.009.

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

Dziura, J. D., Post, L. A., Zhao, Q., Fu, Z., & Peduzzi, P. (2013). Strategies for dealing with missing data in clinical trials: From design to analysis. *The Yale Journal of Biology and Medicine, 86*(3), 343–358.

Epel, E. S., Puterman, E., Lin, J., Blackburn, E., Lazaro, A., & Mendes, W. B. (2012). Wandering minds and aging cells. *Clinical Psychological Science*, 2167702612460234. https://doi.org/10.1177/2167702612460234.

Evers, A., Klusmann, V., Schwarzer, R., & Heuser, I. (2011). Improving cognition by adherence to physical or mental exercise: a moderated mediation analysis. *Aging & Mental Health, 15*(4), 446–455. https://doi.org/10.1080/13607863.2010.543657.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198.

Fountain-Zaragoza, S., Londerée, A., Whitmoyer, P., & Prakash, R. S. (2016). Dispositional mindfulness and the wandering mind: implications for attentional control in older adults. *Consciousness and Cognition, 44*, 193–204. https://doi.org/10.1016/j.concog.2016.08.003.

Fountain-Zaragoza, S., Puccetti, N. A., Whitmoyer, P., & Prakash, R. S. (2018). Aging and attentional control: examining the roles of mind-wandering propensity and dispositional mindfulness. *Journal of the International Neuropsychological Society, 24*(8), 876–888. https://doi.org/10.1017/S1355617718000553.

Greenberg, J., Reiner, K., & Meiran, N. (2012). "Mind the trap": mindfulness practice reduces cognitive rigidity. *PLoS One, 7*(5), e36206. https://doi.org/10.1371/journal.pone.0036206.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: a review and a new view. *The Psychology of Learning and Motivation, 22*, 193–225. https://doi.org/10.1016/S0079-7421(08)60041-9Get.

Heeren, A., Van Broeck, N., & Philippot, P. (2009). The effects of mindfulness on executive processes and autobiographical memory specificity. *Behaviour Research and Therapy, 47*(5), 403–409. https://doi.org/10.1016/j.brat.2009.01.017.

Hodgins, H. S., & Adair, K. C. (2010). Attentional processes and meditation. *Consciousness and Cognition, 19*(4), 872–878. https://doi.org/10.1016/j.concog.2010.04.002.

Jensen, C. G., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2012). Mindfulness training affects attention—or is it attentional effort? *Journal of Experimental Psychology: General, 141*(1), 106–123. https://doi.org/10.1037/a0024931.

Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. *Emotion, 10*(1), 54–64. https://doi.org/10.1037/a0018438.

Jha, A. P., Morrison, A. B., Dainer-Best, J., Parker, S., Rostrup, N., & Stanley, E. A. (2015). Minds "at attention": mindfulness training curbs attentional lapses in military cohorts. *PLoS One, 10*(2). https://doi.org/10.1371/journal.pone.0116889.

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

Kabat-Zinn, J. (2009). *Full catastrophe living: using the wisdom of your body and mind to face stress, pain, and illness*. New York: Random House Publishing Group.

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For whom the mind wanders, and when: an experience-sampling study of working memory and executive control in daily life. *Psychological Science, 18*(7), 614–621. https://doi.org/10.1111/j.1467-9280.2007.01948.x.

Kazazi, L., Foroughan, M., Nejati, V., & Shati, M. (2018). Association between age associated cognitive decline and health related quality of life among Iranian older individuals. *Electronic Physician, 10*(4), 6663–6671. https://doi.org/10.19082/6663.

Lenze, E. J., Hickman, S., Hershey, T., Wendleton, L., Ly, K., Dixon, D., et al. (2014). Mindfulness-based stress reduction for older adults with worry symptoms and co-occurring cognitive dysfunction. *International Journal of Geriatric Psychiatry, 29*(10), 991–1000. https://doi.org/10.1002/gps.4086.

Lockenhoff, C. E., & Cartensen, L. L. (2007). Aging, emotion, and health-related decision strategies: motivational manipulation can reduce age differences. *Psychology and Aging, 22*(1), 134–146. https://doi.org/10.1037/0882-7974.22.1.134.

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: a review and future directions. *Neuropsychology Review, 19*(4), 504–522. https://doi.org/10.1007/s11065-009-9119-9.

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences, 12*(4), 163–169. https://doi.org/10.1016/j.tics.2008.01.005.

MacCoon, D. G., MacLean, K. A., Davidson, R. J., Saron, C. D., & Lutz, A. (2014). No sustained attention differences in a longitudinal randomized trial comparing mindfulness based stress reduction versus active control. *PLoS One, 9*(6), e97551. https://doi.org/10.1371/journal.pone.0097551.

Malinowski, P., Moore, A. W., Mead, B. R., & Gruber, T. (2017). Mindful aging: the effects of regular brief mindfulness practice on electrophysiological markers of cognitive and affective processing in older adults. *Mindfulness, 8*(1), 78–94. https://doi.org/10.1007/s12671-015-0482-8.

Mallya, S., & Fiocco, A. J. (2015). Effects of mindfulness training on cognition and well-being in healthy older adults. *Mindfulness, 7*(2), 453–465. https://doi.org/10.1007/s12671-015-0468-6.

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(1), 196–204. https://doi.org/10.1037/a0014104.

McVay, J. C., Meier, M. E., Touron, D. R., & Kane, M. J. (2013). Aging ebbs the flow of thought: adult age differences in mind wandering, executive control, and self-evaluation. *Acta Psychologica, 142*(1), 136–147. https://doi.org/10.1016/j.actpsy.2012.11.006.

Menezes, C. B., de Paula Couto, M. C., Buratto, L. G., Erthal, F., Pereira, M. G., & Bizarro, L. (2013). The improvement of emotion and attention regulation after a 6-week training of focused meditation: a randomized controlled trial. *Evidence-based Complementary and Alternative Medicine*, 984678. https://doi.org/10.1155/2013/984678.

Morrison, A. B., Goolsarran, M., Rogers, S. L., & Jha, A. P. (2014). Taming a wandering attention: short-form mindfulness training in student cohorts. *Frontiers in Human Neuroscience, 7*. https://doi.org/10.3389/fnhum.2013.00897.

Moynihan, J. A., Chapman, B. P., Klorman, R., Krasner, M. S., Duberstein, P. R., Brown, K. W., & Talbot, N. L. (2013). Mindfulness-based stress reduction for older adults: effects on executive function, frontal alpha asymmetry and immune function.

Neuropsychobiology, 68(1), 34–43. https://doi.org/10.1159/000350949.

Mrazek, M. D., Franklin, M. S., Phillips, D. T., Baird, B., & Schooler, J. W. (2013). Mindfulness training improves working memory capacity and GRE performance while reducing mind wandering. *Psychological Science, 24*(5), 776–781. https://doi.org/10.1177/0956797612459659.

Naumann, J., Richter, T., Christmann, U., & Groeben, N. (2008). Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext. *Learning and Individual Differences, 18*(2), 197–213. https://doi.org/10.1016/j.lindif.2007.08.007.

O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Turin, A., Ward, S., Foxe, J. J., & Robertson, I. H. (2008). Two types of action error: electrophysiological evidence for separable inhibitory and sustained attention neural mechanisms producing error on go/no-go tasks. *Journal of Cognitive Neuroscience, 21*(1), 93–104. https://doi.org/10.1162/jocn.2009.21008.

Oken, B. S., Wahbeh, H., Goodrich, E., Klee, D., Memmott, T., Miller, M., & Fu, R. (2017). Meditation in stressed older adults: improvements in self-rated mental health not paralleled by improvements in cognitive function or physiological measures. *Mindfulness, 8*(3), 627–638. https://doi.org/10.1007/s12671-016-0640-7.

Ortman, J. M., Velkoff, V. A., & Hogan, H. (2014). *An aging nation: the older population in the United States*. U.S. Census Bureau. Retrieved from https://www.census.gov/content/dam/Census/library/publications/2014/demo/p25-1140.pdf . Accessed 13 Aug 2019.

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cerebral Cortex, 18*(5), 1010–1028. https://doi.org/10.1093/cercor/bhm135.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73–89. https://doi.org/10.1146/annurev-neuro-062111-150525.

Prakash, R. S., Voss, M. W., Erickson, K. I., & Kramer, A. F. (2015). Physical activity and cognitive vitality. *Annual Review of Psychology, 66*(1), 769–797. https://doi.org/10.1146/annurev-psych-010814-015249.

Rahe, J., Becker, J., Fink, G. R., Kessler, J., Kukolja, J., Rahn, A., et al. (2015). Cognitive training with and without additional physical activity in healthy older adults: cognitive effects, neurobiological mechanisms, and prediction of training success. *Frontiers in Aging Neuroscience, 7*, 187. https://doi.org/10.3389/fnagi.2015.00187.

Randall, J. G., Oswald, F. L., & Beier, M. E. (2014). Mind-wandering, cognition, and performance: a theory-driven meta-analysis of attention regulation. *Psychological Bulletin, 140*(6), 1411–1431. https://doi.org/10.1037/a0037428.

Seeman, T. E., Lusignolo, T. M., Albert, M., & Berkman, L. (2001). Social relationships, social support, and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur studies of successful aging. *Health Psychology, 20*(4), 243–255. https://doi.org/10.1037/0278-6133.20.4.243.

Segal, Z. V., Williams, J. M. G., & Teasdale, J. D. (2002). *Mindfulness based cognitive therapy for depression*. New York: Guilford Press.

Semple, R. J. (2010). Does mindfulness meditation enhance attention? A randomized controlled trial. *Mindfulness, 1*(2), 121–130. https://doi.org/10.1007/s12671-010-0017-2.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*(6), 946–958. https://doi.org/10.1037/0033-2909.132.6.946.

Smallwood, J., McSpadden, M., Luus, B., & Schooler, J. (2008). Segmenting the stream of consciousness: the psychological correlates of temporal structures in the time series data of a continuous performance task. *Brain and Cognition, 66*(1), 50–56. https://doi.org/10.1016/j.bandc.2007.05.004.

Stawarczyk, D., Majerus, S., Catale, C., & D'Argembeau, A. (2014). Relationships between mind-wandering and attentional control abilities in young adults and adolescents. *Acta Psychologica, 148*, 25–36. https://doi.org/10.1016/j.actpsy.2014.01.007.

Stine-Morrow, E. A. L., Payne, B. R., Roberts, B. W., Kramer, A. F., Morrow, D. G., Payne, L., et al. (2014). Training versus engagement as paths to cognitive enrichment with aging. *Psychology and Aging, 29*(4), 891–906. https://doi.org/10.1037/a0038244.

van Leeuwen, S., Singer, W., & Melloni, L. (2012). Meditation increases the depth of information processing and improves the allocation of attention in space. *Frontiers in Human Neuroscience, 6*. https://doi.org/10.3389/fnhum.2012.00133.

Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging, 25*(2), 343–355. https://doi.org/10.1037/a0017729.

Verhaeghen, P. (2011). Aging and executive control: reports of a demise greatly exaggerated. *Current Directions in Psychological Science, 20*(3), 174–180. https://doi.org/10.1177/0963721411408772.

Verhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: estimates of linear and nonlinear age effects and structural models. *Psychological Bulletin, 122*(3), 231–249.

Visted, E., Vollestad, J., Nielsen, M. B., & Nielsen, G. H. (2015). The impact of group-based mindfulness training on self-reported mindfulness: a systematic review and meta-analysis. *Mindfulness, 6*(3), 501–522. https://doi.org/10.1007/s12671-014-0283-5.

Warner, L. M., Wolff, J. K., Ziegelmann, J. P., & Wurm, S. (2014). A randomized controlled trial to promote volunteering in older adults. *Psychology and Aging, 29*(4), 757–763. https://doi.org/10.1037/a0036486.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology, 54*(6), 1063–1070.

Wechsler, D. (2008). *Wechsler adult intelligence scale—fourth edition (WAIS–IV)*. London: Pearson.

White, I. R., Royston, P., & Wood, A. M. (2011). Multiple imputation using chained equations: issues and guidance for practice. *Statistics in Medicine, 30*(4), 377–399. https://doi.org/10.1002/sim.4067.

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1982). Development and validation of a geriatric depression screening scale: a preliminary report. *Journal of Psychiatric Research, 17*(1), 37–49.

Zavagnin, M., Borella, E., & De Beni, R. (2014). When the mind wanders: age-related differences between young and older adults. *Acta Psychologica, 145*, 54–64. https://doi.org/10.1016/j.actpsy.2013.10.016.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.