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Research Article

Does Intensive Mindfulness Training Strengthen Sustained Attention? Examining Individual Differences in Mind Wandering during the Sustained Attention to Response Task

Joanna E. Witkin [1], Ekaterina Denkova [1], Anthony P. Zanesco [1], Alexandra B. Morrison [2], Joshua Rooks [1], Jane Carpenter [3], Michael Baime [4], Amishi P. Jha [1, *]

1. Department of Psychology, University of Miami, Coral Gables, FL, USA; E-Mails: joanna.witkin@miami.edu; exn67@miami.edu; apz13@miami.edu; j.rooks@umiami.edu; a.jha@miami.edu
2. Department of Psychology, Sacramento State University, Sacramento, CA, USA; E-Mail: alexandra.morrison@csus.edu
3. Department of Psychology, Naropa University, Boulder, CO, USA; E-Mail: Jane@naropa.edu
4. Penn Program for Mindfulness, University of Pennsylvania, School of Medicine, Philadelphia, PA, USA; E-Mail: baime@pennmedicine.upenn.edu

* **Correspondence:** Amishi P. Jha; E-Mail: a.jha@miami.edu

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Abstract

Mindfulness training (MT) has been shown to benefit sustained attention and mind wandering. Yet, few studies have examined whether benefits differ as a function of individual differences in mind wandering. The sustained attention to response task (SART) measured task accuracy (*A′*), response time variability (response time intraindividual coefficient of variation, ICV), and self-reported mind wandering in participants before (T1) and after (T2) a 1-month MT retreat (n = 56), as well as in a control group (n = 32) who received no MT. Only the retreat group demonstrated increased *A′* and reduced mind wandering, but no change in ICV, from T1 to T2. Retreat participants demonstrated reduced ICV compared to the control group only when considering individual differences in mind wandering such that retreat participants with higher levels of mind wandering at T1 demonstrated greater benefits to ICV over time. These findings suggest MT may benefit sustained attention, as seen in changes on both objective and subjective measures, and that considering baseline individual differences may increase our understanding of MT's benefits to sustained attention.

Keywords
Mindfulness; retreat; mind wandering; attention

1. Introduction

Sustained attention refers to the ability to maintain focused attention on the processing of stimuli and is critical for complex goal-directed behavior [1, 2]. Lapses of sustained attention, such as those driven by mind wandering (MW) [3] or induced negative mood [4] often result in performance errors on every-day tasks, as well as laboratory-based paradigms in psychologically healthy populations (see [5] for review). Relatedly, a growing body of research finds compromised sustained attention in clinical cohorts suffering from psychological disorders such as anxiety [6], depression [7, 8], post-traumatic stress disorder (PTSD) [9], attention-deficit/ hyperactivity disorder (ADHD) [10], and others [11]. The ubiquity of such findings has even led to the suggestion that dysregulation of sustained attention may serve as a transdiagnostic marker for psychological disorders [12].

Given the centrality and fragility of sustained attention, there has been growing interest in identifying cognitive training modalities by which to strengthen it and curb MW. One increasingly popular approach is training involving mindfulness meditation [13-19]. Indeed, recent theoretical accounts suggest that improvements in attention and related control processes (e.g., working memory) through mindfulness training (MT) may undergird MT's benefits to psychological health [20].

MT programs offer participants a suite of practices that guide them to regulate attention and monitor present moment attention without judgment or conceptual elaboration [21]. A foundational concentrative mindfulness practice, for example, begins with instructions to focus one's attention on a target object, such as the physical sensations of the breath, and gently return attention back to these sensations after noticing that the mind has wandered. From a cognitive training perspective, repeated engagement in MT practices has been shown to strengthen individuals' capacity to sustain attention over time and curb instances of MW [22-24].

Herein, we investigate MT via participation in an intensive residential MT retreat. Such retreats invite practitioners to completely immerse themselves in practice for many hours each day over a certain length of time, ranging from a few days to several months. The immersive nature of retreats allows participants to practice in an environment free from the distractions and demands of daily life. Owing to their intensity, length, and structure, retreats may provide optimal conditions for sustained and repeated engagement in mindfulness practices [25]. This sustained engagement in practice may, in turn, provide optimal conditions to strengthen sustained attention. Indeed, previous studies in retreats of 1 to 3 months have reported performance improvements on tasks measuring sustained attention (see [26] for review) as well as reductions in the frequency of self-reported MW [27].

Interestingly, cognitive neuroscience research has provided mounting evidence that individual differences in MW contribute to performance differences on tasks of sustained attention, as well as other cognitive tasks [28]. While the importance of considering individual differences in MT-related effects has been recently highlighted in the service of better understanding MT's benefits and mechanisms of action [29], the influence of individual differences in MW on MT-related benefits in sustained attention have not been fully investigated. To our knowledge, only one study, to date, has investigated if baseline levels of MW influenced the magnitude of MT-related benefits [30]. This study investigated the effect of a 2-week, non-residential MT program vs. a nutrition education program on working memory capacity in undergraduate students. Baseline MW was found to correspond with the magnitude of MT benefits in working memory capacity, as indexed by the operational span task [30]. Yet, no studies to our knowledge have investigated the influence of individual differences in baseline levels of MW on the magnitude of MT-related benefits to working memory or sustained attention in the context of intensive MT retreats.

In the present study, we asked two main questions: 1) Do individuals participating in a 1-month retreat demonstrate benefits to sustained attention when compared to those receiving no training (control participants)? 2) Do individual differences in baseline subjective ratings of MW influence MT-related benefits on sustained attention over time?

2. Methods

2.1 Participants

Fifty-seven participants (25 female, M_{age} = 39.52 years old, *SD* = 12.05, years of education *M* = 16.39, *SD* = 2.36) were recruited from individuals taking part in an intensive 1-month residential mindfulness retreat held at Shambhala Mountain Center (SMC) in Red Feather Lakes, Colorado (referred to as the MT group). Participants were generally experienced with meditation practices (*M* = 70.46 months of prior experience, *SD* = 78.74, range = 0–252 months). A control group of 32 participants (no-training controls, NTC; 16 female, M_{age} = 43.84 years old, *SD* = 16.05, years of education *M* = 17.03, *SD* = 2.32) was recruited from the Philadelphia, Pennsylvania community and matched to MT on demographics of age and education [1]. NTC participants had no meditation experience prior to the study. The study was approved by the University of Pennsylvania Institutional Review Board and followed ethical principles set forth by the Belmont Report and the Department of Health and Human Services regulations at 45 CFR 46 and the Food and Drug Administration's regulations at 21 CFR 50 and 21 CFR 56. All participants were informed of the purpose of the study and provided written consent.

2.2 Retreat Curriculum

The month-long retreat followed the Shambhala retreat model [31], which included sitting and walking mindfulness practices, as well as individual meetings with mindfulness instructors. The curriculum emphasized both focused attention and open monitoring mindfulness practices through

[1] Groups did not significantly differ in age (t (51.19) = -1.33, p = 0.191) or years of education (t (65.23) = -1.25, p = 0.215)

tightening and loosening one's attention, cultivating awareness of obstacles, dullness, or agitation, and working with emotions. Practice instruction directed participants to place attention on a selected 'target' of mindfulness practice (e.g., the sensations of breathing) as an anchor [23, 32-34]. During the retreat, participants were instructed to engage in formal mindfulness practice for 8-9 hours per day, with approximately two-thirds of that time dedicated to sitting meditation (6 hours) and one-third dedicated to walking meditation (3 hours). Participants also attended lectures and engaged in contemplative eating practices and individual study.

2.3 Experimental Procedure and Stimuli

All participants completed 2 testing sessions (T1 and T2). MT participants were assessed at SMC before (T1) and after (T2) the 1-month retreat. NTC participants were assessed in a laboratory setting at the University of Pennsylvania before (T1) and after (T2) a 30-day interval during which they did not participate in any form of meditation practice. Testing sessions were completed in a quiet room where participants sat approximately 57 cm from a laptop and completed the behavioral measures.

The measure of interest was the SART [1] presented via E-Prime (Version 1.2, Psychology Software Tools, Pittsburgh, PA). During the SART, a continuous stream of single digits (0-9) were serially presented one at a time for 250 ms each, with a fixation cross following each digit (900 ms) that served as the inter-trial interval (see Figure 1). Participants were instructed to respond to every number (non-targets) except the number 3 (target) by pressing a designated keyboard button with their index finger. Participants could respond during stimulus presentation or the inter-trial interval. Trial order was quasi-random such that targets were separated by at least one non-target trial. Targets comprised 5% of trials, while non-targets comprised 95% of trials.

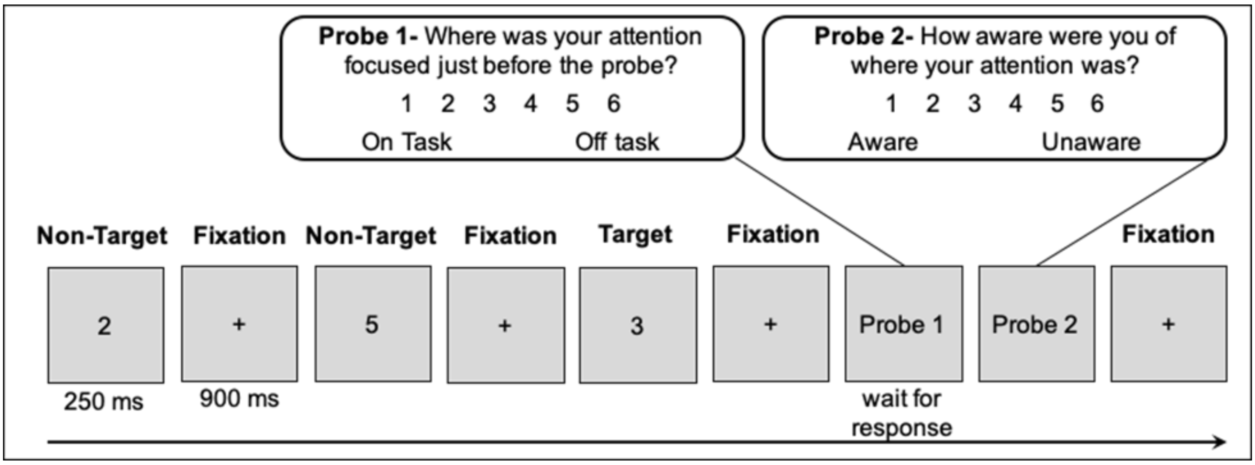

Figure 1 Task schematic for the Sustained Attention to Response Task (SART). Participants viewed a string of single digit numbers and were instructed to press a designated key in response to any digit except 3 (non-target) and to withhold their response when a 3 was presented (target). Self-report probes intermittently asked participants about the focus of their attention and participants responded on a Likert-type scale. The SART employed in the present study included three 329-trial blocks, and one 313-trial practice block.

Intervening between trials, participants were shown a pair of probe questions. The first probe question (Probe 1) asked: "Where was your attention focused just before the probe?" Participants were instructed to respond using a 6-point scale in which 1 represented "On Task" and 6 represented "Off Task." The second probe (Probe 2) asked: "How aware were you of where your attention was?" Participants were instructed to respond using a similar 6-point scale where 1 represented "Aware" and 6 represented "Unaware." These probes were randomly interspersed among the trials, and participants responded at their own pace (Probe 1: M = 2.82s, SD = 7.57; Probe 2: M = 1.54s, SD = 3.34). All participants completed a practice block containing 313 trials followed by 3 blocks of 329 trials each, with self-paced breaks in between each block (939 total trials comprising 48 targets and 891 non-targets, and 48 sets of probes). The total task was approximately 21 minutes in length on average (range: 18.57- 32.32 minutes), where each block was approximately 7 minutes long.

Performance accuracy on the SART was measured using a non-parametric index of signal detection sensitivity, *A′* [35]. *A′* is calculated from "hits" (rate of trials correctly withholding response to targets) and "false alarms" (rate of errors incorrectly withholding response to non-targets) and corrects for the uneven weight of trial types. Variability in response times was indexed by the intraindividual coefficient of variation (ICV), which is calculated by dividing the standard deviation of response time (RT) by mean RT for correct non-target trials. Greater ICV reflects greater variability in RT and has been used as a behavioral correlate of MW [36-38]. Self-reported MW (Probe 1) and awareness of MW (Probe 2) were indexed by the mean rating to each of the two separate probes [2].

2.4 Data Analyses

We employed a hierarchical linear modeling (HLM) approach with PROC MIXED in SAS version 9.4. Maximum likelihood was utilized to estimate parameters despite missing data, and separate residual variances were estimated for each group. Random intercepts were estimated at the level of the individual to allow for between-person variability.

To address our first question of interest, whether participation in a 1-month retreat (MT) benefitted SART performance compared to a no-training control group (NTC), Model 1 investigated whether SART performance changed over sessions (T1 vs. T2) as a function of group (MT vs. NTC). Separate HLM models were specified for each dependent variable (*A′*, ICV, Probe 1, Probe 2). Session (T1 vs. T2) was entered as level-1 fixed effect and group (MT vs. NTC) was entered as a level-2 fixed effect. To account for the structure of the task, block (block 1, 2, 3) was entered as level-1 fixed linear effect to assess the linear within-task rate of change over blocks of the SART, and as a random effect to account for between-person variability in within-task performance slopes.

To address our second question of interest, whether individual differences in baseline self-reported MW influenced MT-related changes in objective SART performance, Probe 1 responses were averaged across the task for each participant at T1 and entered as a level-2 fixed effect in Model 2. As such, Model 2 examined the average response to Probe 1 at T1 as an individual

[2] Participants occasionally (2.28% of all probe responses) gave multiple successive responses when responding to the probe questions. In the case of duplicate responses (e.g, "11"; accounting for 2.11% of all probe responses), responses were re-coded to a single response value and retained for analysis. In the case of different successive responses (e.g, "16"; accounting for 0.83% of all probe responses), responses were excluded from analyses.

differences predictor [3]. Model 2 was a full-factorial model examining main effects and interactions between session (T1 vs. T2), group (MT vs. NTC), and average Probe 1 rating at T1. Separate HLM models were specified for each objective SART outcome (*A′* and ICV).

Type III tests of fixed effects are reported alongside parameter estimates and 95% confidence intervals. Least squares mean comparisons are reported to assess the direction and magnitude of changes between and within groups. Degrees of freedom were determined by Satterthwaite approximation to correct for unequal sample variance [39, 40], and are reported herein rounded to the nearest integer. All participants were included in analyses regardless of dropout or missing data, but observations were excluded if *A′* was less than 0.5 for any given block, indicating an accuracy of below chance levels (6 observations were removed from the MT group and 8 observations were removed from the NTC group).

3. Results

Table 1 shows the observed means for each group at each time point for dependent measures (*A′*, ICV, Probe 1, Probe 2).

Table 1 Observed Group Means and Standard Deviations at Each Session.

Group	*A′* (SD)	ICV (SD)	Probe 1 (SD)	Probe 2 (SD)
NTC				
T1	0.876 (0.093)	0.319 (0.124)	1.965 (0.822)	2.161 (1.146)
T2	0.871 (0.082)	0.319 (0.138)	2.089 (0.886)	2.097 (1.061)
MT				
T1	0.880 (0.086)	0.296 (0.156)	2.412 (0.959)	2.445 (1.033)
T2	0.910 (0.082)	0.270 (0.138)	1.930 (0.731)	1.830 (0.961)

Note: Observed means and standard deviations for each group (NTC = Controls, MT = Retreat) at each session (T1, T2) for each SART outcome (*A′*, ICV, Probe 1, Probe 2).

3.1 MT Retreat-Related Changes in SART Performance

Model 1 included fixed effects of session, group, and block, as well as the interaction between session and group. Table 2 shows the Model 1 parameters for each dependent measure (*A′*, ICV, Probe 1, Probe 2).

[3] Probe 2 responses (assessing awareness of MW) were not examined due to our primary interest in baseline propensity for MW, and Probe 1 and Probe 2 responses were highly correlated within individuals at T1 (r = 0.768, p < 0.001).

Table 2 Parameter Estimates for Model 1.

Model Effects		*b*(SE) A'	ICV	Probe 1	Probe 2
Fixed Effects	Intercept	0.883 (0.014) **	0.307 (0.021) **	1.859 (0.139) **	2.083 (0.175) **
	Session	-0.009 (0.007)	-0.002 (0.010)	0.113 (0.070)	-0.069 (0.073)
	Group	0.004 (0.017)	-0.028 (0.027)	0.426 (0.174) *	0.291 (0.218)
	Session*Group	0.038 (0.010) **	-0.021 (0.015)	-0.564 (0.101) **	-0.536 (0.104) **
	Block	-0.005 (0.003)	0.012 (0.005) *	0.128 (0.034) **	0.086 (0.031) *
Random Effects	Intercept Variance	0.005 (0.001) **	0.012 (0.002) **	0.506 (0.091) **	0.866 (0.140) **
	Block	<0.001 (<0.001)	<0.001 (<0.001)	0.024 (0.015)	<0.001 (<0.001)
Fit Statistics	-2 Log-likelihood	-1222.3	-818.1	978.4	1010.3
	N_{obs}	474	474	474	472

Note: Maximum likelihood estimates are reported for models of *A'*, ICV, Probe 1, and Probe 2 responses. The NTC group served as the reference condition for the effects of group, and T1 served as the reference condition for the effects of session. * $p < 0.05$, ** $p < 0.001$

3.1.1 Accuracy (*A'*)

There were no main effects of session, $F(1, 298) = 3.82$, $p = 0.052$, group, $F(1, 85) = 1.99$, $p = 0.162$, or block, $F(1, 90) = 1.98$, $p = 0.163$. There was, however, a significant session by group interaction, $F(1, 298) = 14.10$, $p < 0.001$ [4].

The interaction between session and group revealed that the increase in *A'* over sessions for the MT group was significantly different from the change in *A'* over sessions for the NTC group (b = 0.038, $p < 0.001$, 95% CI [0.018, 0.057]). Specifically, MT participants increased by 0.029 units of *A'* from T1 to T2 ($p < 0.001$, 95% CI [0.015, 0.042]), whereas the NTC group did not significantly change from T1 to T2 (b = -0.009, p = 0.211, 95% CI [-0.023, 0.005]). While the groups did not differ at T1 (b = 0.004, p = 0.793, 95% CI [-0.029, 0.038]), the MT group had significantly higher *A'* than the control group at T2 (b = 0.042, p = 0.018, 95% CI [0.008, 0.076]). These results suggest that compared to NTC, the MT group improved on *A'* from T1 to T2 (see Figure 2a).

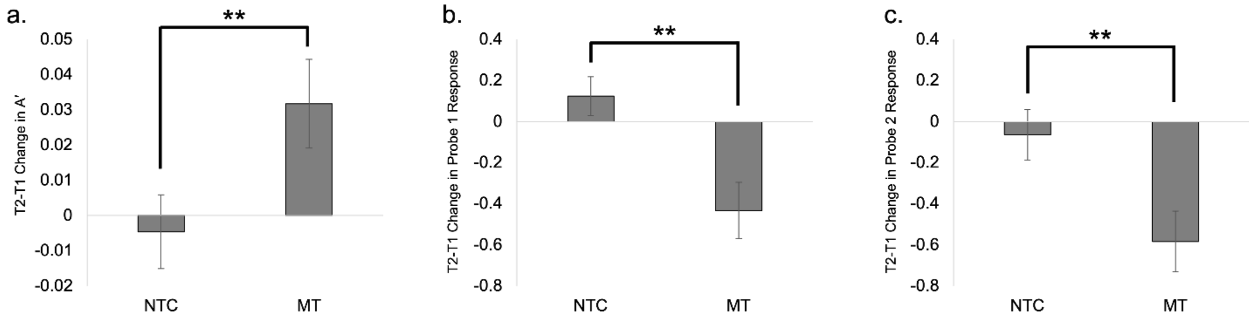

Figure 2 Observed means depicted comparing a 1-month intensive retreat (MT) and no-training control group (NTC) on objective and subjective measures of the SART. a) Magnitude of change in *A'* from T1 to T2 for each group. The MT group demonstrated increased *A'* over sessions compared to the NTC group. b) Magnitude of change in Probe 1 response from T1 to T2 for each group. The MT group demonstrated reductions in MW over sessions compared to the NTC group. c) Magnitude of change in Probe 2 response from T1 to T2 for each group. The MT group demonstrated increased awareness over sessions compared to the NTC group.

3.1.2 ICV

There were no significant main effects of session, $F(1, 347) = 2.94$, $p = 0.087$, or group, $F(1, 82) = 2.26$, $p = 0.136$, but there was a significant effect of block, $F(1, 88) = 6.70$, $p = 0.011$. There was no significant interaction between session and group, $F(1, 348) = 1.93$, $p = 0.166$. The significant effect of block indicated that all participants increased in ICV over blocks of the task by 0.012 units (p = 0.011, 95% CI [0.003, 0.021]).

[4] These results were similar when target accuracy (i.e., correctly withholding responses to rare target stimuli) was analyzed instead of *A'*. For target accuracy, there were no main effects of session, $F(1, 263) = 3.60$, $p = 0.059$, group, $F(1, 86.5) = 2.15$, $p = 0.146$, or block, $F(1, 93.6) = 1.38$, $p = 0.244$. There was, however, a significant session by group interaction, $F(1, 264) = 21.17$, $p < 0.001$, such that the MT group significantly increased in target accuracy over time (b = 0.100, $p < 0.001$, 95% CI [0.062, 0.138]), whereas the control group did not (b = -0.042, p = 0.082, 95% CI [-0.089, 0.005]).

3.1.3 Probe 1

There was a significant main effect of session, $F(1, 327) = 11.35$, $p = 0.001$, no main effect of group, $F(1, 83) = 0.73$, $p = 0.395$, and a significant main effect of block, $F(1, 91) = 13.80$, $p < 0.001$. There was also a significant session by group interaction, $F(1, 327) = 31.48$, $p < 0.001$. The significant effect of block revealed that all participants reported more MW over blocks of the task by 0.13 units ($p < 0.001$, 95% CI [0.060, 0.196]).

The significant interaction between session and group indicated that the reduction in reported MW over sessions for the MT group was significantly different from the change in MW over sessions in the NTC group ($b = -0.564$, $p < 0.001$, 95% CI [-0.762, -0.366]). Specifically, from T1 to T2, the MT group reported less MW ($b = -0.452$, $p < 0.001$, 95% CI [-0.593, -0.310]), whereas NTC participants did not report changes in MW ($b = 0.113$, $p = 0.112$, 95% CI [-0.027, 0.252]). Interestingly, the MT group reported higher MW than the control group at T1 ($b = 0.426$, $p = 0.016$, 95% CI [0.081, 0.771]), but the groups did not significantly differ at T2 ($b = -0.138$, $p = 0.437$, 95% CI [-0.490, 0.213]). While between-group differences were not present at T2, these results suggest that compared to the change in the NTC group over time, the MT group reported a greater reduction in MW from T1 to T2 (see Figure 2b).

3.1.4 Probe 2

There was a significant main effect of session, $F(1, 371) = 42.40$, $p < 0.001$, no main effect of group, $F(1, 87) = 0.01$, $p = 0.915$, and a main effect of block, $F(1, 375) = 7.79$, $p = 0.006$. There was also a significant session by group interaction, $F(1, 371) = 26.78$, $p < 0.001$. The significant main effect of block indicated that all participants reported less awareness of MW over blocks of the task by 0.09 units ($p = 0.006$, 95% CI [0.025, 0.146]).

The significant interaction between session and group revealed that the increase in reported awareness over sessions for the MT group was significantly different from the change in awareness over sessions in the NTC group ($b = -0.536$, $p < 0.001$, 95% CI [-0.739, -0.332]). From T1 to T2, the MT group reported greater awareness of MW ($b = -0.605$, $p < 0.001$, 95% CI [-0.750, -0.460]), whereas the NTC participants did not report changes in awareness of MW ($b = -0.069$, $p = 0.344$, 95% CI [-0.213, 0.075]). There were no differences between groups at T1 ($b = 0.291$, $p = 0.185$, 95% CI [-0.141, 0.723]), or at T2 ($b = -0.245$, $p = 0.268$, 95% CI [-0.682, 0.192]). While the groups did not significantly differ at T2, these results suggest that compared to the change in the NTC group over time, participation in a retreat improved awareness of MW from T1 to T2 (see Figure 2c).

Overall, the findings from Model 1 suggest that when considering overall performance, participation in a retreat improved A′, self-reported MW and awareness of MW, but not ICV, compared to the NTC group. These results also indicate that across both groups and timepoints, ICV was greater, MW increased, and awareness of MW decreased over successive blocks. This pattern is consistent with time-on-task effects reported in several prior studies of the sustained attention (for reviews see, [2, 9, 41]). Yet, exploratory follow-up analyses revealed that these time-on-task effects did not vary across groups or across time (all p's > 0.701 for 3-way interactions between session, group, and block).

3.2 Individual Differences in MW

Model 2 examined individual differences in MW as a predictor of SART performance by including all two- and three-way interactions between session, group, and average ratings for Probe 1 at T1. Table 3 shows the parameters for Model 2 for objective measures of the SART (*A′* and ICV).

Table 3 Parameter Estimates for Model 2.

Model Effects		*b*(SE) A′	ICV
Fixed Effects	Intercept	0.894 (0.034) **	0.302 (0.054) **
	Session	0.015 (0.020)	-0.019 (0.032)
	Group	0.097 (0.043) *	-0.147 (0.069) *
	Session *Group	-0.067 (0.027) *	0.117 (0.042) *
	T1 Probe 1	-0.007 (0.016)	0.008 (0.026)
	Session *T1 Probe 1	-0.012 (0.009)	0.008 (0.015)
	Group*T1 Probe 1	-0.038 (0.019) *	0.049 (0.030)
	Session *Group *T1 Probe 1	0.046 (0.012) **	-0.060 (0.018) *
Random Effects	Intercept	0.004 (0.001) **	0.011 (0.002) **
Fit Statistics	-2 Log-likelihood	-1251.0	-822.4
	N_{obs}	474	474

Note: Maximum likelihood estimates are reported for models of *A′* and ICV. The NTC group served as the reference condition for the effects of group, and T1 served as the reference condition for the effects of session. * $p < 0.05$, ** $p < 0.001$

3.2.1 Accuracy (*A′*)

There were no significant effects of session, $F(1, 389) = 1.90$, $p = 0.169$, or group, $F(1, 84) = 2.33$, $p = 0.131$. There was, however, a significant effect of T1 Probe 1 rating, $F(1, 84) = 5.25$, $p = 0.024$. There were no significant two-way interactions between session and T1 Probe 1 rating, $F(1, 389) = 3.50$, $p = 0.062$ or group and T1 Probe 1 rating, $F(1, 84) = 0.65$, $p = 0.421$, but there were significant interactions between session and group, $F(1, 389) = 6.42$, $p = 0.012$, and session, group, and T1 Probe 1 rating, $F(1, 389) = 15.81$, $p < 0.001$.

Importantly, the three-way interaction between session, group, and T1 Probe 1 rating suggests that baseline self-reported MW influenced how groups changed over sessions in *A′* (see Figure 3a). To better describe the pattern of these results, we provide differences in least squares means estimates for each group over sessions at low (T1 Probe 1 rating of 1) and high levels of baseline MW (T1 Probe 1 rating of 6). For the MT group, *A′* did not significantly change over sessions in participants with low baseline MW ($b = -0.018$, $p = 0.117$, 95%CI [-0.040, 0.004]), but *A′* did significantly improve for participants with high baseline MW ($b = 0.153$, $p < 0.001$, 95% CI [0.103, 0.203]). For the NTC group, *A′* did not significantly change over sessions in participants with low baseline MW ($b = 0.003$, $p = 0.798$, 95% CI [-0.020, 0.027]) or high baseline MW ($b = -0.058$, $p = 0.137$, 95% CI [-0.135, 0.019]). These findings suggest that the benefits of the MT retreat participation were greater for individuals reporting higher baseline levels of MW. Figure 3a shows the magnitude of change in *A′* from T1 to T2 with increasing levels of MW for each group.

3.3.2 ICV

There were no significant effects of session, $F(1, 389) = 3.62$, $p = 0.058$, group, $F(1, 85) = 1.78$, $p = 0.186$, or T1 Probe 1 rating, $F(1, 85) = 2.07$, $p = 0.154$. There was no significant two-way interaction between group and T1 Probe 1 rating, $F(1, 85) = 0.41$, $p = 0.526$, but there were significant interactions between session and group, $F(1, 389) = 7.89$, $p = 0.005$, session and T1 Probe 1 rating, $F(1, 389) = 5.61$, $p = 0.018$, and a three-way interaction between session, group, and T1 Probe 1 rating, $F(1, 389) = 10.81$, $p = 0.001$.

Importantly, the three-way interaction between session, group, and T1 Probe 1 rating suggests that baseline self-reported MW influenced how groups changed over sessions in ICV (see Figure 3b). Analysis proceeded by examining differences in least squares means estimates for each group over sessions at low (T1 Probe 1 rating of 1) and high levels of baseline MW (T1 Probe 1 rating of 6). For the MT group, ICV increased over sessions in participants with low baseline MW ($b = 0.046$, $p = 0.009$, 95% CI [0.011, 0.081]), but ICV decreased for participants with high baseline MW ($b = -0.212$, $p < 0.001$, 95% CI [-0.291, -0.133]). For the NTC group, ICV did not significantly change over time in participants with low baseline MW ($b = -0.010$, $p = 0.578$, 95% CI [-0.047, 0.026]) or high baseline MW ($b = 0.032$, $p = 0.607$, 95% CI [-0.089, 0.152]). These findings suggest that MT retreat-related benefits to ICV were observed for individuals reporting higher levels of MW at T1. Figure 3b shows the magnitude of change in ICV from T1 to T2 with increasing levels of MW for each group.

Overall, Model 2 reveals the influence of baseline MW on MT retreat-related benefits to objective measures of the SART. Specifically, greater benefits to *A′* and ICV were observed for MT participants with higher baseline MW. Interestingly, retreat-related changes in ICV were observed when considering individual differences in MW, but were not observed when examining overall performance (Model 1). Taken together, these findings suggest that participation in an MT retreat benefits objective and subjective measures of the SART compared to a no-training control group (NTC), and these benefits were greater for individuals reporting higher MW at baseline.

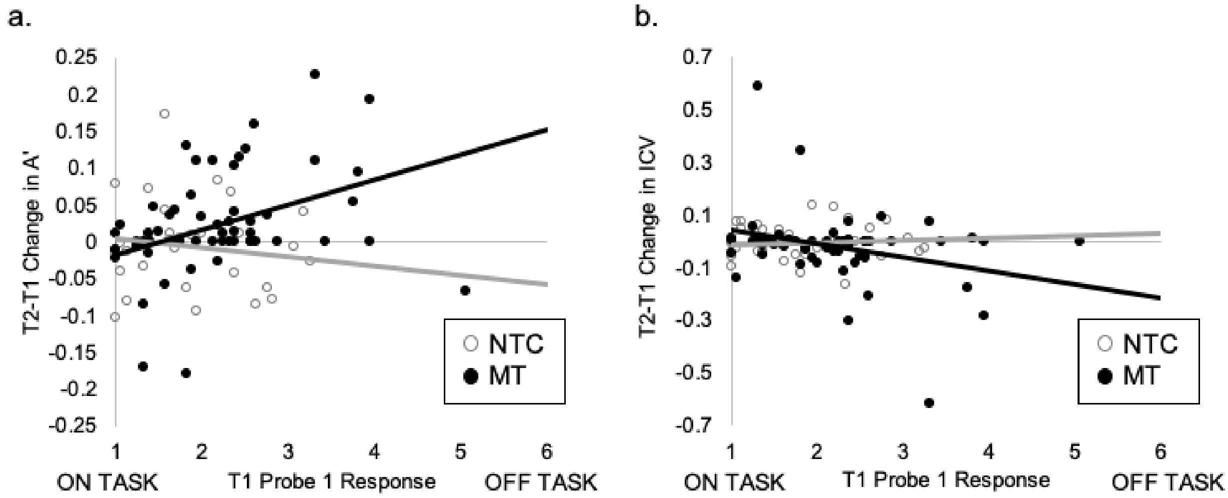

Figure 3 Individual differences in baseline MW influence retreat-related benefits to objective SART performance. a) Probe 1 mean rating at T1 for each individual and change in *A′* over sessions. Individuals in the MT group with higher baseline MW demonstrated greater benefits to *A′* (i.e., higher *A′*) over sessions, while this relationship was not present in the NTC group. b) Probe 1 mean rating at T1 for each individual and change in ICV over sessions. Individuals in the MT group with higher baseline MW demonstrated greater benefits to ICV (i.e., lower ICV reflecting greater stability in reaction time) over sessions, but this relationship was not present in the NTC group.

4. Discussion

The present study examined the effect of a 1-month MT retreat on sustained attention as measured by objective and subjective metrics of the SART. The MT group demonstrated benefits to both objective and subjective measures of sustained attention compared to the NTC group. Individual differences in baseline MW influenced MT-related benefits on objective measures of the SART, such that individuals with higher self-reported MW demonstrated the greatest improvements in *A′* and ICV.

Our findings revealed that participation in a 1-month MT retreat, by participants who were already experienced in MT, improved overall objective and subjective measures of sustained attention as indexed by the SART. These results are consistent with prior retreat research on sustained attention using continuous performance tasks and further extends these benefits to “go”/ “no-go” tasks of sustained attention, such as the SART.

Baseline individual differences in MW in the MT group affected performance changes over time. We observed that individuals endorsing greater MW at baseline demonstrated the greatest benefits to both *A′* and ICV. These findings are consistent with a previous study examining a 2-week MT program in undergraduate students [30], which found greater MT-related benefits to working memory capacity for individuals endorsing greater MW at baseline using probe-caught and retrospective measures. Thus, individuals prone to MW at baseline may benefit the most from training regimes involving MT that emphasize concentrative practices to cultivate focused attention and moment-by-moment awareness of MW. Indeed, there are a growing number of studies exploring whether individual differences in baseline personality features (such as neuroticism, see

[42, 43]) correspond with broad MT-related benefits on psychological and physiological measures. Future studies should examine the relationship between trait-level factors and distinct MT-related benefits to elucidate the specificity of benefits in certain individuals engaging in formal MT programs.

In addition, such studies provide important insights into the putative mechanisms of action by which MT exerts its beneficial effects on sustained attention. The specificity of MT-related improvements in objective metrics of sustained attention (*A′* and ICV) for only those with high baseline MW suggest that MT may specifically target and train processes tied to the occurrence and detection of MW. If so, it would follow that individuals more prone to MW, who may also lack awareness of its occurrence, are more prone to suffering attentional lapses that contribute to objective task performance failures. With MT, their frequency of MW was reduced such that attention was able to be more consistently directed to the task-at-hand in the service of more accurate and consistent task responses. In contrast, for individuals not prone to MW, MT may not have been needed to promote greater task-related focus, since their attention was less prone to wandering away from the task.

Notably, herein we only observed changes in our measure of response time variability, ICV, when considering individual differences in baseline MW. Consistent with these findings, several studies have demonstrated that ICV is highly correlated with self-reported measures of MW [36, 37]. The lack of findings for ICV when collapsing across participants with varying degrees of baseline subjective MW may reflect the dependence of ICV on individual differences in subjective MW. However, MT-related benefits to ICV in the extant literature are mixed, with recent studies finding no change in ICV ([44, 45]; but see [17]), while other studies have demonstrated improvements in ICV only for participants with greater practice time [46, 47], adherence to the program [48], or following participation in longer-term MT retreats [49, 50].

4.1 Limitations

The present study had several limitations. First, participants were not randomly assigned to receive the 1-month mindfulness program or serve as no-training controls. Namely, the retreat participants were recruited from a pool already registered for a residential retreat at the Shambhala Mountain Center. The control participants were then recruited to serve as an age- and education-matched no training comparison for the retreat group. Participants were matched on demographic variables, but the groups may have differed in other variables such as motivation to participate in the study and prior mindfulness experience. Self-reported motivation was not assessed herein, and we cannot formally examine its impact. However, it is important to note that a previous study examining the role of motivation in retreat-related benefits demonstrated improvements in concentration but no difference in self-reported motivation in participants completing a meditation retreat vs. control participants [49]. Prior mindfulness experience was only assessed in the MT group, and it varied widely, from 0 to 242 months. While some previous studies have found that expert meditators demonstrate greater sustained attention performance compared to meditation-naïve participants [19, 22], other studies reported less conclusive results [51, 52]. As such, the change observed over time in the MT group may at least partially be due to their previous experience with meditation. Future studies should address these limitations by including random assignment to retreat participation, self-report measures of motivation, and better controls for prior meditation experience.

Interestingly, our results showed that the MT group reported higher MW than the NTC group at T1 but they did not differ in objective *A′* performance. This suggests there may have been qualitative differences in the way MT participants interpreted the probe question due to their previous experience with meditation. As such, the observed improvements in the MT group over time may have been due to heightened sensitivity to MW or reduced off-task thoughts related to MW. The present study cannot rule out either possibility, although the lack of significant differences between groups on their awareness of MW (Probe 2) at T1 or T2 suggests improvements in the MT group might be driven by a significant reduction in MW rather than an improved ability for participants to detect changes in MW.

Additionally, the sample sizes for each group were relatively small, especially for the NTC group. Moreover, there was considerable dropout in the MT group (14 participants dropped out at T2), but not the NTC group. While our use of multi-level models and maximum likelihood estimators helped to account for the missing data, future studies should employ larger samples to support the effects reported herein.

4.2 Conclusions

Our findings suggest that the MT group demonstrated benefits to sustained attention on both objective and subjective measures of the SART. In addition, examination of individual differences in baseline MW revealed that individuals with higher MW at T1 demonstrated the greatest improvements to objective measures of the SART after participation in a 1-month retreat. These findings suggest that sustained attention benefits due to mindfulness programs should be examined with respect to individual-level factors in order to better capture mindfulness-related improvements in performance. Such an approach will provide necessary insights regarding the mechanisms of action by which MT entrains sustained attention.

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Author Contributions

Joanna E. Witkin: Conceptualization, methodology, formal analysis, writing - original draft, writing - review and editing, visualization. Ekaterina Denkova: Conceptualization, methodology, writing - review and editing. Anthony P. Zanesco: Conceptualization, methodology, formal analysis, writing - review and editing. Alexandra B. Morrison: Conceptualization, writing - review and editing. Joshua Rooks: Conceptualization, formal analysis, writing - review and editing. Jane Carpenter: Investigation, resources, writing - review and editing. Michael Baime: Investigation, writing - review and editing. Amishi P. Jha: Conceptualization, investigation, resources, writing - original draft, writing - review and editing, supervision, project administration, funding acquisition.

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Competing Interests

The authors declare that they have no conflict of interest.

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