Mindfulness training as cognitive training in high-demand cohorts: An initial study in elite military servicemembers

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Abstract

Cognitive ability is a key selection criterion for entry into many elite professions. Herein, we investigate whether mindfulness training (MT) can enhance cognitive performance in elite military forces. The cognitive effects of a short-form 8-h MT program contextualized for military cohorts, referred to as Mindfulness-Based Attention Training (MBAT), were assessed. Servicemembers received either a 2-week ($n=40$) or 4-week ($n=36$) version of MBAT or no training (NTC, $n=44$). Sustained attention and working memory task performance along with self-reported cognitive failures were assessed at study onset (T1) and 8-weeks later (T2). In contrast to both the NTC and 2-week MT groups, the 4-week MT group significantly improved over time on attention and working memory outcome measures. Among the 4-week more so than the 2-week MBAT participants, working memory performance improvements were correlated with their amount of out-of-class MT practice. In addition to these group-wise effects, all participants receiving MBAT decreased in their self-reported cognitive failures from T1 to T2. Importantly, none of these improvements were related to self-reported task motivation. Together, these results suggest that short-form MT, when delivered over a 4-week delivery schedule, may be an effective cognitive training tool in elite military cohorts.

Keywords

Attention, Cognitive training, Mindfulness, Working memory

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1 Introduction

Attention and working memory are cognitive abilities necessary for complex fluid behavior. Whereas attention involves the selection and privileged processing of a subset of available information, working memory allows for the maintenance and manipulation of selected information over short intervals (see Jha, 2002). These cognitive processes are critical for efficient and successful performance. Yet, attentional lapses are frequent and performance errors commonly occur. One compelling context in which cognitive failures may have life or death consequences is during military operations. Lapses of attention during security screening or watch-standing, or failures of working memory in tasks with high workloads, such as operating modern military weapons or aircraft, for example, could lead to death and devastation on a grand scale. Although the value of promoting peak cognitive functioning for such contexts is obvious, successful routes to do so have not been fully investigated (see Blacker et al., 2018). Nonetheless, the field of cognitive neuroscience has been keen to examine if and how such cognitive abilities may be strengthened via training (see Simons et al., 2016).

Special operations forces (SOF) from militaries around the world are tasked with some of the most physically and cognitively demanding military missions. To best ensure their mission success, SOF personnel undergo a rigorous selection process based, in part, on their "cognitive ability domain" (see NATO, 2012). Beyond selection, there has been recent interest in cognitive training approaches to optimize cognitive abilities in such forces. A recent article reported in the *Journal of Special Operations Medicine* suggested that application of mindfulness skills, cultivated by engagement in mindfulness training (MT) programs, may be one route by which cognitive abilities can be augmented in the service of mission-related tasks (Deuster and Schoomaker, 2015).

> *Mindfulness skills can be used for a multitude of mission-related activities. Agile and adaptive reasoning, which is required for mission planning and execution, surely can benefit from improvements in attentiveness and the working memory of factors influencing selection of the best course of action among a multitude of choices.* *(Deuster and Schoomaker, 2015, p. 95)*

Herein, we describe an initial feasibility and effectiveness study (see Bowen et al., 2009) of MT as a form of cognitive training in SOF cohorts. Our overarching goal is to evaluate whether MT has salutary cognitive effects in such elite military cohorts. If so, it may be fruitful to consider its use as a cognitive enhancement tool in other highly skilled and elite professions in civilian contexts, or more broadly in highly demanding but routine settings. In the service of motivating the specific research questions of the present study, prior studies examining cognitive vulnerabilities suffered by those in high-demand circumstances, as well as prior results from cognitive training studies, including those involving MT, are discussed below.

1.1 Cognitive vulnerabilities and cognitive training in military servicemembers

Military operations conducted by conventional forces and SOF routinely place consequential and life-threatening demands on finite cognitive abilities. Attentional lapses and cognitive failures in these situations can prove disastrous (e.g., Loeb, 2002). Many high-demand situations depend heavily on an individual servicemember's ability to attend to the environment, hold mission-critical information in mind, and adjust and monitor thoughts and actions in the service of ongoing goals. While critical for mission success, such cognitive abilities may be at risk of being compromised under demanding circumstances, in which distractions, fatigue, and psychological stress can impair performance (Morgan et al., 2006; see also Jha et al., 2016). Accordingly, specialized military training aims to develop considerable procedural and declarative knowledge necessary for operational success, and inure individuals to constant-yet-unpredictable situational demands (NATO, 2012). Unfortunately, these intensive training and "stress inoculation" programs may themselves degrade and compromise cognitive functions such as attention and working memory (e.g., Morgan et al., 2006).

As such, there is a significant need for training methods that may successfully target cognitive functioning in servicemembers to best support their operational readiness and mission success. One avenue for improving cognitive functioning in servicemembers is computer-based cognitive training. One study recently explored the application of computerized cognitive training for reducing rates of noncombatant injuries in a simulated shooting environment (Biggs et al., 2015). Noncombatant or friendly fire injuries frequently occur when shooters misidentify their target or fail to appropriately inhibit pre-potent responses resulting in unintentional harm to noncombatants or allies with weapons fire. Such errors can have disastrous consequences, promote concerns regarding the harm of servicemembers from those within their own units, and increase the risk of psychiatric illness (e.g., post-traumatic stress disorder) for the survivors of these incidents (Pietrzak et al., 2011). Biggs et al. (2015) found that individuals with poor cognitive control, specifically inhibitory control, were more likely to injure civilians in the simulated scenario. These findings are consistent with other research findings demonstrating the negative consequences of failures in attentional and motor control on the frequency of simulated friendly fire incidents (e.g., Gamble et al., 2018; Wilson et al., 2015). Importantly, however, 3h (over three consecutive days) of computer-based response-inhibition training was shown to reduce the frequency of simulated civilian casualties, providing initial support for the military application of computer-based cognitive trainings (Biggs et al., 2015). Such cognitive training may, therefore, have significant practical and life-saving benefits.

Recently there has been growing interest in the use of such training techniques for broad dissemination in military populations (Blacker et al., 2018). A central issue emerging from this literature is the degree of transfer from the trained context to novel and unrelated tasks (see Blacker et al., 2018; Simons et al., 2016). Far-transfer of training is exemplified when there is minimal or no featural overlap between the training task and tasks on which improved performance is observed. Given that there is a high degree of uncertainty, novelty, variability, and ambiguity in military operations, training which could achieve far-transfer in strengthening attention and working memory, for example, would be highly beneficial. Yet, most computer-based trainings have primarily observed near-transfer effects (Sala and Gobet, 2017), in which performance benefits are restricted to those contexts sharing features with the training program. Despite this, there is great practical utility for computer-based training approaches involving near-transfer of learned skills. For example, in military settings, receiving training to become proficient in the use of a specific piece of equipment could be quite beneficial and cost-effective. Nonetheless, identifying training methods that provide broad and generalizable benefits over many contexts remains of central interest in civilian and military settings.

1.2 Mindfulness training as cognitive training

Interestingly, there has been emerging evidence that mindfulness training (MT) may bolster a range of cognitive control-related functions such as attention and working memory, with studies finding that cognitive benefits transfer between the training context of mindfulness practice and the testing context of computer-based cognitive tasks (see Lutz et al., 2015). Thus, MT has been proposed to lead to generalizable improvements, akin to "far-transfer" effects in cognitive processes involved in directing attention and guiding thoughts and actions in line with internal goals (Slagter et al., 2011). For example, studies investigating MT have demonstrated improvements on measures of attention (e.g., Jha et al., 2007; Zanesco et al., 2013), reductions in mind wandering (i.e., disruptive task-unrelated thought, Mrazek et al., 2013; Zanesco et al., 2016), and improvements in working memory (e.g., Chambers et al., 2008; Mrazek et al., 2013; van Vugt and Jha, 2011). Such benefits are of particular interest for high-performing military servicemembers who are confronted with a variety of demanding tasks on a daily basis (see Blacker et al., 2018; Deuster and Schoomaker, 2015).

Mindfulness training involves didactic content and systematized instruction for mental exercises designed to build attentional skills and cognitive strategies for maintaining attention on present-moment experiences. Mindfulness is defined as a mental mode characterized by attention to present-moment experience without conceptual elaboration or emotional reactivity (see Jha et al., 2010; Kabat-Zinn, 2013). Over time with continued and regular engagement in MT practice exercises, such training is thought to reshape habitual thought and action patterns and facilitate neural and cognitive plasticity among cognitive control processes (Lutz et al., 2015; Slagter et al., 2011). Some of the attentional benefits of MT, for instance, may be maintained for years in regular dedicated practitioners (Zanesco et al., 2018).

In the military context, MT has primarily been explored as a means of cognitive remediation, promoting resilience against declines in attention and working memory performance that may occur over highly demanding and stressful intervals (see Deuster and Schoomaker, 2015; Stanley and Jha, 2009). Prior research has shown that these cognitive functions are susceptible to stress-related degradation, and deficits have been observed over demanding periods such as special operations survival school training (Morgan et al., 2006), and intense combat training in conventional forces (Lieberman et al., 2005). MT has been shown to *protect against* declining cognitive capacity over protracted high-demand intervals such as pre-deployment training in conventional forces (Jha et al., 2010, 2015, 2016, 2017).

Two recent studies examined the protective benefits of short-form MT on Soldiers' sustained attention and working memory over a high-demand pre-deployment training interval (Jha et al., 2015, 2017). Soldiers were assigned to receive an 8-h, 8-week experiential-focused vs. didactic-focused MT program or undergo no training at all. While Soldiers who did not receive training showed decreased cognitive performance over time, Soldiers who received MT, particularly the experiential-focused group that emphasized in-class training and practice, showed less degradation. Moreover, compared to the didactic-focused group, the experiential-focused group demonstrated greater protection from cognitive decline in sustained attention (Jha et al., 2015) and working memory (Jha et al., 2017). Although these studies have provided evidence of "sustainment" (see Deuster and Schoomaker, 2015), such that MT might protect cognitive functions from decline over high-demand intervals, the potential for MT to improve cognitive functioning over baseline has not yet been established in short-form programs made available to military servicemembers. Furthermore, alternative, yet effective, program structures that might better accommodate servicemember's schedules with the time-pressure nature of military service, require further investigation.

1.3 Mindfulness training in elite military cohorts

The present study examined whether an 8-h Mindfulness-Based Attention Training (MBAT) program might improve attentional control and working memory in a cohort of SOF personnel. Participants were assessed on a number of cognitive performance and self-report measures at study onset (T1) and roughly 8 weeks later (T2). In line with prior studies of MT in military cohorts, sustained attention and response inhibition were indexed with the Sustained Attention to Response Task (SART; Robertson et al., 1997), a go/no-go task that includes interspersed self-reported questions designed to catch moments of off-task thinking (i.e., mind wandering; Christoff et al., 2009). Working memory performance was assessed using a delayed-recognition task with affective distracters (WMDA; Jha et al., 2017), in which participants were instructed to remember target stimuli over a delay period during which negative combat-related images or neutral distracting images are presented. Furthermore, cognitive functioning in participants' daily lives was assessed by measuring the frequency of self-reported cognitive failures using the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982).

To determine flexibility in delivery schedule of the 8-h program, SOF servicemembers were recruited from an active U.S. military installation and assigned to receive either a 2-week or 4-week version of MBAT delivered by an experienced mindfulness trainer, or they served as no-training control (NTC) participants and did not participate in any mindfulness training. We compared these groups on measures of attention, working memory, and cognitive failures in daily life before (T1) and after an 8-week interval (T2). To reduce bias in our analyses resulting from prognostic differences between non-compliant participants and program completers, we utilized multi-level linear mixed models in order to include all individuals in our analyses regardless of drop-out or MT program compliance (i.e., intention-to-treat analyses; Armijo-Olivo et al., 2009). As program assignment may contribute to motivational differences between groups, we further compared participants' performance motivation to engage in the post-training assessment in order to evaluate whether motivational differences confounded any potential performance differences between groups.

The present study aimed to address three main issues. First, we examined whether the 2-week MT, 4-week MT, or NTC groups changed on cognitive outcomes from T1 to T2. Second, we assessed whether MT groups differed in amount of out-of-class practice time, and whether practice time was correlated with cognitive improvements across individuals over time. Third, we explored whether motivational differences might have contributed to these outcomes. Given that SOF personnel have been selected for service based on their exemplary physical and cognitive abilities, we predicted that unlike studies in conventional forces, SOF personnel may not demonstrate degradations in their attention and working memory over the study period. Improvements in measures of cognitive functioning, observed with 2- or 4-week delivery of MBAT to SOF cohorts in this initial study, may motivate further investigation of the utility of MT as a route by which to enhance attention and working memory for high-demand settings and professions.

2 Method

2.1 Participants

One hundred and twenty healthy active-duty male participants were recruited from 2 SOF units at a U.S. Military installation. Participants included both operational and support personnel, but all participants had completed a rigorous selection process and had undergone advanced military training in order to serve in their current unit. They had considerable military service experience ($M=10.89$ years in service, $SD=5.01$) and many had prior combat exposure. Personnel were assigned by unit to receive either a 2-week ($n=40$) or 4-week ($n=36$) version of MBAT delivered by an experienced mindfulness trainer, or they served as no-training control (NTC) participants ($n=44$) and did not participate in any mindfulness training but attended study assessments. This group-randomized assignment strategy is commonly utilized

Table 1 Age, education, military and combat experience, and psychological health at study onset.

Measure	NTC	2-Week MT	4-Week MT	All groups	η_P^2
Age (years)	33.95 (5.86)	31.35 (4.57)	34.17 (5.62)	33.14 (5.62)	0.053*
Education	2.32 (0.74)	2.28 (0.78)	2.43 (0.70)	2.34 (0.74)	0.007
Military service (years)	11.18 (4.54)	9.58 (5.04)	12.00 (5.34)	10.89 (5.01)	0.039
CE	2.12 (0.81)	1.93 (0.82)	2.25 (0.81)	2.09 (0.81)	0.026
GAD-7	3.45 (3.58)	3.53 (4.62)	4.74 (5.10)	3.86 (4.42)	0.017
PCL-M	24.86 (9.79)	22.85 (6.27)	28.03 (11.26)	25.12 (9.42)	0.048
PHQ-8	4.48 (5.51)	4.20 (3.94)	5.40 (5.34)	4.66 (4.97)	0.010
PSS	12.32 (6.51)	12.40 (6.61)	13.09 (7.90)	12.57 (6.93)	0.002

Note*: Means and standard deviations for demographic and self-reported psychological health measures for participants (*n*=*119) collected at study onset (T1). Education was scored on the following scale: 1=high school diploma; 2=some college; 3=college degree; 4=graduate degree. Scores from instruments measuring combat exposure (CE), generalized anxiety (GAD-7), post-traumatic stress (PCL-M), depression (PHQ-8), and perceived stress (PSS) are indicated for each group. Effect sizes (*η_P^2*)* from univariate ANOVA group comparisons are reported. *$P<0.05$.

by studies in military cohorts (e.g., Adler et al., 2008; Jha et al., 2015; Johnson et al., 2014) to ease scheduling and provide training in organic unit structures. Table 1 describes age, education, prior military experience and combat exposure, and self-reported psychological health for all study groups. Fig. 1 depicts the Consolidated Standards of Reporting Trials Flow Diagram (CONSORT; Schulz et al., 2010) indicating the flow of participants across each stage of the study.

All servicemember participants provided informed consent in compliance with the Institutional Review Board of the University of Miami with oversight from the Human Research Protections Program of the Uniformed Services University of the Health Sciences. All testing and training occurred during participants' duty day. Participants were not compensated beyond their wages for participation in the project per Department of Defense regulations regarding servicemember compensation during the duty day.

2.2 Mindfulness-Based Attention Training program

Participants received an 8-h Mindfulness-Based Attention Training (MBAT) course contextualized for elite military units and delivered by an experienced mindfulness trainer with high familiarity with the military context. The mindfulness trainer had extensive personal experience with mindfulness practice, having taught >25 Mindfulness-Based Stress Reduction (MBSR) courses to military servicemembers and civilians over a 5-year period. In addition, the trainer had considerable military context expertise regarding elite forces, having spent over a decade serving in such units in both clinical and operational psychologist roles. During this

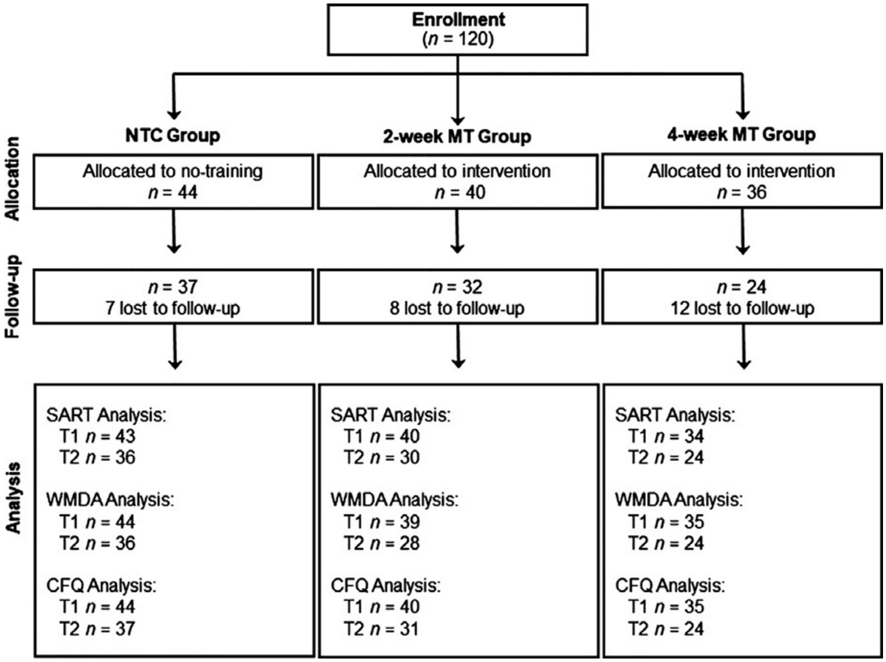

FIG. 1

Consolidated Standards of Reporting Trials Flow Diagram (CONSORT; Schulz et al., 2010) depicting the flow of participants from study allocation (T1) to follow-up (T2) roughly 8 weeks later and analysis. The number of participants included in SART analyses refers to those with complete *A′* and probe data.

time, the trainer had completed three deployments to combat zones with SOF, consulted to SOF leadership at all levels, and taught SOF personnel in training.

Participants were assigned to receive one of two course variants: training delivered in four 2-h sessions that occurred twice weekly for two consecutive weeks (2-week MT) or training delivered in four 2-h sessions that occurred weekly for four consecutive weeks (4-week MT). Training groups were offered identical content and practices, and differed only in the scheduled organization of the MBAT course. At the end of the 2- or 4-week MBAT course interval, all participants were asked to continue daily mindfulness practice until the conclusion of the roughly 8-week study interval at the second testing session (T2).

The MBAT program used herein was developed as a structured and manualized program contextualized for the military environment and modeled on prior short-form MT programs successfully implemented in civilian cohorts (e.g., Morrison et al., 2014) as well as variants used with U.S. Army infantry cohorts (Ramos et al., 2016). The program emphasizes personal mindfulness practice and aims to provide participants with cognitive resilience and psychological health enhancement tools for use throughout their professional and personal lives. MBAT was developed in coordination with an advisory team of mindfulness experts and military leaders who offered guidance and detailed suggestions during the development of the course design and training materials.

MBAT's training content comprises four central themes delivered over four 2-h sessions. The *concentration* theme introduces participants to mindfulness "basics," including discussion of focused attention and mind wandering. The *body awareness* theme involves the cultivation of greater self-awareness, and the development of equanimity. The *open monitoring* theme emphasizes awareness of and receptivity to changing experiences and moments of uncertainty. The theme of *connection* addresses leadership and group cohesion, and the cultivation of kindness and connection with others. These themes are communicated in a manner that is contextualized for active-duty servicemembers. To this end, training incorporates military terminology and cultural references, and examples relatable to those familiar with military life.

Each course session introduces a corresponding mindfulness exercise. The *guided concentration sitting* exercise instructs participants to focus on the breath, notice mind wandering, and return attention to the breath following distraction. The *guided body scan* involves noticing sensations in certain parts of the body with a nonjudgmental stance while attending to the pleasantness, unpleasantness, or neutrality of the sensation without making any adjustments in response. The *open monitoring* exercise involves expanding the field of awareness beyond the breath and noticing the rising, changing, and passing away of sensory and mental phenomena (e.g., sounds, body sensations, thoughts). The *connection* exercise guides participants to engage in expressions of kindness and interpersonal connection directed to the self and to others.

In addition to attending the MBAT course meetings, all participants in the MT groups were asked to complete daily mindfulness exercises corresponding to the current course session exercise as part of their "out-of-class" individual mindfulness practice. Participants were provided with an MP3 player containing practice recordings and were assigned to practice for 15 min a day for at least 5 days per week. To obtain an estimate of participants' out-of-class practice compliance, participants were asked at T2 to report the average amount of daily out-of-class practice (in minutes) they completed over the entire program interval.

2.3 Procedure

Participants were administered a series of computerized cognitive tasks (see Fig. 2 for task schematics) before assignment to groups (T1) and roughly 8 weeks later (T2; $M = 53.18$ days) at the end of the MBAT program interval. The mindfulness trainer helped coordinate the scheduling of SOF cohorts at each assessment but was otherwise uninvolved in data collection and analysis. Testing was proctored by a team of 1–3 experimenters in a group setting of up to 16 participants. Each session lasted approximately 2 h and took place in a quiet classroom on the military

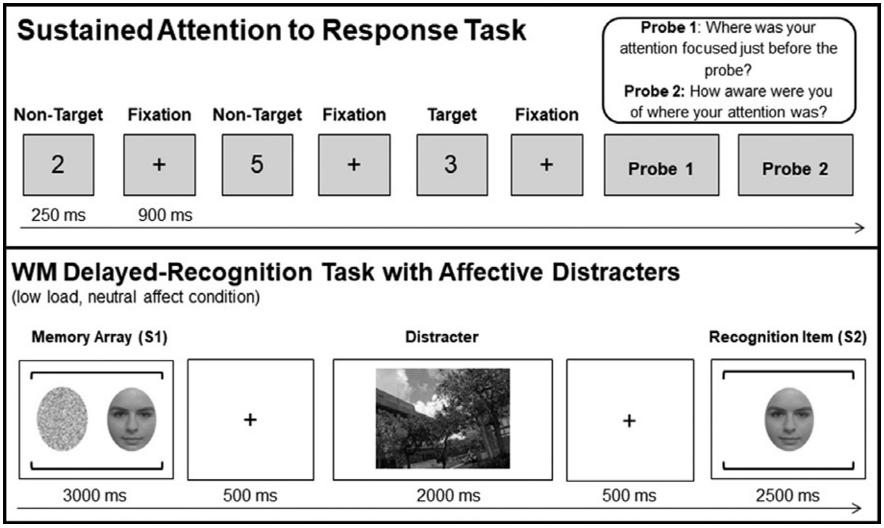

FIG. 2

Schematic for the Sustained Attention to Response Task (SART) and the WM delayed-recognition task with affective distracters (WMDA).

installation. Each participant was seated approximately 57 cm from his own PC laptop, and stimuli were presented via *E*-prime (Version 2.0; Psychology Software Tools, Pittsburgh, PA). An identical assessment battery was utilized at T1 and T2, with the addition of a training and testing feedback questionnaire at T2.

2.4 Cognitive tasks measures

2.4.1 Sustained attention to response task (SART)

Sustained attention was assessed using a modified version of the SART (Robertson et al., 1997). During the task, single digits (0 through 9) were continuously presented on screen one at a time for 250 ms, with each digit followed by an inter-trial-interval of 900 ms during which a fixation cross was presented. Participants were instructed to refrain from pressing the spacebar to the number 3 (target) and to press the spacebar for all other digits (non-targets) while emphasizing both accuracy and speed. Stimuli were presented in black font on a gray screen, and responses were recorded during the stimulus display or the inter-trial interval. Targets comprised 5% of trials, non-targets comprised 90% of trials, and probe questions comprised the remaining 5% of trials. Trial order was quasi-randomized so that targets were always separated by at least one other non-target digit.

Participants responded to two consecutive probe questions, which were randomly dispersed throughout the task, in order to assess spontaneous episodes of mind wandering (MW). The first probe (Probe 1) asked, “Where was your attention focused just before the probe?" with participants responding using a 6-point Likert scale ranging from 1 (*on task*) to 6 (*off task*). The second probe (Probe 2) asked, "How aware were you of where your attention was?" with participants responding from 1 (*aware*) to 6 (*unaware*). The questions were displayed until a response was provided.

After a 163-trial practice block, participants completed two experimental blocks which consisted of a total of 519 non-targets, 27 targets, and 28 sets of probes. Results from the practice block were not included in the analyses. SART outcomes included task *accuracy*, *reaction time variability*, and *subjective probe responses*. Accuracy was indexed by A', a nonparametric measure of detection sensitivity. A' yields a composite of hits (correctly withholding a response to target trials) and false alarms (incorrectly withholding a response to non-target trials) while allowing for the difference in frequency between target and non-target trials (see Stanislaw and Todorov, 1999, for calculations). Reaction time variability was assessed using the intra-individual coefficient of variation (ICV), which was calculated as the standard deviation RT of correct non-target trials divided by the mean RT of correct non-target trials (i.e., for each participant: standard deviation RT/mean RT). Greater ICV reflects more variation in response time, and prior research has suggested ICV may be a valid index of MW (Bastian and Sackur, 2013; Seli et al., 2013). Subjective probe responses were assessed using the mean of probe ratings, separately for each probe question.

2.4.2 Working memory delayed-recognition task with affective distracters (WMDA)

Working memory was assessed using a delayed-recognition task with distracting affective images (WMDA) presented during the delay interval between encoding and retrieval. The WMDA instructed participants to remember faces or shoes over a delay interval. These categories were selected to ensure that the differences between exemplar faces or shoes within each memory set emphasized perceptual, as opposed to verbal, representations of objects in visual WM. This task is the same as one used in a previous study of WM (Jha et al., 2017).

Trials began with the encoding phase during which a memory array (S1) containing either two memory items (high mnemonic load) or one memory item paired with a noise mask (low mnemonic load) was presented for 3000 ms. S1 was followed by a delay interval of 3000 ms, after which a test item (S2) was presented for up to 2500 ms. On half of the trials, S2 was a single image that appeared in S1 (match trials), while on the remaining trials, S2 was a novel image (non-match trials) that did not appear in S1 or elsewhere in the experiment. S2 was always of the same category as S1 (face or shoe). Participants were instructed to determine whether S2 matched either memory item in S1 and indicate a match or non-match response by pressing a designated key. Participants were instructed to respond quickly and accurately. Half of the trials utilized faces as stimuli and the other half utilized shoes, with both trial types intermixed throughout the task.

During the delay interval, a task-irrelevant distracter that was neutral or negative in valence was displayed for 2000 ms and was preceded and followed by a fixation cross for 500 ms. On half of the trials, the delay-spanning distracters were negatively valenced; on the other half of trials, they were neutrally valenced. Instructions at the beginning of the task directed participants to pay attention to the distracting image without trying to remember it. The delay-spanning images were drawn from a previous study conducted in military populations (Morey et al., 2008). The negative stimuli were generated from internet searches and photo collections that depicted combat-related scenes from Afghanistan and Iraq, while the neutral stimuli depicted civilian scenes that matched the negative stimuli in terms of figure/scene ratio, scene complexity, and chromatic structure. Memory items (face or shoe stimuli) and distracter images were not repeated across trials. The task consisted of a 36-trial practice block (with accuracy feedback for the first six trials) and two 30-trial experimental blocks.

Task demands were manipulated along two levels of mnemonic load (low vs. high) and two levels of affective distraction (neutral vs. negative), yielding four distinct trial types that were used for analysis: low load–neutral distracter, low load–negative distracter, high load–neutral distracter, and high load–negative distracter. Each trial type occurred with equal frequency. Across the experiment, trials varied along four variables: S1/S2 category (faces/shoes), match vs. non-match trials, mnemonic load level (low/high), and distracter valence (neutral/negative). Trial order was pseudo-randomly intermixed along these four variables so that identical trial types were never consecutively presented. Accuracy (% correct) was calculated for each individual for each of the experimental trial types. Trials in which the participant did not respond were excluded from these calculations.

2.5 Self-report questionnaires

Alongside our primary cognitive-behavioral measures of interest, participants completed a series of questionnaires. The cognitive failure questionnaire (CFQ) was administered to complement the cognitive tasks by assessing cognitive challenges in participants' everyday lives as another primary outcome measure that emphasized their subjective account of cognitive functioning during daily activities. A second set of questionnaires consisted in a survey of psychological health and wellbeing (e.g., Patient Health Questionnaire PHQ-8; Kroenke et al., 2009), which was assessed in order to ensure groups were matched on these measures at study onset (T1). A third set of questionnaires were related to participants' military and combat experience. Finally, we assessed participants' performance motivation at T2 to ensure groups were matched on motivation during the T2 testing session. Coefficients of internal consistency (Cronbach's alpha) are reported for each self-report questionnaire measure.

2.5.1 Cognitive failures questionnaire

Participants completed the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982) to assess attentional and cognitive lapses occurring in daily life at T1 and T2. Participants were asked a series of 25 questions about "minor mistakes which everyone makes from time to time" occurring over the past month (e.g., "do you daydream when you ought to be listening to something?," "do you fail to hear people speaking to you when you are doing something else?," and "do you fail to notice signposts on the road?"). Each item was rated from 0 (never) to 4 (very often), and items were summed to obtain scale scores. Internal consistency for this scale was high and alphas ranged from 0.917 to 0.947 among groups at T1 and from 0.905 to 0.971 among groups at T2. Alpha was 0.937 combined across all groups and assessments.

2.5.2 Generalized anxiety disorder scale

Participants completed the Generalized Anxiety Disorder 7-item Scale (GAD-7; Spitzer et al., 2006) to assess symptoms of generalized anxiety disorder at T1. Participants were asked to indicate how often they have been bothered by a number of symptoms over the last 2 weeks (e.g., "feeling nervous, anxious, or on edge," "worrying too much about different things," and "feeling afraid as if something awful might happen"). Each item was rated 0 (not at all), 1 (several days), 2 (over half the days), or 3 (nearly every day), and items were summed to obtain scale scores. Internal consistency for this scale was high and alphas ranged from 0.844 to 0.928 among groups at T1.

2.5.3 Post-Traumatic stress disorder checklist

Participants completed the Post-Traumatic Stress Disorder Checklist for military populations (PCL-M; Blanchard et al., 1996) to assess DSM-IV symptoms of PTSD relating to "stressful military experiences" at T1. Participants were asked to indicate how often they have been bothered by 17 possible problems or symptoms over the past month (e.g., "repeated, disturbing memories, thoughts, or images of a stressful military experience," "feeling as if your future somehow will be cut short," and "trouble falling or staying asleep"). Each item was rated 1 (not at all), 2 (a little bit), 3 (moderately), 4 (quite a bit), or 5 (extremely), and items were summed to obtain scale scores. Internal consistency for this scale was high and alphas ranged from 0.833 to 0.921 among groups at T1.

2.5.4 Patient health questionnaire

Participants completed a modified 8-item version of the Patient Health Questionnaire (PHQ-8; Kroenke et al., 2009) at T1 to assess symptoms of depression at study onset. Participants were asked to indicate how often they have been bothered by eight possible problems or symptoms over the last 2 weeks (e.g., "feeling down, depressed, or hopeless," "feeling tired or having little energy," and "feeling bad about yourself, or that you are a failure, or have let yourself or your family down"). Each item was rated 0 (not at all), 1 (several days), 2 (more than half the days), or 3 (nearly every day), and items were summed to obtain scale scores. Internal consistency for this scale was high and alphas ranged from 0.842 to 0.914 among groups at T1.

2.5.5 Perceived stress scale

Participants completed the 10-item Perceived Stress Scale (PSS; Cohen et al., 1983) to assess participants' perceptions of stress at T1. Participants were asked about their feelings and thoughts during the past and to indicate how often they felt or thought a certain way in response to 10 questions (e.g., "in the last month, how often have you felt nervous and stressed?," "in the last month, how often have you found that you could not cope with all the things that you had to do?," and "in the last month, how often have you felt difficulties were piling up so high that you could not overcome them?"). Each item was rated 0 (never), 1 (almost never), 2 (sometimes), 3 (fairly often), or 4 (very often), four items were reverse coded, and all items were summed to obtain scale scores. Internal consistency for this scale was high and alphas ranged from 0.829 to 0.903 among groups at T1.

2.5.6 Combat exposure

Participants completed a measure of combat exposure (CE) at T1 by responding to 17 items adapted from previous studies with military cohorts (e.g., Adler et al., 2009). Participants indicated how many times they had personally experienced combat-related events during any of their combat deployments in the past (e.g., "being attacked or ambushed," "knowing someone seriously injured or killed," or "shooting or directing fire at the enemy"). Each item was rated 1 (never), 2 (1 time), 3 (2–4 times), or 4 (5 or more times), and items were averaged to obtain scale scores. Internal consistency for this scale was high and alphas ranged from 0.942 to 0.950 among groups at T1.

2.5.7 Performance motivation

As part of a set of questions included at T2 assessing program feedback, we investigated participants' performance motivation in order to ensure groups were matched on motivation during the T2 testing session. Participants were asked to "express their own views about the testing sessions of this study" by responding to a series of four statements relating to their motivation to perform well during the study assessments, and one statement assessing their understanding of the task instructions, using a scale from 1 (strongly disagree) to 6 (strongly agree). The statements were: (1) "I did not care about my performance," (2) "I was committed to my performance goals," (3) "I was motivated to perform well during the testing sessions," (4) "I was more motivated now than during the first testing session," and (5) "I did not understand the testing instructions." Statements 1 and 5 were subsequently reverse scored so that values reflect participants' affirmative agreement with each statement. Alpha among these items ranged from 0.689 to 0.817 among groups at T2.

2.6 Analysis

Change in cognitive task performance and CFQ scores were evaluated using multilevel linear mixed models implemented in PROC MIXED in SAS 9.4. We examined the fixed effects of time (T1 and T2) and group (NTC, 2-week MT, and 4-week MT) for each dependent measure. Random intercepts were included for individuals, representing between-person variability, and separate residual variances were estimated for each group to accommodate heterogeneity in group variance. Parameters were estimated using maximum likelihood estimation, and degrees of freedom were approximated by dividing the residual degrees of freedom into between-person and within-person divisions. Model parameters were referenced to T1 and the NTC group. Type III tests of fixed effects are reported alongside parameter estimates, and significant interactions between time and group were investigated with model-estimated mean comparisons examining change from T1 to T2 within each group. Marginal effect sizes for time × group interactions were calculated as f^2 based on the proportion of residual variance (assuming homogeneity among group variances) uniquely explained by that parameter (Selya et al., 2012), and interpreted using the convention (Cohen, 1988) of small (0.02), medium (0.15), and large (0.35) effects.

Multi-level linear mixed models allow for the inclusion of participants with missing data at one or more assessment wave. We therefore included all participants in our analyses who contributed data on a particular dependent measure, and consistent with an intent-to-treat approach (Armijo-Olivo et al., 2009), also included participants who were assigned to receive MT but did not attend all training sessions or participate in out-of-class practice exercises. However, one 4-week MT participant was excluded from all analyses study for noncompliance with testing and task instructions at T1 and subsequently withdrew from participation at T2. In addition, we excluded observations from participants at either assessment in which they failed to respond to at least two-thirds of WMDA trials, or had SART or WMDA performance accuracy 3 *SD* below the grand mean. We further excluded CFQ observations 3 *SD* from the grand mean. For SART, 2 observations were excluded at T1 and 3 observations were excluded at T2 because A' was 3 *SD*'s below the grand mean ($<0.53\ A'$). Additionally, for the analysis of ICV, 1 observation was excluded at T1 and 3 observations were excluded at T2 because ICV was 3 *SD*'s above the grand mean (>0.847 ICV). For the WMDA, 1 observation was excluded at T1 and 1 observation at T2 because each participant responded to fewer than two-thirds of trials, and 4 observations were excluded at T2 because overall accuracy was 3 *SD*'s below the grand mean (<72.6% accuracy). For CFQ, 1 observation was excluded at T2 because CFQ was 3 *SD*'s above the grand mean (>74.32 CFQ). There were a total of 119 participants with data at one or more assessments included in analyses of SART A' and WMDA accuracy, 117 participants with data for ICV, and 118 participants with data for CFQ analyses.

3 Results

Demographic information was compared between groups at T1 using a series of univariate ANOVA. At the study onset, groups did not differ in educational achievement, $F(2,\ 116)=0.42$, $P=0.659$, years of prior military experience, $F(2,\ 117)=2.39$,

$P = 0.096$, or their amount of prior combat exposure, $F(2, 117) = 1.85$, $P = 0.162$, and groups did not significantly differ on measures of psychological health as assessed by GAD, $F(2, 116) = 1.00$, $P = 0.372$, PCL-M, $F(2, 116) = 2.94$, $P = 0.057$, PHQ, $F(2, 116) = 0.59$, $P = 0.558$, and PSS scores, $F(2, 116) = 0.14$, $P = 0.873$. Groups, however, significantly differed in age, $F(2, 115) = 3.19$, $P = 0.045$. The 2-week MT group was younger than the 4-week MT ($P = 0.029$) and NTC ($P = 0.034$) groups. We subsequently examined age (centered to the grand mean) as an additional covariate in secondary analyses to rule out the contribution of age differences on our cognitive outcomes of interest. See Table 1 for demographic and group information based on self-report questionnaire measures of psychological health, and prior military experience and combat exposure.

3.1 Sustained attention to response task (SART)

We analyzed measures of SART A', reaction time variability (ICV), and probe rating responses, using multi-level models with fixed factors of time (T1 and T2) and group (NTC, 2-week MT, and 4-week MT).[1] Summary descriptive statistics are provided in Table 2, and parameter estimates from models of SART performance are provided in Table 3.

3.1.1 A' scores

We observed no significant effect of time, $F(1, 85) = 0.11$, $P = 0.746$, and no significant effect of group, $F(2, 116) = 0.07$, $P = 0.930$. Critically, we observed a significant interaction of time and group, $F(2, 85) = 5.92$, $P = 0.004$,

Table 2 Descriptive statistics of SART and WM performance and cognitive failures.

	NTC		2-Week MT		4-Week MT	
Measure	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
SART (*N*)	43	36	40	30	34	24
A'	0.884 (0.067)	0.877 (0.102)	0.895 (0.089)	0.866 (0.129)	0.868 (0.086)	0.929 (0.077)
MW probe 1	1.894 (0.797)	1.737 (0.612)	1.95 (1.006)	2.177 (1.151)	1.867 (0.764)	1.783 (0.635)
MW probe 2	1.775 (0.686)	1.578 (0.539)	1.764 (0.822)	2.115 (1.142)	1.763 (0.677)	1.637 (0.564)
SART ICV (*N*)	43	35	39	28	34	24
ICV	0.306 (0.122)	0.311 (0.147)	0.278 (0.089)	0.294 (0.178)	0.267 (0.093)	0.213 (0.074)
WMDA (*N*)	44	36	39	28	35	24
% correct	92.62 (8.86)	92.12 (8.63)	92.58 (8.25)	93.77 (8.28)	90.69 (11.13)	93.55 (8.00)
CFQ (*N*)	44	37	40	31	35	24
CFQ score	30.89 (13.94)	32.00 (12.12)	31.65 (15.84)	26.52 (17.26)	31.20 (13.57)	26.54 (12.50)

Note: *Means and standard deviations are provided for dependent measures from the Sustained Attention to Response Task (SART), WMDA, and cognitive failures questionnaire (CFQ), for each group (NTC, 2-week MT, and 4-week MT) before (T1) and after (T2) the training interval. The number of participants (N) contributing data at each assessment is provided.*

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[1] We also examined mean non-target reaction time. Reaction time did not change over time, $F(1, 85) = 2.10$, $P = 0.151$, or differ among groups, $F(2, 116) = 0.47$, $P = 0.624$, and there was no significant interaction of time and group, $F(2, 85) = 1.42$, $P = 0.247$.

Table 3 Parameter estimates from models of SART performance.

	Estimate (SE)			
Model effects	**Accuracy (A')**	**ICV**	**Probe 1**	**Probe 2**
Fixed effects				
Intercept	0.882 (0.013)***	0.306 (0.019)***	1.892 (0.111)***	1.769 (0.098)***
Time	−0.006 (0.013)	0.007 (0.023)	−0.124 (0.118)	−0.151 (0.093)
2-Week MT group	0.014 (0.021)	−0.029 (0.029)	0.058 (0.195)	−0.004 (0.170)
4-Week MT group	−0.017 (0.019)	−0.036 (0.025)	−0.006 (0.165)	0.017 (0.150)
2-Week MT group × time	−0.022 (0.023)	0.013 (0.0037)	0.380 (0.245)	0.482 (0.200)**
4-Week MT group × time	0.048 (0.018)*	−0.041 (0.027)	0.038 (0.180)	0.045 (0.152)
Random effects				
Intercept σ	0.005 (0.001)	0.006 (0.002)	0.273 (0.072)	0.262 (0.061)
NTC residual σ	0.003 (0.001)	0.010 (0.002)	0.256 (0.058)	0.158 (0.037)
2-Week MT residual σ	0.006 (0.001)	0.012 (0.003)	0.762 (0.180)	0.512 (0.131)
4-Week MT residual σ	0.002 (0.001)	0.003 (0.001)	0.236 (0.064)	0.181 (0.049)
−2 Log-likelihood	−443.8	−314.4	479.5	423.1
Observations (*N*)	207	203	207	207

Note*: Maximum likelihood estimates are reported for models of SART accuracy (A′), reaction time variability (ICV), and mean probe 1 and 2 ratings, for fixed effects of time (T1 and T2) and group (NTC, 2-week MT, and 4-week MT). T1 and NTC group serve here as the reference condition. The number of observations (*N*) contributing to the analyses is provided. Standard errors are reported in parentheses. *$P<0.05$, **$P<0.01$, ***$P<0.001$.*

$f^2=0.077$.[2] Only the 4-week MT group significantly increased from T1 to T2 by 0.042 units of A' ($P=0.001$), whereas both the NTC ($b=-0.006$, $P=0.654$) and 2-week MT ($b=-0.028$, $P=0.145$) groups did not change over time. SART A' scores increased significantly more for participants in the 4-week MT group compared to the NTC group ($b=0.048$, $P=0.010$) and the 2-week MT group ($b=0.070$, $P=0.003$). Thus, the 4-week MT group significantly improved in A', and this improvement was larger than changes in either the NTC or 2-week MT groups. Fig. 3 depicts the model-estimated change from T1 to T2 in each group for SART A'.

3.1.2 ICV

We observed no significant effect of time, $F(1, 83)=0.03$, $P=0.865$, a significant effect of group, $F(2, 114)=3.28$, $P=0.041$, and no significant interaction of time and group, $F(2, 83)=2.06$, $P=0.140$, $f^2=0.024$. The main effect of group indicated that the 4-week MT group had significantly lower ICV by −0.056 units ($P=0.013$) compared to the NTC group. The 2-week MT group, however, did not differ

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[2] Age was unrelated to A' ($b=0.002$, $P=0.148$) when added as a predictor in the model, and there were no significant interactions between age, time, and group. The significant interaction between time and group remained significant ($P=0.012$) in the presence of these additional covariates.

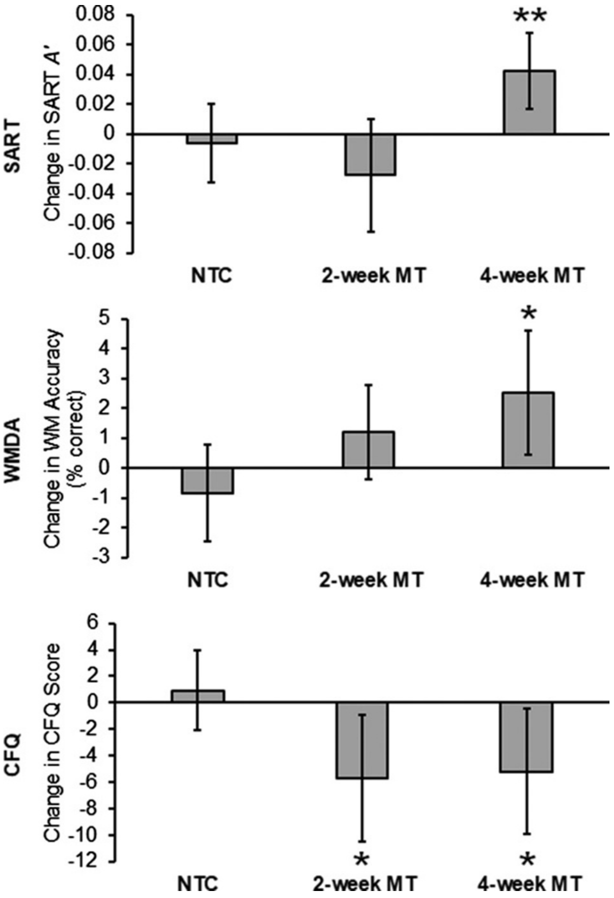

FIG. 3

Parameter estimates derived from multi-level models depicting the change from T1 to T2 for the NTC, 2-week MT, and 4-week MT groups for SART (*A′*), WMDA accuracy (% correct), and scores on the CFQ. Error bars represent 95% confidence intervals surrounding the estimate. $^*P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$.

($b=-0.22$, $P=0.376$) from the NTC group. But the lack of significant effects of time or significant interactions between time and group suggests that groups did not change differentially over time.

3.1.3 Subjective probe responses

For the first probe question, we observed no significant effect of time, $F(1, 85)=0.02$, $P=0.875$, no significant effect of group, $F(2, 116)=1.24$, $P=0.293$, and no significant interaction of time and group, $F(2, 85)=1.24$, $P=0.293$, $f^2=0.043$. For the second probe question, we also observed no significant effect of time,

$F(1, 85) = 0.10$, $P = 0.757$, no significant effect of group, $F(2, 116) = 1.31$, $P = 0.274$, and no significant interaction of time and group, $F(2, 85) = 2.98$, $P = 0.056$, $f^2 = 0.069$. Thus, there were no significant differences over time or between groups in self-reported focus in response to the first or second probe questions.

3.2 Working memory delayed-recognition task with affective distracters (WMDA)

We next analyzed measures of WMDA accuracy (% trials correct) using multi-level models with fixed factors of time (T1 and T2) and group (NTC, 2-week MT, and 4-week MT).[3] In order to confirm the manipulation of load and distracter valence on performance, we also included in the model fixed factors of mnemonic load (low load = 0, high load = 1) distracter valence (neutral = 0, negative = 1), and their interaction, alongside effects of time, group, and the interaction of time and group.[4] Summary descriptive statistics are provided in Table 2, and parameter estimates from multi-level models of WMDA performance are provided in Table 4.

3.2.1 Accuracy

We observed a significant effect of mnemonic load, $F(1, 118) = 251.47$, $P < 0.001$, distracter valence, $F(1, 118) = 110.16$, $P < 0.001$, and a significant interaction between load and valence, $F(1, 118) = 12.59$, $P < 0.001$. Accuracy was lower by 7.54% ($P < 0.001$) on high-load trials compared to low-load trials, and lower by 4.99% ($P < 0.001$) on negatively vs. neutrally valenced trials. The significant interaction between load and valence indicated that negative valence impaired accuracy more for high-load trials than it did for low-load trials. These load and valence effects are consistent with prior use of this task (Jha et al., 2017).

There was no significant effect of time, $F(1, 84) = 3.47$, $P = 0.066$, and no significant effect of group, $F(2, 116) = 0.77$, $P = 0.467$. Critically, however, we observed a significant interaction of time and group, $F(2, 84) = 3.49$, $P = 0.035$, $f^2 = 0.010$.[5] The 4-week MT group significantly increased by 2.52% ($P = 0.018$) from T1 to T2, whereas both the NTC ($b = -0.837$, $P = 0.308$) and 2-week MT ($b = 1.190$,

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[3] Although it was not an outcome measure of central interest, we examined mean reaction time of correct trials for completeness. Response times for correct trials were faster over time, $F(1, 84) = 0.27$, $P < 0.001$, but did not differ among groups, $F(2, 116) = 0.27$, $P = 0.767$, and there was no significant interaction of time and group, $F(2, 84) = 3.03$, $P = 0.054$.

[4] We also examined the full factorial model in order to determine whether effects of time and group were moderated by load and valence. There was no three-way interaction between time, group, and load ($F(2, 84) = 2.98$, $P = 0.056$), or time, group, and valence ($F(2, 84) = 1.07$, $P = 0.349$), and no four-way interaction between time, group, load, and valence ($F(2, 84) = 1.07$, $P = 0.348$). Accordingly, we report only the simplified model.

[5] Age was unrelated to WMDA accuracy ($b = 0.021\%$, $P = 0.774$), and there were no significant interactions between age, time, and group. The significant interaction between time and group remained significant ($P = 0.034$) in the presence of these additional covariates.

Table 4 Parameter estimates from models of WMDA accuracy.

Model effects	Estimate (*SE*)
Fixed effects	
Intercept	98.046 (0.840)***
Load	−5.856 (0.673)***
Valence	−3.305 (0.673)***
Load × valence	−3.377 (0.952)***
Time	−0.837 (0.815)
2-Week MT group	−0.116 (1.034)
4-Week MT group	−1.193 (1.125)
2-Week MT group × time	2.027 (1.139)
4-Week MT group × time	3.355 (1.321)*
Random effects	
Intercept σ	11.311 (2.533)
NTC residual σ	49.154 (4.187)
2-Week MT residual σ	38.351 (3.519)
4-Week MT residual σ	56.869 (5.819)
−2 Log-likelihood	5629.7
Observations (*N*)	824

Note*: Maximum likelihood estimates are reported for models of WMDA accuracy (% correct), for fixed effects of mnemonic load (low load and high load), valence (neutral and negative), time (T1 and T2), and group (NTC, 2-week MT, and 4-week MT). The low load neutral condition, and T1 and the NTC group serve here as the reference condition. The number of observations (*N*) is provided. Standard errors are reported in parentheses.* *$^*P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$.*

$P=0.139$) groups did not change over time. Accuracy increased significantly more for participants in the 4-week MT group compared to the NTC group ($b=3.355$, $P=0.013$) but not the 2-week MT group ($b=1.328$, $P=0.313$). Thus, WM accuracy scores increased for participants in the 4-week MT group, and these increases were greater than changes observed in the NTC group. Fig. 3 depicts the model-estimated change from T1 to T2 in each group for WMDA accuracy.

3.3 Cognitive failures questionnaire

We analyzed CFQ scores using multi-level models with fixed factors of time (T1 and T2) and group (NTC, 2-week MT, and 4-week MT). Summary descriptive statistics are provided in Table 2, and parameter estimates from multi-level models of CFQ scores are provided in Table 5. We observed a significant effect of time, $F(1, 89)=7.27$, $P=0.008$, no significant effect of group, $F(2, 116)=0.58$, $P=0.564$, and a significant interaction of time and group, $F(2, 89)=3.98$,

Table 5 Parameter estimates from models of CFQ scores.

Model effects	Estimate (*SE*)
Fixed effects	
Intercept	30.886 (2.002)***
Time	0.925 (1.502)
2-Week MT group	0.764 (3.116)
4-Week MT group	0.314 (3.142)
2-Week MT group × time	−6.623 (2.839)*
4-Week MT group × time	−6.132 (2.809)*
Random effects	
Intercept σ	133.73 (23.81)
NTC residual σ	42.539 (10.06)
2-Week MT residual σ	94.319 (25.14)
4-Week MT residual σ	71.54 (18.29)
−2 Log-likelihood	1659.3
Observations (*N*)	211

Note*: Maximum likelihood estimates are reported for models of CFQ scores for fixed effects of time (T1 and T2), and group (NTC, 2-week MT, and 4-week MT). The number of observations (*N*) is provided. Standard errors are reported in parentheses.* $^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$.

$P=0.022$, $f^2=0.073$.[6] The 4-week MT group significantly decreased by −5.207 ($P=0.031$) on their CFQ scores from T1 to T2. Change in the 2-week MT group was also significant, indicating CFQ scores decreased by −5.699 ($P=0.020$). The NTC group, however, did not change over time ($b=0.925$, $P=0.540$). CFQ scale scores decreased significantly more for participants in the 4-week MT group ($b=-6.132$, $P=0.032$) and the 2-week MT group ($b=-6.623$, $P=0.022$) than the NTC group. Fig. 3 depicts the model-estimated change from T1 to T2 in each group for CFQ scores.

3.4 Out-of-class MT practice compliance

Participants were asked at the T2 assessment to self-report the average amount of out-of-class MT practice they completed daily over the course of the study by selecting one of the following options: 0, 5, 15, or 20+ minutes of practice. 77.42% (24 out of 31) of participants in the 2-week and 86.96% (20 out of 23) of participants in the 4-week MT group reported engaging in some amount of out-of-class practice. The 2-week MT group practiced a median of 15 (range = 0–20+) minutes per day and the 4-week MT group practiced a median of 15 (range = 0–15) minutes per day. In order to examine whether groups practiced similar amounts of out-of-class practice, we first compared out-of-class practice (in minutes) between groups with

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[6] Age was unrelated to CFQ scores ($b = 0.067$, $P = 0.559$), and there were no significant interactions between age, time, and group. The significant interaction between time and group remained significant ($P = 0.043$) in the presence of these additional covariates.

an independent samples Mann-Whitney *U* test. Groups did not differ on their self-reported average minutes of practice completed over the study interval, $U = 334$, $P = 0.669$.

We next examined the association between the amount of practice completed out-of-class and residualized change scores (T2 regressed on T1) for each dependent measure through a series of bivariate Spearman rank-order correlations for all MBAT participants. Out-of-class practice reports were unrelated to performance changes in SART A', r_s $(51) = 0.086$, $P = 0.548$, SART ICV, r_s $(49) = -0.142$, $P = 0.330$, and CFQ scores, r_s $(53) = 0.074$, $P = 0.599$. Self-reported practice was, however, significantly correlated with change in overall WMDA accuracy, r_s $(50) = 0.300$, $P = 0.034$. In order to examine whether this correlation was specific to particular load and valence conditions of the WMDA, we examined the correlation between self-reported practice and change in accuracy for each of the experimental conditions of the WMDA. Practice time was correlated with changes in accuracy in the high-load/negative valence condition, r_s $(50) = 0.447$, $P = 0.001$, but was not significantly correlated with changes in the other conditions (r_s range $= -0.183$ to 0.222). Furthermore, this correlation was primarily evident in the 4-week MT group, r_s $(23) = 0.627$, $P = 0.001$, but did not reach significance in the 2-week MT group alone, r_s $(27) = 0.320$, $P = 0.103$. Thus, MT groups did not differ in the amount of out-of-class practice each engaged in, and, across all individuals receiving MBAT, and those who engaged in more out-of-class practice had greater improvements in overall WMDA accuracy. This correlation seems to be driven by the strong correlation between practice time and changes in accuracy in the high-load/negative valence condition of the WMDA in the 4-week MT group.

3.5 Self-reported performance motivation

Five items comprising our measures of performance motivation were examined using MANOVA to explore group differences at T2. The multivariate comparison (Wilks' lambda) of the five items between groups was significant, $F(10, 168) = 2.58$, $P = 0.006$. In order to determine which of these items significantly differed between groups, we conducted a series of univariate ANOVAs and adjusted the alpha ($0.05/5 = 0.010$) to account for multiple comparisons. Groups only significantly differed on their response to the statement "I was significantly committed to my performance goals," $F(2, 88) = 8.11$, $P = 0.001$. The 2-week MT group reported feeling significantly less committed to their performance goals at T2 compared to the 4-week MT ($P = 0.012$) group and the NTC ($P < 0.001$) group, while the 4-week MT and NTC groups did not differ ($P = 0.329$) in their rating. Groups did not differ (all Ps > 0.204) in their response to any of the remaining four items assessing performance motivation or task understanding. Table 6 describes means and standard deviations for all the items for each of the groups.

In order to explore whether performance motivation during the assessment was related to any of the significant changes observed among behavioral outcome measures, we next examined the rank-order correlation between the five rating items and

Table 6 Descriptive statistics of performance motivation at T2.

Measure	NTC	2-Week MT	4-Week MT	η_P^2
1. Cared for performance	3.811 (0.967)	3.484 (1.313)	3.957 (1.147)	0.028
2. Committed to goals	3.811 (0.877)	2.903 (1.012)	3.565 (0.945)	0.156**
3. Motivated to perform	3.514 (1.146)	3.290 (1.131)	3.783 (0.951)	0.029
4. More motivated at T2	2.622 (0.794)	2.774 (1.055)	3.087 (1.125)	0.035
5. Understood instructions	4.622 (0.758)	4.419 (0.720)	4.522 (0.730)	0.014

Note*: Means and standard deviations are provided for five ratings of self-reported performance motivation for each group (NTC, 2-week MT, and 4-week MT) collected at the post-training assessment (T2). Effect sizes (η_P^2) from univariate ANOVA group comparisons are reported. $^{**}P<0.01$.*

Table 7 Rank-order correlations between change in outcome measures and performance motivation.

Measure	N	1	2	3	4	5
NTC						
ΔA′	35	0.033	0.056	0.127	−0.044	−0.183
ΔICV	35	−0.319	−0.325	−0.383*	−0.213	0.053
ΔWMDA	35	−0.023	0.120	0.156	0.011	0.230
2-Week MT						
ΔA′	29	0.322	0.231	0.284	0.202	0.133
ΔICV	27	−0.293	−0.360	−0.363	−0.119	−0.133
ΔWMDA	27	0.153	0.095	0.198	0.161	0.122
4-Week MT						
ΔA′	22	0.118	0.194	0.008	0.135	−0.136
ΔICV	22	−0.291	−0.070	−0.042	0.039	0.074
ΔWMDA	23	−0.031	0.216	0.218	0.165	0.190

Note*: Bivariate rank-order correlations are provided between residualized change scores for behavioral measures of SART (ΔA′ and ΔICV) and WMDA accuracy (ΔWMDA), and five ratings of self-reported performance motivation separately for each group (NTC, 2-week MT, and 4-week MT). The number of participants (N) for each set of analyses is provided. $^{*}P<0.05$.*

residualized change scores (T2 regressed on T1) for each of the behavioral dependent measures (A', ICV, and WMDA accuracy). All correlation coefficients are provided in Table 7. Overall, there were few significant correlations between changes in study outcome measures and ratings of motivation in the NTC and 2-week MT groups, and, importantly, no significant correlations were observed in the 4-week MT group. None of these correlations remained significant when alpha ($0.05/5=0.010$) was adjusted to account for multiple comparisons. For all groups, there were no correlations between changes in performance and ratings on statement 2 (the statement which groups significantly differed in mean rating). Taken together, these findings suggest that systematic group differences in motivation were unlikely to account for behavioral group differences in SART or WMDA performance.

4 Discussion

The broad aim of the current study was to investigate whether MT might improve cognitive performance on measures of sustained attention and working memory, and reduce cognitive failures in daily life, in a sample of high-performing SOF personnel. Military servicemembers were assigned to either a 2-week or 4-week version of a short-form (8 h) MT program called MBAT, or they received no training at all. Servicemembers who underwent the 4-week version of MBAT demonstrated significant improvements on behavioral measures of detection accuracy (A') in a task of sustained attention, and increased accuracy (% correct) on a task of working memory. In contrast, neither the NTC nor the 2-week MT groups changed on these behavioral measures over the roughly 8-week program interval. However, both 2-week and 4-week MT groups experienced reductions in self-reported cognitive failures in their daily life. Finally, the amount of out-of-class mindfulness practice engaged in by MT participants was correlated with improvements in working memory accuracy, with the strongest correspondence observed in the most demanding task condition (high load, negative affect) for the 4-week group. These findings suggest that short-form MBAT may be an effective method for *enhancing* cognitive functioning in military cohorts, but these benefits may also depend on the delivery structure of the MT program and relate to individual differences in the amount of out-of-class practice in training participants.

Training and practice in mindfulness techniques over the program interval appeared to improve performance on cognitive tasks involving sustained attention and working memory. Performance on the SART requires participants to maintain attention in order to detect infrequent target stimuli and inhibit pre-potent response tendencies over time. Improvements over time (from T1 to T2) in target detection (A') suggest that participants were better able to maintain their attention over the course of the SART and inhibit inappropriate motor responses in line with task goals. We did not, however, corroborate these attentional improvements with our supplementary measures of ICV and self-reported mind wandering. Improvements in A', however, suggest that 4-week MT participants were better able to maintain their attention over time in the service of task performance on the SART.

Variability in reaction time has been linked to attentional fluctuations and self-reported episodes of mind wandering (e.g., Bastian and Sackur, 2013). That we did not observe reductions in ICV with MT is consistent with the results of the experience sampling probes, which indicated that groups did not change over time in self-reported mind wandering (Probe 1) or their meta-awareness (Probe 2) of their attentional state. It is possible that all participants were sufficiently engaged and focused on the task so as not to experience frequent and salient episodes of disruptive mind wandering. Indeed, on average participants felt generally focused and "on-task" in their responses to the experience sampling probes −76.6% of all responses to probes were rated as being highly on-task (i.e., "1" or "2"). Thus, the frequency of task-unrelated thought may not have been high enough to observe systematic changes in self-reported mind wandering. Nevertheless, behavioral improvements in A'

suggest that attentional processes improved. These benefits might therefore reflect changes in attentional states or cognitive processes unrelated to changes in episodes of explicit mind wandering or trial-to-trial variation in reaction time. Thus, patterns of group-level change in objective and subjective metrics in the SART seem to diverge in the present study, consistent with prior studies of short-form MT (see Jha et al., 2015; Rooks et al., 2017).

We further observed improvements in working memory performance in a delayed-recognition task with affective distracters. Success in the WMDA involves individuals' capacity to accurately maintain memoranda in working memory while regulating distraction by salient, context-relevant, affective images. Thus, improvements in performance reflect an increased capacity to maintain memoranda in mind over short periods of time in the presence of distraction. Furthermore, even though preliminary manipulation checks confirmed that accuracy varied as a function of the factors of load and affective distraction, MT-related improvements in WM performance were observed regardless of load and valence conditions for the 4-week group. Such improvements are in line with previous findings (Jha et al., 2017).

Importantly, future studies should investigate the degree to which attentional benefits might improve performance on operationally relevant tasks in real-world or simulated circumstances. For example, SART performance involves skills that are relevant to the military context. Like the SART, simulated small-arms engagements involve similar speed-accuracy compensation and response inhibition-related processes (Wilson et al., 2015). But the degree to which cognitive training approaches, including MT, might benefit performance outside the laboratory is a topic of much interest and debate. To this end, we investigated self-reported cognitive failures in participants' daily lives as an extension of our computer-based cognitive measures. Indeed, both groups of MT participants self-reported experiencing fewer cognitive failures over the program interval compared to the NTC group. These findings suggest that attentional benefits were directly reported by participants in their daily lives, and the benefits of MT may transfer to a range of real-world situations. Future studies should continue to explore the potential of MT-related cognitive benefits to broadly generalize to important tasks throughout individuals' lives.

Given that training time is finite in the military context, maximizing the efficacy of training interventions is an important research goal. The MBAT program attempts to address this issue by emphasizing first-hand mindfulness practice and minimizing time spent on didactic content during delivery of the course content. While training duration of MT interventions is a critical factor, delivery structure might also be related to efficacy. In the present study, we investigated whether course content delivered over either a 2-week or 4-week interval might be differentially effective in improving cognitive outcomes. Importantly, behavioral improvements across measures of cognitive performance were observed in the 4-week MT group only, when training sessions were spaced across a 4-week training interval. In contrast, the 2-week MT group did not change from study onset to conclusion. These findings suggest that the delivery format of in-person MBAT training sessions may be an important contributor to eventual training outcomes.

Spacing delivery of training over time has demonstrated benefits relative to other training structures in many learning contexts (Gerbier and Toppino, 2015). There is also some evidence suggesting that spaced delivery schedules for cognitive training may confer greater performance benefits relative to other delivery formats (Wang et al., 2014). Whereas both MT groups differed in the scheduled structure of in-class practice and training in the didactic content, groups engaged in the same amount of continued mindfulness practice across the entire program interval (i.e., the roughly 8-week study interval). In this regard, personal out-of-class mindfulness practice is not the only factor critical for beneficial cognitive outcomes. It is possible that spacing the delivery of MBAT over 4-weeks may have promoted learning of the course didactic content, facilitating effective mindfulness practice, and ultimately benefiting cognitive outcomes. This supposition is supported by the strong correlation between practice time and increased WMDA accuracy in the 4-week group, suggesting that daily practice was more effective for 4-week MT participants.

Consistent with other studies of MT in the military context (e.g., Jha et al., 2010), participants' amount of out-of-class mindfulness practice was correlated with certain cognitive outcomes. Specifically, MT practice was correlated with positive changes in working memory. Those participants who engaged in more out-of-class practice had greater improvements over time in WMDA accuracy. Strikingly, the correlation with practice time was strongest in the most demanding condition of high load and negative affect and appeared to be driven in large part by the 4-week MT group. Indeed, the correlation between mindfulness practice duration and WMDA performance may have been driven by the most demanding experimental condition and may relate to why we did not observe correlations between practice time and SART performance or self-reported cognitive failures, in contrast to other studies of MT (e.g., Jha et al., 2016). Mindfulness practice estimates may not correlate with these other measures because these measures are not suitably demanding for SOF personnel resulting in low between-person variability. It is also important to note that less out-of-class practice was required of participants in the MBAT program (15 min) relative to longer-form MT programs (30 min) implemented within the military. Such differences in mandated out-of-class practice duration may underlie discrepancies between the present study and past research.

In addition to individuals' out-of-class practice time, the basic group-wise effects suggested that the 4-week group benefited in cognitive task performance more so than the 2-week group. Yet, the two MT groups did not significantly differ on reductions in self-reported cognitive failures and both groups reported fewer cognitive failures compared to the NTC group. One possibility is that participation in MBAT biased participants to expect cognitive failures in daily life. Based on this expectation, both groups may have been more sensitive to noticing when failures were averted. Future studies should explore the issue of expectations using appropriate experimental control conditions, and the degree to which understanding of the course content facilitates personal mindfulness practice and cognitive outcomes.

Past studies of MT in military cohorts have primarily involved investigations of MT as a means of promoting cognitive resilience (referred to as sustainment; see Deuster and Schoomaker, 2015) in the face of declining capacity over periods of stress and high demand. In these prior studies, Soldier's assigned to MT have been shown to have greater SART A' and WM accuracy at the end of the training interval compared to didactic control groups and no-training groups that demonstrated robust decline in performance over time (Jha et al., 2015, 2017). In contrast to this past research, we did not expect or observe systematic decrements in performance over the MBAT program interval in any group of study participants. Specifically, there were several reasons we expected cognitive enhancement vs. sustainment with MT. First, study participants were SOF members who are known to be psychologically hardy and resilient (Bartone et al., 2008); such characteristics contributed to their selection for entry into their operational units because of their demonstrated fortitude and capacity to excel despite high levels of demand. It may be that those same characteristics are observable here. In addition, all participants had access to psychological support, including a mental skills coach, as part of the regular support their units receive. It is possible that such support may have contributed to the development of cognitive resilience in some participants. Future studies should continue to investigate the factors contributing to cognitive decline over high-demand periods and the psychological profiles that might contribute to resilience.

Experimental groups were matched on a number of demographic and psychological health-related factors despite being assigned by unit to study conditions. These results are therefore preliminary and should be replicated with larger cohorts of military servicemembers in studies employing random assignment at the individual level as well as active comparison designs. While ideal, active experimental controls, and individualized random assignment are difficult to implement in applied settings with active-duty military units. One concern in studies lacking active comparison conditions involves motivational biases that may encourage participants assigned to active training conditions to devote more cognitive resources toward task performance (Jensen et al., 2012).

Although we could not experimentally account for these motivational factors, we attempted to address this issue by assessing participants' testing motivation directly. Importantly, there were no group differences on four out of five of the self-report testing motivation measures utilized presently, and no significant correlations between measures of motivation and change in cognitive performance in the 4-week MT group. These findings provide support for the notion that changes in performance in the 4-week MT group were unrelated to potential motivational biases. There were, however, motivational differences on one of the self-report questions in which the 2-week MT group reported feeling less committed to their performance goals than either the NTC or 4-week MT groups. While scores on that measure were uncorrelated with cognitive outcomes, it is possible that this group difference reflected some level of underlying task disengagement contributing to the 2-week MT group's cognitive outcomes.

The magnitude of the observed improvements in the present study was small, yet, meaningful in the context of enhancing cognitive performance in elite military cohorts. This is perhaps expected given that the training intervention was shorter, and involved less training time, than other standardized mindfulness-based interventions (Creswell, 2017). Although cognitive benefits were observed over 8 weeks of daily practice, the effectiveness of longer duration training will require additional research, and the long-term maintenance of these benefits is uncertain. Nevertheless, the size of intervention effects in the present study is similar in magnitude to those observed following several hours of computer-based cognitive training in an untrained civilian sample (Biggs et al., 2015). It is also possible that improving performance in already high-functioning cohorts is considerably more challenging than cognitive enhancement in those with less capacity. An intriguing future direction might involve direct comparisons of computer-based cognitive training and MT on cognitive outcomes in highly skilled SOF personnel.

Although the present study outcomes are modest, the potential for cognitive training approaches to improve performance in the military context may nonetheless have far reaching consequences. The chance to intervene against even a single attentional lapse or cognitive failure would be consequential if that failure contributed to unnecessary loss of life or the loss of critical mission objectives. Attentional skills may further contribute to the psychological health and wellbeing of these individuals as they manage both their personal and professional demands. The present study provides preliminary evidence that short-form MBAT may be an effective cognitive training tool in elite military cohorts. Generally, participants receiving the 4-week version of MBAT demonstrated improved cognitive performance on computer-based measures of attention and working memory, and reductions in self-reported cognitive failures in their daily lives. Beyond specialized military applications, MT may also be useful in other elite contexts in which individuals have met special selection criteria and undergone high levels of training. The cognitive demands of such professions (e.g., surgeons, judges, or elite athletes) are often high and performance failures can be consequential.

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