The Impact of Mindfulness Training on PTSD Symptoms, Subjective Sleep Quality, and Objective Sleep Outcomes in Police Officers

Theodore P. Imhoff-Smith[1,2] and Daniel W. Grupe[2]

[1]Neuroscience Training Program, University of Wisconsin-Madison

[2]Center for Healthy Minds, University of Wisconsin-Madison

Author Note

Theodore P. Imhoff-Smith iD https://orcid.org/0000-0001-9204-063X

Daniel W. Grupe iD https://orcid.org/0000-0003-4927-7572

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Correspondence should be addressed to Dan Grupe, Center for Healthy Minds, University of Wisconsin-Madison, 625 W Washington Ave, Madison, WI 53703, United States. Email: grupe@wisc.edu.

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Abstract

Objective

Sleep disturbances cooccur with posttraumatic stress disorder (PTSD) and are often correlated with PTSD severity. Previous research has shown that sleep problems mediate the relationship between PTSD and negative physical and mental health outcomes but has relied on self-reported sleep quality. We tested the effects of mindfulness training – previously shown to improve sleep quality and reduce PTSD symptoms – on subjective and objective sleep metrics and relationships with reduced PTSD symptoms.

Method

Following baseline data collection in 114 law enforcement officers, we randomly assigned participants to either an 8-week mindfulness training group or a waitlist control group. We repeated assessments immediately post-training and at 3-month follow-up. Self-reported PTSD symptoms and subjective sleep quality were measured at each visit with the PTSD Checklist and Pittsburgh Sleep Quality Index, respectively. Participants also wore a Fitbit Charge 2 continuously over the course of a 4- to 6-day work week following each visit, from which we extracted two distinct objective sleep metrics, total minutes of sleep and sleep efficiency.

Results

At baseline, PTSD symptoms were correlated with PSQI scores but not objective Fitbit metrics. Relative to waitlist, mindfulness training led to improved subjective sleep quality and reduced PTSD symptoms. Reduced PTSD symptoms mediated the improvement in subjective sleep quality following mindfulness training. Neither objective sleep metric demonstrated improvements following mindfulness training, nor did these metrics mediate reduced PTSD symptoms.

Conclusions

This study provides evidence linking improved subjective sleep quality, but not objective sleep markers, to reductions in PTSD symptoms following mindfulness training.

Keywords: mindfulness, sleep, PTSD, trauma, actigraphy

Clinical Impact Statement

Prior work has demonstrated improvements in subjective sleep quality and reduced PTSD symptoms following mindfulness training, but relationships with objective sleep metrics have been largely untested. In this study of trauma-exposed individuals with significant sleep disturbances, we found that improvements in subjective sleep quality following a mindfulness intervention were mediated by reduced PTSD symptoms, whereas objective sleep metrics showed no change in response to mindfulness training. This highlights the value of subjective reports of sleep quality which, compared to objective, real-world indicators of sleep quality, provide unique insight into etiology and recovery from PTSD.

Posttraumatic stress disorder (PTSD) is a debilitating psychiatric illness that can occur following traumatic experiences and interfere with day-to-day functioning for years. About 7% of the U.S. population will experience PTSD at some point during their life (Kessler et al., 2005), but the prevalence of the illness is elevated in highly trauma-exposed occupations such as law enforcement (Syed et al., 2020). Even subsyndromal or partial PTSD can lead to substantial social and work interference (Stein et al., 1997), and for high-pressure, sometimes life-or-death situations in which police officers work, there is little room for symptoms of PTSD that may compromise job performance (e.g., irritability and aggression, difficulty concentrating, and intrusive trauma reminders). This compounds the urgency to find effective treatments or evaluate preventive interventions to protect against the emergence of clinical manifestations of PTSD in police officers as trauma exposure accumulates over lengthy careers.

Sleep impairments are frequently comorbid with PTSD symptoms and, though historically considered to be secondary to PTSD (Spoormaker & Montgomery, 2008), they are increasingly believed to contribute to the etiology of PTSD and impede recovery (Babson & Feldner, 2010). People with PTSD experience decreased subjective sleep quality, more nightmares, increased time to fall asleep, and more frequent sleep disturbances (Yeh et al., 2021). Some sleep studies conducted in controlled laboratory settings have identified associations between PTSD and altered sleep architecture (Babson & Feldner, 2010), though improved subjective but not objective sleep measures were shown to track with reduced PTSD symptoms at 1-year follow-up (Yeh et al., 2021). Less is known about associations between PTSD symptoms and objective sleep measured “in the wild”, leaving open the question of whether objective sleep disturbances track with PTSD in naturalistic settings using unobtrusive data collection methods.

Impaired sleep has deleterious consequences for police officer health and well-being and in cross-sectional data has been shown to mediate the relationship between PTSD symptoms and downstream health outcomes (Chopko et al., 2021). Poor sleep impacts not just police officer health but the health and well-being of the larger community: officers in a longitudinal study who screened positive for sleep disorders were more likely over the next two years to fall asleep while driving, commit a safety violation due to fatigue, or exhibit uncontrolled anger towards a citizen (Rajaratnam et al., 2011). The inextricable links between sleep, PTSD, and downstream health-related and functional consequences make impaired sleep an important target for intervention in this trauma-exposed population.

Mindfulness-based interventions (MBIs) are of particular interest in this regard, owing to their demonstrated efficacy at improving sleep quality (Rusch et al., 2019) and PTSD symptoms (Hopwood & Schutte, 2017), including in police officers (Grupe, McGehee, et al., 2021). Although meta-analyses have shown the efficacy of MBIs for clinically diagnosed insomnia (Chen et al., 2020) and PTSD (Hopwood & Schutte, 2017), MBIs also reduce symptoms of insomnia (Chan et al., 2022) and PTSD (Grupe, McGehee, et al., 2021; Kelly & Garland, 2016) in participants without a clinical diagnosis. The appeal of MBIs lies partly in their broad benefits for enhancing well-being regardless of diagnosed insomnia, PTSD, or other conditions. Strength-focused MBIs emphasize the cultivation of skills to promote well-being and resilience in the face of significant trauma, a framework that resonates with police officers, a population in which mental health problems are stigmatized and help-seeking is discouraged (Tuckey et al., 2012).

Despite evidence for the effectiveness of MBIs in addressing clinical and subclinical symptoms of sleep and PTSD, covarying changes in sleep and PTSD symptoms following a mindfulness intervention have not, to our knowledge, been analyzed together within the same sample. Moreover, whereas meta-analyses of mindfulness interventions have consistently demonstrated benefits for subjective sleep quality among individuals with (Chen et al., 2020) and without (Chan et al., 2022) diagnosed insomnia, the evidence for these interventions' impact on objective measures of sleep is more subtle and equivocal (Gross et al., 2011; Kelly & Garland, 2016; Perini et al., 2021; Shaif et al., 2022). The present study seeks to unify current knowledge of relationships between sleep, PTSD, and MBIs by testing the impact of mindfulness training on PTSD symptoms and sleep quality using multimodal measurements of sleep in the same sample.

The current results represent secondary analyses of data from a randomized clinical trial examining the efficacy of an 8-week mindfulness intervention on physical and mental health outcomes in 114 Midwestern U.S. police officers (ClinicalTrials.gov identifier NCT03488875; Grupe, Stoller, et al., 2021). Our primary hypotheses (pre-registered prior to the analysis or publication of primary study results) were: (H1) PTSD symptoms will be negatively correlated with both subjective and objective indicators of sleep quality at baseline; Eight weeks of mindfulness training will (H2) reduce PTSD symptoms, (H3a) improve objective sleep quality, and (H3b) improve subjective sleep quality; and (H4) decreased PTSD symptoms will mediate improvements in subjective and/or objective indicators of sleep quality. In light of evidence that impaired sleep can also contribute to the etiology and maintenance of PTSD (Babson & Feldner, 2010), we tested an alternative (non-registered) mediation model in which improved sleep quality following mindfulness training mediated reduced PTSD symptoms.

Methods

Participants and Recruitment

Participants included 115 currently employed law enforcement officers from three different agencies within Dane County, Wisconsin. Following a phone screening to confirm eligibility, these individuals completed informed consent and baseline in-person visits in one of two cohorts in spring 2018 (cohort 1, N = 60) or 2019 (cohort 2, N = 55). One participant from cohort 2 withdrew following consent but prior to baseline data collection, resulting in a sample of 114 for analysis (mean age ± SD = 40.0 ± 8.4; 47 female/57 male; 95 White, 4 Black or African American, 3 Asian or Asian American, 2 Native American, 8 bi- or multi- racial, 2 unknown race; 3 Hispanic/Latinx, 110 not Hispanic/Latinx; 1 unknown ethnicity). While participants' work schedules varied depending on work assignment and agency, for the purpose of analysis we categorized them as working first shift (~0700-1500; N=57), second shift (~1500-2300; N=43), or third shift (~2300-0700; N=14).

There were no inclusion criteria beyond current employment as a law enforcement officer with one of the three participating agencies. Exclusion criteria included significant prior meditation experience or previous participation in a meditation class such as Mindfulness-Based Stress Reduction. For the first cohort, individuals in leadership positions or sheriff's deputies with a primary assignment in the jail were excluded, but these individuals were eligible to take part in the second cohort. Additional participant information can be found in the primary outcomes paper (Grupe, Stoller, et al., 2021).

Study Design and Data Collection

This study was preregistered on Open Science Framework (Grupe et al., 2019). Prior to data processing, cleaning, or analyses, we registered a transparent changes document (https://osf.io/bpjfz) with planned changes to our analysis strategy. Any additional deviations from pre-registered analyses and hypotheses are indicated below. All study activities were approved by the University of Wisconsin-Madison Minimal Risk Institutional Review Board. Although our preregistration was submitted prior to any data analysis on the overall project, a subset of the analyses reported here (specifically, those regarding the impact of mindfulness training on PTSD and subjective sleep quality, H2 and H3b) were previously reported in our primary outcomes paper (Grupe, Stoller, et al., 2021). Those results are again reported here for context and completeness as we present novel results on baseline relationships between objective sleep measures, subjective sleep quality, and PTSD symptoms, and on covarying changes between these measures over time and in response to mindfulness training.

At the baseline visit, participants completed a testing battery that included self-report questionnaires. At the end of the visit, participants shared their upcoming work schedule and the experimenter provided instructions for field data collection, including wearing a Fitbit Charge 2 continuously over the course of a work week. Following baseline data collection, participants were randomly assigned to a mindfulness group or waitlist control group. Block randomization occurred within each of the three police agencies and strata within each agency were based on class time preferences. The intervention was an 8-week mindfulness training based on Mindfulness-Based Stress

Reduction (Kabat-Zinn, 1990) and Mindfulness-Based Resilience Training (MBRT; Christopher et al., 2016) tailored specifically for the culture and unique stressors of policing (Grupe, McGehee et al., 2021; see Supplemental Methods for an overview of the adapted curriculum). Adaptations included less out-of-class practice time, greater emphasis on occupationally specific examples of "informal" practices to integrate into daily activities, and involving a police officer as a co-instructor. The mindfulness group met weekly for 2 hours over 8 weeks, with a 4-hour extended class in week 6. Participants were encouraged to engage in 5-30 minutes of daily formal meditation practice using guided audio recordings, and they logged the duration of formal practice and frequency of integrated practice on a weekly basis.

Participants repeated all laboratory and field-based assessments from the baseline visit in the weeks immediately following the intervention (T2) and at a 3-month follow-up visit (T3). Participants completed T1 visits on average 15.4 days prior to randomization, T2 visits on average 12.1 days after the intervention, and T3 visits on average 106.0 days after the intervention. There was no difference in timing between groups at T2 [$t(107) = 0.38$, $p = 0.71$], but the mindfulness group completed T3 visits on average 3 days later than the waitlist control group (107.5 vs. 104.6 days, $t(102) = 2.04$, $p = 0.04$).

Measures

Self-reported PTSD symptoms were quantified with the PTSD Checklist for DSM-5 (PCL-5; Blevins et al., 2015), a 20-item measure that assesses the severity of PTSD symptoms on a scale of 0-80 with higher scores indicating greater severity. The PCL-5 provides scores for total symptom severity and 4 specific symptom clusters (B: Re-experiencing; C: Avoidance; D: Negative alterations in cognition and mood; E: Hyperarousal). Subjective sleep quality was quantified with the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), a 19-item measure that assesses sleep quality and disturbances on a scale ranging from 0-21, with higher scores indicating greater sleep impairment. Instrument developers suggest a cut-off score of > 5 yields diagnostic sensitivity of 89.6% and specificity of 86.5% in identifying individuals with "poor" vs. "good" sleep quality (Buysse et al., 1989).

To measure sleep objectively, participants were provided with the same commercial grade wearable (Fitbit Charge 2) following each study visit to wear during the upcoming work week, which ranged from 4-6 days. A prior validation study of the Fitbit Charge 2 against EEG in a naturalistic setting (Haghayegh et al., 2020) reported unbiased estimates of wake after sleep onset and total sleep time but overestimates of sleep efficiency by 4%. Fitbits showed no differences in bias relative to actigraphy in this study. Another naturalistic validation study conducted in first responders and other shift workers (Stucky et al., 2021) reported unbiased estimates of total sleep time for the Fitbit Charge 2 relative to PSG but overestimates of wake after sleep onset, likely attributable to use of the "sensitive" sleep tracking setting; in the current study, we set sleep sensitivity to "normal". Fitbit-generated measures of sleep duration (in minutes) and sleep efficiency (minutes asleep / total time in bed; or the proportion of time a participant is in bed and not awake or sleeping restlessly) were extracted from the wearable for each night preceding the first day of work through the night preceding the final day of work.

Wearable Data Processing

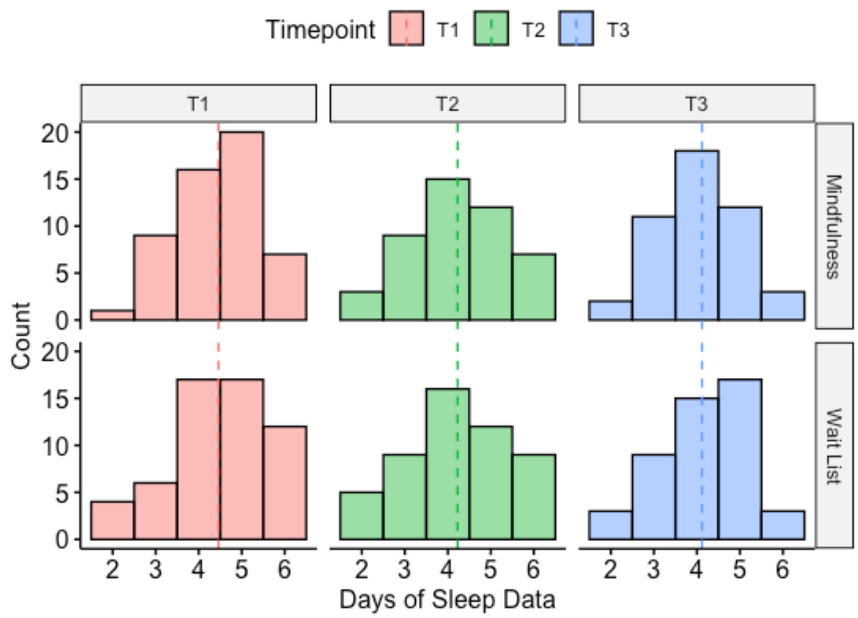
Following sleep data extraction from the wearable, three data cleaning steps were taken. First, sleep epochs that did not precede a scheduled workday were excluded. Second, sleep data were visually reviewed alongside heart rate and step data using in-house software. Epochs with apparently missing data – such as the participant not wearing the Fitbit, a dead battery, or the Fitbit not recording sleep during periods of clear inactivity likely reflecting sleep – were excluded. This visual review resulted in exclusion of 94 of 1382 total epochs. Third, individual timepoints were excluded if a participant had fewer than 2 valid nights of sleep at that timepoint (Rowe et al., 2008). Of the 114 participants enrolled, 109 (T1), 97 (T2), and 93 (T3) had sufficient sleep data and were included in analysis (Figure 1).

Statistical Analysis

We first examined baseline associations between Fitbit sleep duration/efficiency and PSQI scores to relate objective sleep indices to this standard self-report measure of sleep quality. We then

Figure 1

Count of Participants with X Valid Days of Sleep Data by Group and Timepoint



conducted linear regression analyses to test for hypothesized baseline relationships between PSQI and PCL using the lm function in R Statistics (R Core Team, 2020). For each remaining hypothesis, we used the lmerTest library in R to perform linear mixed effects analysis with repeated measures. Each model included a random slope for participant and models for Fitbit data additionally included a random intercept for day of the work week. All models used a Nelder-Mead optimizer and included fixed effect covariates of Cohort (1/2), Shift ($1^{st}/2^{nd}/3^{rd}$), Gender, and Years Policing unless otherwise specified, resulting in a baseline model of, e.g., [minutesAsleep ~ PCL + cohort + workShift + day + gender + yearsPolicing + (1 + day | id)]. Intervention analyses (Hypotheses 2-3) included a Group*Time interaction term and an additional fixed effect covariate of mean T1 score for the response variable to adjust for baseline values. Mediation analyses were conducted using the mediate package in R to conduct causal mediation analysis with bootstrapping and 10,000 iterations, with Group as the independent variable. Change scores were calculated for both sleep quality and PTSD symptoms (T2-T1 and T3-T1) and these change scores were used as mediator and outcome variables in the mediation models. Effect sizes throughout the manuscript are reported as partial η^2.

Sensitivity Analyses

Models including self-report measures were run with and without outliers, defined as scores > 3 standard deviations from the mean. Models were also run excluding participants who had less than 3 nights of sleep instead of 2. A third set of sensitivity analyses repeated all analyses involving the PCL after removing two sleep-related items (item 2: "Repeated, disturbing dreams of the stressful experience"; item 20: "Trouble falling or staying asleep"). Results for all sensitivity analyses were consistent with primary analyses unless otherwise specified.

Results

Descriptive Statistics

At baseline, participants' self-report indicated significant sleep disturbances: 70% of participants met a recommended cutoff (5) for "poor sleep" on the PSQI (M=7.6, SD=3.5; Table 1). PTSD symptoms were slightly elevated in this sample, with 17% of participants meeting a positive screening cutoff (31) for PTSD (M=17.5, SD=13.2; Table 1). Fitbit data indicated that participants obtained on average 6.9 hours of sleep per night at baseline, with an average sleep efficiency score of 94.8 (Table 2).

Relationships Between Objective and Subjective Sleep Measures

Using the lmerTest library in R, we regressed total baseline PSQI scores, reflecting global sleep impairment, on our two Fitbit measures: minutes asleep and sleep efficiency. The test with minutes asleep was not significant ($t(103.4) = -0.032$, $p = 0.975$, $b = -0.05$, 95% CI = [-3.29, 3.20], partial $\eta^2 = 0.00$), and sleep efficiency showed a trend-level negative relationship with total PSQI scores ($t(105.7) = -1.730$, $p = 0.087$, $b = -0.12$, 95% CI = [-0.25, 0.02], partial $\eta^2 = 0.03$).

Next, we evaluated baseline correlations between Fitbit measures and related PSQI subscales, hypothesizing that specific Fitbit metrics would show stronger associations with similarly specific PSQI

Table 1

Self-Report Descriptive Statistics

Measure	Timepoint	N	Mean	SD	Range
PSQI	t1	107	7.6	3.5	0-18
	t2	96	6.8	3.1	1-15
	t3	93	7.2	3.3	0-17
PCL	t1	109	17.5	13.2	0-57
	t2	97	14.1	11.7	0-55
	t3	93	14.1	12.1	0-67

Note. PSQI = Pittsburgh Sleep Quality Inventory, PCL = PTSD Checklist

Table 2

Fitbit Metric Descriptive Statistics

Measure	Timepoint	N	Mean	Median	SD	Range
Duration	t1	109	411.2	414.6	52.6	269.4-533
	t2	97	388.6	401.0	61.4	221.2-507.7
	t3	93	408.2	417.0	56.1	253.2-526.8
Efficiency	t1	109	94.8	95.0	2.4	88.8-98.8
	t2	97	94.9	95.2	2.1	89.5-99.2
	t3	93	94.8	95.2	2.1	89.3-98.2

subscales than with global sleep impairment. Indeed, there was a significant association between PSQI hours asleep and Fitbit sleep duration ($t(105.3) = 2.290$, $p = 0.024$, $b = 12.84$, CI = [1.62, 23.97], partial $\eta^2 = 0.05$). Although the relationship between Fitbit efficiency and PSQI efficiency was not significant ($t(106.3) = 0.286$, $p = 0.776$, $b = 0.00$, CI = [-0.01, 0.02], partial $\eta^2 = 0.00$), there was a strong relationship between Fitbit efficiency and PSQI sleep disturbances ($t(106.5) = -3.707$, $p < 0.001$, $b = -1.26$, CI = [-1.95, -.057], partial $\eta^2 = 0.11$), such that less time asleep while in bed was associated with a greater number and intensity of self-reported sleep disturbances.

Baseline Analyses

H1: PTSD and Sleep.

To test the relationship between PTSD symptoms and sleep, we fit linear mixed effects models regressing PCL total symptom severity on PSQI subjective sleep quality and Fitbit metrics of objective sleep. At baseline, there was a significant relationship between PSQI and PCL ($t(101) = 6.276$, $p < 0.001$, $b = 0.13$, CI = [0.09, 0.17], partial $\eta^2 = 0.28$), but no relationship between baseline PTSD symptoms and objective sleep duration ($t(106.9) = 0.813$, $p = 0.418$, $b = 0.32$, CI = [-0.47, 1.12], partial $\eta^2 = 0.00$) or sleep efficiency for the subsequent week ($t(107.8) = -0.206$, $p = 0.837$, $b = -0.00$, CI = [-0.04, 0.03], partial $\eta^2 = 0.00$). After removing two PCL outliers, we saw a trend-level relationship between PTSD symptoms and objective sleep duration ($t(104.3) = 1.860$, $p = 0.066$, $b = 0.78$, CI = [-0.06, 1.62], partial $\eta^2 = 0.03$).

Intervention-Related Analyses

H2: Mindfulness Training Reduces PTSD Symptoms

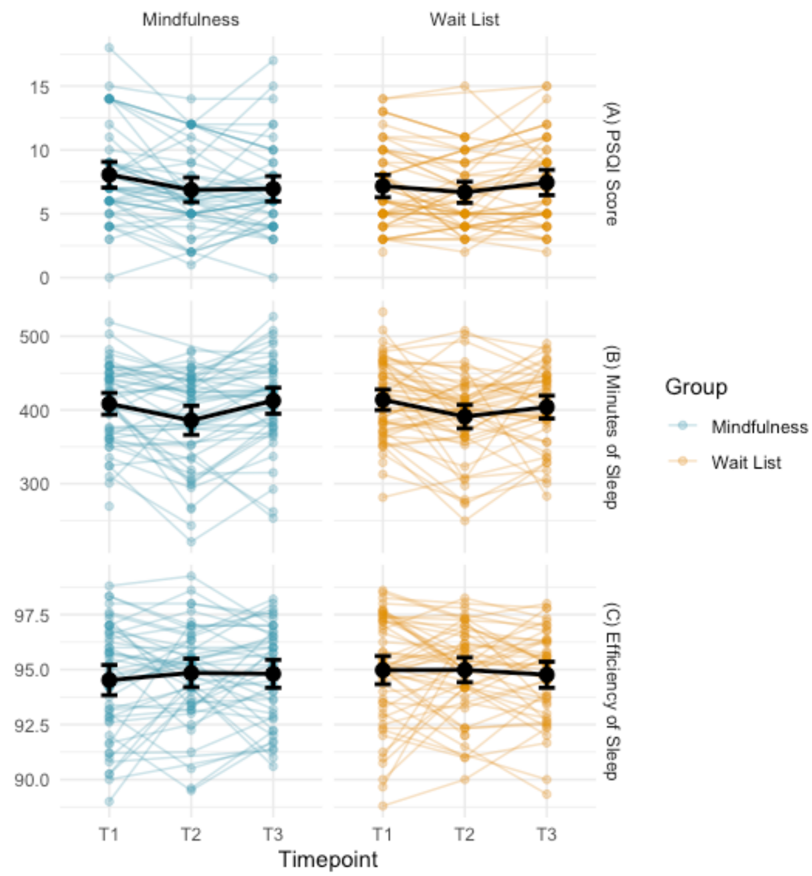
As we previously reported (Grupe, Stoller, et al., 2021), a model testing the effect of mindfulness training on PTSD symptoms revealed a significant Group*Time omnibus effect from an ANOVA test ($\chi^2(2, N=11) = 7.44$, p = 0.0242, partial $\eta^2 = 0.07$). Controlling for baseline symptoms, there was a significant group difference at T2 ($t(153.5) = 2.714$, $p = 0.007$, $b = 4.82$, CI = [1.31, 8.32]) and a trend-level difference at T3 ($t(155.6) = 1.868$, $p = 0.064$, $b = 3.34$, CI = [-0.19, 6.85]). Removing 4 PCL outliers resulted in a trend-level omnibus effect ($\chi^2(2, N=11) = 5.35$, p = 0.069, partial $\eta^2 = 0.06$) and a significant effect of Group at T2 ($t(158.5) = 2.333$, $p = 0.021$, $b = 3.60$, CI = [0.56, 6.65]) but not T3 ($t(160.3) = 0.895$, $p = 0.372$, $b = 1.39$, CI = [-1.68, 4.46]).

H3: Mindfulness Training Improves Subjective but not Objective Sleep

Mindfulness training improved subjective sleep quality on the PSQI, as indicated by a significant Group*Time omnibus effect resulting from an ANOVA test ($\chi^2(2, N=11) = 6.75$, $p = 0.0342$, partial $\eta^2 = 0.07$; Figure 2a; see Grupe, Stoller, et al., 2021). Controlling for baseline PSQI scores, the mindfulness group had lower PSQI scores than waitlist control at T3 ($t(161.3) = 2.622$, $p = 0.010$, $b = 1.20$, CI = [0.30, 2.10) but not at T2 ($t(161.0) = 0.904$, $p = 0.367$, $b = 0.41$, CI = [-0.49, 1.31]).

Figure 2

Sleep Outcomes as a Function of Group



Note. (A) Controlling for baseline scores, participants in the mindfulness group (left) had significantly lower sleep disturbance scores on the Pittsburgh Sleep Quality Inventory (PSQI) relative to waitlist control participants (right). In contrast, groups did not differ on objective Fitbit sleep metrics, including minutes of sleep (B) and sleep efficiency (C). *Note*: Plotted summary variables represent group means and 95% confidence intervals.

Contrary to hypotheses, there was no omnibus Group*Time effect of mindfulness training on objective measures of sleep duration (χ^2(2, N=14) = 1.94, p = 0.3787, partial η^2 = 0.01; Figure 2b) or efficiency (χ^2(2, N=14) = 0.71, p = 0.7009, partial η^2 = 0.00; Figure 2c). Controlling for baseline sleep, there were no group differences at T2 (Duration: $t(168.1) = 0.233$, $p = 0.816$, $b = 2.17$, CI = [-16.1, 20.75];

Efficiency: $t(164.8) = -0.749$, $p = 0.455$, $b = -0.24$, CI = [-0.88, 0.4]) or T3 (Duration: $t(177.4) = -1.176$, $p = 0.241$, $b = -11.05$, CI = [-29.62, 7.49]; Efficiency: $t(175.7) = -0.690$, $p = 0.491$, $b = -0.23$, CI = [-0.88, 0.42]).

Mediation Analyses

H4: Decreased PTSD Symptoms Mediate Improvements in Sleep Quality

Using PCL change scores as a mediator of mindfulness-related improvements in subjective sleep quality, there was no significant mediation at T2 for the Total (TE), Direct (DE), or Indirect (IE) effects (TE: $b = -0.78$, $p = 0.093$; DE: $b = -0.53$, $p = 0.254$; IE: $b = -0.25$, $p = 0.215$; 32% TE accounted for by reduced PTSD symptoms). However, reduced PTSD symptoms from T1-T3 mediated improvements in subjective sleep over the same interval (TE: $b = -1.55$, $p = 0.007$; DE: $b = -1.11$, $p = 0.049$; IE: $b = -0.45$, $p = 0.047$; 29% TE accounted for by reduced PTSD symptoms; Figure S1). This mediation effect was reduced to a trend-level in a sensitivity analysis excluding two sleep-related items from the PCL (IE: $b = -0.40$, $p = 0.057$). We also tested an alternative mediation model in which improved subjective sleep mediated training-related improvements in PTSD symptoms. Once again, improved sleep quality did not mediate the mindfulness-related reduction in PTSD symptoms from T1-T2 (TE: $b = -5.69$, $p = 0.002$; DE: $b = -5.08$, $p = 0.006$; IE: $b = -0.61$, $p = 0.26$; 11% TE accounted for by improved sleep), but the mediation effect was significant for T1-T3 differences (TE: $b = -4.58$, $p = 0.040$; DE: $b = -2.24$, $p = 0.250$; IE: $b = -2.34$, $p = 0.016$; 51% TE accounted for by improved sleep; Figure S2). This alternative mediation model remained significant after removing sleep items from the PCL (IE: $b = -1.99$, $p = 0.016$).

We tested additional mediation models with Fitbit outcomes and found no mediation of reduced PTSD symptoms by changes in objective sleep measures (Supplemental Results).

Discussion

In a sample of 114 sworn law enforcement officers, we identified a robust relationship between self-reported PTSD symptoms and subjective sleep quality on the Pittsburgh Sleep Quality Index at baseline. In contrast, there were no relationships between baseline PTSD symptoms and objective sleep metrics from activity trackers worn during the following work week. An 8-week mindfulness intervention resulted in improvements in subjective but not objective sleep measures at a 3-month follow-up assessment, and this improvement was mediated by reductions in PTSD symptoms.

Baseline analyses in this sample of police officers were consistent with previous research demonstrating a robust link between compromised subjective sleep quality and symptoms of PTSD. In a study comparing police officers to non-first responders with comparable work schedules, officers had elevated total scores and reduced sleep duration on the PSQI, and sleep disturbances were associated with elevated PTSD symptoms (Neylan et al., 2002). Results are also consistent with a large-scale study in a sample of 591 non-first responders with a diagnosis of PTSD, which found complaints of insomnia in 80-90% of participants and frequent nightmares in 60-70% of those with PTSD (Leskin et al., 2002).

We extend prior research by showing that police officers randomized to an 8-week mindfulness training program vs. waitlist control reported statistically significant (albeit not clinically meaningful) improvements in both PTSD symptoms and subjective sleep quality. Whereas we previously reported these group differences in our primary outcomes paper (Grupe, Stoller, et al., 2021), we report here the novel finding that improvements in PTSD symptoms and sleep quality are correlated within participants over time. This suggests either that subjective sleep quality and PTSD symptoms are mechanistically linked or that some third variable targeted by mindfulness training has an influence on each of these outcomes. One potential variable is trait mindfulness, which we found in exploratory analyses to be associated with reduced PTSD symptoms but not improved sleep (see Supplemental Results). Meta-analyses have shown benefits of MBIs for both sleep quality (Rusch et al., 2019) and PTSD symptoms (Hopwood & Schutte, 2017), but few if any published studies have found these two beneficial outcomes of mindfulness training are mechanistically linked. It has been suggested that addressing sleep disturbances may be a valuable preparatory step for treating PTSD symptoms, as improving sleep can enhance cognitive and emotional skills that bolster the effects of behavioral interventions (Dietch et al., 2019), potentially via changes in the activation (Seo et al., 2021) and functional connectivity (Killgore, 2013) of brain circuitry implicated in emotion regulation and fear extinction learning/recall. An eclectic intervention such as mindfulness training provides participants with tools and strategies to promote better sleep through physiological regulation and relaxation (Guendelman et al., 2017) and respond to traumatic memories with non-judgmental awareness (rather than avoidance or suppression) while remaining grounded in the present moment (Colgan et al., 2016). Results suggest that for individuals affected both by sleep disturbances and PTSD symptoms, mindfulness may provide an efficient way to address these comorbid complaints simultaneously rather than in isolation or sequentially.

Results of mediation analyses were equivocal regarding the causality of improvements in subjective sleep quality and PTSD symptoms. At the three-month follow-up, we confirmed our pre-registered hypothesis that the impact of mindfulness training on improved sleep quality was mediated by reductions in PTSD symptoms. Additionally, PTSD symptoms improved immediately following the intervention whereas subjective sleep showed a significant group difference only at 3-month follow-up, providing additional evidence that reduced PTSD symptoms may facilitate longer-term sleep improvements. However, an alternative mediation model in which improved sleep mediated mindfulness-related reductions in PTSD symptoms was also significant (and, in contrast to our pre-registered model, this mediation effect remained significant when removing overlapping sleep items from the PCL). Our a priori hypothesis that PTSD symptoms would mediate sleep improvements was motivated by a historical view in which sleep symptoms are considered a secondary consequence of the underlying disorder of PTSD (Spoormaker & Montgomery, 2008). This historical view has been challenged by multiple lines of evidence that poor sleep can be a risk factor for the etiology or maintenance of PTSD. For example, insomnia symptoms one month following trauma exposure predict a diagnosis of PTSD a year later (Klein et al., 2003). Further, if disrupted sleep was merely a consequence of PTSD one would expect successful PTSD treatment to also address sleep complaints, yet 77% of active duty soldiers whose PTSD symptoms were successfully treated still had residual sleep problems (Pruiksma et al., 2016). Although our results provide some evidence that mindfulness-related improvements in sleep and PTSD symptoms are mechanistically related, additional research is needed to tease apart the temporal and causal nature of this relationship.

Baseline comparisons of subjective and objective sleep metrics demonstrated that Fitbit Charge 2 activity trackers provide objective sleep metrics that are correlated with corresponding subjective sleep metrics in naturalistic settings with police officers. We saw a weak but significant correlation between hours of sleep as recorded by Fitbits and as self-reported by participants on the PSQI. A more robust relationship was observed between Fitbit sleep efficiency and the sleep disturbances subscale on the PSQI (Fitbit efficiency reflects the proportion of time a participant is in bed and not awake or sleeping restlessly, which we expected would correlate with self-reported sleep difficulties). Even for this stronger relationship, baseline PSQI sleep disturbances were only correlated at $r = -0.39$ with Fitbit efficiency, consistent with earlier reports of modest relationships between subjective and objective sleep metrics (O'Donnell et al., 2009; Pavlova et al., 2008). These two means of assessing sleep provide convergent yet non-redundant information, supporting the use of both measures as intervention outcomes. This is particularly true given the relative paucity of intervention studies utilizing objective measures of sleep and discrepant findings for objective and subjective outcomes in studies of cognitive behavioral therapy for insomnia (CBT-I; Mitchell et al., 2019).

To that end, there was no evidence that objective sleep metrics were related to PTSD symptoms at baseline – consistent with a meta-analysis of actigraphy studies comparing PTSD patients and controls (Lewis et al., 2020) – or that objective sleep metrics changed following an 8-week mindfulness training program. These null findings can be interpreted in one of at least three ways. First, one could conclude that this is a "true null" finding, and that subjective but not objective features of sleep quality are associated with PTSD symptoms at baseline and in response to a mindfulness intervention. This interpretation is consistent with a meta-analysis of sleep changes associated with CBT-I, which found improved subjective sleep quality but minimal effects for objective sleep (Mitchell et al., 2019). Improved subjective sleep quality following mindfulness training may be an "artifact" of improved psychological symptoms or, similar to findings for CBT-I, a correction of underreporting of sleep relative to objective measures (Lund et al., 2013).

Second, this null finding may reflect measurement error, particularly if activity trackers are not sensitive enough to identify objective features of sleep associated with PTSD symptoms or responsive to a mindfulness intervention. Although Fitbit activity trackers show assessment of sleep/wake times comparable to polysomnography, these trackers are less accurate at identifying specific sleep stages (de Zambotti et al., 2019). Consumer wearables (such as Fitbits) and research-grade actigraphs have similarly high sensitivity but low specificity in detecting sleep, resulting in underestimates of wake after sleep onset and overestimates of sleep efficiency (de Zambotti et al., 2019). One study comparing the Fitbit Charge 2 to at-home PSG reported a 4% increase in sleep efficiency for Fitbits (Haghayegh et al., 2020), and the high levels of sleep efficiency reported here (around 0.95) may indicate a truncated range and lack of sensitivity to change. Because we did not utilize sleep diaries or event markers to indicate bedtime, we also could not estimate sleep onset latency, a component of sleep efficiency that is greater in some studies of PTSD (e.g., Wang et al., 2020) and the only objective sleep parameter to show improvements in a meta-analysis of the insomnia-specific intervention CBT-I (Mitchell et al., 2019).

Third, it is possible that objective features of sleep *are* correlated with PTSD symptoms and sensitive to a mindfulness intervention, and that these activity trackers *are* sensitive enough to capture these features, but that this study and others (e.g., Mitchell et al., 2019) did not focus on the "right" objective features. For example, within-participant variability in objective sleep features (as measured "in the wild" using wearable devices) is emerging as a key domain for psychological health. One study showed an association between psychological distress symptoms and greater variability in sleep duration over the course of 7 nights, whereas mean sleep duration, sleep onset latency, and time awake after sleep onset showed no such association (Lemola et al., 2013). Within-participant sleep variability using multiple actigraphy measures was greater in a sample of Vietnam veterans with PTSD relative to veterans without PTSD despite the near-absence of differences for mean measures. Similarly, variability in sleep fragmentation but not *mean* sleep fragmentation was positively correlated with PTSD symptoms in a sample of PTSD patients (Howell et al., 2022). At least one study of brief behavioral therapy for insomnia found reduced sleep variability assessed using actigraphy (Chan et al., 2017; but see Sánchez-Ortuño & Edinger, 2012 for a null finding in a CBT intervention study). Unfortunately, we have insufficient observations for most participants to generate a stable measure of sleep variability: 7 nights of sleep is recommended (Rowe et al., 2008), and participants in the current study only contributed 4-6 nights. An exploratory analysis that utilized sleep variability instead of sleep duration or efficiency failed to find associations with PTSD symptoms or benefits of mindfulness training (ps > 0.1), but given the small number of observations per participant we are hesitant to interpret this null finding.

Limitations and Future Directions

One limitation of this paper, as indicated above, is the small number of Fitbit observations per participant. Although this decision allowed us to avoid dramatic changes in sleep schedules as participants moved in and out of their work weeks, it may also have contributed to false negative findings for objective sleep measures. To limit participant burden while amplifying the informational value of data collected, future research might also consider including repeated measurements of low-impact outcomes beyond sleep data. For example, Dietch and colleagues (2019) had participants complete daily brief assessments of PTSD symptoms, sleep duration, and sleep quality over 7 days using ecological momentary assessment. Combined with objective sleep measurement, these measures could provide great insight into dynamic and mechanistic relationships between disrupted sleep and PTSD symptoms in response to MBIs or other interventions believed to address both problems.

As discussed above, the Fitbit Charge 2 used here likely overestimated sleep efficiency, possibly restricting our ability to measure intervention-related changes with high fidelity. Although this is a shared limitation with research-grade actigraphs (de Zambotti et al., 2019), Fitbits and similar consumer wearables have other limitations relative to actigraphy. In contrast with other studies, a Fitbit Charge 2 validation study conducted in shift workers (Stucky et al., 2021) *overestimated* wake after sleep onset, potentially due to the authors' decision to utilize the "sensitive" rather than the "normal" sleep tracking setting. This illustrates the uncertainty introduced by proprietary and non-transparent data processing algorithms, most of which have not been independently validated, and which keep researchers at a greater distance from the raw data. Compared to actigraphs, it is more challenging to blind participants to their own data with Fitbits or other consumer wearables. We removed sleep information and other tiles from the Fitbit app screen and asked participants not to modify this screen, but we cannot with certainty say participants complied with this instruction. Additional concerns have been raised about the absence of regulation of these devices and concerns about privacy, data security, and other ethical considerations (de Zambotti et al., 2020). Researchers should weigh these concerns against the benefits of consumer-grade devices – which are generally less expensive, less obtrusive, and easier to use than actigraphs – when considering what device to utilize.

Caution is warranted in extending findings from this relatively healthy and unselected sample of police officers to clinically diagnosed PTSD or insomnia. The mean baseline PCL-5 score of 17.5 was well below the screening cutoff for a PTSD diagnosis (31), and although 70% of participants exceeded the PSQI cutoff for "poor" sleep quality (5), this is not a diagnostic instrument. One potential consequence of these low symptom levels was correspondingly modest post-mindfulness reductions in PTSD and insomnia symptoms, which were statistically significant but not clinically meaningful. Future studies selecting participants based on elevated PTSD and/or insomnia symptoms will be helpful in extending findings in a more symptomatic group, which may reveal more robust effects of mindfulness training on both subjective and objective outcomes. Finally, although 41% of participants identified as female – which is notable in the male-dominated law enforcement profession – our sample was over 80% white and non-Hispanic, and consisted entirely of law enforcement officers from a single urban Wisconsin county. As such, future work is needed to generalize study results to non-white officers from other geographical regions or the larger population of trauma-exposed individuals.

References

Babson, K. A., & Feldner, M. T. (2010). Temporal relations between sleep problems and both traumatic event exposure and PTSD: A critical review of the empirical literature. *Journal of Anxiety Disorders*, *24*(1), 1–15. https://doi.org/10.1016/j.janxdis.2009.08.002

Blevins, C. A., Weathers, F. W., Davis, M. T., Witte, T. K., & Domino, J. L. (2015). The Posttraumatic Stress Disorder Checklist for DSM-5 (PCL-5): Development and Initial Psychometric Evaluation. *Journal of Traumatic Stress*, *28*(6), 489–498. https://doi.org/10.1002/jts.22059

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213. https://doi.org/10.1016/0165-1781(89)90047-4

Chan, S. H.-W., Lui, D., Chan, H., Sum, K., Cheung, A., Yip, H., & Yu, C. H. (2022). Effects of mindfulness-based intervention programs on sleep among people with common mental disorders: A systematic review and meta-analysis. *World Journal of Psychiatry*, *12*(4), 636–650. https://doi.org/10.5498/wjp.v12.i4.636

Chan, W. S., Williams, J., Dautovich, N. D., McNamara, J. P. H., Stripling, A., Dzierzewski, J. M., Berry, R. B., McCoy, K. J. M., & McCrae, C. S. (2017). Night-to-Night Sleep Variability in Older Adults With Chronic Insomnia: Mediators and Moderators in a Randomized Controlled Trial of Brief Behavioral Therapy (BBT-I). *Journal of Clinical Sleep Medicine*, *13*(11), 1243–1254. https://doi.org/10.5664/jcsm.6790

Chen, T.-L., Chang, S.-C., Hsieh, H.-F., Huang, C.-Y., Chuang, J.-H., & Wang, H.-H. (2020). Effects of mindfulness-based stress reduction on sleep quality and mental health for insomnia patients: A meta-analysis. *Journal of Psychosomatic Research*, *135*, 110144. https://doi.org/10.1016/j.jpsychores.2020.110144

Chopko, B. A., Palmieri, P. A., & Adams, R. E. (2021). Trauma-Related Sleep Problems and Associated

Health Outcomes in Police Officers: A Path Analysis. *Journal of Interpersonal Violence*, *36*(5–6), NP2725–NP2748. https://doi.org/10.1177/0886260518767912

Colgan, D. D., Christopher, M., Michael, P., & Wahbeh, H. (2016). The Body Scan and Mindful Breathing Among Veterans with PTSD: Type of Intervention Moderates the Relationship Between Changes in Mindfulness and Post-treatment Depression. *Mindfulness*, *7*(2), 372–383. https://doi.org/10.1007/s12671-015-0453-0

de Zambotti, M., Cellini, N., Goldstone, A., Colrain, I. M., & Baker, F. C. (2019). Wearable Sleep Technology in Clinical and Research Settings. *Medicine & Science in Sports & Exercise*, *51*(7), 1538–1557. https://doi.org/10.1249/MSS.0000000000001947

de Zambotti, M., Cellini, N., Menghini, L., Sarlo, M., & Baker, F. C. (2020). Sensors Capabilities, Performance, and Use of Consumer Sleep Technology. *Sleep Medicine Clinics*, *15*(1), 1–30. https://doi.org/10.1016/j.jsmc.2019.11.003

Dietch, J. R., Ruggero, C. J., Schuler, K., Taylor, D. J., Luft, B. J., & Kotov, R. (2019). Posttraumatic stress disorde symptoms and sleep in the daily lives of world trade center responders. *Journal of Occupational Health Psychology*, *24*(6), 689–702. https://doi.org/10.1037/ocp0000158

Gross, C. R., Kreitzer, M. J., Reilly-Spong, M., Wall, M., Winbush, N. Y., Patterson, R., Mahowald, M., & Cramer-Bornemann, M. (2011). Mindfulness-Based Stress Reduction Versus Pharmacotherapy for Chronic Primary Insomnia: A Randomized Controlled Clinical Trial. *EXPLORE*, *7*(2), 76–87. https://doi.org/10.1016/j.explore.2010.12.003

Grupe, D. W., Imhoff-Smith, T., Westby, S. C., & Davidson, R. (2019, October 23). The Impact of Mindfulness-Based Resilience Training on Stress-Related Biological, Behavioral, and Health-Related Outcomes in Law Enforcement Officers. https://doi.org/10.17605/OSF.IO/MQNGA

Grupe, D. W., McGehee, C., Smith, C., Francis, A. D., Mumford, J. A., & Davidson, R. J. (2021). Mindfulness Training Reduces PTSD Symptoms and Improves Stress-Related Health Outcomes in

Police Officers. *Journal of Police and Criminal Psychology*, *36*(1), 72–85. https://doi.org/10.1007/s11896-019-09351-4

Grupe, D. W., Stoller, J. L., Alonso, C., McGehee, C., Smith, C., Mumford, J. A., Rosenkranz, M. A., & Davidson, R. J. (2021). The Impact of Mindfulness Training on Police Officer Stress, Mental Health, and Salivary Cortisol Levels. *Frontiers in Psychology*, *12*(September). https://doi.org/10.3389/fpsyg.2021.720753

Guendelman, S., Medeiros, S., & Rampes, H. (2017). Mindfulness and Emotion Regulation: Insights from Neurobiological, Psychological, and Clinical Studies. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00220

Haghayegh, S., Khoshnevis, S., Smolensky, M. H., Diller, K. R., & Castriotta, R. J. (2020). Performance assessment of new-generation Fitbit technology in deriving sleep parameters and stages. *Chronobiology International*, *37*(1), 47–59. https://doi.org/10.1080/07420528.2019.1682006

Hopwood, T. L., & Schutte, N. S. (2017). A meta-analytic investigation of the impact of mindfulness-based interventions on post traumatic stress. *Clinical Psychology Review*, *57*(April), 12–20. https://doi.org/10.1016/j.cpr.2017.08.002

Howell, K., Casteen, E., Rahimi-Eichi, H., Akman, E., Baker, J., Ravichandran, C., Rauch, S., & Rosso, I. (2022). Objective Index of Sleep Fragmentation Correlates With Smaller Hippocampi in Posttraumatic Stress Disorder. *Biological Psychiatry*, *91*(9), S345–S346. https://doi.org/10.1016/j.biopsych.2022.02.870

Kabat-Zinn, J. (1990). *Full catastrophe living: Using the wisdom of your body and mind to face stress, pain and illness*. Delacorte.

Kearney, D. J., Simpson, T. L., Malte, C. A., Felleman, B., Martinez, M. E., & Hunt, S. C. (2015). Mindfulness-based Stress Reduction in Addition to Usual Care Is Associated with Improvements in

Pain , Fatigue , and Cognitive Failures Among Veterans with Gulf War Illness. *The American Journal of Medicine*, *129*(2), 204–214. https://doi.org/10.1016/j.amjmed.2015.09.015

Kelly, A., & Garland, E. L. (2016). Trauma-Informed Mindfulness-Based Stress Reduction for Female Survivors of Interpersonal Violence: Results From a Stage I RCT. *Journal of Clinical Psychology*, *72*(4), 311–328. https://doi.org/10.1002/jclp.22273

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication. *Archives of General Psychiatry*, *62*(6), 593–602. https://doi.org/10.1001/archpsyc.62.6.593

Killgore, W. D. S. (2013). Self-Reported Sleep Correlates with Prefrontal-Amygdala Functional Connectivity and Emotional Functioning. *Sleep*, *36*(11), 1597–1608. https://doi.org/10.5665/sleep.3106

Lemola, S., Ledermann, T., & Friedman, E. M. (2013). Variability of Sleep Duration Is Related to Subjective Sleep Quality and Subjective Well-Being: An Actigraphy Study. *PLoS ONE*, *8*(8). https://doi.org/10.1371/journal.pone.0071292

Leskin, G. A., Woodward, S. H., Young, H. E., & Sheikh, J. I. (2002). Effects of comorbid diagnoses on sleep disturbance in PTSD. *Journal of Psychiatric Research*, *36*(6), 449–452. https://doi.org/10.1016/S0022-3956(02)00025-0

Lewis, C., Lewis, K., Kitchiner, N., Isaac, S., Jones, I., & Bisson, J. I. (2020). Sleep disturbance in post-traumatic stress disorder (PTSD): a systematic review and meta-analysis of actigraphy studies. *European Journal of Psychotraumatology*, *11*(1), 1767349. https://doi.org/10.1080/20008198.2020.1767349

Lund, H. G., Rybarczyk, B. D., Perrin, P. B., Leszczyszyn, D., & Stepanski, E. (2013). The Discrepancy between Subjective and Objective Measures of Sleep in Older Adults Receiving CBT for Comorbid

Insomnia. *Journal of Clinical Psychology*, *69*(10), 1108–1120. https://doi.org/10.1002/jclp.21938

Mitchell, L. J., Bisdounis, L., Ballesio, A., Omlin, X., & Kyle, S. D. (2019). The impact of cognitive behavioural therapy for insomnia on objective sleep parameters: A meta-analysis and systematic review. *Sleep Medicine Reviews*, *47*, 90–102. https://doi.org/10.1016/j.smrv.2019.06.002

Neylan, T. C., Metzler, T. J., Best, S. R., Weiss, D. S., Fagan, J. A., Liberman, A. M., Roger, C., Vedantham, K., Brunet, A., Lipsey, T. L., Marmar, C. R., Rogers, C., Vedantham, K., Brunet, A., Lipsey, T. L., Marmar, C. R., Roger, C., Vedantham, K., Brunet, A., … Marmar, C. R. (2002). Critical incident exposure and sleep quality in police officers. *Psychosomatic Medicine*, *64*(2), 345–352. https://doi.org/10.1097/00006842-200203000-00019

O'Donnell, D., Silva, E. J., Münch, M., Ronda, J. M., Wang, W., & Duffy, J. F. (2009). Comparison of subjective and objective assessments of sleep in healthy older subjects without sleep complaints. *Journal of Sleep Research*, *18*(2), 254–263. https://doi.org/10.1111/j.1365-2869.2008.00719.x

Pavlova, M. K., Duffy, J. F., & Shea, S. A. (2008). Polysomnographic Respiratory Abnormalities in Asymptomatic Individuals. *Sleep*, *31*(2), 241–248. https://doi.org/10.1093/sleep/31.2.241

Perini, F., Wong, K. F., Lin, J., Hassirim, Z., Ong, J. L., Lo, J., Ong, J. C., Doshi, K., & Lim, J. (2021). Mindfulness-based therapy for insomnia for older adults with sleep difficulties: a randomized clinical trial. *Psychological Medicine*, 1–11. https://doi.org/10.1017/S0033291721002476

Pruiksma, K. E., Taylor, D. J., Wachen, J. S., Mintz, J., Young-McCaughan, S., Peterson, A. L., Yarvis, J. S., Borah, E. v., Dondanville, K. A., Litz, B. T., Hembree, E. A., & Resick, P. A. (2016). Residual sleep disturbances following PTSD treatment in active duty military personnel. *Psychological Trauma: Theory, Research, Practice, and Policy*, *8*(6), 697–701. https://doi.org/10.1037/tra0000150

R Core Team. (2020). *R: A Language and Environment for Statistical Computing*. https://www.r-project.org/

Rajaratnam, S. M. W., Barger, L. K., Lockley, S. W., Shea, S. a, Wang, W., Landrigan, C. P., O'Brien, C. S., Qadri, S., Sullivan, J. P., Cade, B. E., Epstein, L. J., White, D. P., Czeisler, C. a, & Harvard Work Hours, Health and Safety Group, for the. (2011). Sleep Disorders, Health, and Safety in Police Officers. *JAMA*, *306*(23), 2567. https://doi.org/10.1001/jama.2011.1851

Rowe, M., McCrae, C., Campbell, J., Horne, C., Tiegs, T., Lehman, B., & Cheng, J. (2008). Actigraphy in older adults: comparison of means and variability of three different aggregates of measurement. *Behavioral Sleep Medicine*, *6*(2), 127–145. https://doi.org/10.1080/15402000801952872

Rusch, H. L., Rosario, M., Levison, L. M., Olivera, A., Livingston, W. S., Wu, T., & Gill, J. M. (2019). The effect of mindfulness meditation on sleep quality: a systematic review and meta-analysis of randomized controlled trials. *Annals of the New York Academy of Sciences*, *1445*(1), 5–16. https://doi.org/10.1111/nyas.13996

Sánchez-Ortuño, M. M., & Edinger, J. D. (2012). Internight sleep variability: its clinical significance and responsiveness to treatment in primary and comorbid insomnia. *Journal of Sleep Research*, *21*(5), 527–534. https://doi.org/10.1111/j.1365-2869.2012.01010.x

Seo, J., Pace-Schott, E. F., Milad, M. R., Song, H., & Germain, A. (2021). Partial and Total Sleep Deprivation Interferes With Neural Correlates of Consolidation of Fear Extinction Memory. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *6*(3), 299–309. https://doi.org/10.1016/j.bpsc.2020.09.013

Shaif, N. A. S., Doshi, K., & Lim, J. (2022). Effects of mindfulness-based therapy for insomnia and a sleep hygiene/exercise programme on subjective-objective sleep discrepancy in older adults with sleep disturbances: Exploratory secondary analysis of a randomised clinical trial. *Journal of Sleep Research*, *31*(6). https://doi.org/10.1111/jsr.13700

Spoormaker, V. I., & Montgomery, P. (2008). Disturbed sleep in post-traumatic stress disorder: Secondary symptom or core feature? *Sleep Medicine Reviews*, *12*(3), 169–184.

https://doi.org/10.1016/j.smrv.2007.08.008

Stein, M. B., Walker, J. R., Hazen, A. L., & Forde, D. R. (1997). Full and partial posttraumatic stress disorder: Findings from a community survey. *American Journal of Psychiatry*, *154*(8), 1114–1119. http://www.ncbi.nlm.nih.gov/pubmed/9247398

Stucky, B., Clark, I., Azza, Y., Karlen, W., Achermann, P., Kleim, B., & Landolt, H. P. (2021). Validation of fitbit charge 2 sleep and heart rate estimates against polysomnographic measures in shift workers: naturalistic study. *Journal of Medical Internet Research*, *23*(10), 1–20. https://doi.org/10.2196/26476

Syed, S., Ashwick, R., Schlosser, M., Jones, R., Rowe, S., & Billings, J. (2020). Global prevalence and risk factors for mental health problems in police personnel: a systematic review and meta-analysis. *Occupational and Environmental Medicine*, *77*(11), 737–747. https://doi.org/10.1136/oemed-2020-106498

Tuckey, M. R., Winwood, P. C., & Dollard, M. F. (2012). Psychosocial culture and pathways to psychological injury within policing. *Police Practice and Research*, *13*(3), 224–240. https://doi.org/10.1080/15614263.2011.574072

Wang, Y. Y., Wang, F., Zheng, W., Zhang, L., Ng, C. H., Ungvari, G. S., & Xiang, Y. T. (2020). Mindfulness-Based Interventions for Insomnia: A Meta-Analysis of Randomized Controlled Trials. *Behavioral Sleep Medicine*, *18*(1), 1–9. https://doi.org/10.1080/15402002.2018.1518228

Yeh, M. S. L., Poyares, D., Coimbra, B. M., Mello, A. F., Tufik, S., & Mello, M. F. (2021). Subjective and objective sleep quality in young women with posttraumatic stress disorder following sexual assault: a prospective study. *European Journal of Psychotraumatology*, *12*(1). https://doi.org/10.1080/20008198.2021.1934788

Supplemental Materials: The Impact of Mindfulness Training on PTSD Symptoms, Subjective Sleep Quality, and Objective Sleep Outcomes in Police Officers

Theodore P. Imhoff-Smith[1,2] and Daniel W. Grupe[2]

[1]Neuroscience Training Program, University of Wisconsin-Madison

[2]Center for Healthy Minds, University of Wisconsin-Madison

Contents

Supplemental Methods

<u>Description of data collected from the same sample</u>

We previously published a paper from the same dataset (MS1) examining relationships between perceived stress, trait mindfulness, and daily reports of stress exposure; none of these variables are included in the current report. We published a second paper (MS2) from this dataset investigating the impact of mindfulness training on an array of physical and mental health outcomes, including the same sleep quality (PSQI) and PTSD symptom measures (PCL-5) included in the present paper (MS3). As detailed in the enclosed article, the outcomes and research questions included in MS3 (which were pre-registered prior to conducting analyses for MS2) differ from MS2 in 1) the inclusion of objective sleep measures, which have not previously been reported and 2) the examination of relationships *between* sleep measures and PTSD symptoms, both at baseline and in response to mindfulness training.

Intervention Summary

Overview of 8-week mindfulness curriculum adapted from our previous work (Grupe, McGehee, et al., 2021) and inspired by the Mindfulness-Based Resilience Training curriculum created by Mike Christopher, Rich Goerling, and Brant Rogers at Pacific University (Christopher et al., 2016, 2018). We are deeply grateful to them for sharing their wisdom and experience with us.

Week 1: Introduction to Resilience and Mindfulness.

Content: Introduction of course. Definitions of mindfulness, neuroplasticity and how we can foster resilience. Creation of community agreements and discussion of culture. Movement and body scan practices. Practice debriefing.

Homework: Explanation of practice log. Formal practice: 9 minutes movement or 9 minutes body scan 6 out of 7 days. Informal practice: "Dropping in" and 3 good breaths.

Week 2: Settling into Resilience and Mindfulness.

Content: Normalizing mind wandering and addressing other (mis)conceptions about doing the practices "correctly." Movement, body scan and debrief. Introduce walking practice.

Homework: Formal practice: Alternate 9 minutes movement and 9 minutes body scan 6 out of 7 days. 5 minutes of walking practice 3 times. Informal practice: "Dropping in" and 3 good breaths.

Week 3: Meeting our experiences through Resilience and Mindfulness.

Content: Movement, exploration of physical posture in sitting meditation, introduction to breath awareness practice, and debrief. Reading and video to reconnect to participants' inspiration and motivation.

Homework: Formal practice: Alternate 9 minutes movement and 5 minutes breath awareness practice 6 out of 7 days. Informal practice: Pleasant Events Calendar, integrated walking practice and 3 good breaths.

Week 4: Meeting Stress with Resilience and Mindfulness.

Content: Review and discuss Pleasant Events Calendar. Movement practice, breath awareness practice, and debrief. Introduction of mindful eating.

Homework: Formal practice: Alternate 15 minutes movement and 15 minutes breath awareness practice. Informal practice: Integrated walking practice, Unpleasant Events Calendar and 3 good breaths.

Week 5: Reactivity, Resilience and Mindfulness.

Content: Review and discuss Unpleasant Events Calendar. Movement practice, breath awareness practice, and debrief. Reflection of practice and course at halfway point and resetting of intentions. Introduction to compassion practice.

Homework: Alternate movement/breath awareness practice with compassion practice 6 days out of 7. Informal practice: Walking practice (1x per week) and 3 good breaths.

Week 6: Compassion, Resilience and Mindfulness.

Content: Movement, awareness of breath practice, compassion practices, and debriefing. Discussion and preparation for the day of extended practice.

Homework: Alternate between 15 minutes breath awareness and compassion practice. Informal practice: Walking practice (1x per week), and 3 good breaths.

Week 7: Extended Practice Session (4 hours).

Content: This session includes all previous practices along with mountain meditation and a period of silent practice.

Homework: Practice log. Participant decides their practice.

Week 8: Resilience and Mindfulness: Beginning Again.

Content: Movement practice, breath awareness practice, and debriefing. Debriefing about the course. Review of resources and supports for participants. Plan for implementation and integration of mindfulness after the class.

Homework: Practice Log. Participant decides their practice.

References

Christopher, M. S., Goerling, R. J., Rogers, B. S., Hunsinger, M., Baron, G., Bergman, A. L., & Zava, D. T. (2016). A Pilot Study Evaluating the Effectiveness of a Mindfulness-Based Intervention on Cortisol Awakening Response and Health Outcomes among Law Enforcement Officers. *Journal of Police and Criminal Psychology*, *31*(1), 15–28. https://doi.org/10.1007/s11896-015-9161-x

Christopher, M. S., Hunsinger, M., Goerling, R. J., Bowen, S., Rogers, B. S., Gross, C. R., … Pruessner, J. C. (2018). Mindfulness-based resilience training to reduce health risk, stress reactivity, and aggression among law enforcement officers: A feasibility and preliminary efficacy trial. *Psychiatry Research*, *264*, 104–115. https://doi.org/10.1016/j.psychres.2018.03.059

Grupe, D. W., McGehee, C., Smith, C., Francis, A. D., Mumford, J. A., & Davidson, R. J. (2021). Mindfulness Training Reduces PTSD Symptoms and Improves Stress-Related Health Outcomes in Police Officers. *Journal of Police and Criminal Psychology*, *36*(1), 72–85. https://doi.org/10.1007/s11896-019-09351-4

Supplemental Results

Mediation analyses with objective sleep measures

Although mindfulness training was not associated with changes in objective sleep outcomes measured using activity trackers, for thoroughness, we also tested mediation models in which changes in objective sleep indicators mediated training-related improvements in PTSD symptoms. Changes in sleep duration did not mediate mindfulness-related reductions in PTSD symptoms from T1-T2 (Total Effect: $b = -6.34$, $p = 0.001$; Direct Effect: $b = -6.36$, $p < 0.001$; Indirect Effect: $b = 0.02$, $p = 0.870$; 0.4% Total Effect accounted for by the indirect effect of change in sleep) or from T1-T3 (Total Effect: $b = -4.57$, $p = 0.049$; Direct Effect: $b = -5.09$, $p = 0.024$; Indirect Effect: $b = 0.52$, $p = 0.354$; 11% Total Effect accounted for by the indirect effect of change in sleep). Similarly, changes in sleep efficiency did not mediate mindfulness-related reductions in PTSD symptoms from T1-T2 (Total Effect: $b = -6.34$, $p < 0.001$; Direct Effect: $b = -6.35$, $p < 0.001$; Indirect Effect: $b = 0.01$, $p = 0.93$; 0.2% Total Effect accounted for by the indirect effect of change in sleep) or from T1-T3 (Total Effect: $b = -4.57$, $p = 0.049$; Direct Effect: $b = -4.72$, $p = 0.036$; Indirect Effect: $b = 0.15$, $p = 0.569$; 3.3% Total Effect accounted for by the indirect effect of change in sleep).

Correlations between trait mindfulness and outcome measures

As noted in the main text, it is possible that some third variable targeted by mindfulness training has an influence on subjective sleep quality and PTSD symptoms. In exploratory analyses, we tested the zero-order correlations within the mindfulness group between changes in trait mindfulness (measured using the Five Facet Mindfulness Questionnaire; FFMQ) and changes in PCL and PSQI scores. These analyses revealed significant associations between increased FFMQ scores and reduced PCL symptoms from T1 to T2 ($r(41) = -0.39$, $p = 0.010$) and from T1 to T3 ($r(41) = -0.63$, $p < 0.001$). In contrast, non-significant associations were observed between changes in FFMQ and PSQI scores from T1 to T2 ($r(41) = -0.09$, $p = 0.566$) and from T1 to T3 ($r(41) = -0.27$, $p = 0.079$).

Figure S1. PTSD Symptoms as Mediator of Reduced PSQI Scores

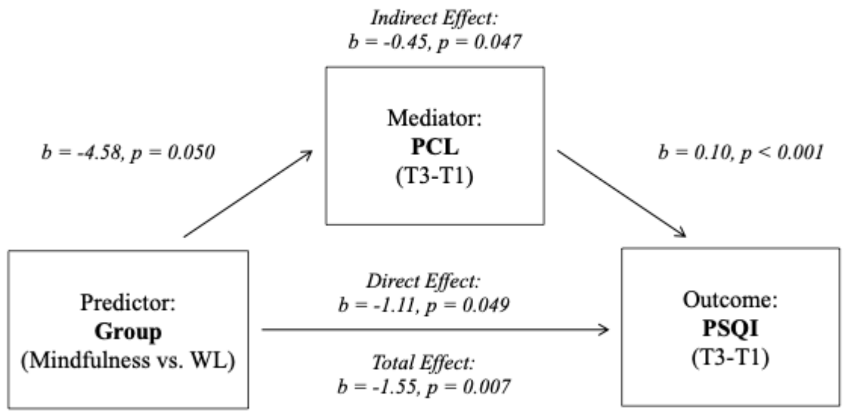


Figure S2. PSQI Scores as Mediator of Reduced PTSD Symptoms