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Posttraumatic Stress Disorder Symptoms and Sleep in the Daily Lives of World Trade Center Responders

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Abstract

Sleep disturbances are common in Posttraumatic Stress Disorder (PTSD) and can have major impacts on workplace performance and functioning. Although effects between PTSD and sleep broadly have been documented, little work has tested their day-to-day, temporal relationship particularly in those exposed to occupational trauma. The present study examined daily, bidirectional associations between PTSD symptoms and self-reported sleep duration and quality in World Trade Center (WTC) responders oversampled for PTSD.

A sample of WTC responders (N = 202; 19.3% with current PTSD diagnosis) were recruited from the Long Island site of the WTC health program. Participants were administered the Structured Clinical Interview for DSM-IV Disorders and completed daily assessments of PTSD symptoms and sleep duration and quality for seven days.

PTSD symptoms on a given day were prospectively associated with shorter sleep duration ($\beta = -.13$) and worse sleep quality ($\beta = -.18$) later that night. Reverse effects were also significant but smaller, with reduced sleep duration (not quality) predicting increased PTSD the next day ($\beta = -.04$). Effects of PTSD on sleep duration and quality were driven by numbing symptoms whereas effects of sleep duration on PTSD were largely on intrusion symptoms.

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Results related to sleep and PTSD were presented at the annual convention of the Association for Psychological Science. Results related to baseline PTSD (not sleep data) were presented in a prior publication (Dornbach-Bender et al., 2019) and at a prior annual meeting of the International Society for Traumatic Stress Studies.

PTSD symptoms and sleep have bi-directional associations that occur on a daily basis, representing potential targets to disrupt maintenance of each. Improving PTSD numbing symptoms may improve sleep, and increasing sleep duration may improve intrusion symptoms in individuals with exposure to work-related traumatic events. Specific targeting of symptoms may maximize benefits to improve work performance and functioning.

Keywords

Longitudinal studies; ecological momentary assessment; sleep; post-traumatic stress; World Trade Center; disaster responders

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Certain classes of occupations, such as first responders, are exposed to traumatic events on a frequent basis due to the nature of their work (McFarlane, Williamson, & Barton, 2009). Psychological and physical sequelae of occupational trauma exposure are numerous and appear to persist for many years (Huizink et al., 2006). In particular, first responders are at an elevated risk of developing posttraumatic stress disorder (PTSD; Skogstad et al., 2013). Among first responders, the prevalence of PTSD ranges from 5–40% (Galea, Nandi, & Vlahov, 2005), which is substantially higher than the general population (5–10%; Wise & Beck, 2015). PTSD is associated with significant functional impairment in occupational domains (Rodriguez, Holowka, & Marx, 2012), and exposure to occupational trauma specifically has wide-ranging physical and psychological effects (Graham, 2012).

Occupational trauma and subsequent PTSD have been linked with numerous consequences in the workplace including absenteeism, presenteeism, decrease in work productivity (el-Guebaly et al., 2007; Honkonen et al., 2007; Kessler & Frank, 1997; Osinubi et al., 2008), difficulty managing time demands, output demands, and mental-interpersonal demands at work (Wald, 2009). A study reporting on the WHO World Mental Health Surveys of over 60,000 people across 24 countries demonstrated those with PTSD reported an average of 43 days of work missed compared to the overall average of 15 days missed (Alonso et al., 2011). PTSD among first responders in particular has been linked with specific performance deficits in job-related domains like verbal memory, focused attention, complex cognitive tasks, and commission errors (Brewin, Kleiner, Vasterling, & Field, 2007; Horner, Mintzer, Turner, Edmiston, & Brawman-Mintzer, 2013; LeBlanc et al., 2011; LeBlanc et al., 2012; Regehr, LeBlanc, Shlonsky, & Bogo, 2010). Trauma exposure and consequent PTSD are clearly linked with poor occupational outcomes across many domains and thus ameliorating PTSD should be a top priority for employers in occupations at high risk of trauma exposure. However, PTSD occurring as a result of traumatic events in occupational settings is understudied (McFarlane & Bryant, 2007).

Occupational Trauma of World Trade Center Responders

Responders to the 9/11 attacks on the World Trade Center (WTC) were exposed to significant physical and emotional trauma during the rescue, recovery, and clean-up efforts (Landrigan et al., 2004; Neria, Digrande, & Adams, 2011). Up to 20% reported symptoms consistent with PTSD at some point since 9/11 (Berninger et al., 2010; Chiu et al., 2011; Cukor et al., 2011; Evans, Giosan, Patt, Spielman, & Difede, 2006; Evans, Patt, Giosan, Spielman, & Difede, 2009; Jayasinghe, Giosan, Evans, Spielman, & Difede, 2008; Luft et al., 2012; Perrin et al., 2007; Stellman et al., 2008) with a significant portion of responders (up to 9.7%) still reporting clinical levels of PTSD symptoms over a decade after the attacks (Bromet et al., 2016). In addition to PTSD symptoms, WTC and other disaster responders commonly report various sleep disturbances (Benedek, Fullerton, & Ursano, 2007; de la Hoz et al., 2012; Giosan et al., 2015; Sunderram et al., 2011; Thormar et al., 2014). Studies have consistently found sleep disturbances are associated with PTSD symptom severity and also impact daytime occupational functioning, concentration, and memory in similarly exposed populations (Giosan et al., 2015; Sunderram et al., 2011). A cross-sectional study found increased subjective sleep disturbances were linked with greater PTSD symptom severity, suggesting disturbed sleep may exacerbate PTSD symptoms or vice versa (Germain, Buysse, Shear, Fayyad, & Austin, 2004). Existing evidence about the directionality of the temporal relationship between sleep disturbances and PTSD symptoms is still unclear (Babson & Feldner, 2010; Germain, 2013; Spoormaker & Montgomery, 2008). Examining the experience of WTC responders almost two decades after 9/11 gives us the unique opportunity to examine the long-lasting impacts of occupational trauma on PTSD and sleep.

PTSD and Sleep Disturbances

Few studies have examined the link between occupational trauma and subsequent sleep disturbances, particularly among first responders (Jones, 2017). Previous studies of first responders have estimated the prevalence of sleep disturbances (e.g., sleep deprivation, “poor sleep”) to be between 51–70%, which is much higher than the general population (Carey, Al-Zaiti, Dean, Sessanna, & Finnell, 2011; Courtney, Francis, & Paxton, 2013; Vargas de Barros, Martins, Saitz, Bastos, & Ronzani, 2013). One study compared sleep in 747 police officers and 338 non-first responder controls and found police officers demonstrated significantly worse subjective sleep quality and significantly shorter subjective sleep duration (Neylan et al., 2002). Among police officers, exposure to critical incidents was associated with worse subjective sleep quality and nightmares (Neylan et al., 2002). Evidence suggests even minor occupational traumas such as workplace verbal aggression, harassment, bullying, injustice, violence, unwanted sexual attention, and accidents are related with subsequent sleep disturbances (Hansen et al., 2016; Khubchandani & Price, 2015; Min, Park, Kim, & Min, 2014; Niedhammer et al., 2009). Due to the scarcity of literature, it is difficult to make firm conclusions about the link between occupational trauma and sleep disturbances. However, if occupational trauma follows a similar course to non-occupational trauma, it is likely that sleep disturbance is a core feature of the post-traumatic period.

Disturbed sleep may be one explanation for the relationship between PTSD and poor work outcomes, as substantial research has demonstrated a relationship between sleep disturbances and negative workplace outcomes across numerous domains. Sleep difficulties like insomnia are related to higher rates of sick leave and absenteeism (Alonso et al., 2011; Bolge, Doan, Kannan, & Baran, 2009; Daley, Morin, LeBlanc, Grégoire, & Savard, 2009; Jacquinet-Salord, Lang, Fouriaud, Nicoulet, & Bingham, 1993; Kuppermann et al., 1995; Linton & Bryngelsson, 2000; Swanson et al., 2011), leaving work early (Swanson et al., 2011), and clinical burnout (Söderström, Jeding, Ekstedt, Perski, & Åkerstedt, 2012). Sleep difficulties have also been linked with presenteeism, specifically across domains such as reduced productivity and efficiency (Bolge et al., 2009; Daley et al., 2009; Erman, Guiraud, Joish, & Lerner, 2008; Stoller, 1994; Swanson et al., 2011; Walsh et al., 2007), poor performance in motor and cognitive domains (e.g., difficulty with concentration and organization; Erman et al., 2008; Kuppermann et al., 1995; Linton & Bryngelsson, 2000; Pilcher & Huffcutt, 1996; Swanson et al., 2011) and falling asleep at work (Swanson et al., 2011). Finally, insomnia has been linked with increased risk for occupational injuries or accidents (Brossoit et al., 2018; Kao, Spitzmueller, Cigularov, & Wu, 2016; Swanson et al., 2011), which may put individuals at risk for experiencing additional traumatic events. Sleep represents a unique intervention point to improve worker productivity and wellbeing and thus benefit both employers and employees (Magnavita & Garbarino, 2017). However, more research is needed to understand the relationship of sleep and PTSD in the context of occupational trauma.

Sleep Disturbances and PTSD

Mounting evidence suggests sleep disturbances may be a risk factor for PTSD, not merely a secondary symptom of the disorder (Koffel, Khawaja, & Germain, 2016; Taylor et al., 2016). First, disturbed sleep prior to a traumatic event may put people at greater risk for development of PTSD (Bryant, Creamer, O'Donnell, Silove, & McFarlane, 2010). For example, one longitudinal study of over 300 U.S. construction workers that found baseline insomnia symptoms were associated with workplace cognitive failures at 6 months and worse safety participation and minor workplace injuries at 12 months (Brossoit et al., 2018). Extended further, this may suggest that individuals with pre-existing sleep disturbances may be more likely to experience occupational accidents related with post-traumatic stress, although studies exploring this relationship are limited. Second, sleep following a trauma may meaningfully alter the course of PTSD, demonstrated by Kleim, Wysokowsky, Schmid, Seifritz, and Rasch (2016) who exposed 65 women to a laboratory trauma and found those randomly assigned to sleep directly afterwards reported significantly fewer intrusive memories than those assigned to stay awake. Similarly, a longitudinal study of 102 victims of motor vehicle accidents found insomnia symptoms at 1 month following the trauma predicted development of PTSD diagnosis at 12-month follow-up (Klein, Koren, Arnon, & Lavie, 2003). Finally, sleep disturbances may not merely reflect secondary symptoms of PTSD, but instead be independent comorbid disorders with a life of their own. This is suggested by a study of 108 active duty Army soldiers, a group frequently exposed to workplace traumatic events, which found after successful treatment for PTSD, insomnia complaints remained in 77% of the sample (Pruiksma et al., 2016).

The short-term dynamics between sleep and symptoms of PTSD are not well-understood. Studies using ecological momentary assessment (EMA) or daily diary methods are necessary to capture the daily fluctuations in PTSD symptoms and sleep duration and quality (Black et al., 2016). Research that looks at the two independently indicates significant short-term within-person variability for both PTSD and sleep (Black et al., 2016; Buysse, Cheng, et al., 2010; Gaher et al., 2014; McFarlane, 2000; Possemato et al., 2012). Most previous research has failed to examine such dynamics on a daily basis, which may be important for understanding how symptoms of sleep disturbance and/or PTSD are maintained because the dynamics between PTSD and sleep may play out in the very short term (e.g., day-to-day). Recently, Short, Allan, and Schmidt (2017) examined daily relationships between overall PTSD symptom severity and sleep disturbances (i.e., nightmares, sleep quality, duration, efficiency) in a community sample with PTSD ($N = 30$; 61% female) and found PTSD symptom severity predicted next-day nightmares but no other sleep domains. This study also found sleep quality and efficiency (not duration) predicted next day PTSD symptom severity and negative affect. However, the results of this study are only moderately comparable to the current sample of WTC responders with varying levels of PTSD symptoms, as participants all had a PTSD diagnosis, were primarily female, and the majority endorsed sexual assault as their Criterion A traumatic event. Thus, additional research is necessary to understand the short-term links between PTSD and sleep disturbances in a group whose symptoms are related to a traumatic workplace event that occurred many years prior. Given these previous findings, in the current study we hypothesized greater overall PTSD symptom severity during the day would predict shorter sleep duration and worse sleep quality that night (Hypothesis 1a). We also expected to find a reciprocal relationship, and therefore hypothesized shorter sleep duration and worse sleep quality the previous night would predict greater overall PTSD symptoms the next day (Hypothesis 1b).

Dimensions of PTSD and Sleep

Beyond looking at overall dynamics, PTSD is a heterogeneous syndrome (Zoellner, Pruitt, Farach, & Jun, 2014) and therefore sleep may have more relevance for some dimensions of the syndrome than others. Previous research has provided strong evidence for at least four dimensions underlying PTSD (Elhai & Palmieri, 2011; Yufik & Simms, 2010), yet most previous research on sleep disturbances and PTSD has examined PTSD as a whole (Mellman, Pigeon, Nowell, & Nolan, 2007). To our knowledge, only one cross-sectional study (Babson et al., 2011) has examined the associations between sleep disturbances and each PTSD symptom dimension separately. The four dimensions commonly described in PTSD, namely hyperarousal, numbing, avoidance, and intrusion, may be differentially related to sleep disturbances and act through varying mechanisms.

The links between hyperarousal symptoms and sleep disturbances have received the most attention in this area, but the directionality of the relationship is still unclear. Research suggests individuals with PTSD demonstrate greater cognitive and physiological arousal during sleep and alterations in sleep architecture compared to individuals without PTSD (Kobayashi, Boarts, & Delahanty, 2007; Woodward, Murburg, & Bliwise, 2000). One proposed mechanism for this relationship is that chronic hyperarousal may spur the development of insomnia due to the inappropriate and chronic simultaneous activation of the sleep and arousal systems (Bonnett & Arand, 2010). Simultaneously, sleep disturbances at night may result in next-day hyperarousal, evidenced by previous research that demonstrated short sleep duration and poor sleep quality are associated with daytime increases in sympathetic nervous system activation (Castro-Diehl et al., 2016; Stamatakis & Punjabi, 2010). Thus, we hypothesized greater hyperarousal during the day would predict worse sleep quality and shorter sleep duration that night (Hypothesis 2a). We also hypothesized worse sleep quality and shorter sleep duration the previous night would predict greater compensatory hyperarousal the next day (Hypothesis 2b).

Limited research has examined links between intrusion and sleep disturbances but existing evidence suggests intrusions may be associated with poor sleep quality. In a cross-sectional study, Babson et al. (2011) reported daytime re-experiencing, one form of intrusion, was related to sleep onset problems, sleep maintenance difficulties and nightmares in women with PTSD. One mechanism that may be responsible for this finding is that repeated intrusive thoughts and memories that occur during the day and prior to bedtime may contribute to cognitive rumination and arousal that is not conducive to restful sleep, manifesting as increased sleep onset latency (Zoccola, Dickerson, & Lam, 2009) or poor sleep quality (Berset, Elfering, Lüthy, Lüthi, & Semmer, 2011; Guastella & Moulds, 2007). Similarly, previous research suggests that specifically work-related affective rumination and perseverative cognitions are associated with poor sleep quality (Berset et al., 2011; Querstret & Cropley, 2012; Radstaak, Geurts, Beckers, Brosschot, & Kompier, 2014). Given existing evidence, we hypothesized greater intrusions during the day would predict worse sleep quality that night (Hypothesis 3).

Previous research on avoidance and sleep disturbances is limited and does not demonstrate strong evidence for a relationship between these variables. Indeed, Babson et al. (2011) found in a cross-sectional study that avoidance was not related to sleep onset, sleep maintenance, or nightmares in a group of women with PTSD. We might expect that avoiding reminders of the traumatic event might be associated with a short-term reduction in negative affect and thus not directly impact sleep on a daily basis above the impact of other PTSD symptom dimensions. Given the limited evidence in this area, we do not expect to find any relationship between avoidance and sleep variables.

To our knowledge, no studies have examined relationships between emotional numbing and sleep disturbances in a PTSD population, but some limited work has been done in other populations. For example, several studies in healthy individuals have demonstrated short sleep duration, both chronic and acute, is associated with daytime blunting in emotional intensity in response to positive stimuli (McGlinchey et al., 2011; Minkel, Htaik, Banks, & Dinges, 2011; Van Der Helm, Gujar, & Walker, 2010). Further, in a trauma-exposed population, poor sleep quality was linked with emotion regulation difficulties which may result in emotional numbing (Pickett, Barbaro, & Mello, 2016). We hypothesized worse sleep quality and shorter sleep duration the previous night would predict greater emotional numbing the next day (Hypothesis 4).

The Current Study

Previous literature has demonstrated relationships between traumatic stress at work, sleep disturbances, and PTSD symptoms. However, no studies have addressed this relationship in a sample with a remote history of traumatic work stress such as WTC responders. Furthermore, few studies have accounted for the heterogeneous nature of PTSD symptoms by examining the four PTSD dimensions' independent relationships with sleep. To address these critical gaps in understanding short-term dynamics between sleep and PTSD, the present study examined daily, bi-directional associations between sleep duration/quality and PTSD symptom dimensions in a sample of WTC responders.

Method

Participants

A total of 202 participants (M_{age} = 54.28, *SD* = 9.69) were recruited from the Long Island site of the World Trade Center Health Program for a larger EMA study examining associations between PTSD and respiratory problems between October 2014 and February 2016. All participants worked or volunteered as a part of rescue, recovery, restoration, or cleanup of the WTC sites. Several recruitment methods were used, including flyers posted in the WTC clinic and direct presentation of study information by nurses in the clinic.

The sample was deliberately oversampled for PTSD symptoms based on stratification: a certain *n* was selected for four levels of PTSD symptom severity on a screening measure and after that *n* was achieved the stratum was closed. Specifically, in the present sample, 39 (19.3%) participants carried a current diagnosis of PTSD, 32 (15.8%) participants carried a current diagnosis of Major Depressive Episode (MDE), and 20 (9.9%) participants had both diagnoses at the time of baseline assessment. Participants were primarily male (82.7%, *n* = 167), Caucasian (88.1%, *n* = 178), and non-Hispanic (80.7%, *n* = 163), with an average of 14.82 (*SD* = 2.26) years of education. The majority were current or former police (62.9%, *n* = 127) and almost half (48.5%, *n* = 98) were retired, although several reported they continued to work part-time (*n* = 7). More than half (56.4%, *n* = 114) of the participants arrived and responded in the dust cloud of 9/11 and 66.3% of the sample (*n* = 167) was exposed to human remains during response. Most of the participants (82.7%, *n* = 167) were early arrival responders (i.e., arriving on the day of the attack). All participants provided informed consent and the study was approved by the Stony Brook Committees on Research Involving Human Subjects.

Procedure

Once participants signed informed consent and enrolled in the study, they proceeded to complete the baseline assessment which included a battery of self-report questionnaires and the Structured Clinical Interview for *DSM-IV* (SCID; First, Spitzer, Gibbon, & Williams, 1997). Participants were then trained on the EMA component of the study, which allowed participants to become familiar with the research device and app interface, as well as ask any questions they may have about the study. Given the specific occupational background of this sample, assessment times were predetermined and fixed to each participant based on the schedules they provided at baseline.

Participants completed the EMA surveys on an iPod provided by the research site. Participants were prompted prior to the pre-designated assessment times. PTSD symptoms were assessed three times (i.e., mid-morning, afternoon, and evening) per day over seven consecutive days. Sleep variables were assessed upon awakening. The average adherence rate (i.e., percentage of completed surveys) for the EMA was 93.8% in the present sample.

Measures

PTSD diagnosis.—Trained Masters-level diagnostic interviewers administered the SCID to participants at baseline. All interviewers were supervised by two clinical psychologists

(R.K. and C.R.). PTSD diagnosis was operationalized as meeting the *DSM-IV* diagnostic criteria (American Psychiatric Association, 2000). Previous assessments of reliability of the trained interviewers in this population demonstrated very good inter-rater agreement (κ = 0.82; Bromet et al., 2016).

PTSD assessments.—Momentary PTSD symptoms were assessed using eight items drawn from the PTSD Checklist for *DSM-5* (PCL-5; Weathers et al., 2013). The PCL-5 is a self-report questionnaire consisting of 20 items corresponding to the 20 PTSD symptoms in *DSM-5* (American Psychiatric Association, 2013). Items were selected based on the emotional numbing model of PTSD symptoms, which posits PTSD is composed of four factors: intrusion, avoidance, numbing, and hyperarousal (King, Leskin, King, & Weathers, 1998). This model was selected for the present study because (1) the model has received strong empirical support (Grubaugh, Long, Elhai, Frueh, & Magruder, 2010; Mansfield, Williams, Hourani, & Babeu, 2010; Palmieri, Weathers, Difede, & King, 2007) and (2) it was very similar to the four-factor model proposed in the *DSM-5*, with only four items being added to the *DSM-5*. In the present study, based on factor analytic results in each PTSD symptom dimension and an intention of balancing reliability and validity to avoid the "attenuation paradox," (Loevinger, 1954; Tucker, 1946) two items were chosen for each of the four PTSD dimensions to assess momentary PTSD symptoms resulting in a total of eight items. Items were as follows: Intrusion items included (1) disturbing memories, thoughts, or images and (2) being upset by reminders; Avoidance items included: (1) avoidance of thinking or talk about the experience and (2) avoiding activities related to it; Numbing items included: (1) feeling distant and (2) feeling emotionally numb; and Hyperarousal items included (1) being "super alert" and (2) feeling jumpy or startled. Each of the momentary items began with the stem "In the past 5 hours…" For this abbreviated version of the PCL-5, the within-person reliability (i.e., reliability of change) was R_C = .78, and the between-person reliability was R_{KF} = .99 (both calculated according to equations provided by Mehl & Cornner, 2012).

Sleep assessments.—Participants reported on the previous night's sleep each morning. They completed two items, one asking about their subjective sleep duration (in hours), adapted from the Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989); "*How many hours did you sleep last night? Don't include time spent in bed not sleeping [or previous daytime naps]. Round to the nearest half hour.*" and one asking about their subjective sleep quality, adapted from the Patient-Reported Outcomes Measurement Information System (PROMIS) sleep disturbance (Buysse, Yu, et al., 2010): "*My sleep quality last night was…*") with responses on a Likert scale ranging from 1 = *very poor* to 5 = *very good*.

Analytic Plan

Prior to the analyses, data were inspected for any missingness. One participant completed less than 50% of the EMA and therefore was removed, leaving a sample of 201 participants in the final analyses. Daily overall PTSD symptom severity was calculated by averaging the three momentary PCL-5 total scores on a given day. The same calculation was repeated for each symptom dimension. Prior to running analyses, all predictors and outcomes for the current study were standardized using the PROC STANDARD procedure in SAS® 9.3 (SAS Insitute Inc., 2011) across the entire sample.

Multilevel modeling (MLM) was used to assess daily associations between PTSD symptoms and sleep. MLM was chosen because of its ability to model the nested structure of the data (Peugh, 2010). In the present study, the models consisted of two levels, with Level 1 being the within-person level (i.e., repeated assessments) and Level 2 being the between-person level. All models were estimated with random effects in the intercept and the slope. Because of the repeated assessments design, an autoregressive structure, AR(1), was estimated in the models (Bolger & Laurenceau, 2013). Missing data were estimated using maximum likelihood. Daily variables, including sleep duration, sleep quality, and PTSD symptoms, were considered within-person variables and therefore entered as Level 1 predictors. Importantly, each Level 1 predictor was entered independently. For the present study the Level 1 equation can be written:

$$Y_{ij} = \beta_{0j} + \beta_{1j}X_1 + \varepsilon_{ij}$$

Where Y_{ij} is the outcome variable (i.e., overall PTSD, intrusion, avoidance, numbing, hyperarousal, sleep duration, and sleep quality) at the i^{th} time of participant j, β_{0j} is the intercept of participant j, and β_{1j} represents the slope of predictors X_1 (i.e., overall PTSD, intrusion, avoidance, numbing, hyperarousal, sleep duration, and sleep quality) of participant j. Because each Level 1 predictor was entered independently, there was only one predictor in the above Level 1 equation. εij is the residual at the i^{th} time of participant j. At the between-person level (Level 2), because no Level 2 predictor was estimated in the present study, the intercept and the slope were only estimated with a fixed effect and variance around the corresponding the fixed effect. The equations are written:

$$\beta_{0j} = \gamma_{00} + \mu_{0j}$$

$$\beta_{1j} = \gamma_{10} + \mu_{1j}$$

Where γ_{00} and γ_{10} are the intercepts, and μ_{0j} and μ_{1j} are the errors at between-person level. All models were estimated using PROC MIXED procedure in SAS® 9.3 (SAS Insitute Inc., 2011). Prior to testing hypotheses, we estimated an unconditional model with a random intercept for each outcome variable (i.e., overall PTSD, intrusion, avoidance, numbing, hyperarousal, sleep duration, and sleep quality) separately and calculated intraclass correlation (ICC) for each model.

Primary analyses to assess the bidirectional relationships between sleep and PTSD symptoms were conducted in two ways. First, we examined the prospective effects of PTSD symptoms on sleep. In this model, sleep duration and sleep quality on a given night were predicted by overall PTSD severity or the severity of each of the PTSD symptom dimensions during the day. Because sleep variables were assessed in the morning, we lagged overall

PTSD and PTSD symptom dimensions by one day in order to capture the daytime PTSD symptoms. Accordingly, we included the lagged overall PTSD or each PTSD symptom dimension as a Level 1 predictor independently on sleep duration and sleep quality at night. Notably, we did not included lagged effects of the outcome variable in the model because doing so leads to substantial bias in the size of the coefficients (i.e., underestimating coefficients for predictors of interest; Allison, Williams, & Moral-Benito, 2017).

Second, we examined the prospective effects of sleep duration and quality on PTSD symptoms. In this model, the severity of overall PTSD or the severity of each of the PTSD symptom dimensions on a given day was predicted by sleep duration or sleep quality on the preceding night. Accordingly, sleep duration or sleep quality on the preceding night was entered as a Level 1 predictor independently. Since there is no consensus on which effect size index is the most appropriate to report in longitudinal MLM (Peugh, 2010; Singer & Willett, 2003), following the recommendations by Singer and Willett (2003) we calculated proportion reduction in variance (PRV; Peugh, 2010) as an index of effect size using the equation: $PRV = [\sigma^2_{(\text{null model})} - \sigma^2_{(\text{model of interest})}]/\sigma^2_{(\text{null model})}$ where σ^2 represents within-person (Level 1) variance estimated in the present study. In the present study, PRVs are reported as proportion reduction in the within-person (Level 1) variance after adding a given predictive variable.

Primary analyses were repeated using the same SAS procedure to control for three potential covariates: age, sex, and current PTSD diagnosis. Moreover, given that nearly half of the sample was retired, the analyses were also repeated with retirement status (i.e., retired versus not retired) being included as a covariate in each model. Each covariate was included as a between-person (Level 2) predictor independently. Random intercept and slope were estimated in all the models with a given covariate. The additional analyses were run to investigate the robustness of daily associations between PTSD symptoms and sleep.

Results

Table 1 presents descriptive statistics for outcome variables and ICC for each unconditional model with the corresponding outcome. Average sleep duration across the week in this non-representative sample was between 6–7 hours a night and the average sleep quality was between fair and good. There was a large degree of within-person variability in both duration and quality of sleep (i.e., ICC's of .42 and .37, respectively, corresponding to 58% and 63% of variability due to within-person change). Current PTSD was diagnosed in 18.3% of the sample. Unlike with sleep, variability in daily PTSD symptoms was largely from between-person differences (ICC =.85). Among the four symptom dimensions, hyperarousal had the highest daily mean score and most variability. Between 68–87% of the variance in PTSD symptom dimensions was explained at the between-person level.

Sleep: Within-person Associations with PTSD

Table 2 summarizes the fixed-effect parameter estimates and PRV calculated for the models with PTSD symptoms during the day predicting sleep duration or quality at night. Consistent with Hypothesis 1a, PTSD during the day was a significant predictor of sleep duration ($\beta = -.13$, $p = .014$, PRV = 2.9%) and quality ($\beta = -.18$, $p < .001$, PRV = 0.9%) the subsequent night. Specifically, greater overall PTSD symptom severity predicted shorter sleep duration and worse sleep quality later that night.

When examining the effect of each symptom dimension separately, results showed only numbing symptoms predicted shorter sleep duration ($\beta = -.17$, $p = .001$, PRV = 4.2%). That is, the within-person residual variance of numbing symptoms decreased by 4.2% after adding sleep duration. This was partially inconsistent with Hypotheses 2a and 3; however, partially consistent with these Hypotheses was the finding that all four PTSD symptom dimensions predicted poor sleep quality (βs = −.21 to −.12, ps < .001 to .007, PRV = 0.6% to 3.8%) that night.

Additional analyses with covariates indicated the predictive effects of PTSD symptoms on both sleep duration and sleep quality were robust. Specifically, after controlling for age, overall PTSD remained a significant predictor of sleep duration ($\beta = -.12$, $p = .017$) and sleep quality ($\beta = -.18$, $p < .001$) the subsequent night. Numbing significantly predicted shorter sleep duration ($\beta = -.18$, $p = .001$) and all four symptom dimensions remained significant predictors of poor sleep quality at night (βs = −.21 to −.12, ps < .001 to .004). Similarly, after controlling for sex, daily PTSD symptoms remained significant predictors of sleep duration ($\beta = -.15$, $p = .014$ for overall PTSD; $\beta = -.10$, $p = .050$ for avoidance; and $\beta = -.21$, $p < .001$ for numbing) and sleep quality (βs = −.25 to −.15, ps < .001 to .004). Regardless of current PTSD diagnosis, numbing significantly predicted sleep duration ($\beta = -.16$, $p = .027$). Daily PTSD symptoms, including overall PTSD, intrusion, and numbing, remained significant predictors of sleep quality (βs = −.22 to −.10, ps < .001 to .05), with numbing showing the strongest predictive effect ($\beta = -.22$, $p < .001$).[i] Additionally, after including retirement status in the analyses, numbing remained as a significant predictor of shorter sleep duration ($\beta = -.20$, $p = .007$) the subsequent night, although the effect of overall PTSD on sleep duration was not significant ($\beta = -.12$, $p = .098$). Overall PTSD ($\beta = -.13$, $p = .020$), intrusion ($\beta = -.12$, $p = .024$), and numbing ($\beta = -.18$, $p < .001$) remained significant predictors of poor sleep quality the subsequent night. Importantly, the interaction effect between retirement status and overall PTSD, as well as the interaction with each PTSD symptom dimension was not significant in any of the models.

PTSD: Within-person Associations with Sleep

Table 3 reports the fixed-effect parameter estimates for the models with sleep predicting PTSD symptoms the next day. Consistent with Hypothesis 1b, shorter sleep duration significantly predicted greater overall PTSD symptom severity ($\beta = -.04$, $p = .004$). Consistent with Hypothesis 2a, shorter sleep duration specifically predicted greater hyperarousal ($\beta = -.03$, $p = .011$). Shorter sleep duration also predicted greater intrusion ($\beta = -.06$, p <.001). The within-person residual variance decreased by 0.6% to 3.7% after adding sleep duration. Although the predictive effect of sleep quality on all PTSD variables

[i]Additional analyses were conducted to examine whether timing of PTSD assessment would meaningfully alter the results. In these models, we focused on the relationship between sleep during the previous night predicting PTSD symptoms at the following morning assessment. Results from the analysis using individual time points showed that sleep duration was a significant predictor of overall PTSD ($\beta = -.05$, $p = .023$), intrusion ($\beta = -.06$, $p = .042$), and hyperarousal ($\beta = -.06$, $p = .002$) the next morning. The predictive effects of sleep quality were not significant, except for the effects on avoidance ($\beta = -.05$, $p = .021$) and hyperarousal ($\beta = -.05$, $p = .015$). These results were similar to what we originally reported using the average of the three assessments within a given day.

the next day was not statistically significant (partially inconsistent with Hypotheses 1b, 2b, and 4), adding sleep quality to the model produced PRV ranging from 3.8% to 9.8%.[ii]

The significant effects of sleep duration predicting PTSD remained significant even after controlling for age, sex, current PTSD diagnosis, and retirement status. Specifically, after controlling for age, sleep duration remained a significant predictor of daily PTSD symptoms ($\beta = -.03$, $p = .013$ for overall PTSD, and $\beta = -.03$, $p = .016$ for hyperarousal). After controlling for sex, sleep duration significantly predicted overall PTSD ($\beta = -.03$, $p = .020$), intrusion ($\beta = -.04$, $p = .004$), and hyperarousal ($\beta = -.04$, $p = .008$). Regardless of current PTSD diagnosis, sleep duration remained a significant predictor of daily overall PTSD ($\beta = -.04$, $p = .026$). Similarly, when including retirement status in the models, shorter sleep duration remained a significant predictor of greater overall PTSD symptom severity ($\beta = -.05$, $p = .014$), greater intrusion ($\beta = -.06$, $p = .041$), and greater hyperarousal ($\beta = -.05$, $p = .018$). Unlike the model without retirement status, the predictive effect of sleep duration on numbing was also significant ($\beta = -.06$, $p = .028$) in the model including retirement status as a covariate, with shorter sleep duration being associated with more severe numbing symptoms the next day. Similar to the results in Table 3, the predictive effects of sleep quality on overall PTSD symptom severity and each individual symptom dimension were not significant when including retirement status in the model. The interaction effect between retirement status and sleep duration, as well as the interaction with sleep quality were also not significant in any of the models. Taken together, these results suggested that the patterns of sleep and PTSD reported in the current sample were largely robust to the influence of age, sex, current PTSD diagnosis, and retirement status.

Discussion

The current study examined daily relationships between sleep (i.e., subjective sleep duration and quality) and overall PTSD symptoms and PTSD symptom dimensions (i.e., intrusion, avoidance, numbing, hyperarousal) in a sample of WTC responders. We examined daytime PTSD symptoms as predictors of that night's sleep duration and quality, and nighttime sleep duration and quality as predictors of the next day's PTSD symptoms.

PTSD Symptoms and Sleep that Night

Consistent with Hypothesis 1a and with previous research, overall PTSD symptoms during the day predicted shorter subjective sleep duration and worse sleep quality that night. For specific symptom dimensions, the results are partially consistent with Hypotheses 2a and 3. For sleep duration this finding appears to be largely driven by daytime numbing. For sleep quality all symptom dimensions contributed to the model although daytime numbing was the strongest predictor. These findings were surprising given our lack of hypotheses about sleep predicting emotional numbing. Daytime numbing may contribute to poor sleep that night in

[ii]Additional analyses were conducted to examine whether timing of PTSD assessment would meaningfully alter the results. In these models, we focused on the relationship between PTSD symptoms at the evening time point predicting subsequent sleep duration and sleep quality that night. Results from this analysis showed that overall PTSD ($\beta = -.16$, $p < .001$), intrusion ($\beta = -.08$, $p = .016$), avoidance ($\beta = -.10$, $p = .011$), numbing ($\beta = -.14$, $p < .001$), and hyperarousal ($\beta = -.16$, $p < .001$) in the evening significantly predicted sleep duration that night. Similarly, overall PTSD and the symptom dimensions, except avoidance ($\beta = -.07$, $p = .076$), in the evening significantly predicted sleep quality that night.

a variety of ways. First, similar to individuals with depression, disengagement from enjoyable activities may result in decreased circadian signaling and a diminished sleep drive that contributes to reduced sleep duration and quality (Nutt, Wilson, & Paterson, 2008). Second, disengagement from emotional experiences throughout the day may result in sleep-incongruent behaviors (e.g., delay of bedtime) which lead to reduced sleep opportunity or disturbed sleep. Previous cross-sectional research in a sample of first responders suggested sleep disturbances and negative affect were linked through emotion dysregulation and specifically a lack of access to emotion regulation strategies (Hom et al., 2016). In the current study, this suggests inability to regulate emotion during the day may carry over and interfere with sleep that night. Finally, "sleep quality" is a broad, heterogeneous construct that encompasses sleep disturbances across many domains (e.g., nighttime arousals, insomnia, irregular sleep architecture; Ohayon et al., 2017). Further research is needed to 1) better understand the mechanisms linking daytime numbing to shortened sleep, 2) examine sleep-related effects of PTSD interventions targeting emotional numbing, and 3) explore differential relationships between PTSD symptom dimensions and sleep domains.

Sleep Disturbances and PTSD Symptoms the Next Day

Importantly, our study found reverse effects as well. Partially consistent with Hypothesis 1b, subjective sleep duration at night predicted global next-day PTSD symptoms, although sleep quality was minimally related to next-day PTSD. Inconsistent with Hypotheses 2b and 4, the relationship between sleep duration and PTSD appears to be primarily driven by intrusion, which is congruent with a previous finding that experimental sleep deprivation resulted in an increase in intrusive memories (Kleim et al., 2016). One proposed mechanism is that shortened or disturbed sleep duration may limit the opportunity for memory consolidation during the night, resulting in the intrusion of emotional memories the next day (Kleim et al., 2016). However, more research is needed to understand the specific aspects of short subjective sleep duration that contribute to increased intrusions the following day.

We have considered two possible explanations for the differences in results between sleep duration and sleep quality predicting next-day PTSD symptoms. From a measurement perspective, sleep duration was assessed as a continuous variable, whereas sleep quality was assessed on a 1–5 scale thereby limiting variability in the responses. Although sleep duration significantly predicted next-day PTSD, the effect sizes (PRV) were, in some cases, larger for sleep quality than for sleep duration. Therefore, although sleep quality was not a statistically significant predictor of next-day PTSD, it did lead to variance reduction when included in the model. A second possibility is that self-reported "sleep quality" is a broad term that may reflect different aspects of sleep across different individuals (Krystal & Edinger, 2008). Sleep quality may capture sleep duration in addition to other sleep constructs such as underlying apnea, pain, and social or environmental interferences. Unlike sleep duration, there is no single objective marker of sleep quality (Krystal & Edinger, 2008). The broadness of sleep quality may have resulted in too much error to reliably detect a relationship with next-day PTSD symptoms.

Occupational Trauma, Sleep, and PTSD symptoms

The findings have clinical implications for the care of WTC responders and others exposed to work-related traumatic stress. Results suggest that targeted interventions focused on improving numbing or dysphoria related symptoms of PTSD may improve sleep. Alternatively, responders who receive treatments focused on sleep could have ancillary benefits for PTSD (Riedel & Lichstein, 2000) particularly in the domain of intrusions. Indeed, previous research has pointed out the benefits of treating insomnia as a preparatory step in treating PTSD (Baddeley & Gros, 2013; Germain, Shear, Hall, & Buysse, 2007; Pigeon et al., 2015). Treating insomnia symptoms prior to PTSD may bolster PTSD treatment outcomes by improving cognitive and emotional processing (Pace-Schott, Germain, & Milad, 2015; Pace-Schott et al., 2009) which is considered a primary mechanism of action in behavioral interventions for PTSD (Foa & Kozak, 1986). Moreover, this work provides impetus for development of highly targeted, ecological momentary interventions (Heron & Smyth, 2010), particularly ones that can be delivered to disrupt symptoms as they emerge for populations expected to be exposed to traumatic stress in a work context like disaster responders.

The impact of traumatic work events is long-lasting and pervasive, as demonstrated by the prevalence of PTSD symptoms and sleep disturbances in the current sample of WTC responders. The extended chronicity of PTSD is not unique to this group, with significant prevalence of PTSD for 40+ years in a variety of groups including Holocaust survivors (Yehuda, Kahana, Schmeidler, & Southwick, 1995), World War II Veterans (Port, Engdahl, & Frazier, 2001), and Vietnam Veterans (Schnurr, Lunney, Sengupta, & Waelde, 2003). Not only is further work needed to examine PTSD symptoms and sleep in workers with remote occupational trauma exposure, but ongoing work is needed to examine the experiences of workers with recent trauma exposure.

Potential Interventions in the Context of Occupational Trauma

The prevalence and impact of traumatic events in the workplace among disaster responders suggests a high need for early intervention following traumatic exposure which may help to minimize suffering and reduce functional impairments. It is well-documented that symptoms of acute stress following traumatic events and workplace stress in general can have significant repercussions in the work environment, such as absenteeism and decreased productivity (Byron & Peterson, 2002). Additionally, poor sleep has been linked with poor outcomes in the workplace including worse productivity, difficulties with self-control, cognitive failures, and unethical behavior (Barnes, Schaubroeck, Huth, & Ghumman, 2011; Budnick & Barber, 2015). Thus, it is in employers' best interests to ensure that employees' symptoms of PTSD and sleep disturbances are ameliorated as quickly as possible.

Previous research has demonstrated early interventions following traumatic exposure can reduce the chance of progression from acute stress to posttraumatic stress disorder (Birur, Moore, & Davis, 2017; Feldner, Monson, & Friedman, 2007), but this is a relatively new line of research. Several studies have demonstrated work-related interventions for occupational trauma show promise, although further research is needed to examine tailoring of work-related interventions for specific populations (e.g., first responders; Stergiopoulos, Cimo, Cheng, Bonato, & Dewa, 2011). One important area in which employers could intervene would be to increase screening for PTSD symptoms among workers exposed to occupational stress and the provision of appropriate referrals. After identification of individuals at-risk for the development of PTSD, provision of evidence-based interventions targeting either information processing or cognitive avoidance and emotion regulation show promise as early interventions for PTSD (Feldner et al., 2007). One implication of the current findings is that an area for future research is in brief interventions that target emotional numbing symptoms of PTSD as an intervention point to improve sleep quality and increase sleep duration.

Cognitive behavioral interventions for insomnia and related sleep disorders have excellent empirical support (Qaseem, Kansagara, Forciea, Cooke, & Denberg, 2016; Trauer, Qian, Doyle, Rajaratnam, & Cunnington, 2015) and have been shown to be deliverable in a work context (Atlantis, Chow, Kirby, & Singh, 2006). One study examined the impact of treating insomnia using a web-based cognitive behavioral treatment and demonstrated improvements on negative affect, job satisfaction, and self-control (Barnes, Miller, & Bostock, 2017). The results of the current study suggest an area for future research is to examine the impact of brief, focused interventions that target sleep extension, particularly as a means of improving PTSD symptoms like intrusions and hyperarousal. Further, a brief intervention targeting both PTSD symptoms and sleep disturbances might be an efficient means of improving employee wellness.

Limitations

The current study had several limitations. First, the present study investigated the daily associations between sleep disturbance and PTSD symptoms in WTC responders only, so it remains unknown whether results generalize to groups with other types of trauma (e.g., childhood sexual abuse, combat trauma). Second, daily PTSD symptom scores used in the present analyses were calculated by averaging the symptom scores across the three assessment points within a given day. This approach may have a disadvantage of introducing bias to the within-person variance, which may speak to the high ICC values reported in the present study. However, averaging across multiple assessment points also had an advantage of obtaining reliable information on daily symptom severity. Third, the present study used only subjective and brief (i.e., single-item) assessments of limited sleep domains (i.e., duration and quality), as well as self-reported PTSD symptoms. It is well-established that subjective and objective sleep parameters are distinct yet related constructs (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008) and previous studies have demonstrated a stronger relationship between subjective sleep parameters and PTSD compared to objective measures (Kleim et al., 2016; Stout et al., 2017). Therefore, we cannot assume our findings are consistent across objective markers of sleep duration and quality or other sleep domains. However, it is also possible that the present study under-estimated effects. Briefer measures are less reliable, and test theory shows lower reliability attenuates effects. The fact that the present study found effects, despite this attenuation, speaks to the potential strength of the associations. Regardless, future research is needed to examine the relationship of PTSD symptoms, assessed both subjectively via self-report and objectively via clinician ratings, and objective sleep parameters in individuals exposed to occupational trauma. Fourth, the present study did not assess nightmares, which is a very common sleep disturbance in PTSD (Lamarche & De Koninck, 2007). Fifth, results are naturalistic. Future research must confirm whether intervening on sleep duration disrupts maintenance of PTSD generally and intrusive thoughts in particular or similarly how intervening on daytime numbing might improve nighttime sleep quality and increase sleep duration.

Future Directions

Additional research in this sample and related samples with a history of occupational stress is warranted, as these groups demonstrate unique needs and concerns. In particular, examination of work-related factors such as levels of work stress and current work hours may provide fruitful insights into the mechanisms that continue driving PTSD symptoms and sleep disturbances many years after trauma. Examination of the impact of shift work or rotating shift schedules on the perpetuation of both PTSD symptoms and sleep disturbances may provide additional insight into potential intervention points within a work context. Additionally, the use of objective measures of sleep in combination with subjective measures may provide additional insight into the nature of sleep complaints that are associated with PTSD symptoms. Sleep is an essential domain that must be examined in order to fully investigate the functioning of an employee during work hours (Crain, Brossoit, & Fisher, 2018) and improvement of sleep assessment in research will increase precision and accuracy of results. Further work is needed to examine whether sleep is a mediator of the relationship between occupational trauma and impaired workplace functioning. Finally, more work is needed to develop and test interventions integrated into the workplace to remediate the impact of occupational trauma on both PTSD symptoms and sleep disturbances (Graham, 2012; Stergiopoulos et al., 2011).

Summary and Conclusions

The present work points to a critical dynamic between sleep disturbances and PTSD in individuals exposure to occupational trauma, even in the very short term. Such links represent a potential pathway by which symptoms are maintained as well as an opportunity to develop and implement highly targeted and momentary interventions focused on disrupting this dynamic for disaster responders and other individuals who work in stressful environments with a high chance of trauma exposure.

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Table 1

Descriptive Statistics and Intraclass Correlation for Unconditional models of PTSD, Symptom Dimensions, and Sleep Variables

Outcomes	*M*	*SD*	Minimum	Maximum	ICC[a]
PTSD	12.85	5.44	8.00	33.37	.85
Intrusion	2.94	1.20	2.00	7.00	.68
Avoidance	3.42	1.78	2.00	9.95	.79
Numbing	2.98	1.37	2.00	8.95	.81
Hyperarousal	3.52	1.81	2.00	10.00	.87
Sleep duration (hrs)	6.43	1.14	2.08	9.00	.42
Sleep quality	3.19	.67	1.00	5.00	.37

Note. PTSD = Posttraumatic Stress Disorder; ICC = Intraclass correlation.

[a]The ICCs calculated and reported here for PTSD and symptom dimensions were based on averaged daily scores. Using the scores for each assessment point, the ICC values were .79 for overall PTSD, .57 for intrusion, .72 for avoidance and numbing, and .82 for hyperarousal.

Table 2

Multilevel Modeling Within-person Fixed-effect of PTSD Symptoms in the Day Predicting Sleep Duration and Sleep Quality at Night

	Outcomes									
	Sleep Duration					Sleep Quality				
Model Predictor[a]	AIC	BIC	*β (SE)*	*p*	PRV (%)	AIC	BIC	*β (SE)*	*p*	PRV (%)
PTSD	2948.10	2964.70	−.13 (.05)	.014	2.9	2928.10	2941.40	−.18 (.04)	<.001	0.9
Intrusion	2957.70	2974.20	−.07 (.04)	.086	2.1	2934.00	2950.50	−.13 (.04)	<.001	1.4
Avoidance	2957.50	2974.10	−.09 (.04)	.055	1.3	2937.90	2951.10	−.12 (.04)	.002	0.6
Numbing	2939.50	2956.00	−.17 (.05)	.001	4.2	2919.20	2935.70	−.21 (.04)	<.001	1.8
Hyperarousal	2953.90	2970.40	−.07 (.05)	.230	2.7	2937.20	2953.80	−.14 (.05)	.007	3.8

Note. PTSD = Posttraumatic Stress Disorder; PRV = Proportion reduction in variance.

[a]Each predictor was entered in the model independently, and therefore, each predictor had its own model. As such, a total of 10 models were estimated.

Table 3

Multilevel Modeling Within-person Fixed-effect of Sleep Duration and Sleep Quality on the Preceding Night Predicting PTSD Symptoms the Next Day

Model Predictor[a]	AIC	BIC	*β*	*SE*	*p*	PRV (%)
Outcome: PTSD						
Sleep duration	1522.50	1539.00	−.04	.01	.005	1.6
Sleep quality	1484.00	1500.30	−.01	.02	.432	8.0
Outcome: Intrusion						
Sleep duration	2156.40	2169.60	−.06	.01	<.001	3.7
Sleep quality	2132.60	2149.00	−.01	.02	.609	7.8
Outcome: Avoidance						
Sleep duration	1749.50	1965.90	−.03	.02	.070	3.0
Sleep quality	1663.90	1680.30	−.02	.02	.284	9.8
Outcome: Numbing						
Sleep duration	1845.10	1861.50	−.03	.02	.056	1.8
Sleep quality	1834.80	1851.20	−.02	.02	.346	7.1
Outcome: Hyperarousal						
Sleep duration	1351.30	1364.50	−.03	.01	.011	0.6
Sleep quality	1325.60	1341.90	−.01	.01	.319	3.8

Note. PTSD = Posttraumatic Stress Disorder; PRV = Proportion reduction in variance.

[a]Each predictor was entered in the model independently, and therefore, each predictor had its own model. As such, a total of 10 models were estimated.