Sleep disturbance as a predictor of affective functioning and symptom severity among individuals with PTSD: An ecological momentary assessment study

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A B S T R A C T

Recent research has transformed the way we view sleep disturbances in the context of mental illness from a common yet mechanistically unimportant symptom to an independent comorbid diagnosis that is potentially an etiological factor in various conditions (Harvey, 2008). This is due to evidence suggesting insomnia prospectively predicts a variety of psychological disorders (Breslau, Roth, Rosenthal, & Andreski, 1996; Johnson, Roth, & Breslau, 2006; Sivertsen et al., 2014; Taylor, Lichstein, & Durrence, 2003), and by emerging findings that sleep is critical for mood regulation and appropriate emotional responding (Goldstein & Walker, 2014). Considering this evidence, insomnia may affect psychological conditions via impaired affective functioning (Harvey, 2008). This area of research is exciting because of the potential to leverage sleep medicine to improve quality of life for individuals with mental illness. Indeed, cognitive behavioral therapy for insomnia (CBT-I) decreases symptoms of mood and anxiety disorders (Belleville, Cousineau, Levrier, & St-Pierre-Delorme, 2011; Manber et al., 2008).

One disorder receiving abundant attention due to its close ties with sleep disturbance is posttraumatic stress disorder (PTSD), an impairing condition characterized by the inability to recover from a stress reaction following an extreme stressor (Kessler, Sonnega, Bromet, Hughes, & Nelson, 1995). Individuals with PTSD experience a range of symptoms, including re-experiencing, avoidance, negative alterations in cognition and mood, and alterations in arousal (American Psychiatric Association, 2013). Those with PTSD and comorbid sleep disturbance have more severe presentations of PTSD, including increased symptom severity (Short, Babson, Boden, & Bonn-Miller, 2014a; Short, Raines, Oglesby, Zvolensky, & Schmidt, 2014b), functional impairment (DeViva, Zayfert, & Mellman, 2004), substance use, depression, and self-injurious behavior (Krakow et al., 2000; Nishith, Resick, & Mueser, 2001; Short et al., 2015). Furthermore, prospective studies find that sleep disturbance following trauma predicts PTSD diagnosis (Koren, Arnon, Lavie, & Klein, 2002; Mellman, Pigeon, Nowell, & Nolan, 2007), as well as other posttrauma psychological disorders (Bryant, Creamer, O’Donnell, Silove, & McFarlane, 2010). Finally, sleep problems do

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not remit spontaneously or through PTSD treatment, and are associated with ongoing PTSD symptoms (Wright et al., 2011). These lines of evidence suggest sleep disturbances may play an etiological role in PTSD symptoms.

Sleep-dependent affective processes may be important in explaining how sleep disturbance affects PTSD symptoms (Germain, 2013; Goldstein & Walker, 2014). Sleep loss is associated with increases in depressive (Caldwell, Caldwell, Brown, & Smith, 2004; Fredriksen, Rhodes, Reddy, & Way, 2004) and anxiety symptoms (Sagaspe et al., 2006; Talbot, McClinchey, Kaplan, Dahl, & Harvey, 2010). This is often paired with decreases in positive affect (Paterson et al., 2011; Talbot et al., 2010). These impairments in affective responding may be one mechanism explaining why sleep disturbances are associated with increased PTSD symptoms (Germain, 2013; Goldstein & Walker, 2014). Poor sleep can be associated with next day affective impairment, such as unstable mood that is easily disrupted by mild stressors (Short et al., 2016). This increased negative affect could exacerbate re-experiencing symptoms, which may be more upsetting to the individual, and lead to increased avoidance of trauma reminders. Furthermore, poor sleep can exacerbate negative alterations in cognition, mood, and arousal in PTSD, maintaining those symptoms as well.

To test the hypothesis that sleep disturbances predict increases in daytime PTSD symptoms via increases in negative affect, the current study used an ecological momentary assessment (EMA) design. Throughout the current manuscript, we refer to insomnia symptoms and nightmares collectively as “sleep disturbance.” However, it is important to note that insomnia and nightmare disorders are considered to be comorbid disorders with their own unique etiology and prognosis, rather than simply symptoms of PTSD (Harvey, 2001).

Yet, we are unable to formally diagnose these disorders in the current paper, hence utilizing the term “sleep disturbance.” First, we hypothesized that sleep disturbances (i.e., sleep efficiency, duration, quality, and nightmare frequency) would be associated with increased next day PTSD symptoms after covarying for the prior evening’s PTSD symptoms. Second, we hypothesized sleep disturbances would be associated with increased next day negative affect, decreased positive affect, and more negatively valenced affect ratios after covarying for the prior evening’s PTSD symptoms. Third, we hypothesized that the effect of sleep disturbances on next day midmorning and afternoon PTSD symptoms would be mediated by increases in morning negative affect, after covarying for the prior evening’s PTSD symptoms. Additionally, we examined positive affect as an alternative mediator, given lack of theoretical basis for decreased positive affect alone as an etiological factor. Fourth, we hypothesized our results would hold when only examining the unique symptom clusters of PTSD (i.e., re-experiencing and avoidance), excluding the symptoms that could be construed as general negative affectivity (i.e., alterations in cognition and mood, alterations in arousal and reactivity). Fifth, consistent with recent research (Alvaro, Roberts, & Harris, 2013), we hypothesized there would be a bidirectional relationship, such that daytime elevated PTSD symptoms would negatively influence sleep.

1. Method

1.1. Participants

We recruited 30 participants diagnosed with PTSD according to the Structured Clinical Interview for DSM-V (SCID; First, Williams, Karg, & Spitzer, 2015). Participants were at least 18 years of age and were recruited from the local community (n=24, 80.0%) and the university’s undergraduate student research pool (n=6, 20.0%). Participants were screened via phone or the university’s research pool using the PTSD Checklist (Weathers, Litz, Herman, Huska, & Keane, 1993), and then scheduled for a baseline appointment, in which PTSD diagnoses were confirmed. Participants were required to have a diagnosis of PTSD and own a smartphone with access to texting and the internet to participate in the EMAs. Exclusion criteria included being diagnosed with a psychotic disorder not stable on psychiatric medication, and a diagnosis of severe substance use disorder.

Participants were by majority female (61.3%) with ages ranging from 18 to 60 (M=38.03, SD=15.14). The majority of the sample identified as White (64.5%), followed by Black (29.0%), and American Indian/Alaskan Native (3.2%). Participants reported the following as their most bothersome trauma: sexual assault (43.3%), non-sexual assault (16.6%), other (e.g., witnessing a death, mass grave sites; 13.3%), serious accident (10.0%), combat (6.7%), imprisonment (6.7%), while one participant did not select a most bothersome event on the PCL (3.3%). At baseline, participants scored an average on 39.28 on the PCL-5, with specific symptom cluster averages as follows: re-experiencing (12.17), avoidance (5.79), alterations in cognition and mood (9.90), and alterations in arousal and reactivity (11.41). The majority (63%) reported receiving psychopharmacological treatment. Most participants had chronic PTSD as time since traumatic event ranged from several months to 50 years (M = 9.18 years). In addition, 93.3% of the participants met criteria for at least one comorbid disorder. Specifically, 80% of the sample met criteria for an anxiety disorder, followed by mood disorder (73.3%), obsessive compulsive or related disorder (26.7%), substance use disorder (13.3%), and eating disorder (6.7%). PTSD was the primary diagnosis for the majority of participants (73.3%).

1.2. Procedure

1.2.1. Baseline appointment

Written informed consent was obtained upon arrival to the laboratory. Then, the PTSD module of the SCID was used to confirm PTSD diagnostic status (First et al., 2015). Participants not meeting criteria for PTSD were dismissed. All other participants continued by completing the remaining SCID modules and a battery of self-report questionnaires. Next, participants were asked for their normal sleep schedule to optimize assessment time points. Individuals were then instructed how to participate in the remainder of the study, and received a sample link and practiced filling out measures on their smartphone with a research assistant to ensure their understanding. Specifically, participants filled out the PTSD section with the experimenter to ensure they understood the questions and the time period they referred to. Participants were encouraged to call the laboratory with any questions regarding the EMA questionnaires. The EMA questionnaires took less than 5 min to complete on average (typically 2–3 min). EMAs were time stamped and checked for temporal accuracy. To reduce participant burden, we used brief versions of all measures used and ensured each time point took less than 5 min to complete. Participants were also compensated for their time.

1.2.2. EMA period

Starting the day after each individual’s baseline appointment, participants received 4 text messages daily linking to surveys to complete their assessments over the next 8 days. Data regarding average wake and sleep times collected during the baseline appointment were used to determine an appropriate assessment schedule. Participants received text messages on a quasi-random schedule, with one survey upon waking, one in the mid-morning, one in the afternoon, and one in the evening before bedtime (see Fig. 1). Text messages contained a link to the participant’s appropriate assessment. If the participant did not complete the survey after receiving a reminder and 60 min had elapsed, that time point was considered missed (5.3% of assessments). Participants’ survey responses were time stamped and reviewed to ensure temporal
accuracy. After the EMA period, participants received compensation.

1.3. Measures

1.3.1. Baseline

1.3.1.1. Structured clinical interview for DSM-5 (SCID). The SCID is a semi-structured clinical interview used to determine diagnostic status for DSM-5 disorders (First et al., 2015), which we used to assess PTSD and other psychological diagnoses. SCIDs were administered by trained doctoral students and were reviewed by a licensed clinical psychologist. Agreement between interviewers for a random sample of 20 SCID interviews from a large clinical trial in our laboratory resulted in high inter-rater agreement: percent agreement across all diagnoses was 80% with a kappa value of 0.86, while for PTSD specifically percent agreement was 100% with a kappa value of 1.0 (Schmidt, Capron, Raines, & Allan, 2014).

1.3.1.2. Pittsburgh sleep quality index (PSQI). The PSQI is a 19-item self-report measure of sleep quality (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) and was administered at baseline to provide a comprehensive measure of sleep quality. In the current study, the PSQI demonstrated good internal consistency ($\alpha = 0.81$).

1.3.1.3. Positive and negative affect schedule (PANAS). The PANAS is a 20-item self-report questionnaire assessing two dimensions of affectivity: positive and negative (Watson & Clark, 1994), with good psychometric properties. The PANAS trait version was administered at baseline to assess typical levels of positive and negative affect, and demonstrated good to excellent internal consistency in the current study for NA ($\alpha = 0.95$) and PA ($\alpha = 0.86$) subscales.

1.3.1.4. PTSD checklist (PCL-5). The PCL measures DSM-5 PTSD symptoms (U. S. Department of Veterans Affairs, 2016; Weathers et al., 1993). Previous research has determined that the PCL-5 has strong psychometric properties, including test-retest reliability, convergent and discriminant validity, and the ability to detect PTSD cases. The PCL-5 was administered at baseline to provide a self-report measure of PTSD symptoms. The PCL-5 demonstrated excellent internal consistency in the current study ($\alpha = 0.91$).

1.3.2. EMA measures

1.3.2.1. Sleep disturbances. Each morning, surveys assessed previous night’s sleep using the PSQI modified for daily use (see the Appendix for the entirety of the EMA measures). Sleep duration was self-reported in hours (Item 2 in Appendix). Sleep Efficiency was calculated by dividing self-reported sleep duration by time in bed (hours) and is expressed in a percentage. Time in bed was calculated by summing self-reported sleep duration, sleep onset latency (Item 1: how long it takes one to fall asleep), and wake after sleep onset (Items 3 and 4, waking up throughout the night and being unable to fall back asleep). Note that sleep efficiency and duration are actual percentages and hours of sleep, therefore, higher scores represent better sleep. Sleep quality was rated on a 1 (very good) through 4 (very bad) scale using the PSQI’s subjective sleep quality component. Finally, nightmares were assessed with the traumatic nightmare item of the PSQI’s PTSD addendum (German, Hall, Krakow, Shear, & Buysse, 2005), which is rated as 0 (no) or 1 (yes).

1.3.2.2. Affect. Affect was assessed during each time point of the EMA using instructions and select items from the PANAS—state (Watson & Clark, 1994). Participants rate the extent they feel each emotion at the current moment. Eight items were selected using the items loading most strongly onto positive and negative affect factors of the PANAS, excluding similar items, and including emotions relevant to sleep (alert; Ratcliff, Lam, Arun, Valero, & Cohen, 2014) or PTSD (guilty; Ehlers & Clark, 2000). Specifically, participants reported on a 1 (very slightly or not at all) to 5 (extremely) scale how much they felt upset, guilty, scared, irritable (NA), and interested, enthusiastic, alert, and determined (PA). Affect ratio was calculated by dividing negative affect from positive affect. The abbreviated version of the PANAS demonstrated adequate internal consistency for NA (session-level $\alpha = 0.70$, day-level $\alpha = 0.93$, person-level $\alpha = 0.91$), and PA subscales (session-level $\alpha = 0.70$, day-level $\alpha = 0.80$, person-level $\alpha = 0.74$).

1.3.2.3. PTSD symptoms. PTSD symptoms were assessed during each time point of the EMA. Items and instructions were drawn from the PCL-5 and modified to ask the symptoms they have been experiencing since their last assessment. This method is consistent with prior EMA research (Possemato et al., 2012). Only 10 were administered, which reflect the symptoms that load most strongly onto the 4 symptom clusters of PTSD (American Psychiatric Association, 2013; King, Leskin, King, & Weathers, 1998). Sleep items were excluded. Internal consistency for the abbreviated PCL-5 was good to excellent in the present study (session-level $\alpha = 0.80$, day-level $\alpha = 0.91$, person-level $\alpha = 0.93$). Furthermore, an unconditional model indicated significant levels of variance at the session, day, and individual level, suggesting there was individual variability in PTSD symptoms across sessions as well as across days.

2. Data analytic plan

Multilevel modeling was used due to its ability to take into account nested data and missing data better than classical analyses used to analyze EMA studies (Schwartz & Stone, 1998). Analyses were conducted using MPlus Version 7.4 with full information maximum likelihood estimation using the robust estimator (Muthén & Muthén, 1998–2012). The models consisted of 3 levels with random effects: sessions nested within days nested within individuals. The models were estimated using an unstructured covariance matrix. Throughout the results section, unstandardized

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Fig. 1. Depiction of assessment schedule. Note. Days 3–8 not pictured.
estimates are reported, consistent with current recommendations. Currently there is no agreed-upon consensus method for reported effect size in multilevel modeling (Raudenbush & Bryk, 2002; Singer & Willet, 2003). However, it is possible to identify the relative effect size of a certain variable in multilevel modeling by calculating the proportion reduction in variance (PRV; Peugh, 2010), which are reported for primary analyses. Chi-square and related model fit statistics are not available for random effects multilevel models in MPlus, therefore they are not reported. However, it is difficult to compare model fit across multilevel models given the variance partitioned at each level differs as variables are added, making these indexes less useful.

For direct effect models, the dependent variable was PTSD symptoms at daily sessions 1–3 (i.e., waking, morning, afternoon; see Fig. 1), with variance partitioned at the session- and day-level. Independent day-level variables were the relevant sleep disturbance variable and, as a covariate, night PTSD symptoms (see Fig. 1). As such, we examined the contribution of sleep disturbances to next day PTSD symptoms, after accounting for the previous evening’s PTSD symptoms. For mediation models, the Monte Carlo method for assessing mediation was used (Selig & Preacher, 2008).

The dependent variable was PTSD symptoms at sessions 2–3 (morning, afternoon; see Fig. 1). The independent day-level predictors were the relevant sleep variable, with prior evening’s PTSD symptoms as a covariate (night; see Fig. 1). Waking negative affect (session 1) served as the mediator. As such, we tested a full temporal mediation model in which sleep disturbances predicted morning NA and later afternoon and evening PTSD symptoms.

3. Results

First, data were screened to confirm accurate data entry, assess for outliers, and evaluate skewness and kurtosis. Evaluation of ranges confirmed that the majority of responses were entered correctly. In three cases, participants entered numbers that were logically impossible (e.g., sleeping over 300 h in one night). Consistent with recommendations of Bell and Malacova (2004), these responses were omitted. No outliers were indicated that could potentially influence the models. Regarding missing data, 80% of the possible EMAs were completed by participants, while the remaining 20% were not completed by participants and are thus missing. No participants were excluded because dropping participants with missing data can introduce bias (Schafer & Graham, 2002).

Means and standard deviations were examined for the variables of interest at baseline to provide descriptive information (see Table 1). PTSD symptoms exceeded the clinical cut-off of 33 (U. S. Department of Veterans Affairs, 2016), and PSQI scores surpassed the clinical cut-off of 5 (Buysse et al., 1989). Average sleep efficiency in the current sample was 74.68% while average sleep duration was 5.83 h. Sleep quality was in the fairly to very bad range, and traumatic nightmares were reported an average of less than once a week. Correlations were in the expected directions. Regarding scores throughout the EMA period, participants reported poor sleep quality across measures (i.e., average sleep quality was rated as in between “fairly good” and “fairly bad,” average sleep duration was 6.61 h [SD = 5.88], average sleep efficiency was 74.7%). Nightmares occurred in 23% of the sleep-related assessments. Average levels of PTSD symptoms were rated as at least a “little bit.” Finally, participants indicated average current levels of both positive and negative affect were in the “a little” range.

3.1. Primary analyses

3.1.1. Sleep disturbances predicting daytime PTSD symptoms

Poor sleep quality and reduced sleep efficiency were each significantly associated with increased daytime PTSD symptoms after accounting for prior evening’s PTSD symptoms (Table 2). The PRV after adding sleep variables was 26.8% for sleep quality and 20.8% for sleep efficiency.

3.1.2. Sleep disturbances predicting daytime affect

Increased next day negative affect was significantly predicted by poor sleep quality (PRV = 57.1%) and decreased sleep efficiency (PRV = 46.3%; Table 2). Decreased next day positive affect was only predicted by poor sleep quality (PRV = 2.8%). Finally, more negative

Table 1

<table>
<thead>
<tr>
<th>Sleep Variable</th>
<th>B</th>
<th>SE</th>
<th>p</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable: PTSD Symptom Severity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nightmares</td>
<td>1.02</td>
<td>0.94</td>
<td>0.280</td>
<td>-0.53, 2.57</td>
</tr>
<tr>
<td>Sleep quality</td>
<td>1.45</td>
<td>0.33</td>
<td>-0.001</td>
<td>0.92, 1.99</td>
</tr>
<tr>
<td>Sleep efficiency</td>
<td>-5.57</td>
<td>1.58</td>
<td>-0.001</td>
<td>-8.16, -2.98</td>
</tr>
<tr>
<td>Sleep duration</td>
<td>-0.002</td>
<td>0.03</td>
<td>0.941</td>
<td>-0.05, 0.05</td>
</tr>
<tr>
<td>Dependent Variable: Negative Affect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nightmares</td>
<td>-0.34</td>
<td>0.49</td>
<td>0.488</td>
<td>-1.15, 0.47</td>
</tr>
<tr>
<td>Sleep quality</td>
<td>0.62</td>
<td>0.22</td>
<td>0.005</td>
<td>0.19, 1.06</td>
</tr>
<tr>
<td>Sleep efficiency</td>
<td>-1.89</td>
<td>0.96</td>
<td>0.048</td>
<td>-3.46, -0.02</td>
</tr>
<tr>
<td>Sleep duration</td>
<td>-0.02</td>
<td>0.02</td>
<td>0.358</td>
<td>-0.05, 0.02</td>
</tr>
<tr>
<td>Dependent Variable: Positive Affect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nightmares</td>
<td>0.82</td>
<td>0.56</td>
<td>0.148</td>
<td>-0.11, 1.75</td>
</tr>
<tr>
<td>Sleep quality</td>
<td>-0.40</td>
<td>0.18</td>
<td>0.027</td>
<td>-0.70, -0.10</td>
</tr>
<tr>
<td>Sleep efficiency</td>
<td>-0.29</td>
<td>1.05</td>
<td>0.780</td>
<td>-2.02, 1.76</td>
</tr>
<tr>
<td>Sleep duration</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.323</td>
<td>-0.03, 0.01</td>
</tr>
<tr>
<td>Dependent Variable: Affect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nightmares</td>
<td>0.05</td>
<td>0.12</td>
<td>0.643</td>
<td>-0.14, 0.24</td>
</tr>
<tr>
<td>Sleep quality</td>
<td>-0.20</td>
<td>0.04</td>
<td>-0.001</td>
<td>-0.28, -0.12</td>
</tr>
<tr>
<td>Sleep efficiency</td>
<td>0.26</td>
<td>0.23</td>
<td>0.263</td>
<td>-0.02, 0.01</td>
</tr>
<tr>
<td>Sleep duration</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.983</td>
<td>-0.01, 0.01</td>
</tr>
</tbody>
</table>

Note: Bold—Significant with 95% confidence interval not passing through zero.

Table 2

Effect of sleep parameters on next-day PTSD and affect, accounting for prior evening’s PTSD symptoms (adjusted models).

Table 3

Means, standard deviations, and zero-level correlations for baseline variables.

<table>
<thead>
<tr>
<th>Sleep Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PANAS — NA</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2. PANAS — PA</td>
<td>-0.18</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3. PCL-5 Total</td>
<td>0.55**</td>
<td>-0.14</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4. PSQI Total</td>
<td>0.23</td>
<td>-0.53**</td>
<td>0.52**</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5. Sleep Efficiency</td>
<td>-0.07</td>
<td>0.17</td>
<td>-0.32</td>
<td>0.63***</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>6. Sleep Quality</td>
<td>0.45*</td>
<td>-0.17</td>
<td>0.28</td>
<td>0.54*</td>
<td>-0.29</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7. Sleep Duration</td>
<td>-0.50</td>
<td>0.04</td>
<td>-0.38*</td>
<td>-0.61***</td>
<td>-0.33</td>
<td>-0.36*</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>8. Nightmares</td>
<td>0.45*</td>
<td>-0.15</td>
<td>0.23</td>
<td>0.36*</td>
<td>-0.31</td>
<td>0.44*</td>
<td>-0.18</td>
<td>–</td>
</tr>
<tr>
<td>M (SD)</td>
<td>31.62 (10.75)</td>
<td>23.17 (6.64)</td>
<td>50.86 (15.76)</td>
<td>12.50 (4.35)</td>
<td>72.35 (18.21)</td>
<td>1.93 (0.65)</td>
<td>5.83 (1.29)</td>
<td>2.21 (0.86)</td>
</tr>
</tbody>
</table>

Note: *p < 0.05, **p < 0.01, ***p < 0.001. PANAS—Positive and Negative Affect Schedule; PCL-5 — PTSD Checklist for DSM-5; PSQI—Pittsburgh Sleep Quality Index; Sleep Efficiency is reported in a percentage; Sleep Duration is reported in hours.
affect ratios were significantly associated with poor sleep quality (PRV = 25.0%).

3.1.3. Indirect effects of sleep disturbance on PTSD symptoms through negative affect
Because only sleep quality and sleep efficiency were significantly associated with PTSD symptoms, we focused on these two variables for mediation analyses. First, regarding the model with sleep quality, morning NA significantly predicted PTSD symptoms (i.e., the b path; B = 0.39, SE = 0.96, 95% CI [0.20, 0.87]). Next, the indirect effect of sleep quality on PTSD symptoms through NA was significant (B = 0.80, SE = 0.45, 95% CI [0.23, 1.97]). However, the indirect effect of sleep efficiency on PTSD symptoms via NA was not significant (B = -0.28, SE = 0.92, 95% CI [-5.61, 4.80]).

3.1.4. Alternative mediation model with positive affect
Next, we tested positive affect as an alternative mediator of the association between sleep quality and PTSD symptoms. The effect of positive affect on PTSD symptoms was not significant (B = 0.06, SE = 0.15, 95% CI [-0.22, 0.35]). As such, the indirect effect of sleep quality on PTSD symptoms through positive affect was not significant (B = -0.06, SE = 0.13, 95% CI [-0.32, 0.26]).

3.1.5. PTSD specificity analyses
Finally, because of the high level of conceptual overlap between PTSD symptom clusters D and E (negative alterations in cognition and mood, alterations in arousal and reactivity) and negative affect, we replicated the PTSD-related analyses using only symptom clusters B and C (re-experiencing and avoidant) as the dependent variable. After accounting for the effects of prior evening’s PTSD symptoms (clusters B and C), elevated daytime B and C PTSD symptom clusters were associated with: poor sleep quality (B = -0.26, SE = 0.16, 95% CI [0.45, 1.08]) and sleep efficiency (B = -0.32, SE = 0.82, 95% CI [-4.88, -1.65]); but not nightmares (B = -0.53, SE = 0.53, 95% CI [-0.50, 1.57]) or sleep duration (B = 0.01, SE = 0.02, 95% CI [-0.03, 0.04]). In terms of the mediation model, morning NA did not significantly predict PTSD symptom clusters B and C at sessions 2 and 3 (B = 0.17, SE = 0.14, 95% CI [-0.10, 0.44]), thus the indirect effect of sleep quality on PTSD symptom clusters B and C was not significant (B = -0.37, SE = 0.31, 95% CI [-0.23, 0.96]).

3.1.6. Effect of PTSD symptoms on sleep
Finally, we tested whether analyses remained consistent in the opposite direction (Table 3) — that is, do increased daytime PTSD symptoms predict worsened sleep? After adjusting for baseline severity of insomnia symptoms, daytime PTSD symptoms did not significantly predict worsened sleep quality or efficiency, or lower sleep duration. After accounting for baseline nightmare severity, daily PTSD symptom severity continued to predict nightmares (PRV = 3.8%).

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE</th>
<th>p</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nightmares</td>
<td>0.02</td>
<td>0.01</td>
<td>0.001</td>
<td>0.01, 0.02</td>
</tr>
<tr>
<td>Sleep quality</td>
<td>0.03</td>
<td>0.02</td>
<td>0.148</td>
<td>-0.01, 0.06</td>
</tr>
<tr>
<td>Sleep efficiency</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.391</td>
<td>-0.01, 0.01</td>
</tr>
<tr>
<td>Sleep duration</td>
<td>-0.03</td>
<td>0.03</td>
<td>0.324</td>
<td>-0.08, 0.02</td>
</tr>
</tbody>
</table>

*Note: Bold—Significant with 95% confidence interval not passing through zero.
*a for nightmares, we covaried for baseline Disturbing Dreams and Nightmares Severity Index (DDNS) while for sleep quality, sleep efficiency, and sleep duration, we covaried for baseline Insomnia Severity Index (ISI) scores.

4. Discussion
The current study utilized EMA to evaluate relationships between sleep disturbance, PTSD symptoms, affect, and whether the relationships between sleep and PTSD symptoms can be accounted for by negative affect. Consistent with hypothesis, after accounting for prior evening’s PTSD symptoms, poor sleep quality and efficiency were significantly associated with increased daytime PTSD symptoms. This is consistent with prior research (Short et al., 2014b; Wright et al., 2011), but we expand upon it by finding that daily worsening in sleep quality and efficiency is associated with increased PTSD symptom severity the next day — and that these relations cannot be accounted for by prior evening’s PTSD symptom severity. Also consistent with our hypothesis, poor sleep quality was significantly associated with increased daytime negative affect, decreased positive affect, and negatively valenced affect ratios after accounting for prior evening’s PTSD symptoms. Furthermore, reduced sleep efficiency was associated with increased negative affect. Our results complement laboratory work (Sagapone et al., 2006; Talbot et al., 2010) by finding that daily variations in sleep quality are associated with changes in effect among those with PTSD. Furthermore, results are consistent with EMA studies in other clinical samples indicating daily variations in sleep are associated with changes in next-day affect (Ebner-Priemer & Trull, 2009; Mulligan, Haddock, Emsley, Neil, & Kyle, 2016). This is important as it suggests that natural variations in sleep quality and efficiency impact daytime affect. Finally, it is important to note that poor sleep quality and efficiency are likely due to underlying sleep disorders, such as insomnia disorder.

Results also indicated that elevated daytime PTSD symptoms predicted increased nightmares, but not poor sleep quality, efficiency, or duration. These findings go against the traditional view that sleep disturbances are produced by PTSD symptoms. Instead, our results indicate that PTSD symptoms are more consistently influenced by sleep quality and efficiency, rather than influencing them. On the other hand, PTSD symptoms appear to exacerbate nightmares, which is compatible with traditional views.

In terms of mediation models, consistent with hypothesis, multilevel mediation analysis indicated a significant indirect effect of sleep quality on PTSD symptoms via negative affect. These findings fit within models suggesting that sleep disturbances play a causal and/or maintaining role in PTSD via their impact on affective functioning (Germain, 2013; Harvey, 2008). Specifically, sleep disturbances may lead to increased negative affect and increased reactivity to stressors, including trauma reminders, which may motivate increases in avoidance of internal and external trauma cues, exacerbating PTSD symptoms.

Regarding specificity analyses, we ruled an alternative mediator, providing increased confidence for negative affect as a mediator of the relationship between sleep quality and PTSD symptoms. Furthermore, we confirmed that when only unique PTSD symptoms (i.e., re-experiencing, avoidance) are included, and general negative affect-related clusters (i.e., negative alterations in cognition and mood, alterations in arousal and reactivity) are excluded, poor sleep quality and efficiency continued to predict elevated PTSD symptoms. These results provide confidence for the specificity of the relationship between sleep quality and PTSD that cannot be attributed solely to the negative affect-related symptoms of PTSD.

Inconsistent with hypotheses, neither nightmares nor sleep duration were associated with PTSD symptoms or affect after accounting for prior evening’s PTSD symptoms. This could be because nightmares are closely tied to PTSD symptom severity, as results indicated that nightmares were the only aspect of sleep disturbance, and that these relations cannot be accounted for by prior evening’s PTSD symptom severity. Additionally, other aspects of psychological functioning we did not measure (e.g., emotional memory) may be more closely tied to nightmares.
(Goldstein & Walker, 2014). Regarding sleep duration, the lack of significant findings is somewhat expected given that individuals differ in the amount of sleep they need (Van Dongen, Vitellaro, & Dinges, 2005). Finally, negative affect did not mediate the relationship between sleep efficacy and PTSD symptoms, or sleep quality and PTSD symptom clusters B and C. Several other viable mediators, including problems with executive and cognitive functioning, and fear learning (Germain, 2013; Walker, 2009), are associated with poor sleep, and could influence PTSD symptoms. Further research is needed to determine the mechanism of these relationships.

The current findings also have clinical implications: targeting sleep disturbances may improve outcomes for individuals with PTSD. Interventions promoting sleep quality and efficiency may be particularly beneficial. Cognitive Behavioral Therapy for Insomnia (CBT-I) is an empirically supported treatment for insomnia that would address these problems (Edinger, Wohlgenuth, Radtke, Marsh, & Quillian, 2001). CBT-I is effective among those with PTSD in ameliorating insomnia (Margolies, Rybarczyk, Vrana, Leszczyszyn, & Lynch, 2013; Talbot et al., 2014). Further research is needed to determine the effects of sleep interventions on emotional functioning in PTSD. However, findings suggest improving sleep may improve individuals’ day-to-day affective functioning, potentially improving engagement in and tolerance of trauma-focused treatment.

Results from the current study must be considered in the context of limitations. First, this study did not utilize an objective measure of sleep, such as actigraphy. Self-reported and actigraphy-assessed sleep measures tend to converge fairly well (Carney, Lajos, & Waters, 2004). However, those with PTSD may underestimate their sleep quality and number of awakenings in self-report (Dagan, Zinger, & Lavie, 1997; Westermeyer et al., 2007). As such, actigraphy could complement self-report in future studies. Furthermore, use of polysomnography to assess baseline sleep could add further precision to our understanding of participants’ sleep (Chesson et al., 1997). Second, individuals’ ratings of their sleep and mood may have been influenced by the other (e.g., I feel bad, so I must have slept poorly). However, we assessed affect throughout the day, including times when sleep was likely to be less salient and thus less likely to influence self-report. Third, the majority of our sample was diagnosed with comorbid psychiatric disorders. Although this is a strength of the study, as it is reflective of the reality of PTSD (Kessler et al., 1995), it also makes it more difficult to determine the specificity of the relationship between sleep disturbances and PTSD. Fourth, the current findings cannot draw causal conclusions as we cannot establish a temporal precedence for sleep problems prior to PTSD. Future research is necessary to evaluate the causal role of sleep disturbances in the development and maintenance of PTSD. Fifth, the sample size was small and results may not generalize to the population of individuals with PTSD. However, findings are grounded within theoretical rationale and the sample size is typical for clinical EMA studies (Mulligan et al., 2016; Ratcliff et al., 2014). Sixth, it is possible the text messages themselves served as trauma reminders, artificially inflating the presence and severity of PTSD symptoms during the EMA period. However, this method is standard for PTSD EMA research (Priebe et al., 2013), and, considering all participants received text messages, it is unlikely this would affect associations between sleep disturbance and PTSD.

Despite these limitations, findings add to research highlighting sleep disturbances as a critical factor in affect and PTSD symptoms. Additionally, this study integrated separate lines of research and suggested that sleep disturbances may worsen symptoms of PTSD via problems with affective functioning. Future research is necessary to further elucidate whether sleep-related interventions could help to reduce the burden of PTSD.

### Funding

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### APPENDIX A. EMA assessment

#### Sleep

The following questions relate to your sleep habits last night only. Your answers should indicate the most accurate reply for last night only.

1. Last night, how long (in minutes) did it take you to fall asleep? ______ minutes
2. Last night, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.) __________ hours
3. Last night, how many times did you wake up? __________
   a Last night, on average, how long did each awakening last? ______ minutes
4. This morning, did you wake earlier than you intended?
   Yes ______
   No ______
   a This morning, how much earlier did you wake than intended? ______ minutes
5. Last night, how would you rate your sleep quality overall?
   Very good ______
   Fairly good ______
   Fairly bad ______
   Very bad ______
6. Last night, did you take medicine to help you sleep?
   Yes ______
   No ______
7. Last night, did you have trouble sleeping because you…
   a Felt hot flashes? Yes ______ No ______
   b Felt general nervousness? Yes ______ No ______
   c Had memories or nightmares of a traumatic experience? Yes ______ No ______
d. Had severe anxiety or panic, not related to traumatic memories?
   Yes ______
   No ______

e. Had bad dreams, not related to traumatic memories?
   Yes ______
   No ______

f. Had episodes of terror or screaming during sleep without fully awakening?
   Yes ______
   No ______

g. Had episodes of “acting out” your dreams, such as kicking, punching, running, or screaming?
   Yes ______
   No ______

Affect

Read each item and then mark the appropriate answer. Indicate to what extent you have felt this way indicate how you feel right now, that is, at this moment.

<table>
<thead>
<tr>
<th>Very Slightly or Not at All</th>
<th>A Little</th>
<th>Moderately</th>
<th>Quite a Bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interested</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Upset</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Guilty</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Scared</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Enthusiastic</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Irritable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Alert</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Determined</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

PTSD symptoms

Please read each statement carefully, then select one of the numbers to the right to indicate how much you have been bothered by that problem since your last online survey assessment.

<table>
<thead>
<tr>
<th>Response: Not at all</th>
<th>A little</th>
<th>Moderately</th>
<th>Quite a Bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Repeated, disturbing, and unwanted memories of the stressful experience?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Repeated, disturbing, and unwanted memories of the stressful experience?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Having strong physical reactions when something reminded you of the stressful experience (for example, heart pounding, trouble breathing, sweating)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Avoiding memories, thoughts, or feelings related to the stressful experience?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Avoiding external reminders of the stressful experience (for example, people, places, conversations, activities, objects, or situations)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Feeling distant or cut off from other people?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References


