






## Original Article

# Bidirectional links between sleep and pain among heavy-drinking veterans with insomnia

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## Abstract

**Study Objectives:** Military veterans often suffer from chronic pain and sleep issues at a greater frequency than the general population, leading some to self-medicate with alcohol. While research shows a connection between sleep and pain, few studies have examined bidirectional links between sleep and pain at the daily level—or the extent to which alcohol use may moderate these associations.

**Methods:** Heavy-drinking veterans seeking treatment for insomnia ( $N = 109$ , 82.5% male, mean age 38.9 years) completed 14 days of morning diaries documenting sleep patterns, pain intensity, and alcohol consumption. Multilevel modeling examined within- and between-person associations between sleep (quality, duration, and efficiency) and next-day pain as well as pain and same-night sleep.

**Results:** Individuals with longer sleep duration, better sleep quality, and higher sleep efficiency (SE) reported lower pain levels compared to those with shorter sleep, poorer sleep quality, and lower SE ( $p$  values  $<.001$  to  $.01$ ). In addition, on days when individuals experienced better sleep quality compared to their own average, they reported lower pain levels the following day ( $p = .01$ ). In contrast to hypotheses, daily pain levels did not predict sleep outcomes at the daily within-person level, although significant between-person correlations were noted. Daily alcohol intake did not affect these relationships.

**Conclusions:** Sleep quality is associated with the daily experience of pain among heavy-drinking veterans with insomnia. Daily variations in sleep quality significantly impact pain, irrespective of alcohol consumption, highlighting a predominantly unidirectional influence from sleep to pain. These findings underscore the importance of optimizing sleep to mitigate pain in this population.

**Key words:** alcohol; military veterans; multilevel modeling; pain; sleep quality

## Statement of Significance

This study is among the first to explore day, within-person level associations between sleep and pain in veterans, a group disproportionately affected by these issues. It provides novel insights into the dynamic interplay between daily sleep and pain, revealing that improved sleep quality significantly reduces pain the following day. Importantly, this relationship appears to be unidirectional, as daily fluctuations in pain did not significantly alter sleep quality. These findings are particularly critical for heavy-drinking veterans with symptoms of insomnia, highlighting sleep optimization as a potential strategy for pain management. Future research should investigate the mechanisms underlying these associations. Such research is essential for developing targeted interventions to improve the quality of life and health outcomes for Veterans.

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## Introduction

Those who serve and have served in the military experience unique occupational stressors, such as combat exposure, deployments, and frequent relocations (i.e. permanent changes of station) that make this population susceptible to physical injury and mental health issues [1]. Indeed, military veterans exhibit higher prevalence rates of mental health disorders (e.g. depression, post-traumatic stress disorder; PTSD) and alcohol misuse compared to the general adult population [2, 3]. Pain is one of the most common problems among veterans, with rates between 48% and 81% among those enrolled in Veterans Health Administration (VHA) healthcare [4, 5]. Again, compared to the general adult population, chronic pain disproportionately affects veterans. In a population-based survey from 2010 to 2014 sampling 67,696 adults in the United States, veterans reported experiencing persistent severe pain at a 40% higher rate than nonveterans [6]. Moreover, although rates of chronic pain are increasing in general, the prevalence of any pain increased at a greater rate among veterans than nonveterans from 2002 to 2018 [7].

Veterans also commonly experience sleep disturbances that can stem from or be exacerbated by military service, including deployments with little sleep opportunity, incommensurate sleeping environments, shiftwork, and exposure to stressors. A meta-analysis assessing sleep quality in the military reported that the pooled prevalence rate of clinically significant “poor” sleep quality (based on the Pittsburgh Sleep Quality Index global score of >5) was 83% among veterans [8]. Like chronic pain, diagnoses of sleep disorders are also increasing in this population. In a recent review [9], virtually every sleep disorder diagnosed within the VHA increased from 2012 to 2018, with the largest increases in sleep-related breathing disorders and insomnia. Chronic pain and sleep problems (e.g. insomnia, nightmares) are independently associated with other adverse health outcomes, such as suicide risk [10, 11], mental health symptoms [12, 13], and worse overall quality of life [11, 12]. As such, both pain and sleep problems constitute significant clinical concerns within the federal healthcare system.

A wealth of cross-sectional research has documented relationships between pain and sleep. In a recent meta-analysis [14], the pooled prevalence of sleep disorders among those with chronic pain was 44%, with worse objectively estimated sleep onset latency (SOL), sleep efficiency (SE) (i.e. percentage of time in bed spent asleep), and nighttime awakenings among this group as well. Short sleep duration [15] and worse subjective sleep quality have also been shown to be associated with more severe chronic pain [16, 17].

It has been posited that the relationship between sleep and pain is bidirectional, such that sleep disturbances worsen pain and pain also contributes to disrupted sleep. Indeed, longitudinal epidemiological studies have found evidence of reciprocal relationships between sleep disturbances and pain [18]. Prospective studies examining sleep and pain among veterans are fewer, and their findings are less consistent. Koffel et al. [19] examined relationships between sleep and pain across a 12-month randomized clinical trial for the treatment of chronic pain; they found that changes in sleep at 3 months predicted changes in pain at 12 months. They also found support for the inverse relationship, but the strength was weaker. In contrast, another randomized clinical trial did not show evidence that changes in sleep predicted changes in pain or vice versa among patients with chronic pain [20]. Although at least one study has shown sleep disturbances and pain to be relatively stable across time [21], deciphering daily

variations in both sleep patterns and pain levels would help identify tangible targets for intervention. However, micro-longitudinal studies capable of assessing these patterns are scarce.

Of the micro-longitudinal studies on sleep and pain to date, findings are somewhat mixed. In 2017, Edwards and colleagues conducted a micro-longitudinal study examining daily sleep duration and pain ratings across 1 week in the general population. They found that both short (i.e. <6 h) and long (i.e. >9 h) sleep duration predicted greater next-day pain [22]. They also found that pain significantly predicted shorter next-day sleep duration, though this association was weaker. In another study, Tang et al. found that pre-sleep pain was not a significant predictor of subsequent sleep quality, though sleep quality was predictive of pain upon awakening and throughout the first half of the day [23]. To the best of our knowledge, micro-longitudinal study designs have yet to be utilized in a Veteran sample, which may clarify previous conflicting findings by shedding more light on potential diurnal changes among these variables, as well as the influence of other covariates that influence sleep and pain.

Given that veterans often have comorbid health conditions that influence sleep and pain, like mental health symptoms [5], they may be more susceptible to self-medication of pain with alcohol. Of note, alcohol misuse is common in veterans, with nearly 41% of veterans estimated to have a lifetime diagnosis of alcohol use disorder [24]. Veterans with sleep problems are also more likely to report using alcohol as a sleep aid [25, 26]. Alcohol use may be especially pertinent for both pain and sleep due to its role as a central nervous system depressant. Veterans may drink alcohol for its sedating effects to temporarily ease pain and/or initiate sleep at the cost of long-term symptom maintenance. Indeed, symptoms of alcohol use disorder have been independently linked to worse pain interference (i.e. interference with daily function) [27] and insomnia symptoms [28, 29].

Despite veterans' high risk for alcohol misuse and associated comorbid health issues, there is a notable lack of systematic research on daily associations between pain and sleep among veterans with alcohol use disorders, who demonstrate high rates of both pain and insomnia [30, 31]. The interplay between sleep and pain is further complicated by the introduction of alcohol, given alcohol's dual role as a disruptor of sleep architecture and a temporary analgesic. Clarifying the extent to which alcohol use modifies the daily dynamics of sleep and pain is not only of theoretical interest but also of critical importance for developing tailored interventions for veterans who struggle with these inter-related issues.

This secondary analysis of baseline data from a clinical trial tested the bidirectional relationship between sleep and pain among heavy-drinking veterans seeking treatment for insomnia. At the between-person level, we hypothesized that veterans with shorter average sleep duration, worse average sleep quality, and lower average SE would report more pain over the 14 days period compared to those with longer average sleep duration, better average sleep quality, and higher average SE. At the day, within-person level, we hypothesized that following days of longer sleep duration, better sleep quality, and higher SE—compared to each participant's own average—participants would report lower pain levels the next day, and vice versa. In addition, we hypothesized that alcohol use would moderate these daily associations between sleep and pain. Due to the paucity of existing studies and the complex nature of alcohol's impact (as both a sedative and sleep disruptor), we did not hypothesize the direction of this moderating effect; our investigation into this relationship is exploratory. The goal of this research is to uncover patterns and

connections that could inform the development of interventions for individuals who are concurrently managing pain, sleep disturbances, and alcohol use.

## Methods

### Participants and procedure

Participants were heavy-drinking veterans seeking treatment for insomnia through a research study. They were recruited between June 2019 and March 2023 to participate in the larger treatment study via digital marketing advertisements, which routed to an online screening survey. Those who screened eligible provided informed consent and met with trained research staff to complete a semi-structured interview. In addition, they completed self-report baseline measures and daily sleep diaries for 14 consecutive days. Sleep diaries were completed remotely and time stamped via Qualtrics. The institutional review board approved all procedures.

Eligible participants [1] served in the United States military after November 9, 2001; (2) reported 1+ heavy-drinking episode (4/5+ drinks for women/men) in the past 30 days; (3) reported >30 minutes SOL or wake after sleep onset (WASO) on 3+ nights per week; (4) scored  $\geq 10$  on the Insomnia Severity Index [28]; and (5) completed  $\geq 8$  of the 14 sleep diaries [29]. Of those who completed the screening ( $N = 1064$ ), 109 met all eligibility criteria.

## Measures

### Demographics

Participants provided information regarding their age, sex assigned at birth, gender identity, sexual orientation, education, and military involvement (i.e. active duty, reserves, Veteran). For race/ethnicity, participants were asked to choose all that apply (see response options in Table 1), and those who chose more than one race were categorized as “multi-racial.”

### Sleep

On each morning sleep diary, participants reported the time they got into bed (“down” time), the time they started trying to fall asleep (bedtime), minutes it took to fall asleep (SOL), minutes awake throughout the night (WASO), time of final awakening (waketime), time they got out of bed for the day (“up” time), and their subjective sleep quality on a scale of 0 (*very poor*) to 4 (*very good*) [32]. Primary sleep outcomes in the current study included sleep quality, total sleep time (TST), and SE. Prior nights’ TST was calculated by subtracting SOL and WASO from time in bed (time elapsed between “down” time and “up” time). Sleep efficiency is the ratio of TST to time spend in bed, expressed as a percentage. Self-reported measures of sleep were used, as this is the recommended method for assessing insomnia [33].

### Pain

The previous day’s pain was assessed each morning on the daily sleep diary. Participants were asked to report the “intensity of pain” they felt yesterday on a scale from 0 (*no pain*) to 100 (*worst pain possible*) [34].

### Alcohol use

Participants were provided with standard drink definitions [e.g. 1.5 oz liquor (1 shot) = 1 standard drink] and then asked to report the number of standard drink(s) they consumed the day before.

**Table 1.** Demographic Information for Heavy-Drinking Veterans With Insomnia ( $N = 109$ )

Characteristic	Value
Age, M (SD)	38.8 (9.6)
Male, n (%)	92 (84.4%)
Race/ethnicity, n (%)	—
Asian, American Indian, or Alaska Native	4 (3.7%)
Black or African American	4 (3.7%)
Hispanic or Latino/a/x	3 (2.8%)
Multiracial or Multi-Ethnic	12 (11.0%)
White	86 (78.9%)
Military branch, n (%)	—
Air force	12 (11.0%)
Army	69 (63.3%)
Coast guard or marines	18 (16.5%)
Navy	10 (9.2%)
Military involvement, n (%)	—
Active	30 (27.5%)
Reserves	11 (10.1%)
Veteran	68 (62.4%)
Number of deployments, M (SD)	2.0 (2.1)
Diary variables	—
Pain, M (SD)	28.5 (22.8)
Mild (avg daily scores 0–30), n (%)	63 (57%)
Moderate (avg daily scores 31–60), n (%)	33 (31%)
Severe (avg daily scores 61–100), n (%)	13 (12%)
Sleep duration (hours), M (SD)	6.2 (1.3)
Sleep efficiency, M (SD)	72.4 (12.4)
Sleep quality, M (SD)	1.8 (0.6)
Drinks per day, M (SD)	2.4 (2.1)

Abbreviations: Avg, average; M, mean; n, number of participants; SD, standard deviation.

Heavy drinking was defined as the consumption of 4+ drinks for women or 5+ drinks for men in a single day.

## Data Screening and Analysis

Analyses were conducted in IBM SPSS Statistics 29. Outcome variables were first screened for missingness, integrity, and normality. Data were collected for 14 days. On average, participants ( $N = 109$ ) completed 12.53 diaries ( $SD = 1.82$ ; 1366 data points) and reported 6.63 drinking days ( $SD = 4.07$ ; 723 data points). Sleep and alcohol variables were missing on <1% of data points, and pain variables were missing on 1.6%.

Preliminary unconditional models were conducted to determine the intraclass correlation coefficient for each outcome. Significant within-person (70%) and between-person (30%) variability was observed in TST. Comparable variations were noted in sleep quality (71% within; 29% between), SE (66% within; 34% between), SOL (73% within; 27% between), WASO (71% within; 29% between), pain (21% within; 79% between), and drinking quantity (65% within; 35% between). Multilevel modeling was used to examine within- (Level 1) and between-person (Level 2) effects of sleep variables on pain intensity and vice versa [35].

Full models were then specified. Continuous Level 1 (L1 represented variability from within-person repeated measures collected on a daily basis) variables were centered by person means, and Level 2 (L2 represented between-person variability) variables

were centered by grand means [36]. In models examining pain effects on sleep parameters (sleep duration, SE, and sleep quality), pain was assumed to precede sleep. In models examining sleep effects on pain, pain was lagged so that sleep parameters would predict pain the following day. Sex (0 = female, 1 = male), weekend versus weekday reports (0 = Sunday to Thursday, 1 = Friday or Saturday), and day in the study [1–14] were included as covariates. Intercepts were specified as random, and an autoregressive covariance structure was specified for repeated effects. All available data were used.

To examine the moderating effect of alcohol consumption on the relationship between sleep and pain (and vice versa), we computed interaction terms between Level 1 sleep quality and Level 1 alcohol use as predictors of pain. Similarly, we computed interaction terms between Level 1 pain and Level 1 alcohol use as predictors of sleep.

## Results

Participants consisted of 92 (84%) men and 17 (16%) women who ranged in age from 21 to 67 years ( $M = 38.8$ ,  $SD = 9.6$ ). The majority were non-Hispanic (97%) and White (79%). Table 1 presents descriptive data for the analytic sample.

### Is sleep related to next-day pain?

We examined whether sleep is associated with next-day pain, as depicted in Table 2. Sleep duration and SE were not associated with next-day pain at the within-person level. However, a negative association was observed between sleep quality and pain at the within-person level, indicating that participants experienced about a 1-point decrease in pain on days they reported better sleep quality than their own average. Between-person differences in pain intensity were observed for all three sleep variables. Specifically, individuals with longer sleep duration, better sleep quality, and higher SE reported lower pain levels compared to those with shorter sleep, poorer sleep quality, and lower SE, respectively.

### Is pain related to same-day sleep?

To test the reverse directionality between pain and sleep, we modeled pain as a predictor of sleep parameters that evening. No within-person associations between pain and sleep were observed (see Table 3). However, significant between-person effects were observed between pain and all three sleep variables, such that veterans reporting high levels of pain reported worse sleep parameters (i.e. shorter sleep duration, poorer sleep quality, and lower SE) compared to those with lower levels of pain.

### The moderating role of daily alcohol use between daily sleep and daily pain

Daily alcohol use did not moderate the relationships between daily sleep and pain in either direction (sleep quality to pain,  $p = .97$ ; pain to sleep quality,  $p = .23$ ; sleep duration to pain,  $p = .44$ ; pain to sleep duration,  $p = .09$ ; SE to pain,  $p = .29$ ; pain to SE,  $p = .48$ ).

## Discussion

This study is one of few to examine day-level, within-person associations between sleep and pain. To the best of our knowledge, it is also the first to do so among veterans, who disproportionately experience these problems. Building upon existing

**Table 2.** Sleep Predicting Next-Day Pain ( $N = 109$ )

Total sleep time model	Pain		
	b	SE	p
Intercept	15.94	8.82	.07
Day in study	0.20	0.13	.13
Male (vs female) sex	0.01	5.10	.99
Weekend (vs weekday)	2.10	0.76	.01
Military involvement	6.45	4.50	.15
Number of deployments	0.69	1.03	.51
L1 total sleep time	-0.29	0.18	.12
L2 total sleep time	-4.64	1.63	.01
<b>Sleep quality model</b>	<i>b</i>	<i>SE</i>	<i>p</i>
Intercept	12.78	8.44	.13
Day in study	0.19	0.13	.13
Male (vs female) sex	1.54	4.89	.75
Weekend (vs weekday)	2.00	0.75	.01
Military involvement	7.11	4.28	.10
Number of deployments	1.02	0.98	.30
L1 sleep quality	-0.94	0.38	.01
L2 sleep quality	-15.55	3.44	<.001
<b>Sleep efficiency model</b>	<i>b</i>	<i>SE</i>	<i>p</i>
Intercept	17.03	8.52	.05
Day in study	0.18	0.13	.16
Male (vs female) sex	1.87	4.96	.38
Weekend (vs weekday)	2.11	0.76	.01
Military involvement	4.80	4.34	.27
Number of deployments	0.67	1.00	.50
L1 sleep efficiency	-0.003	0.02	.88
L2 sleep efficiency	-0.65	0.16	<.001

Note. Table reports unstandardized coefficients (b) with standard errors (SE) in parentheses. L1 = level 1 (daily within-person) effects. L2 = level 2 (between-person) effects.

research at the between-person level, our study supports the finding that veterans who get better sleep—longer durations, higher quality, and greater efficiency—experience less pain than those who get worse sleep, and vice versa [15, 16]. This study extends past research by also testing these associations at the within-person level. Veterans reported significantly less pain following nights of better-than-usual sleep quality, but their sleep did not change significantly as a function of daily variations in pain. This suggests a unidirectional influence of sleep quality on pain, consistent with research among non-veteran adults [37] and adolescents [38]. These findings indicate that sleep quality may play a role in the management of pain among heavy-drinking veterans with insomnia. Studies testing the impact of sleep interventions on pain may be especially warranted in this population.

In contrast to the hypotheses, we did not find daily, within-person associations between pain and same-day sleep. Several potential explanations exist for why fluctuations of daily pain did not affect daily sleep quality. One reason might be that the effects of pain experienced early in the day do not persist until bedtime. In addition, given the high prevalence of chronic pain in this clinical population [4, 5], veterans may adapt to or manage their pain during the day through medication or other coping strategies, which might reduce its perceived impact on sleep [39–41]. In addition, there is a high comorbidity of mental health

**Table 3.** Pain Predicting Same-Night Sleep (N = 109)

Parameter	Primary sleep outcomes								
	Total sleep time			Sleep quality			Sleep efficiency		
	b	SE	p	b	SE	p	b	SE	p
Intercept	6.06	0.50	<.001	1.49	0.22	<.001	70.43	4.63	<.001
Day in study	0.05	0.01	<.001	0.02	0.01	<.001	0.48	0.12	<.001
Male (vs female) sex	-0.54	0.31	.08	-0.002	0.13	.99	0.64	2.84	.82
Weekend (vs weekday)	0.41	0.11	<.001	0.06	0.05	.28	2.65	1.02	.01
Military involvement	0.26	0.25	.31	-0.15	0.11	.16	-0.33	2.32	.89
Number of deployments	0.03	0.06	.60	0.03	0.02	.20	0.16	0.53	.77
L1 pain	0.004	0.004	.41	-0.003	0.002	.20	0.05	0.04	.20
L2 pain	-0.01	0.01	.01	-0.01	0.002	<.001	-0.22	0.05	<.001

Note. Table reports unstandardized coefficients (b) with standard errors (SE) in parentheses. L1 = level 1 (daily within-person) effects. L2 = level 2 (between-person) effects.

symptoms among veterans [42], so psychological factors such as stress or anxiety related to pain could have a more pronounced effect on sleep quality than the physical sensation of pain itself [43, 44]. Alternatively, because daily pain intensity in this sample was relatively low ( $M = 28.50$  on a scale from 0 to 100), this insignificant association could be due to floor effects. Indeed, studies among veterans with chronic pain do tend to find longitudinal evidence of bidirectional associations between pain and sleep [19].

Also contrary to hypotheses, alcohol use did not moderate associations between sleep and pain. This is notable, given that veterans in this study were recruited for heavy drinking. This lack of effect may be attributed to several factors. First, the mechanisms by which sleep quality facilitates pain reduction—such as enhanced immune system function or improved endocrine balance [45]—may be robust enough to withstand the effects of alcohol on sleep. Alternatively, the total drinking quantity measure used in this study may have been inadequate to detect meaningful associations. For example, perhaps drinking right before bed (vs earlier in the day) has different effects than total drinks per day. Similarly, tolerance to the effects of alcohol may lead to diminished physiological responses among those who drink heavily, potentially blunting any expected moderating effects of alcohol on sleep-related pain reduction. Because military culture may normalize heavy drinking while in service and onward [46], and patterns of alcohol consumption tend to remain stable without intervention [47], it is possible that this sample of veterans had developed physiological tolerance to the effects of alcohol. Regardless, data seem to indicate that the beneficial effects of good sleep on pain reduction are relatively robust, irrespective of total alcohol consumption. These findings underscore the importance of examining the variability of sleep quality in daily life, which is especially salient for pain management, regardless of alcohol use.

The findings of the current study offer valuable clinical insights. First, considering the link between sleep and next-day pain, cognitive behavioral therapy for insomnia (CBT-I) should be offered as an adjunct to pain treatment for those with insomnia. Cognitive behavioral therapy for insomnia is highly effective in reducing insomnia symptoms [5] and also reduces pain in chronic pain populations [48]. Thus, CBT-I holds potential to alleviate overall pain. Veterans have access to formal insomnia treatments, such as CBT-I, through the VHA, a key provider of these services across the United States. However, despite the

availability of these services, some veterans may face barriers, such as extended wait times (longer than 28 days) or long commutes to VHA specialty providers. As such, continued efforts to improve access to CBT-I are encouraged. Non-sleep providers may overlook sleep problems among veterans presenting to the VHA for chronic pain and/or alcohol use and therefore may not refer for this treatment. For instance, in a study among VHA primary care physicians (PCPs), it was reported that PCPs did not proactively assess for insomnia and that sleep was viewed as a relatively low priority compared to other health concerns (REF) [49]. Findings from studies like this can be instrumental in educating providers on the importance of sleep on health outcomes.

Our process-oriented investigation into the relationship between sleep and pain could also help identify targets for prevention and intervention efforts. Specifically, the relationship between within-person sleep quality and next-day pain underscores the importance of targeted interventions focused on enhancing sleep quality, as opposed to sleep duration or SE. While improvements in sleep duration or SE may theoretically be expected to correlate with improved sleep quality, sleep quality can also be influenced by non-sleep factors, such as mood and overall health status [50]. For veterans who are unable to access VHA or community care services due to logistical or personal reasons, alternative strategies to improve subjective sleep quality—such as using blackout curtains, noise machines, regular exercise, or relaxation techniques—may be recommended as preliminary first steps.

This study examined 14 days of diary data to elucidate the intricate daily interplay between sleep and pain in a clinical sample of veterans at both the between- and within-person levels. However, results should be interpreted within the context of some limitations. First, the data were solely obtained through self-report. Future research would benefit from incorporating objective measures of sleep, such as actigraphy and polysomnography, to provide deeper insights into how sleep duration and SE relate to pain in real time. Second, it would be advantageous to measure different aspects of pain, including psychological components (e.g. pain catastrophizing), to gain a more comprehensive understanding of pain dynamics. Third, the study population was limited in both demographic and clinical characteristics. For example, participants were predominantly male and non-Hispanic White. All participants also reported heavy drinking and sleep complaints and only 43% reported moderate

to severe levels of chronic pain. This limits the generalizability of findings, which may differ for those with chronic insomnia and more severe levels of pain. Future studies should aim to include a more diverse sample to explore potential variations in sleep-pain interactions across different genders and ethnic groups, enhancing the applicability of the research to a broader range of individuals.

In conclusion, this study offers insight on the dynamic interplay between daily sleep and pain among heavy-drinking veterans. Findings highlight the role of within-person variability in sleep quality on pain experiences and establish a groundwork for future longitudinal studies designed to test the complex physiological, psychological, and behavioral mechanisms underlying these relationships. It also underscores the necessity for continued longitudinal investigations to explore how the day-to-day fluctuations in sleep quality and pain experiences impact long-term health consequences for this specific population. Such studies are essential for developing targeted interventions that could substantially improve the quality of life and health outcomes for veterans facing these challenges.

## Disclosure Statement

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## Author Contributions

Eunjin Tracy (Conceptualization [Lead], Data curation [Lead], Formal analysis [Lead], Investigation [Lead], Methodology [Lead], Writing—original draft [Lead], Writing—review & editing [Lead]), Christine J. So (Validation [Equal], Writing—original draft [Lead], Writing—review & editing [Lead]), Sydney Shoemaker (Validation [Equal], Writing—original draft [Equal], Writing—review & editing [Equal]), Jill Kanaley (Validation [Equal], Writing—review & editing [Equal]), Timothy Trull (Validation [Equal], Writing—review & editing [Equal]), Camila Manrique-Acevedo (Validation [Equal], Writing—review & editing [Equal]), Christina McCrae (Validation [Equal], Writing—review & editing [Equal]), Brian Borsari (Validation [Equal], Writing—review & editing [Equal]), and Mary Beth Miller (Conceptualization [Supporting], Data curation [Lead], Formal analysis [Supporting], Funding acquisition [Lead], Investigation [Equal], Methodology [Supporting], Project administration [Lead], Supervision [Lead], Validation [Lead], Writing—original draft [Equal], Writing—review & editing [Lead])

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author, ELT, upon reasonable request.

## References

- Campbell DJ, Nobel OBY. Occupational stressors in military service: a review and framework. *Mil Psychol.* 2009;**21**(suppl 2):S47–S67. doi:10.1080/08995600903249149
- Rhead R, MacManus D, Jones M, Greenberg N, Fear NT, Goodwin L. Mental health disorders and alcohol misuse among UK military veterans and the general population: a comparison study. *Psychol Med.* 2022;**52**(2):292–302. doi:10.1017/S0033291720001944
- Schein J, Houle C, Urganus A, et al. Prevalence of post-traumatic stress disorder in the United States: a systematic literature review. *Curr Med Res Opin.* 2021;**37**(12):2151–2161. doi:10.1080/03007995.2021.1978417
- Kerns RD, Otis J, Rosenberg R, Reid MC. Veterans' reports of pain and associations with ratings of health, health-risk behaviors, affective distress, and use of the healthcare system. *J Rehabil Res Dev.* 2003;**40**(5):371–379. doi:10.1682/jrrd.2003.09.0371
- Lew HL, Otis JD, Tun C, Kerns RD, Clark ME, Cifu DX. Prevalence of chronic pain, posttraumatic stress disorder, and persistent postconcussive symptoms in OIF/OEF veterans: polytrauma clinical triad. *J Rehabil Res Dev.* 2009;**46**(6):697–702. doi:10.1682/jrrd.2009.01.0006
- Nahin RL. Severe pain in veterans: the effect of age and sex, and comparisons with the general population. *J Pain.* 2017;**18**(3):247–254. doi:10.1016/j.jpain.2016.10.021
- Taylor KA, Kapos FP, Sharpe JA, Kosinski AS, Rhon DI, Goode AP. Seventeen-year national pain prevalence trends among U.S. Military Veterans. *J Pain.* 2024;**22**(5). doi:10.1101/2023.03.27.23287408
- Bai W, Gui Z, Chen MY, et al. Global prevalence of poor sleep quality in military personnel and veterans: a systematic review and meta-analysis of epidemiological studies. *Sleep Med Rev.* 2023;**71**:101840. doi:10.1016/j.smrv.2023.101840
- Folmer RL, Smith CJ, Boudreau EA, et al. Prevalence and management of sleep disorders in the Veterans Health Administration. *Sleep Med Rev.* 2020;**54**:101358. doi:10.1016/j.smrv.2020.101358
- Pigeon WR, Britton PC, Ilgen MA, Chapman B, Conner KR. Sleep disturbance preceding suicide among veterans. *Am J Public Health.* 2012;**102**(Suppl 1):S93–S97. doi:10.2105/AJPH.2011.300470
- Boska RL, Bishop TM, Ashrafoun L. Pain conditions and suicide attempts in military veterans: a case-control design. *Pain Med.* 2021;**22**(12):2846–2850. doi:10.1093/pm/pnab287
- Gatchel RJ. Comorbidity of chronic pain and mental health disorders: the biopsychosocial perspective. *Am Psychol.* 2004;**59**(8):795–805. doi:10.1037/0003-066X.59.8.795
- Swinkels CM, Ulmer CS, Beckham JC, Buse N, Calhoun PS. The association of sleep duration, mental health, and health risk behaviors among U.S. Afghanistan/Iraq Era Veterans. *Sleep.* 2013;**36**(7):1019–1025. doi:10.5665/sleep.2800
- Duo L, Yu X, Hu R, Duan X, Zhou J, Wang K. Sleep disorders in chronic pain and its neurochemical mechanisms: a narrative review. *Front Psychiatry.* 2023;**14**:1157790. doi:10.3389/fpsy.2023.1157790
- Zaidel C, Musich S, Karl J, Kraemer S, Yeh CS. Psychosocial factors associated with sleep quality and duration among older adults with chronic pain. *Popul Health Manag.* 2021;**24**(1):101–109. doi:10.1089/pop.2019.0165
- Powell MA, Corbo V, Fonda JR, Otis JD, Milberg WP, McGlinchey RE. Sleep quality and reexperiencing symptoms of PTSD are associated with current pain in U.S. OEF/OIF/OND Veterans with and without mTBIs. *J Trauma Stress.* 2015;**28**(4):322–329. doi:10.1002/jts.22027

17. Sayar K, Arikan M, Yontem T. Sleep quality in chronic pain patients. *Can J Psychiatry*. 2002;**47**(9):844–848. doi:[10.1177/070674370204700905](https://doi.org/10.1177/070674370204700905)
18. Amtmann D, Bamer AM, Askew R, Jensen MP. Cross-lagged longitudinal analysis of pain intensity and sleep disturbance. *Disab Health J*. 2020;**13**(3):100908. doi:[10.1016/j.dhjo.2020.100908](https://doi.org/10.1016/j.dhjo.2020.100908)
19. Koffel E, Kroenke K, Bair MJ, Leverty D, Polusny MA, Krebs EE. The bidirectional relationship between sleep complaints and pain: analysis of data from a randomized trial. *Health Psychol*. 2016;**35**(1):41–49. doi:[10.1037/hea0000245](https://doi.org/10.1037/hea0000245)
20. Wilson M, Skeiky L, Muck RA, et al. Sleep and pain in veterans with chronic pain: effects of psychological pain treatment and temporal associations. *Nat Sci Sleep*. 2023;**15**:1061–1077. doi:[10.2147/NSS.S418532](https://doi.org/10.2147/NSS.S418532)
21. Griffin SC, Ravvits SG, Bourchtein E, et al. Sleep disturbance and pain in U.S. adults over 50: evidence for reciprocal, longitudinal effects. *Sleep Med*. 2021;**86**:32–39. doi:[10.1016/j.sleep.2021.08.006](https://doi.org/10.1016/j.sleep.2021.08.006)
22. Edwards RR, Almeida DM, Klick B, Haythornthwaite JA, Smith MT. Duration of sleep contributes to next-day pain report in the general population. *Pain*. 2008;**137**(1):202–207. doi:[10.1016/j.pain.2008.01.025](https://doi.org/10.1016/j.pain.2008.01.025)
23. Tang NK, Goodchild CE, Sanborn AN, Howard J, Salkovskis PM. Deciphering the temporal link between pain and sleep in a heterogeneous chronic pain patient sample: a multilevel daily process study. *Sleep*. 2012;**35**(5):675–687A. doi:[10.5665/sleep.1830](https://doi.org/10.5665/sleep.1830)
24. Panza KE, Kline AC, Na PJ, Potenza MN, Norman SB, Pietrzak RH. Epidemiology of DSM-5 alcohol use disorder in U.S. military veterans: results from the National Health and Resilience in Veterans study. *Drug Alcohol Depend*. 2022;**231**:109240. doi:[10.1016/j.drugalcdep.2021.109240](https://doi.org/10.1016/j.drugalcdep.2021.109240)
25. Schweizer CA, Hoggatt KJ, Washington DL, et al. Use of alcohol as a sleep aid, unhealthy drinking behaviors, and sleeping pill use among women veterans. *Sleep Health*. 2019;**5**(5):495–500. doi:[10.1016/j.sleh.2019.06.005](https://doi.org/10.1016/j.sleh.2019.06.005)
26. Brower KJ, Aldrich MS, Robinson EA, Zucker RA, Greden JF. Insomnia, self-medication, and relapse to alcoholism. *Am J Psychiatry*. 2001;**158**(3):399–404. doi:[10.1176/appi.ajp.158.3.399](https://doi.org/10.1176/appi.ajp.158.3.399)
27. Larance B, Campbell G, Peacock A, et al. Pain, alcohol use disorders and risky patterns of drinking among people with chronic non-cancer pain receiving long-term opioid therapy. *Drug Alcohol Depend*. 2016;**162**:79–87. doi:[10.1016/j.drugalcdep.2016.02.048](https://doi.org/10.1016/j.drugalcdep.2016.02.048)
28. He S, Brooks AT, Kampman KM, Chakravorty S. The relationship between alcohol craving and insomnia symptoms in alcohol-dependent individuals. *Alcohol Alcohol*. 2019;**54**(3):287–294. doi:[10.1093/alcac/agz029](https://doi.org/10.1093/alcac/agz029)
29. Miller MB, Chan WS, Boissoneault J, et al. Dynamic daily associations between insomnia symptoms and alcohol use in adults with chronic pain. *J Sleep Res*. 2018;**27**(3):e12604. doi:[10.1111/jsr.12604](https://doi.org/10.1111/jsr.12604)
30. De Aquino JP, Sloan ME, Nunes JC, et al. Alcohol use disorder and chronic pain: an overlooked epidemic. *Am J Psychiatry*. 2024;**181**(5):391–402. doi:[10.1176/appi.ajp.20230886](https://doi.org/10.1176/appi.ajp.20230886)
31. Chakravorty S, Chaudhary NS, Brower KJ. Alcohol dependence and its relationship with insomnia and other sleep disorders. *Alcohol Clin Exp Res*. 2016;**40**(11):2271–2282. doi:[10.1111/acer.13217](https://doi.org/10.1111/acer.13217)
32. Carney CE, Buysse DJ, Ancoli-Israel S, et al. The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep*. 2012;**35**(2):287–302. doi:[10.5665/sleep.1642](https://doi.org/10.5665/sleep.1642)
33. Schutte-Rodin S, Broch L, Buysse D, Dorsey C, Sateia M. Clinical guideline for the evaluation and management of chronic insomnia in adults. *J Clin Sleep Med*. 2008;**4**(5):487–504.
34. Krebs EE, Carey TS, Weinberger M. Accuracy of the pain numeric rating scale as a screening test in primary care. *J Gen Intern Med*. 2007;**22**(10):1453–1458. doi:[10.1007/s11606-007-0321-2](https://doi.org/10.1007/s11606-007-0321-2)
35. Heck RH, Thomas SL, Tabata LN. *Multilevel and Longitudinal Modeling with IBM SPSS*. 2nd ed. New York, NY: Routledge/Taylor & Francis Group; 2014.
36. Enders CK, Tofighi D. Centering predictor variables in cross-sectional multilevel models: a new look at an old issue. *Psychol Methods*. 2007;**12**(2):121–138. doi:[10.1037/1082-989X.12.2.121](https://doi.org/10.1037/1082-989X.12.2.121)
37. Finan PH, Goodin BR, Smith MT. The association of sleep and pain: an update and a path forward. *J Pain*. 2013;**14**(12):1539–1552. doi:[10.1016/j.jpain.2013.08.007](https://doi.org/10.1016/j.jpain.2013.08.007)
38. Lewandowski AS, Palermo TM, De la Motte S, Fu R. Temporal daily associations between pain and sleep in adolescents with chronic pain versus healthy adolescents. *Pain*. 2010;**151**(1):220–225. doi:[10.1016/j.pain.2010.07.016](https://doi.org/10.1016/j.pain.2010.07.016)
39. Umucu E, Reyes A, Carrola P, et al. Pain intensity and mental health quality of life in veterans with mental illnesses: the intermediary role of physical health and the ability to participate in activities. *Qual Life Res*. 2021;**30**(2):479–486. doi:[10.1007/s11136-020-02642-y](https://doi.org/10.1007/s11136-020-02642-y)
40. Lakshman R, Tomlinson E, Bucknall T. A systematic review of chronic pain management interventions among veterans of recent wars and armed conflicts. *Pain Manag Nurs*. 2024;**25**(3):285–293. doi:[10.1016/j.pmn.2024.03.008](https://doi.org/10.1016/j.pmn.2024.03.008)
41. Gros DF, Szafranski DD, Brady KT, Back SE. Relations between pain, PTSD symptoms, and substance use in veterans. *Psychiatry*. 2015;**78**(3):277–287. doi:[10.1080/00332747.2015.1069659](https://doi.org/10.1080/00332747.2015.1069659)
42. Byrne SP, McCarthy E, DeViva JC, Southwick SM, Pietrzak RH. Prevalence, risk correlates, and health comorbidities of insomnia in US military veterans: results from the 2019–2020 National Health and Resilience in Veterans Study. *J Clin Sleep Med*. 2021;**17**(6):1267–1277. doi:[10.5664/jcsm.9182](https://doi.org/10.5664/jcsm.9182)
43. Alschuler KN, Otis JD. Coping strategies and beliefs about pain in veterans with comorbid chronic pain and significant levels of posttraumatic stress disorder symptoms. *Eur J Pain*. 2012;**16**(2):312–319. doi:[10.1016/j.ejpain.2011.06.010](https://doi.org/10.1016/j.ejpain.2011.06.010)
44. Jakupcak M, Osborne T, Michael S, Cook J, Albrizio P, McFall M. Anxiety sensitivity and depression: mechanisms for understanding somatic complaints in veterans with posttraumatic stress disorder. *J Trauma Stress*. 2006;**19**(4):471–479. doi:[10.1002/jts.20145](https://doi.org/10.1002/jts.20145)
45. Herrero Babiloni A, De Koninck BP, Beetz G, De Beaumont L, Martel MO, Lavigne GJ. Sleep and pain: recent insights, mechanisms, and future directions in the investigation of this relationship. *J Neural Transm (Vienna)*. 2020;**127**(4):647–660. doi:[10.1007/s00702-019-02067-z](https://doi.org/10.1007/s00702-019-02067-z)
46. Jones E, Fear NT. Alcohol use and misuse within the military: a review. *Int Rev Psychiatry*. 2011;**23**(2):166–172. doi:[10.3109/09540261.2010.550868](https://doi.org/10.3109/09540261.2010.550868)
47. Na PJ, Montalvo-Ortiz J, Petrakis I, et al. Trajectories of alcohol consumption in U.S. military veterans: results from a 10-year population-based longitudinal study. *Drug Alcohol Depend*. 2023;**246**:109833. doi:[10.1016/j.drugalcdep.2023.109833](https://doi.org/10.1016/j.drugalcdep.2023.109833)
48. Selvanathan J, Pham C, Nagappa M, et al. Cognitive behavioral therapy for insomnia in patients with chronic pain—a systematic review and meta-analysis of randomized controlled trials. *Sleep Med Rev*. 2021;**60**:101460. doi:[10.1016/j.smrv.2021.101460](https://doi.org/10.1016/j.smrv.2021.101460)
49. Koffel E, Hagedorn H. Provider perspectives of implementation of an evidence-based insomnia treatment in Veterans Affairs (VA) primary care: barriers, existing strategies, and future directions. *Implement Sci Commun*. 2020;**1**:107. doi:[10.1186/s43058-020-00096-4](https://doi.org/10.1186/s43058-020-00096-4)
50. Krystal AD, Edinger JD. Measuring sleep quality. *Sleep Med*. 2008;**9**(Suppl 1):S10–S17. doi:[10.1016/S1389-9457\(08\)70011-X](https://doi.org/10.1016/S1389-9457(08)70011-X)