Received: 19 April 2024 | Accepted: 18 December 2024

DOI: 10.1111/add.16770

RESEARCH REPORT

ADDICTION SSA

Daily associations between sleep and alcohol use among veterans: Acute and cumulative effects

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Funding information
American Academy of Sleep Medicine Foundation and the National Institute on Alcohol Abuse and Alcoholism, Grant/Award Number: K23AA026895

Abstract

Background and Aims: Military veterans demonstrate high rates of heavy drinking and insomnia, but few if any studies have tested real-world, daily associations between sleep and alcohol use within this population. Moreover, although daily diary and experimental studies among civilians have found negative associations between alcohol use and sleep, these patterns change with consecutive days of drinking and may differ for those with insomnia. This study measured (a) acute and cumulative day-level associations between sleep and alcohol use among heavy-drinking US veterans and (b) the extent to which insomnia moderates these associations.

Design: Self-reported ambulatory assessments occurring daily for 14 days.

Setting: USA.

Participants: Heavy-drinking veterans (n = 118, 84% male, 79% White, M = 39y) with sleep complaints. Seventy-one met criteria for insomnia disorder.

Measurements: Participants completed a semi-structured clinical interview and baseline self-report measures, followed by 14 consecutive days of morning sleep diaries. Data were analyzed using multilevel models.

Findings: Insomnia moderated day-level associations between alcohol use and sleep. Heavier drinking was associated with worse same-night sleep quality among those without insomnia [b = −0.06; 95% confidence interval (CI) = −0.09, −0.03], but this pattern was not statistically significant among those with insomnia (b = 0.02; 95% CI = −0.01, 0.04). Similarly, more consecutive nights of poor sleep efficiency were linked to lower drinking quantity among those without insomnia [incidence rate ratio (IRR) = 0.91; 95% CI = 0.83, 1.00), while better sleep efficiency was linked to heavier next-day drinking among those with insomnia (IRR = 1.01; 95% CI = 1.00, 1.01). More consecutive nights of drinking were linked to shorter sleep duration, regardless of insomnia status (b = −0.09; 95% CI = −0.18, −0.002).

Conclusions: US military veterans with insomnia do not appear to experience the same negative day-level associations between alcohol use and sleep that those without insomnia report. However, over time, drinking is linked to worse sleep in both groups.

KEYWORDS
alcohol, cognitive behavioral therapy, insomnia, military, sleep, veteran

INTRODUCTION

Heavy alcohol use is common among United States veterans, 41% of whom report a lifetime history of alcohol use disorder (AUD) [1] and 35% to 45% of whom report heavy episodic drinking (4/5+ drinks for women/men) in the past month [2]. Insomnia symptoms are also common among veterans, with rates ranging from 27% to 54% in national samples [3] and rates as high as 78% among those who engage in hazardous drinking [4]. This creates huge public health cost because both alcohol misuse and insomnia symptoms have been linked to accidents, poor workplace performance and increased healthcare utilization [5, 6], in addition to other mental health symptoms [7–9]. A wealth of research has documented that individuals with disturbed sleep have higher risk for alcohol-related problems than those who sleep well—and those who drink heavily tend to have worse sleep than those who do not [10–15]. However, these between-person studies may obscure event-specific patterns that occur within individuals. Understanding the real-world, daily associations between sleep and alcohol use within persons may be more informative for prevention and treatment, as one in four adults with insomnia uses alcohol to help with sleep that night [16]. To our knowledge, these day-level associations have not been tested in military/veteran samples, which tend to have higher rates of both alcohol use and sleep disorders than the general population [3, 17].

Studies indicate primarily negative day-level effects of alcohol use on sleep. Within persons, heavy drinking is consistently associated with later bed/waketimes [18–20], increased wakefulness [21–23] and more next-day fatigue [24–26]. It also tends to be associated with less total sleep time and worse sleep quality [18, 20, 26–31]. However, heavy drinking can reduce the time it takes to fall asleep [20, 30, 32], and for those with insomnia, it may reduce night-time awakening and 'lighter' stages of sleep [20, 23, 33]. This may be why, in clinical samples, alcohol is sometimes used as a hypnotic.

Despite consistent acknowledgement of bidirectional associations between sleep and alcohol use, few studies have tested sleep as a predictor of next-day alcohol use—and those that do tend to report conflicting results. For example, studies have found no association between sleep duration and alcohol use [34], heavier drinking following nights of shorter-than-average sleep duration [18] and heavier drinking following nights of longer-than-average sleep duration [20]. Similarly, one study found heavier drinking following nights of better sleep quality [18], whereas others report no significant link [20, 35]. Perhaps the most reliable finding in this literature is a positive association between poor sleep parameters (insomnia symptoms and short sleep duration) and next-day alcohol craving [34, 35].

One potential reason for the inconsistency across studies may be the populations assessed. Most studies have tested associations between sleep and alcohol in young adult and/or college student samples. Individuals with clinical levels of insomnia seem to demonstrate different (potentially more reinforcing) associations between sleep and alcohol use [20, 33]. In this case, daily associations seen in mostly healthy young adults may not generalize to individuals meeting quantitative criteria for insomnia disorder (>30 minutes sleep onset latency or wake after sleep onset 3+ times per week for 3+ months) [36, 37].

It also may be important to consider the cumulative effects of poor sleep on alcohol use and vice versa. For example, although individuals with insomnia initially show benefits from alcohol on slow wave sleep, they develop a tolerance to these sleep-promoting effects within six consecutive nights of drinking [23, 33]. Similarly, although healthy adults show modest improvements in some sleep parameters following repeated nights of alcohol administration, they tend to experience worse sleep ('rebound' effects) on the first couple nights after they stop drinking ('withdrawal') [22]. These cumulative effects may be difficult to study in healthy samples because few consume alcohol for more than 2 to 3 days in a row [20].

This study advances existing literature by testing daily, bidirectional, acute and cumulative associations between sleep and alcohol use among heavy-drinking veterans with and without insomnia. Total sleep time (hours of actual sleep), sleep efficiency (percentage of time in bed actually spent sleeping) and subjective sleep quality (from very poor to very good) were chosen as primary because they are central to the diagnosis and maintenance of insomnia [38, 39]. Consistent with most previous studies, we hypothesized that veterans would report shorter total sleep time and worse sleep quality on days of heavier drinking. Because alcohol may decrease sleep onset latency [20, 32], we hypothesized that heavier drinking would be linked to better sleep efficiency—but that this effect would disappear with consecutive days of drinking. Moreover, we hypothesized that any negative associations between alcohol use and sleep would be less evident among those who met quantitative criteria for insomnia. Given the inconsistency of previous studies testing sleep as a predictor of subsequent alcohol use, we did not make hypotheses about the direction of associations between sleep and next-day drinking quantity. Hypotheses were not pre-registered, so findings should be considered exploratory.

METHOD

Participants and procedure

Data were derived from the baseline portion of a larger insomnia treatment study [40]. The parent study recruited participants via online digital marketing between June 2019 and March 2023. For the 2-week baseline period, eligibility included (a) military service after 11 September 2001; (b) 1+ heavy drinking episode in the past 30 days, defined as 4+ drinks for women and 5+ drinks for men; and (c) >30 minutes trying to fall or stay asleep at least 3 nights per week on the screening survey. Veterans who served after 11 September 2001 were chosen as a population of interest because they are disproportionately affected by both insomnia and alcohol problems, relative to non-veterans and veterans of other eras [3, 41, 42].

Participants provided written informed consent, completed a semi-structured clinical interview with a trained research assistant and completed baseline self-report measures. They were then asked to do 14 consecutive days of sleep diaries, which were completed (and time stamped) on-line from remote locations. Data for the proposed analyses were collected before initiation of treatment. All procedures were approved by the institutional review board.

Of the 155 participants who screened eligible and provided informed consent, 145 completed baseline self-report measures. Of those, 130 completed at least one daily diary, and 118 reported drinking on at least one daily diary. Table 1 presents descriptive data for the analytic sample, and Table 2 depicts the number and percentage of participants reporting 0 to 14 consecutive days of drinking and poor sleep parameters. Reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [43].

Measures

Descriptive information

Participants self-reported demographic characteristics (see Table 1). They also completed the Insomnia Severity Index (ISI) [44] and Alcohol Use Disorder Identification Test (AUDIT) [45], which are reported for descriptive purposes. On the ISI, cut-scores ≥15 minimize false positives [46]. On the AUDIT, a cut-score ≥8 is recommended to indicate any alcohol-related harm and ≥15 maximizes discrimination for inpatient alcohol-related admissions [47].

Sleep parameters

Sleep diaries assessed the time participants got into bed, the time they started trying to go to sleep, sleep onset latency (SOL; minutes to fall asleep), wake after sleep onset (WASO; minutes awake during the night), time of final awakening, time they got out of bed for the day and subjective sleep quality (0 very poor to 4 very good) [48]. Primary sleep outcomes included total sleep time, sleep efficiency and sleep quality. 'Cumulative' variables were created to indicate the number of consecutive days that participants reported short sleep duration, low sleep efficiency and poor sleep quality (see Table 2). Consistent with previous studies, 'short' sleep duration was defined as total sleep time <6 hours [49, 50] and 'low' sleep efficiency was defined as <85% [51]. 'Poor' sleep quality was defined as subjective reports of 'poor' or 'very poor' sleep quality.

Quantitative criteria for insomnia disorder were assessed using daily diary reports. Specifically, participants were coded as meeting criteria for insomnia if they reported >30 minutes sleep onset latency or wake after sleep onset on three or more nights per week [36, 37]. Because not all participants completed a full week of diaries, the three of seven criterion was quantified as 43% of diary reports.

Alcohol use

Daily diaries asked participants to indicate the number of standard drinks (e.g. 12 oz beer, 4–5 oz wine) they consumed yesterday. Those who reported drinking were asked if they had used alcohol specifically to help with sleep (yes/no).

Data screening and analysis

Participants (n = 118) completed an average of 11.97 diaries (SD = 2.54; range, 4–14; 1414 data points) and reported an average of 6.83 drinking days (SD = 3.72; range, 1–14 drinking days and 0–23 drinks per day). Sleep and alcohol variables were missing on <1% of data points. However, models testing 'cumulative' effects required consecutive days of data collection. If participants skipped a diary and it was not possible to determine how many days in a row a variable of interest had occurred (e.g. they reported drinking on days 2, 3, 5 and 6 but were missing day 4), then data after the missing day were also coded as missing (in this example, days 4, 5 and 6 would be coded as missing). The only exception to this rule was for participants who reported drinking daily at baseline and also reported drinking on every diary submitted; in these six cases, consecutive days of drinking were assumed. Of the 1414 data points available for alcohol use, 45 (3%) were missing for cumulative effects. Missingness on cumulative sleep variables were as follows: 38 of 1405 (3%) for total sleep time, 97 of 1403 (7%) for sleep efficiency and 30 of 1413 (2%) for sleep quality.

First, unconditional multilevel models nesting days within person were conducted separately for each outcome in IBM SPSS Statistics 29 to determine intraclass correlation coefficients (ICC), or the amount of variability attributable to between- versus within-person effects. Unconditional models included no predictor variables, specified a random intercept for person and used a variance components covariance structure. The amount of between-person variance observed in each outcome was as follows: 27% in total sleep time, 31% in sleep efficiency, 26% in sleep quality and 33% in drinking quantity. Given repeated assessments [level 1 (L1)] within individuals [level 2 [L2)] and evidence of both within- and between-person variability, multilevel modeling (MLM) was used to examine within- and between-person effects of alcohol variables on sleep parameters and vice versa [52].

Full models were specified separately for each outcome in SAS 9.4 (see Tables 3–4). Continuous L1 variables were centered by person means to capture within-person variability over time, and L2 variables were centered by grand means to capture between-person variability [53]. In models examining alcohol effects on sleep parameters (total sleep quality, sleep efficiency and sleep quality), alcohol use was assumed to precede sleep. Sleep parameters were modeled as continuous outcomes with an identity link function and restricted maximum likelihood estimation in SAS PROC MIXED. An autoregressive covariance structure (assuming smaller correlations with increased distance in time) was specified for repeated days within person. In models examining sleep effects on drinking quantity, sleep

TABLE 1 Descriptive data for heavy-drinking veterans with sleep complaints (n = 118).

Characteristic	Full sample (n = 118)	Insomnia disorder[a] (n = 71)	Subclinical insomnia symptoms (n = 47)
Age, M (SD)	38.8 (9.6)	37.3 (8.4)	40.9 (10.9)
Female (vs. male), *n* (%)	16 (14)	11 (16)	5 (11)
Race/ethnicity, *n* (%)			
Asian	0 (0)	0 (0)	0 (0)
American Indian or Alaska Native	5 (4)	2 (3)	3 (6)
Black or African American	4 (3)	2 (3)	2 (4)
Hispanic or Latino/a/x	2 (2)	2 (3)	0 (0)
Native Hawaiian or Pacific Islander	0 (0)	0 (0)	0 (0)
Multi-racial or multi-ethnic	11 (9)	8 (11)	3 (6)
White	96 (81)	57 (80)	39 (83)
Sexual orientation, *n* (%)			
Heterosexual	108 (92)	64 (90)	44 (94)
Bisexual	5 (4)	3 (4)	2 (4)
Other	5 (4)	4 (6)	1 (2)
Highest level of education, *n* (%)			
Grade 12 or GED	10 (9)	7 (10)	3 (6)
Some college or technical school	46 (39)	30 (42)	16 (34)
College graduate	31 (26)	17 (24)	14 (30)
Some graduate school	10 (9)	7 (10)	3 (6)
Completed graduate program	21 (18)	10 (14)	11 (23)
Military branch, *n* (%)[b]			
Air Force	13 (11)	8 (11)	5 (11)
Army	74 (63)	47 (66)	27 (57)
Coast Guard	1 (<1)	0 (0)	1 (2)
Marines	20 (17)	11 (16)	9 (19)
Navy	12 (10)	6 (9)	6 (13)
AUDIT score, M (SD)	12.2 (6.4)	12.3 (6.3)	12.1 (6.6)
AUDIT ≥8, *n* (%)	86 (73)	52 (74)	34 (72)
AUDIT ≥15, *n* (%)	39 (33)	26 (37)	13 (28)
Insomnia severity, M (SD)	16.2 (4.8)	17.0 (4.9)	15.0 (4.5)
ISI ≥15, *n* (%)	70 (59)	45 (63)	25 (53)
Diary variables			
No. of drinking days, M (SD)	6.8 (3.7)	6.6 (3.7)	7.1 (3.7)
Drinks per day, M (SD)	2.6 (2.0)	2.5 (1.9)	2.7 (2.3)
Use of alcohol as a sleep aid, *n* (%)	42 (36)	24 (34)	18 (38)
Cannabis use, *n* (%)	27 (23)	20 (28)	8 (17)
SOL (min)	41.9 (29.6)	54.9 (31.0)	22.3 (11.0)
WASO (min)	36.3 (31.1)	47.6 (34.3)	19.2 (13.1)
Total sleep time (h)	6.2 (1.2)	5.8 (1.2)	6.8 (0.9)
Sleep efficiency (%)	72.7 (11.8)	66.9 (10.8)	81.4 (6.7)
Sleep quality (very poor to very good)	1.9 (0.6)	1.7 (0.6)	2.1 (0.5)

Abbreviations: GED, General Educational Development; M, mean; SOL, sleep onset latency; WASO, wake after sleep onset.
[a]Defined as >30 min SOL or WASO on 43% of diary reports (e.g. 3/7 nights).
[b]Not mutually exclusive.

TABLE 2 Maximum number of consecutive days of drinking and poor sleep health among heavy-drinking veterans with sleep complaints (n = 118).

Max no. of consecutive days	Drinking, *n* (%)	<6 h TST, *n* (%)	<85% SE, *n* (%)	Poor SQ, *n* (%)
0	0 (0)	5 (4)	0 (0)	10 (9)
1	24 (20)	43 (36)	14 (12)	48 (41)
2	26 (22)	25 (21)	17 (14)	24 (20)
3	14 (12)	19 (16)	25 (21)	13 (11)
4	11 (9)	7 (6)	14 (12)	9 (8)
5	6 (5)	8 (7)	5 (4)	5 (4)
6	7 (6)	2 (2)	7 (6)	4 (3)
7	8 (7)	1 (<1)	10 (9)	2 (2)
8	1 (<1)	1 (<1)	8 (7)	0 (0)
9	5 (4)	3 (3)	4 (3)	0 (0)
10	0 (0)	1 (<1)	1 (<1)	0 (0)
11	2 (2)	0 (0)	5 (4)	0 (0)
12	2 (2)	1 (<1)	0 (0)	2 (2)
13	4 (3)	1 (<1)	1 (<1)	0 (0)
14	8 (7)	1 (<1)	7 (6)	1 (<1)

Note: Sleep variables were only dichotomized to code for 'consecutive' days of sleep impairment (sleep variables in multilevel models were not dichotomized).
Abbreviations: SE, sleep efficiency; SQ, sleep quality; TST, total sleep time.

TABLE 3 Drinking quantity predicting same-night sleep among heavy-drinking veterans with sleep complaints (n = 118).

	Total sleep time			Sleep efficiency			Sleep quality		
Parameter	***b***	**95% CI**	***P***	***b***	**95% CI**	***P***	***b***	**95% CI**	***P***
Intercept	7.50	[6.87, 8.13]	<0.001	83.85	[78.31, 89.39]	<0.001	2.26	[1.97, 2.55]	<0.001
L2 male sex	**−0.79**	**[−1.38, −0.19]**	**0.010**	−2.57	[−7.78, 2.65]	0.331	−0.20	[−0.47, 0.07]	0.143
L2 age	0.003	[−0.02, 0.03]	0.760	−0.04	[−0.23, 0.16]	0.704	0.01	[−0.004, 0.02]	0.225
L2 depression	−0.02	[−0.09, 0.04]	0.511	−0.31	[−0.88, 0.26]	0.285	**−0.03**	**[−0.06, −0.002]**	**0.040**
L2 anxiety	0.002	[−0.06, 0.07]	0.955	0.08	[−0.51, 0.66]	0.790	0.004	[−0.03, 0.03]	0.814
L2 PTSD	−0.01	[−0.02, 0.01]	0.259	−0.08	[−0.20, 0.04]	0.208	−0.01	[−0.01, <0.001]	0.050
L2 insomnia[a]	**−0.89**	**[−1.33, −0.46]**	**<0.001**	**−13.39**	**[−17.21, −9.56]**	**<0.001**	**−0.27**	**[0.003, 0.03]**	**0.008**
L2 drinking quantity	−0.04	[−0.19, 0.11]	0.608	0.13	[−1.21, 1.47]	0.849	−0.06	[−0.13, 0.01]	0.104
L2 cumul. drinking days	0.02	[−0.11, 0.15]	0.727	−0.10	[−1.23, 1.03]	0.860	0.03	[−0.02, 0.09]	0.258
L1 day in study	**0.04**	**[0.01, 0.07]**	**0.013**	**0.30**	**[0.03, 0.57]**	**0.030**	**0.02**	**[0.003, 0.03]**	**0.015**
L2 days in study	0.08	[−0.02, 0.17]	0.104	0.57	[−0.24, 1.37]	0.165	0.02	[−0.02, 0.06]	0.412
L1 weekend (vs. weekday)	**0.33**	**[0.11, 0.55]**	**0.004**	1.45	[−0.52, 3.42]	0.148	−0.03	[−0.13, 0.07]	0.571
L1 drinks	0.06	[−0.002, 0.12]	0.058	0.47	[−0.06, 1.01]	0.081	**−0.06**	**[−0.09, −0.03]**	**<0.001**
Drinks × insomnia[a]	−0.04	[−0.12, 0.04]	0.317	0.59	[−0.10, 1.29]	0.094	**0.08**	**[0.04, 0.11]**	**<0.001**
L1 cumul. drinking days	**−0.09**	**[−0.18, −0.002]**	**0.044**	−0.37	[−1.18, 0.43]	0.363	0.01	[−0.03, 0.05]	0.695
Cumul. days × insomnia[a]	0.06	[−0.05, 0.17]	0.262	0.11	[−0.91, 1.13]	0.831	−0.01	[−0.06, 0.04]	0.761

Note: Gray shading indicates significant associations. Estimates are reported as unstandardized coefficients (*bs*).
Abbreviations: Cumul., cumulative; L1, level 1 (daily within-person) effects; L2, level 2 (between-person) effects; PTSD, post-traumatic stress disorder; SOL, sleep onset latency; WASO, wake after sleep onset.
[a]Based on quantitative criteria for insomnia (>30 min SOL or WASO on 43% of diary reports; e.g. 3/7 days).

parameters were lagged to predict alcohol use the following day. Because drinking quantity is a count variable that was over-dispersed [mean (M) = 2.54, SD = 3.20], analyses testing drinking quantity as the outcome assumed a negative binomial distribution and used a log link function with quadrature estimation in SAS PROC GLIMMIX. Sex (0 = female, 1 = male), age, comorbid mental health symptoms

TABLE 4 Sleep predicting next-day alcohol use among heavy-drinking veterans with sleep complaints (n = 118).

	Total sleep time			Sleep efficiency			Sleep quality		
Parameter	**IRR**	**95% CI**	***P***	**IRR**	**95% CI**	***P***	**IRR**	**95% CI**	***P***
Intercept	1.14	[0.53, 2.47]	0.741	1.65	[0.33, 8.36]	0.542	1.84	[0.87, 3.90]	0.112
L2 male sex	**1.73**	**[1.05, 2.83]**	**0.031**	1.57	[0.96, 2.57]	0.072	**1.63**	**[1.01, 2.63]**	**0.044**
L2 age	1.01	[0.99, 1.03]	0.194	1.01	[0.99, 1.06]	0.182	1.01	[1.00, 1.03]	0.110
L2 depression	0.99	[0.94, 1.05]	0.810	1.00	[0.95, 1.06]	0.940	0.99	[0.94, 1.04]	0.665
L2 anxiety	0.99	[0.94, 1.05]	0.723	0.99	[0.94, 1.05]	0.817	0.99	[0.94, 1.05]	0.773
L2 PTSD	1.01	[1.00, 1.02]	0.056	1.01	[1.00, 1.02]	0.146	1.01	[1.00, 1.02]	0.120
L2 insomnia[a]	0.87	[0.59, 1.27]	0.460	1.02	[0.65, 1.58]	0.945	0.86	[0.60, 1.22]	0.386
L2 sleep predictor	1.02	[0.81, 1.29]	0.838	0.99	[0.97, 1.02]	0.611	0.76	[0.50, 1.15]	0.188
L2 cumul. poor sleep[b]	1.09	[0.91, 1.29]	0.370	0.91	[0.83, 1.00]	0.125	1.04	[0.87, 1.24]	0.683
L1 day in study	1.00	[0.98, 1.02]	0.632	1.00	[0.98, 1.02]	0.772	1.00	[0.98, 1.02]	0.872
L2 days in study	0.95	[0.88, 1.02]	0.181	0.97	[0.90, 1.05]	0.499	0.96	[0.90, 1.03]	0.297
L1 weekend (vs. weekday)	**1.50**	**[1.28, 1.75]**	**<0.001**	**1.48**	**[1.27, 1.74]**	**<0.001**	**1.50**	**[1.29, 1.75]**	**<0.001**
L1 sleep predictor	1.01	[0.93, 1.09]	0.838	0.99	[0.98, 1.00]	0.141	1.01	[0.86, 1.18]	0.794
Sleep × insomnia[a]	1.05	[0.96, 1.16]	0.289	**1.02**	**[1.00, 1.03]**	**0.009**	0.89	[0.73, 1.09]	0.266
L1 cumul. poor sleep[a]	1.09	[0.91, 1.29]	0.345	**0.91**	**[0.83, 1.00]**	**0.040**	0.97	[0.80, 1.19]	0.794
Cumul. sleep × insomnia[b]	0.96	[0.80, 1.15]	0.632	**1.12**	**[1.02, 1.24]**	**0.024**	1.00	[0.81, 1.24]	0.984

Note: Gray shading indicates significant associations.

Abbreviations: IRR, incidence rate ratio for a one-unit change in the predictor; L1, level 1 (daily within-person) effects; L2, level 2 (between-person) effects; PTSD, post-traumatic stress disorder; SOL, sleep onset latency; WASO, wake after sleep onset.

[a]Based on quantitative criteria for insomnia (>30 min SOL or WASO on 43% of diary reports; e.g. 3/7 days).

[b]'Poor sleep' defined as <6 h total sleep time, <85% sleep efficiency and ratings 'poor' or 'very poor' sleep quality, respectively.

(of anxiety, depression and post-traumatic stress disorder) and number of diaries completed ('days in study') were included as between-person covariates at L2. Time ('day in study;' 1–14) and weekend (0 = Sunday–Thursday, 1 = Friday or Saturday) were included as within-person covariates at L1. We specified random intercepts for person with variance components covariance structure to allow for individual differences in mean levels of each outcome.

Given experimental data indicating that the effects of alcohol on sleep may differ for those with and without insomnia [23], we tested quantitative criteria for insomnia (coded 0 = not meeting criteria, 1 = meeting criteria) as a moderator of all sleep/alcohol associations.

RESULTS

Alcohol use and same-night sleep

Inferential statistics for models testing alcohol use as a predictor of same-night sleep are depicted in Table 3. Drinking quantity was not significantly associated with total sleep time (95% CI = −0.002, 0.12) or sleep efficiency (95% CI = −0.06, 1.01) at the within-person level. Drinking quantity was negatively associated with sleep quality at the within-person level (95% CI = −0.09, −0.03); however, this association was qualified by a significant drinking-quantity-by-insomnia interaction (95% CI = 0.04, 0.11). For those with insomnia, heavier drinking was not significantly associated with same-night sleep quality [B = 0.02, standard error (SE) = 0.01, P = 0.137; 95% CI = −0.01, 0.04]; however, for those without insomnia, heavier drinking was associated with worse sleep quality that night (B = −0.06, SE = 0.01, P < 0.001; 95% CI = −0.09, −0.03).

The number of consecutive days of drinking was not significantly linked to sleep efficiency or sleep quality at the within- or between-person levels (see Table 3). However, participants reported less total sleep time after drinking more nights than average in a row (∼5 minutes for every additional day of drinking; 95% CI = −0.18, −0.002).

As noted in Table 3, individuals with insomnia reported worse sleep parameters than those without insomnia, sleep variables tended to improve across days, men reported shorter sleep duration than women, participants reported sleeping longer on weekends than weekdays and those reporting more severe symptoms of depression reported worse sleep quality than those reporting less depression. No other predictors or covariates were statistically significant.

Sleep and next-day alcohol use

Total sleep time and sleep quality were not significantly linked to next-day alcohol use at the within- or between-person levels (see Table 4). However, insomnia interacted with both acute sleep efficiency (95% CI = 0.004, 0.03) and the cumulative effects of multiple days of poor sleep efficiency (95% CI = 0.01, 0.22) in the prediction of

next-day drinking. For individuals with insomnia, better sleep efficiency tonight was linked to slightly heavier drinking tomorrow [incidence rate ratio (IRR) = 1.01, SE = 0.003, P = 0.015; 95% CI = 1.00, 1.01]; but this association was reversed and non-significant among those without insomnia (IRR = 0.99, SE = 0.005, P = 0.141; 95% CI = 0.98, 1.00). In contrast, for individuals with insomnia, longer-than-average sequences of low sleep efficiency were not associated with drinking quantity (IRR = 1.02, SE = 0.02, P = 0.38; 95% CI = 0.97, 1.07); however, for those without insomnia, longer-than-average sequences of low sleep efficiency were associated with lower drinking quantity (IRR = 0.91, SE = 0.05, P = 0.024; 95% CI = 0.83, 1.00).

As depicted in Table 4, men tended to report drinking more than women, and participants drank more on weekends than weekdays. No other predictors or covariates were statistically significant.

DISCUSSION

This study provides a more nuanced understanding of the acute and cumulative associations between sleep and alcohol use in real-life context. As seen in young adults with sleep complaints [18, 20], alcohol is linked to worse sleep quality among veterans with subclinical sleep complaints, but this day-level association is not as clear among those with insomnia disorder. We tentatively speculate that this may be because of floor effects in sleep quality among those with insomnia. Specifically, people with insomnia tend to report poor sleep quality at baseline, in which case it may be difficult to document further detriments in sleep quality as a function of alcohol use. However, these data, combined with previous polysomnography studies [23, 33], support the conclusion that heavy alcohol use does not have the same negative effect on sleep among those with insomnia as it does in healthy adults. This may explain why adults with insomnia are not necessarily deterred from use of alcohol as a sleep aid [16]. Conversely, for those without insomnia, heavier-than-average drinking was associated with worse sleep quality that night, consistent with studies in the general population [26, 29, 30].

More consecutive days of drinking were also associated with shorter sleep duration—and this association did not differ for those with and without insomnia. These data are consistent with experimental findings among adults with insomnia, where relatively heavy alcohol use improved sleep efficiency and total sleep time relative to placebo on night 2 of drinking, but had non-significant (if not reverse) effects on these sleep parameters by night 6 [23]. Roehrs and Roth [23] did not collect polysomnography data on nights 3, 4, or 5, so it is unclear how many nights are needed to build a tolerance to the sleep-promoting effects of alcohol. However, in this study, the effect was very small (~5 minutes decrease in total sleep time for every additional day of drinking beyond one's norm), therefore, we speculate that extensions of several days may be needed to notice this pattern in real-world contexts.

In contrast to findings linking alcohol use to sleep quality and total sleep time, neither of these sleep parameters was linked to next-day drinking quantity in this sample. However, more consecutive days of poor sleep efficiency was linked to drinking, again in a pattern that differed for those with and without insomnia. For those with insomnia, more consecutive nights of poor sleep efficiency was not associated with alcohol use (perhaps because this is the norm for insomnia), but one night of better-than-average sleep efficiency was linked to slightly heavier next-day drinking. We speculate that heavier drinking after better sleep may be related to improved mood and/or willingness to engage in social activity, both of which correlate with sleep [54]. In contrast, for those without insomnia, last night's sleep efficiency was unrelated to alcohol use today, but longer-than-average sequences of poor sleep efficiency were associated with slightly lower drinking quantity. Ostensibly, successive nights of inefficient sleep would lead to daytime fatigue, which has been linked to lower likelihood and quantities of alcohol consumption at the daily level [24]. We strongly encourage work replicating these analyses in diverse samples.

Clinical implications

From a clinical perspective, the primary take-away of this work is that patients with insomnia do not experience the same negative acute effects of alcohol on sleep that those without insomnia report. However, alcohol use does have negative associations with sleep in the long-term. In this study, more consecutive days of drinking were linked to shorter sleep duration, and in myriad previous studies [10–15], those who drink heavily report more sleep problems than those who do not. This means that debunking the belief that alcohol helps with sleep may require evidence over weeks, not 1 or 2 days. For example, providers may ask patients to track their sleep and drinking for a couple weeks—or to compare a week of regular drinking to a week of no drinking—to demonstrate that alcohol does not 'benefit' sleep. In this sample, 36% of participants reported using alcohol to help with sleep on approximately 30% of days. Evidence-based insomnia treatment seems especially important for these individuals, whose alcohol use may be causing long-term damage not only to their sleep but to their overall physical health as well.

Limitations and future directions

This study extends previous literature by testing bidirectional associations between two prevalent health behaviors in the real-life context of a vulnerable population. However, it also had limitations. First, data are observational, which means they cannot determine causal effects and may be influenced by unmeasured confounding variables (e.g. day-level variations in symptoms of depression may impact both sleep and alcohol use). We also took a first step in testing bidirectional associations. However, studies designed specifically to test bidirectionality while allowing for correlations between outcomes (e.g. cross-lagged panel models) are encouraged in future research. Similarly, we included all available diary data, regardless of the number of diaries completed. This increases the generalizability of results, but may

reduce the reliability of diary data [55]. Recruitment also spanned the coronavirus disease 2019 epidemic, which prevented us from collecting actigraphy. Inclusion of objective data is important in determining if subjective daily associations are objectively verifiable. In general, adults tend to over-estimate sleep time relative to actigraphy or polysomnography [56–58]. However, self-report is the recommended method of assessment for insomnia [39] and subjective sleep patterns are linked more strongly to future drinking than objective measures [59]. Therefore, in this sample, subjective sleep reports may be the most clinically relevant.

Our sample was also limited. For example, participants were US veterans of recent eras who identified primarily as male and non-Hispanic White. It is unclear if findings will generalize to civilians, veterans of previous eras, women or those from other racial/ethnic backgrounds, although findings were largely consistent with literature in civilian populations [18, 23, 33, 60]. Use of cannabis was also relatively uncommon in this sample. Future studies testing cannabis use as a moderator of sleep/alcohol associations are encouraged, because cannabis appears to buffer the effects of alcohol use on sleep among young adults [25].

CONCLUSION

Veterans with insomnia do not report the same day-level associations between heavy drinking and sleep observed among those without insomnia; but, like those without insomnia, they report shorter sleep duration with more consecutive nights of drinking. Findings converge with experimental data [23, 33] and highlight a need for interventions to debunk the belief that alcohol use helps with sleep. We encourage continued research testing the bidirectional associations between sleep and alcohol use in the context of other substance use and comorbid mental health disorders.

AUTHOR CONTRIBUTIONS

Mary Beth Miller: Conceptualization (lead); data curation (equal); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); validation (equal); visualization (equal); writing—original draft (lead). **Andrea M. Wycoff:** Data curation (supporting); formal analysis (lead); visualization (supporting). **Eunjin L. Tracy:** Data curation (lead); formal analysis (supporting); methodology (supporting); validation (equal); writing—original draft (supporting). **Katie R. Moskal:** Writing—original draft (supporting). **Brian Borsari:** Funding acquisition (supporting); methodology (supporting). **Bruce Bartholow:** Funding acquisition (supporting); methodology (supporting). **Douglas Steinley:** Funding acquisition (supporting); methodology (supporting). **Christina S. McCrae:** Conceptualization (supporting); funding acquisition (supporting); investigation (supporting); methodology (supporting); supervision (lead).

ACKNOWLEDGEMENTS

This work was supported by funding from the American Academy of Sleep Medicine Foundation and the National Institute on Alcohol Abuse and Alcoholism (K23AA026895). National Institutes of Health (NIH) had no role in study design; data collection, analysis, or interpretation; manuscript preparation; or the decision to submit the paper for publication. The content is solely the responsibility of the authors and does not necessarily represent the official views of NIH, the Department of Veterans Affairs, or the United States Government. The parent trial was pre-registered on clinicaltrials.gov (NCT03804788). Analyses for this manuscript were not pre-registered.

DECLARATION OF INTERESTS

None.

DATA AVAILABILITY STATEMENT

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

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How to cite this article: Miller MB, Wycoff AM, Tracy EL, Moskal KR, Borsari B, Bartholow BD, et al. Daily associations between sleep and alcohol use among veterans: Acute and cumulative effects. Addiction. 2025;120(5):895–904. https://doi.org/10.1111/add.16770