

Sleep and Substance Use Among Firefighters: Associations with Alcohol, Caffeine, and Nicotine Use

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Purpose: Firefighters are at high risk for sleep disruption due to shift work. Use of alcohol, caffeine, and nicotine can also affect sleep. Thus, we evaluated daily, bidirectional associations between substance use and actigraphy-assessed sleep among firefighters.

Patients and methods: Micro-longitudinal data were drawn from 120 firefighters participating in the Shiftwork in Firefighters (SWIFT) Study. Participants completed surveys on daily alcohol and caffeine use, current and lifetime tobacco use, and wore actigraphy devices to assess sleep timing, duration, and quality (2,617 observations). Multilevel models were used to examine both between- and within-person associations between substance use and subsequent sleep, and between sleep and next-day substance use. Models were adjusted for covariates (shift schedule, on-shift status, nighttime call volume, and naps).

Results: Alcohol use demonstrated strong bidirectional associations with sleep. Greater within-person alcohol consumption predicted shorter sleep and earlier waketimes, while later sleep timing and shorter sleep predicted greater next-day alcohol use. Unexpectedly, greater caffeine consumption was associated with higher sleep efficiency and fewer nighttime awakenings at the between-person level and longer total sleep time at the within-person level. Current between-person use of smokeless tobacco was associated with approximately 30 minutes shorter total sleep time, whereas lifetime cigarette use showed no association with sleep outcomes.

Conclusion: Substance use among firefighters exhibited substance-specific and temporally dynamic relationships with sleep. Nicotine and caffeine effects were largely person-dependent, whereas daily alcohol showed consistent bidirectional effects on sleep. These findings highlight potential intervention targets aimed at improving sleep and reducing alcohol-related risk among firefighters.

Keywords: shift workers, actigraphy, multilevel, chewing tobacco, nicotine, caffeine, alcohol

Introduction

Across emergency response occupations, sleep disturbances are common due to irregular schedules and high operational demands, posing important risks to both worker health and public safety.^{1,2} Firefighters represent a distinct subgroup of shift workers characterized by unpredictable overnight call demands and extended duty periods often lasting 24 hours or more, albeit with the opportunity to obtain sleep in operational environments.^{3,4} Emergency response services frequently delay time in bed, interrupt sleep throughout the night, and precipitate early morning awakenings, all of which constrain sleep opportunity, shorten sleep duration, and degrade overall sleep quality.⁴⁻⁹ Moreover, firefighters are routinely exposed to intense psychosocial stressors, including traumatic events, unpredictable emergencies, and sustained demands for vigilance and rapid physical exertion.¹⁰⁻¹³ These exposures are closely intertwined with sleep, with evidence suggesting bidirectional relationships in which stress disrupts sleep and insufficient or fragmented sleep exacerbates emotional and physiological stress reactivity.¹⁴ Together, this dynamic interplay contributes to elevated risk for adverse mental health outcomes and highlights sleep as a central mechanism linking occupational stress to downstream health behaviors.¹⁵

In this context, substance use may emerge as a behavioral strategy to manage sleep disruption and operational demands. Firefighters frequently rely on substances such as caffeine, nicotine, and alcohol to combat fatigue, sustain performance, or facilitate psychological detachment from work.^{7,16,17} While stimulants may temporarily enhance alertness,^{7,18–20} they may interfere with subsequent sleep, whereas alcohol that is used to unwind or induce sleep may further degrade sleep quality.^{21,22} These coping behaviors highlight the potential for dynamic, bidirectional relationships between substance use and sleep among firefighters.

Alcohol use is widespread in the fire service, with estimates suggesting that 72–90% of firefighters report regular use^{23–25} and approximately half engage in binge drinking behaviors.^{7,21,24} Within the fire service, alcohol use is often embedded in social contexts for the expected purpose of fostering social cohesion and to facilitate unwinding after demanding shifts.^{7,21,23,24} Alcohol is also commonly used to promote sleep initiation.²⁶ Although alcohol may initially shorten sleep onset latency through its sedative effects, these effects dissipate as alcohol is metabolized, leading to rebound sympathetic activation, light sleep, and increased awakenings during the second half of the night.^{8,23,26} Together, these patterns highlight the clinical relevance of alcohol use for sleep health in firefighters and underscore its potential role in contributing to disrupted and non-restorative sleep,^{8,23} although findings have been inconsistent across studies.⁷

Caffeine is another commonly used substance among firefighters, primarily for its stimulant properties that can improve daytime performance, vigilance, and mood regulation.^{17,27,28} Although the Food and Drug Administration recommends healthy adults limit daily consumption of caffeine to 400 mg,²⁹ average daily caffeine consumption among firefighters may exceed 500 mg,³⁰ with approximately 5% overconsuming caffeine (>700 mg/day).⁷ Consequently, mistimed or excessive caffeine consumption may disrupt sleep.^{17,31–33} Among Korean firefighters, consuming any caffeine was associated with lower odds of insomnia symptomatology³⁴ but worse overall sleep quality.³⁵ Among U.S. firefighters, caffeine overconsumption was associated with worse physical and mental health but was not associated with sleep.⁷ These inconsistent findings highlight the need to better understand how caffeine use and sleep interact within the unique occupational context of firefighting.

Nicotine is a different stimulant used within the fire service,^{7,16} delivered through a range of tobacco products, particularly among male firefighters.³⁶ Although overall tobacco use has declined in recent decades, primarily due to decreasing use of combustible tobacco products,³⁷ current estimates suggest that approximately 10–12% of firefighters smoke cigarettes,^{7,16} down from nearly 25% in the early 1990s.³⁷ Conversely, use of noncombustible, smokeless tobacco products has increased³⁷ to approximately 14%.¹⁶ Evidence suggest that entry into the fire service is associated with increased use of smokeless tobacco.³⁸ Tobacco use also clusters with other health-risk behaviors, as firefighters who use tobacco products are more likely to engage in heavy or binge consumption of alcohol.^{16,36,39} Regarding sleep, the stimulating properties of nicotine can increase arousal and delay sleep onset, while overnight withdrawal may contribute to increased wake after sleep onset and early morning awakenings.^{40–42} However, findings in firefighters are limited with some studies reporting no association between current use of tobacco products on sleep patterns or quality.^{7,35}

Overall, the majority of studies examining substance use and sleep among firefighters have relied on cross-sectional analyses of self-reported sleep. While prior studies have demonstrated that there may be a relationship between substance use and sleep among firefighters, these studies cannot report on the dynamics of any such relationship. For example, among this unique population, poor sleep may precede the total daily use of stimulants or alcohol, or vice versa. Alternatively, the relationship may be bidirectional, with poor sleep preceding substance use, which then undermines subsequent sleep. Thus, this study aims to determine any systematic bidirectional associations between substance use and sleep health among firefighters. It also leverages objectively assessed sleep health compared to relying on self-report. We hypothesized that firefighters who used nicotine products would have worse sleep on average. We also hypothesized that sleep would be worse after days of greater caffeine and alcohol use, which in turn would be associated with greater next-day caffeine and alcohol use. To that end, we leveraged multilevel modeling to investigate both the between- and within-person micro-longitudinal associations of substance use on subsequent sleep, and of sleep on subsequent substance use.

Methods

Participants

Data were collected from 120 participants in the Shiftwork in Firefighters (SWIFT) Study⁴³ across one to three repeated 14-day sampling periods between 2020 and 2024 from four Pacific Northwest regional fire districts. Recruitment strategy and other study procedures have been previously reported.⁴³ This study was conducted according to the guidelines established in the Declaration of Helsinki of 1975 (revised 1983). All participants provided written informed consent to the protocol, which was approved by the Oregon Health & Science University Institutional Review Boards (IRB# 20553).

Measures

Substance Use Variables

Daily alcohol use was assessed once every evening by asking participants to report their total number of standard drinks consumed that day. Examples of standard drinks were provided, including 12 fl oz of regular beer (5% alcohol), 5 fl oz of wine (12% alcohol), and 1.5 fl oz of distilled spirits (40% alcohol). Daily alcohol use was calculated as the summed number of standard drinks consumed that day.

Daily caffeine consumption was assessed using the Caffeine Consumption Questionnaire-Revised.⁴⁴ Participants reported their total caffeine intake from various food and beverage sources, including coffee, tea, soda, energy drinks, and chocolate. Daily caffeine use was determined by summing all caffeine sources from that day.

Tobacco use was assessed once at the start of the study using items from the Behavioral Risk Factor Surveillance System. Participants reported whether they had smoked at least 100 cigarettes in their lifetime (“yes”, “no”, or “don’t know/not sure”). Those responding “yes” were asked about current cigarette smoking (“every day”, “some days”, or “not at all”). Participants also reported current use of smokeless tobacco products, including chewing tobacco, snuff, or snus (“every day”, “some days”, or “not at all”). Responses of “every day” and “some days” were combined to indicate current use.⁴⁴

Self-Reported Sleep Variables

Participants completed daily morning sleep diaries⁴⁵ via Email or automated text across one to three 14-day sampling periods, reporting bedtimes, waketimes, sleep onset latency, sleep duration, sleep quality, and naps. Diary data were used to verify actigraphic sleep periods, helping to distinguish periods of inactivity from the actual initiation of sleep including naps or nighttime awakenings related to emergency events.⁴⁶

Actigraphic Sleep Variables

Participants continuously wore an Actigraph GT3X actiwatch (Actigraph LLC, Pensacola, FL) on their non-dominant wrist throughout each 14-day sampling period (both on-shift and off-shift), except when showering or bathing. Times in and out of bed for sleep periods were automatically estimated using the Cole-Kripke and Tudor-Locke algorithms with default settings and 60-second epochs in the ActiLife software (Actigraph LLC, Pensacola, FL). Sleep periods were excluded from analysis if there were no sleep diaries to verify the software-detected sleep periods. Whenever a sleep period was not reliably detected by the software (eg, due to excessive light, movement, or short duration; ≤ 1 night/recording), the sleep period was manually adjusted using information from the sleep diary. Approximately 2,617 of the 3,198 provided actigraphic sleep periods were verified using participant sleep diaries. Assessed sleep variables include timing of sleep onset and waketime (midnight-centered minutes, reported as clocktime), total 24-hour sleep time (minutes scored as asleep), sleep efficiency (percentage of time scored as asleep versus time between self-reported bedtime and waketime), number of awakenings during sleep, and wakefulness after sleep onset (WASO; minutes scored as awake during nighttime sleep). All actigraphic sleep variables were treated as continuous outcomes.

Covariates

Time-varying occupational factors were included as covariates, including work schedule, whether they were on-shift or off-shift, and nighttime call volume (from 11pm to 6am). Participants reported the shift schedule in effect during data collection, defined as either “24/48” (24 hours on followed by 48 hours off) or “1/3/2/3” (1-day on/3-days off/2-days on/

3-days off). Finally, whether the participant napped at least once in a 24-hour period (“yes”, “no”) was included as an additional time-varying covariate.⁴⁷

Statistical Analysis

Multilevel models were used to examine the between- and within-person associations of substance use on subsequent nighttime sleep and nighttime sleep on next-day substance use, adjusted for covariates (schedule, shift, nighttime call count, and naps), which were treated as fixed effects. Because tobacco use was assessed once, multilevel models were used to examine only the between-person associations of lifetime cigarette use and current chewing tobacco use on sleep. The between-person component consisted of person mean responses to examine *interindividual* variability, and the within-person component consisted of person-mean-centered responses to examine *intraindividual* variability. For example, between-person associations show how greater average substance use is associated with worse average sleep; within-person associations show how greater than average daily substance use is associated with nightly changes in sleep. Survey and actigraphy data were merged based on the date when participants awoke from sleep; person-mean-centered substance use predictors were therefore lagged by one day to examine their effect on subsequent sleep.

All analyses were conducted in R (version 4.4.0) using the packages *nlme* (version 3.1.166)⁴⁸ for sleep and caffeine use outcomes and *glmmTMB* (version 1.1.10)⁴⁹ for the zero-inflated alcohol use outcome due to 65% of days on which no consumption of alcohol was reported. Multilevel linear models were estimated using restricted maximum likelihood, whereas multilevel negative binomial models were estimated using maximum likelihood. The intercept and slope of the within-person predictor were treated as random variables nested within each participant. The random slope was removed from models whenever model convergence failed. Statistical significance was interpreted when $p < 0.05$.

Results

Participant demographics are shown in Table 1. Firefighters in the analytical sample ($N=120$) were predominantly male, younger than 45 years old, White, non-Hispanic/Latino, and married. Firefighters provided an average $\pm$ SD of 21.8 ± 11.2 days of daily survey and sleep data (2,617 diary-verified observations), with a median of 21.5 days. Firefighters reported consuming on average 1.4 ± 1.3 alcoholic beverages on off-shift days and 228.0 ± 118.2 mg of caffeine daily. 18% of firefighters reported smoking at least 100 cigarettes in their lifetime, while only 8% currently used chewing tobacco and only 1 firefighter currently smoked cigarettes. Mean sleep onset of the sample was $22:59\pm 00:42$, waketime was $06:41\pm 00:36$, and sleep duration was 7.0 ± 0.8 hours.

Greater alcohol use was bidirectionally associated with worse sleep. Between-person findings in Table 2 showed that firefighters who consumed more drinks had on average 11 ± 5 minutes later sleep onset ($p=0.019$). Within-person findings showed that waketime was 2 ± 1 minutes earlier ($p=0.009$) and total sleep time was 3 ± 1 minutes shorter ($p=0.005$) for each additional drink more than average consumed the prior day (see Figure 1). Conversely, within-person findings in Table 3 showed that poorer sleep also predicted greater next-day alcohol use, whereby firefighters consumed up to 33% more drinks the next day for each hour that sleep timing had been later than average (95% CI=1.05, 1.47), whereas each additional hour of sleep was associated with 8% fewer drinks the following day (95% CI=0.86, 0.98). There were no associations between alcohol use and actigraphic measures of sleep quality.

Associations between caffeine use and sleep were observed. Between-person findings in Table 2 showed that firefighters who consumed more daily caffeine had slightly higher sleep efficiency ($p=0.031$) and fewer awakenings at night ($p=0.030$). Between-person findings in Table 3 showed that firefighters who woke up later ($p=0.014$) or had more nighttime awakenings consumed fewer mg of caffeine ($p=0.009$). Within-person findings revealed that firefighters' total sleep time was longer ($p=0.001$) for every additional 100 mg of caffeine (approximately one 8 fl oz cup of home brewed coffee) consumed the prior day (see Table 2).

There was no association between lifetime cigarette use and sleep ($p\geq 0.172$). Compared to firefighters who do not currently use chewing tobacco, between-person findings in Table 2 showed that firefighters who did use chewing tobacco had on average $\pm$ SE 30 ± 14 minutes shorter total sleep time ($p=0.031$), after adjusting for covariates. Current use of chewing tobacco was otherwise not associated with any sleep outcomes.

**Table 1** Participant Demographics (N=120)

Demographic Characteristics	N	%	Missing
Biological sex			
Female	10	8.3%	0
Male	110	91.7%	
Age (years)			
Less than 25	2	1.7%	0
25–34	31	25.8%	
35–44	53	44.2%	
45–54	32	26.7%	
55 or older	2	1.7%	
Race			
White	104	86.7%	0
Black	1	0.8%	
Asian/Pacific Islander	4	3.3%	
Multiracial/Other	11	9.2%	
Ethnicity			
Hispanic/Latino	7	5.8%	0
Relationship			
Married	107	89.2%	0
Single/unmarried	13	10.8%	
Substance use	N	M±SD or %	Missing
Alcohol use (n drinks)^a	120	1.4±1.3	0
Caffeine use (mg)	120	228.0±118.2	0
Tobacco use^b			
Smoked at least 100 cigarettes in lifetime	21	17.7%	1
Currently smoke cigarettes	1	0.8%	
Currently use chewing tobacco	9	7.6%	
Actigraphy^c	N	M±SD	
Sleep onset (clocktime)	120	22:59±00:42	
Waketime (clocktime)		06:41±00:36	
24-hour total sleep time (hrs)		7.0±0.8	
Sleep efficiency (%)		87.0±3.5	
Number of awakenings (n)		14.6±4.9	
Wake after sleep onset (min)		54.9±17.0	

Notes: ^aAverage calculated based on only off-shift days. ^b% excludes missing data.

^cApproximately 2,617 of the 3,198 provided actigraphic sleep periods were verified using participant sleep diaries.

Table 2 Adjusted Multilevel Models of Associations Between Substance Use Predictors and Sleep Outcomes

	Sleep Onset (b±SE min)	Waketime (b±SE min)	Total Sleep Time (b±SE min)	Sleep Efficiency (b±SE %)	Number of Awakenings (b±SE n)	Wake After Sleep Onset (b±SE min)
Alcohol (n drinks)^a						
Person-mean-centered	0.1±0.9‡	−2.3±0.9**	−3.2±1.1**‡	0.0±0.1	−0.1±0.1‡	0.0±0.4
Person mean	10.8±4.5*‡	0.8±4.3	−4.8±4.9‡	0.3±0.4	−0.3±0.6‡	−3.6±1.9‡

(Continued)

Table 2 (Continued).

	Sleep Onset (b±SE min)	Waketime (b±SE min)	Total Sleep Time (b±SE min)	Sleep Efficiency (b±SE %)	Number of Awakenings (b±SE n)	Wake After Sleep Onset (b±SE min)
Caffeine (100 mg)^a						
Person-mean-centered	−1.8±1.3	3.2±1.7†‡	6.6±2.0**‡	0.1±0.1	−0.0±0.1‡	−0.3±0.7
Person mean	−3.4±3.1	−5.3±2.8†‡	−0.4±3.3‡	0.5±0.3*	−0.8±0.4*‡	−2.4±1.3†
Tobacco^b						
Lifetime cigarette use	3.5±9.8	11.7±8.5	6.0±9.6	−0.7±0.8	0.6±1.2	3.6±4.1
Chewing tobacco	19.6±13.9	−14.0±12.0	−29.7±13.6*	−0.8±1.2	−0.0±1.8	−3.4±5.8

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; † $p < 0.10$; b±SE = estimate ± standard error. Person-mean-centered variables are within-person deviations. Person mean variables represent between-person differences. ‡Model includes random slopes for the person-mean-centered (within-person) substance use predictor. Random slopes allow within-person associations to vary across individuals. When models failed to converge, random slopes were removed and models were estimated with random intercepts only. ^aN=120, observations=2,422. ^bN=118, observations=2,453; 2 participants were excluded due to missing tobacco use responses. All models adjusted for covariates (schedule, shift, nighttime call count, and naps), which were treated as fixed effects. Bold indicates statistical significance of $p < 0.05$.

Discussion

This study aimed to examine daily bidirectional associations between substance use and actigraphically assessed sleep in this micro-longitudinal study of firefighters. Several key findings emerged. First, alcohol use demonstrated consistent bidirectional associations with sleep. Second, greater caffeine consumption was unexpectedly associated with slightly better sleep at the between-person level, and total sleep time was *longer* after days of greater caffeine use. Third, current use of smokeless tobacco was associated with shorter total sleep time, whereas lifetime cigarette use was not associated with sleep outcomes. Greater alcohol consumption predicted shorter subsequent sleep and earlier morning waketimes, while later sleep timing and shorter total sleep time predicted greater next-day alcohol use. Together, these findings underscore a complex and substance-specific relationship with sleep among firefighters.

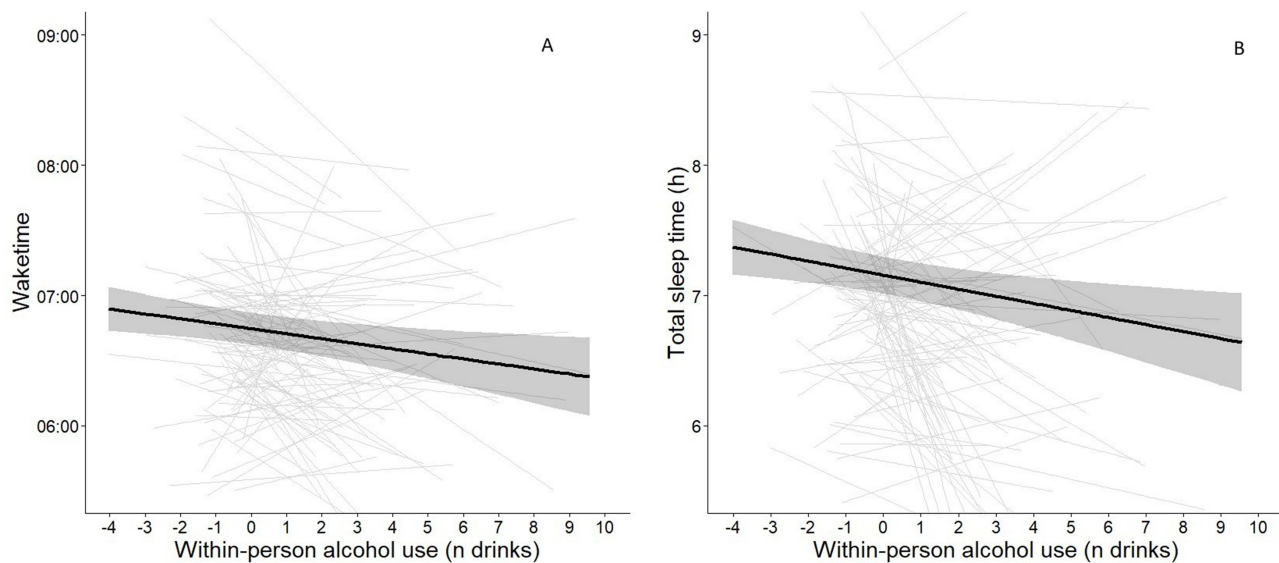


Figure 1 Within-person associations of alcohol use (n drinks) with A) waketime (clocktime) and B) total sleep time (h) from Table 2. On the X-axis, zero denotes the person mean number of drinks, and other values indicate daily deviation (person-mean-centered) from that person mean. All multilevel models adjusted for covariates (shift, schedule, nighttime call count, and naps). Shaded bands show 95% confidence interval of sleep outcome predicted across daily deviations of alcohol use; grey lines in the background depict individual firefighter slopes across repeated within-person observations.

Note: N=120, observations=2,422.

Table 3 Adjusted Multilevel Models of Associations Between Sleep Predictors and Substance Use Outcomes

	Alcohol (RR [95% CI] Drinks)	Caffeine (b±SE mg)
Sleep onset (hrs)		
Person-mean-centered	1.33 [1.20, 1.47]‡	2.8±2.3‡
Person mean	1.18 [0.86, 1.61]‡	−15.0±16.8‡
Waketime (hrs)		
Person-mean-centered	1.15 [1.06, 1.25]‡	2.5±1.9‡
Person mean	1.06 [0.73, 1.54]‡	−47.8±19.2**‡
Total sleep time (hrs)		
Person-mean-centered	0.92 [0.86, 0.98]‡	0.4±1.6‡
Person mean	0.99 [0.74, 1.31]‡	−15.2±15.5‡
Sleep efficiency (%)		
Person-mean-centered	0.99 [0.97, 1.01]‡	−0.0±0.3‡
Person mean	1.01 [0.95, 1.08]‡	4.4±3.1‡
Number of awakenings (n)		
Person-mean-centered	1.00 [1.00, 1.00]‡	0.1±0.3‡
Person mean	0.99 [0.98, 1.01]‡	−6.2±2.3***‡
Wake after sleep onset (min)		
Person-mean-centered	1.00 [1.00, 1.00]‡	0.0±0.1
Person mean	0.99 [0.98, 1.01]‡	−0.9±0.7

Notes: ***p<0.001; ** p<0.01; *p<0.05; ‡p<0.10. RR [95% CI] = relative risk [95% confidence interval]. b±SE = estimate ± standard error. Person-mean-centered variables are within-person deviations. Person mean variables represent between-person differences. ‡Model include random slopes for the person-mean-centered (within-person) sleep predictor. Random slopes allow within-person associations to vary across individuals. When models failed to converge, random slopes were removed and models were estimated with random intercepts only. N=120, observations=2,494. All models adjusted for covariates (schedule, shift, nighttime call count, and naps), which were treated as fixed effects. Bold indicates statistical significance of p<0.05.

Alcohol use showed the most consistent pattern with sleep. Firefighters who consumed more alcohol on average had later sleep onset, and days of greater alcohol consumption were associated with 2–3 minutes earlier waketimes and shorter sleep per each additional drink more than average. These results are consistent with extensive literature demonstrating that alcohol may have initial sedating effects but otherwise disrupts and limits sleep.⁴¹ Mechanistically, alcohol acutely enhances GABAergic inhibition, promoting sedation and facilitating sleep onset; however, as alcohol is metabolized, this effect wanes and is followed by increased arousal and awakenings, particularly in the second half of the night.⁵⁰ Meta-analytic evidence further indicates dose-dependent suppression of REM sleep with overall reductions in REM duration, despite possible rebound later in the sleep opportunity.²⁶ As shown in Figure 1, days of heavier drinking may considerably curtail subsequent sleep⁵¹ and influence next-day vigilance and behaviors. Indeed, we also observed evidence of reverse directionality. Nights with later sleep timing and shorter sleep predicted greater next-day alcohol consumption, possibly due to sleep-attenuated prefrontal cortex activity impairing decision-making or increasing impulsivity.^{52,53} This bidirectionality reinforces earlier cross-sectional findings among firefighters that link alcohol use severity with worse sleep quality and greater sleep disturbances.^{8,23} Furthermore, the dynamics of these relationships suggest a potentially reinforcing cycle of sleep disruption and alcohol use.

Contrary to our hypothesis, greater caffeine consumption was associated with slightly better actigraphic sleep outcomes, including higher sleep efficiency and fewer nighttime awakenings at the between-person level and longer sleep at the within-person level. These findings run counter to laboratory and epidemiological studies of the general population that demonstrate how caffeine disrupts sleep,^{31,32} likely through adenosine receptor antagonism that reduces sleep pressure and can delay sleep onset depending on dose and timing.^{54–56} However, these findings are partially consistent with studies of firefighters. Among Korean firefighters, caffeine consumption was associated with lower odds of insomnia symptoms despite worse overall sleep quality,^{34,35} whereas caffeine overconsumption was associated with worse health but not sleep among U.S. firefighters.⁷

Regardless, because the time of day when caffeine was ingested was not assessed in this study, these reported findings should be interpreted with skepticism. Future studies should query when during the day caffeine or any other substance is consumed.

Findings partially supported our hypothesis that use of nicotine products would be cross-sectionally associated with worse sleep. We observed null associations between combustible tobacco products and sleep outcomes, consistent with prior studies of firefighters.^{7,35} However, unlike prior studies, this study leveraged actigraphy to assess sleep. In the general population, nicotine use is more consistently associated with worse objective sleep than with self-reported sleep quality.^{40,41} Mechanistically, nicotine binds to nicotinic acetylcholine receptors, enhancing cholinergic signaling and downstream dopaminergic and serotonergic activity, all of which increases cortical arousal and promotes wakefulness.⁵⁷ As a result, individuals may feel more alert following acute nicotine use;⁵⁸ however, this increased arousal can delay sleep onset when used close to bedtime.⁵⁷ As nicotine levels decline overnight, withdrawal-related increases in arousal may contribute to nighttime or early morning awakenings.^{42,57} The null findings for combustible tobacco products in the present study likely reflect limited variability and statistical power rather than a true absence of association. Measures of tobacco use were also coarse, and current smoking status identified only one participant, whose sleep outcomes were largely within one standard deviation of the sample mean (with the exception of sleep onset timing). Conversely, 8% of the sample currently used noncombustible, smokeless tobacco products. Smokeless tobacco use was associated with approximately half an hour of shorter sleep, a clinically meaningful difference consistent with findings in the general population,^{40,41} although estimates were imprecise due to the limited number of participants who used smokeless tobacco. Future studies should continue to explore the relationship between tobacco use and shorter sleep among firefighters, especially if the prevalence of smokeless tobacco use continues to increase in the fire service.^{16,37,38}

Limitations

Several limitations should be considered when interpreting the findings of the present study. The sample was modestly sized and primarily derived from relatively healthy firefighters in Oregon. As such, the current sample may not represent other career or volunteer firefighters, other shift-working populations, or women firefighters. Substance use was assessed via self-report, which may have been subject to recall or social desirability bias, particularly in an occupational context where use of nicotine, caffeine, or especially alcohol is likely underreported. Nicotine use was operationalized using coarse indicators (ie, current or lifetime use), without any daily items that queried use of cigarettes or chewing tobacco. Consequently, only between-person, cross-sectional associations between nicotine use and sleep were assessed, precluding characterization of directionality, the dose-response relationship, or concurrent use of different nicotine products. Fortunately, there were daily items to assess approximate alcohol and caffeine use. However, these daily items did not capture the time of day of use, such as whether alcohol was primarily ingested in the evenings or caffeine in the mornings. Participants may have consumed additional alcohol or caffeine following completion of their evening survey, thereby underestimating their actual substance use. Moreover, total calculated caffeine use was based on assumed standard caffeine values,⁴⁴ whereas actual caffeine content varies widely, particularly for energy drinks and specialty coffees. The sleep of firefighters in this study may have been overestimated, because actigraphy systematically misclassifies low-activity periods of wakefulness as sleep,⁵⁹ and therefore should be interpreted with some reservation.^{60,61} We leveraged a micro-longitudinal design with multilevel modeling to disentangle the between- and within-person effects. This allowed the examination of directionality between substance use and sleep, yet analyses ultimately remain observational and causal inference cannot be drawn. Finally, other unassessed factors (eg, mental health, acute occupational stress, shift-specific workload, heterogeneity of emergency calls) may explain some observed associations. For example, post-traumatic stress experienced by firefighters has been linked to poorer sleep quality,⁶² including through pathways such as burnout and depressive symptomatology.⁶³ Future studies of firefighters should consider the daily, time-varying experience of mental health symptoms on both sleep and substance use.

Conclusions

This study revealed how firefighters' alcohol use and sleep temporally relate using micro-longitudinal study design, objective sleep assessment, and multilevel analyses. Based on between-person findings, the relationship between use of nicotine and caffeine with sleep seemed primarily person-dependent, with caffeine use being particularly nuanced. Conversely, alcohol use

was strongly and bidirectionally tied to sleep. Taken together, these findings highlight potential targets for sleep health interventions among firefighters or within fire departments, pending confirmation from experimental and prospective studies. For example, interventions that promote healthier coping strategies for occupational health and trauma may have downstream benefits on both alcohol use and sleep health.

Data Sharing Statement

Data are available upon reasonable request from the corresponding author.

Ethics Approval

This study involved human participants. The study was approved by the Institutional Review Board at Oregon Health & Science University. All participants provided informed consent.

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Author Contributions

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