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ORIGINAL ARTICLE

Daily-level effects of alcohol, marijuana, and simultaneous use on young adults' perceived sleep health

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Abstract

Study Objectives: Simultaneous alcohol and marijuana (SAM) use is increasingly prevalent among young adults but has adverse health consequences. The current study examined daily-level associations between perceived sleep health and SAM use, relative to non-substance-use days and alcohol- or marijuana-only days. We also estimated linear associations between alcohol/marijuana use and perceived sleep health and explored whether effects were moderated by combined use of alcohol and marijuana.

Methods: A community sample of SAM-using young adults (N = 409; M_{age} = 21.61, SD = 2.17; 50.9% female; 48.2% White; 48.9% college students) completed twice-daily surveys for five 14-day sampling bursts. Daily measurements assessed substance use and perceived sleep health in terms of subjective sleep quality, negative impact of sleep on functioning, and symptoms of insomnia.

Results: Multilevel models indicated that, relative to non-substance-use days, participants reported poorer perceived sleep health on alcohol-only days, better perceived sleep health on marijuana-only days, and mixed evidence regarding SAM use (i.e. fewer perceived symptoms of insomnia, but poorer perceived next day functioning attributed to sleep). Daily-level estimates showed increased alcohol use was associated with poorer perceived sleep health, while stronger effects from marijuana were associated with better perceived sleep health. Across all indices of sleep health, only one linear association was moderated by combined use: The adverse association between alcohol and next day functioning was weaker on days alcohol was combined with marijuana.

Conclusions: Findings provide additional evidence for daily-level effects of alcohol and marijuana use on perceived sleep health and address an important literature gap regarding potential adverse effects of SAM use.

Statement of Significance

Alcohol and marijuana use are common among young adults but can have harmful effects on sleep health. Notably, the prevalence of simultaneous alcohol and marijuana (SAM) use has been on the rise, so there is a need to examine how combining alcohol and marijuana may impact sleep health. This study found that, compared to non-substance-use days, young adults reported poorer perceived sleep health on alcohol-only days and better perceived sleep health on marijuana-only days, but there was mixed evidence for SAM use (i.e. fewer perceived symptoms of insomnia, but poorer perceived next day functioning attributed to sleep). As we learn more about the harms of SAM use on sleep health, sleep interventions and guidelines should be adjusted accordingly.

Key words: cannabis; ethanol; insomnia; consequences; daily diary; SAM use; young adult

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Introduction

Sleep is a central component of human functioning that is imperative for physical and mental health and well-being [1]. In a joint consensus statement on the recommended amount of sleep for a healthy adult, the American Academy of Sleep Medicine and Sleep Research Society [2] aggregate the consequences of insufficient and/or inadequate sleep into the following broad categories: general health, cardiovascular health, metabolic health, mental health, immunologic health, human performance, cancer, pain, and mortality. Conversely, *sleep health* has been defined along five central dimensions: (1) subjective satisfaction with sleep, (2) appropriate timing of sleep, (3) adequate sleep duration, (4) high sleep efficiency, and (5) sustained alertness during waking hours [3]. Improving sleep health has accordingly been positioned as a top public health priority [4].

Sleep health is essential across the lifespan, but it may be of critical importance during adolescence and young adulthood [5]. Notably, sleep promotes learning and cognitive functioning [6], which are crucial as brain development processes continue through young adulthood [7]. Unfortunately, despite the importance of sleep health for optimal development, young adults may be at greater risk for having poor sleep health relative to other age groups. For example, data from >150 000 US adults showed sleep disturbances were most frequently reported in young adults [8]. As such, there is a need to identify correlates of young adult sleep health to inform policy and translational strategies specific to this developmental period.

Substance use and sleep health

Young adulthood is a high-risk period for substance use, given US national estimates that 67.2% of young adults engaged in past-month alcohol use and 26.7% engaged in past-month marijuana use [9]. Health behaviors during this developmental period are particularly concerning as longitudinal evidence has shown that lifestyle behaviors (both healthy and risky) persist and may even increase into adulthood [10, 11]. Given that young adulthood is a period associated with both substance use and poor sleep health, there is a pressing need to examine the intersection of these behaviors in young adults.

Commonly used substances—particularly alcohol and marijuana (i.e. cannabis) —can have significant adverse impact on sleep health. The harmful effects of both acute and chronic alcohol use on sleep health have been extensively documented and reviewed [12–15]. These harmful effects of alcohol on sleep health have been specifically documented in young adult samples [16–19]. Summarizing this vast literature succinctly, alcohol can depress the central nervous system causing brain activity to slow down and also induce feelings of sleepiness, but once asleep, alcohol can disturb sleep stage transition (resulting in sleep fragmentation and early awakening), can increase sleep disturbances (i.e. difficulty remaining asleep), and can even cause respiratory issues such as sleep apnea [20, 21]. It is important to note, however, that the effect of alcohol on sleep depends on a number of factors such as amount, rate, and time since consumption [22], as well person-specific factors such as age, sex, and alcohol use history [13]. As noted in a review by Kwon and colleagues [15], nonexperimental studies examining associations between sleep health and alcohol use are largely cross-sectional studies that are limited to between-person interpretation and, thus, there remains a need for additional studies using daily-level sampling.

Compared to the well-documented negative impacts of alcohol use, the potential effects of marijuana use on sleep health are less clear. Many young adults report expecting positive effects of marijuana use on sleep [23] and commonly endorse sleep as a motive for using marijuana [24]. Despite these commonly held expectancies and motivations, there is between-person evidence that chronic use of marijuana is associated with poorer subjective sleep quality and more symptoms of insomnia [25, 26]. Few recent studies have examined acute effects of marijuana on sleep, although there is experimental evidence indicating even low-dose THC cannabis can have a mild sedative effect that reduces sleep onset latency and increases total sleep time [27], which could explain commonly held perceptions that marijuana aids sleep health. Indeed, many US adults believe that cannabis can effectively treat their symptoms of insomnia [28]. A recent daily-diary study found that, when used for purposes of sleep-aid, marijuana use is associated with longer sleep duration and shorter periods of nighttime wakefulness after sleep onset; nevertheless marijuana use also predicted *greater* next-day fatigue, highlighting the potential negative impact of marijuana on overall sleep health [29]. Given this mixed evidence, additional research is needed to further clarify the within-person effects of marijuana use on young adults' sleep health.

Simultaneous alcohol and marijuana use. Alcohol and marijuana are the most commonly used substances among young adults [9, 30], and most people that use both alcohol and marijuana tend to report engaging in the two simultaneously such that the effects of alcohol and marijuana overlap in additive or synergistic ways [31]. Longitudinal data show simultaneous alcohol and marijuana (SAM) use prevalence has been increasing among young adults [32], which is alarming given that SAM use has been associated with negative consequences above and beyond the consequences experienced from alcohol or marijuana use alone [33–36]. For example, Linden-Carmichael et al. examined 2 weeks of daily data collected from young adults and found days with SAM use were associated with more negative consequences (e.g. vomiting, hangover, blacking out) compared to alcohol-only and marijuana-only days. Furthermore, when alcohol and marijuana are combined, ethanol may increase plasma THC levels, which could contribute to greater impairment [37], though additional research is needed to better understand potential synergistic physiological effects of SAM use. Despite growing evidence of harmful effects of SAM use, very few studies have examined potential effects of SAM use on perceptions of sleep health. One experimental study found that, compared to placebo conditions, participants administered both alcohol and marijuana before sleeping reported falling asleep more easily, but interaction estimates indicated the perceptions of sleep quality were lower when both substances were administered compared to either alcohol or marijuana alone [38]. Thus, there is a need for additional daily-level research on the effects of SAM use on perceived sleep health in a natural environment (nonexperimental).

Current study

Considering the high prevalence of alcohol and marijuana use among young adults [9, 30] and increasing prevalence of SAM use [32], there is a need to better understand the potential health implications of using these substances. Specifically, intensive measurement longitudinal studies (e.g. daily data collection studies) that can capture within-person variability are needed to disentangle person-level effects from daily-level effects of substance use on sleep health. Thus, the current study was designed to fill this gap in the literature by examining daily-level effects of alcohol, marijuana, and SAM use on indices of young adults' sleep health across five 14-day bursts of data collection.

The first study aim was to examine within-person associations between sleep health and patterns of substance use by contrasting (1) non-use days, (2) alcohol-only days, (3) marijuana-only days, (4) days in which both alcohol and marijuana were used, but not simultaneously, and (5) SAM use days. As demonstrated in past research [16, 20], we anticipated that young adults would report poorer indices of sleep health on alcohol-only days, relative to non-substance use days. However, given mixed findings regarding marijuana use and the novelty of exploring the effects of SAM use on sleep health, no specific hypotheses were formulated for these comparisons (i.e. exploratory analyses). The second aim of the study entailed estimating within-person linear associations between sleep health and (1) the amount of alcohol used and (2) the extent participants reported being high from marijuana. We hypothesized that greater alcohol use would be associated with relatively poorer indices of sleep health but did not make a specific hypothesis regarding marijuana use. The third aim entailed examining whether the linear associations between alcohol/marijuana use and sleep health were moderated (i.e. amplified/reduced) by using both substances on that day (i.e. same day use of both alcohol and marijuana, but not necessarily simultaneous). Given our expectations that alcohol use would have adverse effects on perceived sleep health and that using both substances on the same day may confer greater impairment, we anticipated that combined use may amplify the effects of each respective substance on perceived sleep health. This third aim was exploratory, however, as no extant evidence is available to formulate specific hypotheses.

Methods

Participants and procedures

Young adults were recruited into this longitudinal study [34, 39] from the community via newspapers ads, social media posts, and flyers—all of which promoted a study about daily health behaviors and experiences—and invited young adults ages 18–25 to complete an online eligibility screening survey. Eligibility criteria entailed being 18–25 years old, reporting at least one SAM use occasion in the past month, reporting drinking alcohol three or more times in the past month, living within 60 miles of the study office in Seattle, WA, and willingness to complete baseline and daily surveys. A total of 409 young adults were enrolled into the study (M_{age} = 21.61, *SD* = 2.17; 50.9% female). The sample was 48.2% White, 15.9% Hispanic/Latinx, 15.9% Asian/South Asian, 4.4% Black/African American, 11.2% multiracial, and 4.2% identified as another race. At baseline, 48.9% were enrolled in a 4-year college, 6.7% were enrolled in a 2-year or vocational college, 35.7% had a college degree (2- or 4-year) but were not currently a student, and 8.4% were not currently a student and had not obtained a college degree. Pertaining to work status, 25.18% reported working full-time and 40.83% reported working part-time. The average annual income (assessed using ordered categorical response options) was between $10 000 and $15 000. Less than 1% of the sample reported past-year alcohol use treatment/rehabilitation and 1.47% reported past-year drug-related treatment/rehabilitation.

Participants who met screening criteria completed an in-person session with members of the research team during which they verified their age with photo identification, completed informed consent, and received a 30-minute training session regarding the daily aspects of the study and measures (e.g. discussed what constitutes a "standard drink"). Following the training session, participants completed a baseline assessment and were remunerated with a $40 e-gift card.

The daily assessments entailed five 14-day bursts every four months for two years (i.e. 70 days total). During the bursts, participants were asked to complete 5–10-minute online surveys twice daily—once in the morning and once in the afternoon. Participants could choose the time their surveys opened from 8 am, 9 am, or 10 am for the morning survey, and 2 pm, 3 pm, or 4 pm for the afternoon surveys. Surveys were open for 3 hours and text-message reminders were sent 30 minutes prior to the close of each survey window if the participant had not yet completed the survey. The surveys asked participants to retrospectively report alcohol and marijuana use behaviors for the prior day, and indices of sleep for the past night. Morning reports were primarily intended to ask about health behaviors on the previous day (e.g. alcohol use), while afternoon reports asked about additional daily experiences including those not examined in the current study (e.g. affect). Participation was remunerated with $2.50 for each completed survey and a bonus of $10 for each burst if at least 25 assessments (out of 28) were completed for any 14-day burst. Institutional Review Board (IRB) approval was obtained from the authors' university and no adverse events were reported. Additional information on study procedures for this project can be found in a recent paper by Fairlie and colleagues [39].

Measures

Sleep health. Each morning survey assessed the number of hours that participants spent in bed (calculated using time they went to bed and time they got out of bed), and two indices of sleep health: subjective sleep quality and symptoms of insomnia. An additional indicator of sleep health, perceived negative impact of sleep on next day functioning, was assessed during the afternoon surveys. Subjective sleep quality was assessed using a modified daily-item from the Pittsburgh Sleep Quality Index [40] that read "How would you rate your sleep quality last night?" with response options from 0 = *very poor* to 4 = *very good*. Three yes/no items were used to assess symptoms of insomnia in alignment with the DSM-5 criteria: (1) "Have a problem falling asleep?," (2) "Have a problem staying asleep?," and (3) "Wake up earlier than you wanted?" These three items were summed such that nightly symptoms of insomnia ranged from 0 to 3. The effect of sleep on daily functioning was assessed in the afternoon survey

by the following item: "To what extent did your sleep last night negatively impact your functioning today?" Response options ranged from 0 = *not at all* to 4 = *extremely*; higher scores reflected poorer functioning due to sleep.

Note that, while sleep duration is considered a central element of sleep health [3], we currently focus on subjective sleep quality, negative impact of sleep on next day functioning, and symptoms of insomnia as the three indices of sleep health. Because young adults may engage in greater substance use on days on which they have opportunities for longer sleep duration (e.g. do not have to wake up early for work or school) we did not examine duration as an outcome measure to avoid this expected confound. We nevertheless controlled for hours of sleep within statistical models to hold duration constant when examining effects of substance use on these indicators of sleep health.

Substance use. Morning surveys assessed substance use behaviors on the previous day, and when participants missed a morning survey, items assessing substance use were piped into the afternoon survey. Participants were asked: (1) "Did you drink any alcohol yesterday?," (2) "Did you use marijuana yesterday?," and if they answered yes to both alcohol and marijuana use, they were asked about SAM use (3) "Yesterday, did you use alcohol and marijuana at the same time—that is, so that their effects overlapped?" Responses were coded 0 = *no* and 1 = *yes*. For each day, substance use was categorized as: (1) no alcohol or marijuana use, (2) alcohol use only, (3) marijuana use only, (4) alcohol and marijuana use but not simultaneously, or (5) SAM use.

If participants reported drinking alcohol, they were additionally asked "How many total drinks did you have yesterday?" with responses ranging from 1 = *one drink* to 25 = *25 or more drinks*. If participants did not report alcohol use, a 0 was recorded for number of drinks. Similarly, if participants reported using marijuana, they were asked "Yesterday, how high did you get when you used marijuana?" with responses ranging from 0 = *not at all high* to 4 = *extremely high*. A 0 was recorded if participants did not report any marijuana use. Although we assessed use of prescription sleep medicine on the prior day/night, this was only endorsed on 89 (0.31%) daily responses, so it was not included in the analyses.

Analyses

Prior to testing the main aims, preliminary analyses examined missing data patterns and calculated descriptive statistics for the study variables, including the proportion of total study days on which varying substance use patterns were reported (i.e. no use, alcohol only, marijuana only, both but not simultaneously, and SAM use), as well as the average proportion of days on which participants engaged in each substance use pattern. Zero-order correlations were computed at both the between- and within-person level given the multilevel structure of these data (i.e. responses nested within individuals).

To test Aim 1—estimating associations between alcohol and marijuana use patterns and sleep health—we fit a multilevel regression model for each of the three sleep outcome variables: sleep quality, negative impact of sleep on next day functioning, and symptoms of insomnia. At the between-person level, we controlled for birth sex (0 = Female; 1 = Male), age at baseline, education level (ranging from 1 = Less than High School Diploma to 8 = Graduate or Professional Degree), ethnicity/race (1 = White non-Hispanic; 2 = Asian/Asian-American, 3 = Other non-Hispanic, 4 = Hispanic), average hours spent in bed (across all study days), proportion of days that were alcohol use days, proportion of days that were marijuana use days, and proportion of days that were SAM use days. Within-person covariates included hours spent in bed that night, whether it was a weekend or not (0 = Sunday–Wednesday; 1 = Thursday–Saturday[1]), the burst number (i.e. 1–5), and the day number within the burst (i.e. 1–14). Finally, the within-person effect of substance use behavior was a categorical variable that was dummy coded to contrast each of the patterns of substance use to days on which the participant engaged in no substance use. Supplemental models entailed dummy coding the substance use behavior variable to make additional contrasts with alcohol only and marijuana only days.

Similar multilevel models were specified to assess Aims 2 and 3. These models examined the extent to which alcohol and marijuana use have linear associations with sleep health (Aim 2) and whether these associations are moderated by SAM use (Aim 3). Given the focus on linear associations, alcohol-related associations were modeled using only days on which alcohol was used and marijuana-related associations were modeled using only days on which marijuana was used. These models added variables hierarchically to examine main effects of alcohol and marijuana use separately from hypothesized interaction effects. The effects of alcohol and marijuana use were estimated at both the between-person level (i.e. aggregated across all study days) and within-person level (i.e. person-mean-centered within participants). Aim 3 entailed examining whether the linear associations between sleep and alcohol/marijuana use were moderated by using *both* alcohol and marijuana on the given day (i.e. including both SAM use and non-simultaneous use). This aim required adding a binary indicator of combined use to the models in Step 2, followed by interaction terms in Step 3. These interaction terms specifically estimated the extent that the associations between alcohol/marijuana use and sleep health differed on combined use days relative to alcohol or marijuana only days.

Whereas sleep quality and negative impact of sleep on daily functioning are continuous variables scored on Likert-type scales, the insomnia symptoms variable is a count variable that requires a nuanced count regression approach [41]. Models examining symptoms of insomnia were therefore estimated using multilevel Poisson regression, which yields rate ratios that describe the proportional change in an outcome variable associated with a one-unit increase in the independent variable (conditional on random effects). Although data were nested in days, nested in measurement bursts, nested within participants, none of the research questions pertained to the burst level, so we conducted more parsimonious two-level models and included burst number as a covariate. Multilevel models were specified to have a random intercept and fixed slope given no theoretical rationale for specifying complex random slopes. Multilevel modeling was conducted in R using the "glmmTMB" package [42] and the "nlme" package [43].

[1] Because many young adults use substances on Thursdays, we coded Thursday as a weekend [35]. Sensitivity analyses with weekend coded as only Friday and Saturday did not change the interpretation of effects.

Results

Responses were recorded on 25 347 days out of a possible 28 630 (88.53%). Percentage of missing days was significantly correlated with several study variables at the between-person level: symptoms of insomnia ($r = -.11$, $p = .021$), alcohol use ($r = .16$, $p = .001$), and marijuana use ($r = .21$, $p < .001$). That is, missingness was greater among those who typically reported fewer symptoms of insomnia, those who typically drank more alcohol, and those who typically reported being higher from marijuana use. Nevertheless, the contemporary multilevel modeling approach used to test the study aims is highly flexible when handling missing responses (i.e. maximum likelihood estimation), and it is argued that all participants should be retained in longitudinal studies when missingness is minimal [44, 45].

Descriptive statistics pertaining to substance use patterns across days and aggregated at the person-mean level are shown in Table 1. Notably, participants reported no substance use on 42.10% of days, alcohol only on 20.87% of days, marijuana only on 21.43% of days, non-simultaneous use of alcohol and marijuana on 6.11% of days, and SAM use on 9.48% of days. The sample thus comprised a relatively heavy marijuana-using group of individuals. Zero-order correlations and mean values for study variables, at both between- and within-person levels, are shown in Table 2. Between-person correlations indicated those who typically drank more alcohol typically reported less negative impact of sleep on next day functioning. However, within-person correlations indicated that on days on which participants drank relatively more alcohol than usual, they reported poorer sleep quality, and *greater* negative impact on next day functioning. At the between-person level, marijuana was not significantly associated with any indices of sleep health, but at the within-person level, days that participants reported relatively stronger marijuana highs were associated with better subjective sleep quality, fewer perceived symptoms of insomnia, and less perceived negative impact of sleep on next day functioning. Intraclass correlation coefficients, estimating the proportion of variability that is due to between-person differences indicated that most of the variability in perceived sleep health and substance use indices are due to within-person variability across study days, thus highlighting the value in daily-level multilevel modeling.

Aim 1: Associations between alcohol/marijuana use patterns and sleep health

The results from the multilevel models estimating associations between sleep health and substance use patterns are displayed in Table 3. Relative to men, women tended to report more perceived symptoms of insomnia. Between-person estimates indicated that those who more frequently drank alcohol tended to report less perceived negative impact of sleep on daily functioning, while those who more frequently used marijuana tended to report poorer perceived sleep quality and more perceived symptoms of insomnia. Central to the first aim are the within-person estimates contrasting indices of perceived sleep health on substance use days relative to non-substance-use days. On alcohol-only days, participants reported relatively poorer perceived sleep quality and more perceived negative impact of sleep on next day functioning, relative to non-substance-use days. Conversely, marijuana-only days were associated with relatively better perceived sleep quality and fewer perceived symptoms of insomnia, relative to non-substance-use days. Days on which both alcohol and marijuana were used nonsimultaneously were associated with relatively fewer perceived symptoms of insomnia, compared to non-substance-use days. Finally, on SAM use days participants reported poorer perceived sleep quality (though this effect narrowly missed significance) and greater perceived negative impact of sleep on next day functioning, relative to non-substance-use days; however, participants also reported relatively fewer perceived symptoms of insomnia on SAM use days, relative to non-substance use days.

The lower portion of Table 3 displays additional contrast estimates of models in which alcohol-only days and marijuana-only days were coded as the reference category. Note that these models are the same as the original model but with different dummy-codes to examine the remaining contrasts using different referent categories of substance use. These models indicated that on marijuana-only days, young adults reported better perceived sleep quality, lower perceived negative impact of sleep on next day functioning, and fewer perceived symptoms of insomnia, relative to alcohol-only days. Similarly, young adults reported better perceived sleep health across all three indices on days in which both substances were used non-simultaneously, relative to alcohol-only days. This was also the case for SAM use days, relative to alcohol-only days, except for perceived negative

Table 1. Descriptive statistics for number of total responses of each substance use pattern and mean proportion of days in which substances were used (N = 409)

Substance use patterns	*n* responses	% of responses	
No substance use	10 672	42.10	
Alcohol use only	5289	20.87	
Marijuana use only	5433	21.43	
Alcohol and marijuana use not simultaneously	1549	6.11	
Simultaneous alcohol and marijuana use	2404	9.48	
Total responses	25,347	100%	
Person-level proportion of use days (N = 409)	**Mean proportion (%)**	***SD* (%)**	**Range of proportions (%)**
Alcohol use	36.92	21.01	0–100
Marijuana use	38.72	32.37	0–100
Simultaneous alcohol and marijuana use	9.90	12.14	0–70

Of the 28 630 possible daily responses, we received 25 347 valid responses (88.53%).

Table 2. Zero-order correlations (at between- and within-person levels) and descriptive statistics (*N* = 409 persons with 25 347 total daily responses)

	1.	2.	3.	4.	5.	6.	7.	8.
1. Time in Bed (hours)	—	.30*	−.21*	−.26*	−.05*	.03*	—	—
2. Sleep Quality	.29*	—	−.50*	−.41*	−.09*	.04*	—	—
3. Insomnia Symptoms Sum	−.01	−.53*	—	.29*	.01	−.06*	—	—
4. Negative Functioning	−.19*	−.50*	.43*	—	.10*	−.02†	—	—
5. Number of Drinks	−.04	−.03	.01	−.10†	—	.05*	—	—
6. Marijuana High	−.04	−.09	.09	.05	.11†	—	—	—
7. Age at Baseline	.06	−.02	.09	−.09	.07	.01	—	—
8. Education Level	.13†	.06	−.05	−.12†	−.08†	−.11†	.51*	—
9. Sex (F=0, M=1)	−.22*	−.06	−.21*	.01	.14†	.17*	−.03	−.06
Between-Person Mean	7.96	2.53	0.79	1.02	1.39	0.82	21.55	5.14
Between-Person *SD*	0.68	0.46	0.43	0.48	1.11	0.76	2.41	1.88
Between-Person Range	4.89–9.75	0.82–4	0–2.28	0–2.88	0–6.63	0–3.76	18–26	1–8
Within-Person Mean	7.97	2.52	0.80	0.98	1.35	0.78	—	—
Within-Person *SD*	1.76	0.94	0.90	1.02	2.48	1.14	—	—
Within-Person Range	0–16	0–4	0–3	0–4	0–25	0–4	—	—
Intraclass Correlation Coefficient	.12	.21	.21	.23	.18	.43	—	—

Between-person level correlation coefficients are shown below the diagonal and within-person correlation coefficients are shown above the diagonal. †$p < .01$, *$p < .001$.

Table 3. Multilevel models predicting perceived sleep quality, perceived negative impact of sleep on next day functioning, and perceived symptoms of insomnia by categorical substance use behavior compared to no-substance-use days (*N* = 409 persons with 25 347 total daily responses)

	Sleep quality			Negative impact of sleep on functioning			Symptoms of insomnia*			
	b	*SE*	*p*	*b*	*SE*	*p*	Rate Ratio	$CI_{95\%\ LL}$	$CI_{95\%\ UL}$	*p*
Level-2 Variables: Between-Person										
Sex (F=0, M=1) γ^{01}	.00	.04	.925	−.05	.05	.371	0.744	0.661	0.837	<.001
Age at baseline γ^{02}	−.01	.01	.245	.00	.01	.991	1.028	0.999	1.058	.055
White non-Hispanic (referent category)										
Asian / Asian American γ^{03}	−.08	.06	.203	.14	.07	.053	1.044	0.879	1.241	.622
Other non-Hispanic γ^{04}	−.02	.06	.715	.09	.07	.174	0.997	0.854	1.164	.966
Hispanic γ^{05}	.01	.06	.863	−.05	.07	.527	1.002	0.848	1.183	.985
Education level γ^{06}	.01	.01	.393	−.02	.02	.189	0.972	0.937	1.007	.115
Average hours spent in bed γ^{07}	.17	.03	<.001	−.15	.04	<.001	0.974	0.890	1.066	.566
Proportion of alcohol use days γ^{08}	.17	.13	.201	−.46	.15	.003	1.032	0.723	1.472	.863
Proportion of marijuana use Days γ^{09}	−.20	.10	.034	.04	.11	.701	1.378	1.064	1.785	.015
Proportion of SAM use days γ^{010}	−.05	.29	.857	.51	.33	.129	1.080	0.495	2.359	.846
Level-1 Variables: Within-Person										
Hours spent in bed γ^{10}	.15	.00	<.001	−.14	.00	<.001	0.893	0.886	0.900	<.001
Weekend (No=0, Yes=1) γ^{20}	.00	.01	.864	.00	.01	.799	0.969	0.940	0.999	.040
Burst number γ^{30}	.00	.00	.871	.00	.00	.548	0.998	0.988	1.009	.749
Day number within burst γ^{40}	−.00	.00	.033	.01	.00	.001	1.001	0.997	1.004	.778
(Compared to non-substance-use days)										
Alcohol use only γ^{50}	−.10	.02	<.001	.10	.02	<.001	1.007	0.965	1.050	.761
Marijuana Use Only γ^{60}	.05	.02	.005	−.03	.02	.146	0.880	0.838	0.924	<.001
Alcohol and Marijuana but not SAM γ^{70}	.03	.03	.285	−.03	.03	.346	0.859	0.798	0.926	<.001
SAM use γ^{80}	−.04	.02	.063	.06	.03	.028	0.879	0.826	0.935	<.001
Supplemental Models with Additional Contrasts										
(Compared to alcohol only days)										
Marijuana use only	.15	.02	<.001	−.13	.02	<.001	0.874	0.828	0.923	<.001
Alcohol and Marijuana but not SAM	.13	.03	<.001	−.13	.03	<.001	0.853	0.791	0.921	<.001
SAM use γ^{80}	.06	.02	.008	−.04	.03	.094	0.873	0.819	0.931	<.001
(Compared to marijuana only days)										
Alcohol use only	−.15	.02	<.001	.13	.02	<.001	1.144	1.084	1.207	<.001
Alcohol and marijuana but not SAM	−.02	.03	.386	.00	.03	.967	0.976	0.907	1.051	.526
SAM use	−.09	.02	<.001	.08	.03	.001	0.999	0.940	1.061	.972

*Because symptoms of insomnia is a count variable, Poisson count regression was used to estimate Rate Ratios that represent proportional change for each unit increase in the predictor (e.g. a Rate Ratio of 1.10 = 10% increase for each unit change in the predictor).

impact of sleep on functioning. When contrasted to marijuana-only days, SAM use was associated with poorer perceived sleep quality and more perceived negative impact of sleep on next day functioning.

Aim 2: Linear associations between alcohol/marijuana use and sleep health

The second aim entailed examining linear associations of alcohol and marijuana use on indices of sleep health (Tables 4 and 5, respectively). Focusing first on the association of alcohol use and perceived sleep health (on alcohol use days), within-person effects showed that participants reported relatively poorer perceived sleep quality and greater perceived negative impact of sleep on next day functioning following days in which participants drank relatively more alcohol (Table 4). This indicates adverse linear effects of alcohol use on sleep quality and daily functioning such that each additional drink is associated with a 0.03 decrease in subjective sleep quality score and a 0.05 increase in the negative functioning score, after accounting for the effects of covariates, but alcohol use was not related to symptoms of insomnia. Conversely, on marijuana use days, participants reported relatively better perceived sleep quality and fewer perceived symptoms of insomnia on days in which participants reported a relatively stronger high from marijuana use (Table 5). This shows potentially favorable linear effects of marijuana such that a one-unit increase in reported marijuana high was associated with a 0.04 increase in perceived sleep quality and 6% fewer symptoms of insomnia at the daily level. However, there was a significant between-person effect of person-mean marijuana high on daily functioning such that a one-unit increase in average scores on daily highs from marijuana was associated with 0.13 greater perceived negative functioning attributed to sleep, on average (Table 5).

Aim 3: Does combined use amplify the effects of alcohol/marijuana use on sleep health?

Further extending the associations found in Aim 2, the third aim examined whether the linear associations between alcohol/marijuana use and perceived sleep health were moderated by combined use of the two substances on a given day. Combined alcohol and marijuana use, considered as a dichotomous variable at the within-person level, was entered into the multilevel models in step two. Interaction terms were then entered into the models in step three.

Relative to alcohol-only days, participants reported better perceived sleep quality and fewer perceived symptoms of insomnia on days that both alcohol and marijuana were used (Table 4). Combined use did not moderate the significant linear association between alcohol use and perceived sleep quality. However, a significant interaction was detected in the model examining perceived negative effects of sleep on next day functioning such that the association of alcohol use on daily functioning was significantly decreased on days that alcohol and marijuana were both used.

Compared to marijuana-only days, participants reported worse perceived sleep quality on days that both alcohol and marijuana were used (Table 5). No significant interactions were detected in any of the models, indicating that the linear associations between marijuana and perceived sleep health were not moderated by combined use of marijuana and alcohol.

Discussion

Sleep is critical to the overall health and wellbeing of young adults, but whether young adults get adequate sleep is a

Table 4. Multilevel models estimating dose-response associations between alcohol use and perceived sleep quality, perceived negative impact on next day functioning, and perceived symptoms of insomnia on alcohol-use days (*N* = 405 persons with 7303 total daily responses)

	Sleep quality			Negative impact of sleep on functioning			Symptoms of insomnia*			
	b	*SE*	*p*	*b*	*SE*	*p*	Rate Ratio	$CI_{95\%\ LL}$	$CI_{95\%\ UL}$	*p*
Step 1: Main Effects of Alcohol and Marijuana										
Sex (F=0, M=1) γ^{01}	−.01	.05	.883	−.02	.06	.769	0.799	0.706	0.903	<.001
Age at Baseline γ^{02}	−.02	.01	.065	.00	.01	.721	1.029	0.998	1.060	.062
White non-Hispanic (referent category)										
Asian / Asian American γ^{03}	−.06	.07	.370	.17	.08	.036	1.012	0.849	1.207	.982
Other non-Hispanic γ^{04}	−.02	.06	.768	.02	.07	.783	0.982	0.837	1.152	.854
Hispanic γ^{05}	.11	.07	.123	−.15	.08	.056	0.990	0.837	1.172	.901
Education level γ^{06}	.02	.02	.295	−.03	.02	.065	0.980	0.944	1.018	.285
Average hours spent in bed (*BW*) γ^{07}	.19	.04	<.001	−.17	.04	<.001	0.971	0.883	1.067	.545
Hours spent in bed (*WI*) γ^{10}	.13	.01	<.001	−.15	.01	<.001	0.906	0.892	0.920	<.001
Weekend (No=0, Yes=1) γ^{20}	.01	.02	.551	−.01	.02	.770	0.928	0.877	0.983	.013
Burst number γ^{30}	−.01	.01	.469	.01	.01	.155	1.004	0.984	1.024	.900
Day number within burst γ^{40}	−.01	.00	.023	.01	.00	<.001	1.003	0.996	1.010	.448
Mean number of drinks (*BW*) γ^{08}	−.03	.01	.022	.01	.01	.399	0.997	0.966	1.029	.786
Daily number of drinks (*WI*) γ^{50}	−.03	.01	<.001	.05	.01	<.001	1.004	0.990	1.017	.452
Step 2: Both alcohol and marijuana use										
Combined use (No=0, Yes=1) γ^{60}	.05	.03	.034	−.05	.03	.116	0.907	0.846	0.972	.006
Step 3: Interaction Effects										
Combined use × Number of drinks (*WI*) γ^{70}	.01	.01	.407	−.03	.01	.014	1.003	0.979	1.027	.799

BW = Between-person level (i.e. aggregated person means); WI = Within-person level (i.e. person-mean centered).

*Because symptoms of insomnia is a count variable, Poisson count regression was used to estimate Rate Ratios that represent proportional change for each unit increase in the predictor (e.g. a Rate Ratio of 1.10 = 10% increase for each unit change in the predictor). Combined use in Steps 2 and 3 is a categorical indicator of days in which both alcohol and marijuana were used, compared to alcohol only days.

Table 5. Multilevel models estimating dose–response associations between strength of marijuana high and perceived sleep quality, perceived negative impact on next day functioning, and perceived symptoms of insomnia on marijuana-use days (N = 383 persons with 9386 total daily responses)

	Sleep quality			Negative impact of sleep on functioning			Symptoms of insomnia*			
	b	*SE*	*p*	*b*	*SE*	*p*	Rate ratio	$CI_{95\%\ LL}$	$CI_{95\%\ UL}$	*p*
Step 1: Main Effects of Alcohol and Marijuana										
Sex (F=0, M=1) γ^{01}	−.01	.05	.894	−.05	.06	.423	0.755	0.658	0.866	<.001
Age at Baseline γ^{02}	−.02	.01	.146	−.01	.01	.505	1.038	1.007	1.070	.016
White non-Hispanic (referent category)										
Asian / Asian American γ^{03}	.05	.07	.467	.05	.08	.583	0.873	0.710	1.073	.589
Other non-Hispanic γ^{04}	.06	.06	.321	−.03	.07	.637	0.967	0.814	1.149	.197
Hispanic γ^{05}	.06	.07	.363	−.10	.08	.194	0.970	0.806	1.167	.699
Education Level γ^{06}	.03	.01	.061	−.02	.02	.176	0.953	0.915	0.992	.018
Average Hours Spent in Bed (*BW*) γ^{07}	.21	.04	<.001	−.16	.04	<.001	0.903	0.817	0.999	.047
Hours spent in bed (*WI*) γ^{10}	.15	.01	<.001	−.14	.01	<.001	0.891	0.879	0.903	<.001
Weekend (No=0, Yes=1) γ^{20}	.00	.02	.887	.00	.02	.956	0.942	0.897	0.990	.023
Burst number γ^{30}	.00	.01	.826	.00	.01	.571	0.998	0.981	1.016	.843
Day number within burst γ^{40}	−.01	.00	.008	.01	.00	.005	0.999	0.993	1.005	.850
Mean marijuana high (*BW*) γ^{08}	.03	.05	.490	.13	.06	.024	0.991	0.863	1.138	.901
Daily marijuana high (*WI*) γ^{50}	.04	.01	<.001	.02	.01	.179	0.959	0.926	0.993	.019
Step 2: Both Alcohol and Marijuana Use										
Combined use (No=0, Yes=1) γ^{60}	−.06	.02	.003	.04	.02	.079	0.993	0.940	1.050	.824
Step 3: Interaction Effects										
Combined use × Marijuana High (*WI*) γ^{70}	.02	.03	.331	−.05	.03	.177	1.068	0.994	1.148	.073

BW = Between-person level (i.e. aggregated person means); WI = Within-person level (i.e. person-mean centered).
*Because symptoms of insomnia is a count variable, Poisson count regression was used to estimate Rate Ratios that represent proportional change for each unit increase in the predictor (e.g. a Rate Ratio of 1.10 = 10% increase for each unit change in the predictor). Combined use in Steps 2 and 3 is a categorical indicator of days in which both alcohol and marijuana were used, compared to marijuana only days.

concern, given that this is a high-risk age period for alcohol and marijuana use as well as simultaneous use of both substances, all of which may jeopardize young adults' sleep health [14]. We used intensive longitudinal sampling of substance-using young adults to investigate daily-level effects of alcohol, marijuana, and SAM use on indices of sleep health. Relative to non-substance-use days, participants reported poorer perceived sleep health on alcohol-only days, better perceived sleep health on marijuana-only days, and a mixture of perceived sleep health on SAM use (i.e. fewer symptoms of insomnia, but poorer next day functioning attributed to sleep). Additional contrasts between substance use patterns further revealed that young adults reported the poorest perceived sleep health on alcohol-only days compared to days on which marijuana was used either alone or alongside alcohol. Similarly, young adults reported poorer perceived sleep health indices on SAM use days, relative to marijuana-only days. Taken together, young adults reported poorer perceived sleep health when they used alcohol and better perceived sleep health when they used marijuana on a given day; when used simultaneously, any potential perceived benefits of marijuana may be negated by the adverse effects of alcohol.

We also found partial support for linear associations between substance use and sleep at the daily-level. Young adults reported poorer perceived sleep quality and worse impact on functioning following days that they had engaged in relatively more alcohol use. Conversely, young adults reported relatively better perceived sleep quality and fewer perceived symptoms of insomnia following days that they reported relatively stronger effects from marijuana. These models were extended to examine whether linear associations were stronger/weaker on days that both substances were used. Only one significant interaction was found: The adverse association between alcohol use and next day functioning was weaker when young adults also used marijuana in combination with alcohol. Otherwise, SAM use did not amplify or reduce the other linear effects of these substances on young adults' perceived sleep health.

All daily-level effects considered, these data highlight the harmful effects of alcohol use on indices of sleep health and provide evidence that substance-using young adults report favorable daily-level effects of marijuana use on perceived sleep health in terms of subjective sleep quality and symptoms of insomnia. However, the current findings provide limited evidence for adverse effects of SAM use on sleep health beyond those attributable to alcohol. Indeed, as it pertains to perceived sleep health, the effects of SAM use appear to be an amalgam of the effects related to alcohol and marijuana, as was found in an experimental study on young adults that administered both alcohol and marijuana prior to sleep [38]. Harmful effects of alcohol use could be partially mitigated by marijuana use, though this is not to say that SAM use is beneficial to sleep, as perceived effects of marijuana use could similarly be negated by alcohol use. Moreover, when compared directly to non-substance-use days, SAM use days were associated with poorer perceived sleep quality and more negative perceived impacts of sleep on next day functioning. While this ecologically valid observational study represents a critical first step, experimental research is needed to better understand the physiological effects of SAM use on sleep health, relative to alcohol or marijuana only, using more objective markers (e.g. polysomnography).

Regarding alcohol use, the daily-level associations extend our understanding of the harmful effects on sleep health,

beyond what has been documented in previous cross-sectional and daily-sampling studies [16, 46]. Moreover, the finding that alcohol may have a linear effect on perceived sleep health aligns with the limited extant literature [18], and adds to previous experimental findings that even low doses of ethanol can result in rapid development of tolerance in individuals with insomnia [47] and dose escalation in healthy individuals [48]. This finding is critical given that a significant portion of young adults who drink tend to engage in relatively heavy use patterns (e.g. heavy episodic and high-intensity drinking) [30, 49, 50]. Despite the seemingly clear implications for sleep health (i.e. alcohol use should be avoided), further studies are needed to continue expanding our understanding of these harmful effects including timing of use prior to sleep onset [22].

Given that few studies have examined daily-level associations between marijuana use and sleep health, the current findings contribute to this growing literature. Building upon recent findings that using marijuana for sleep aid predicts increased sleep duration and shorter nighttime wakefulness [29], we found marijuana use was associated with better perceived sleep quality and fewer perceived symptoms of insomnia. Unlike the study by Goodhines and colleagues, which reported marijuana use was associated with greater next-day fatigue, we found marijuana use was not significantly associated with negative perceived impacts of sleep on next day functioning, when considered as a continuous independent variable in the linear model. However, we note that diurnal fatigue, as assessed in the Goodhines study, may be distinct from the measure of broad sleep-related functional impairment currently examined, and there are sample differences between the two studies that preclude direct comparisons (e.g. college student sample vs. community sample). While the current findings add to this important area of study, the evidence regarding daily-level effects of marijuana on sleep health is burgeoning, especially as recreational use becomes legal across the United States. Further research is needed to clarify the effects of marijuana use on sleep health, particularly as it pertains to adverse effects of chronic use over time and sleep problems during withdrawal from frequent marijuana use [51].

Although the focus of the current study was on the within-person effects of substance use at the daily-level, several significant between-person effects warrant discussion. Whereas marijuana use was associated with better perceived sleep health at the daily level, those who tend to experience stronger effects of marijuana use, on average, reported significantly poorer perceived sleep quality and more perceived symptoms of insomnia overall. While this may highlight harmful long term effects of marijuana on sleep health and aligns with previous literature [25], it may also be that those with poorer sleep health are more likely to be heavier marijuana users, as has been demonstrated in previous studies [52]. Indeed, the use of marijuana may have short-term sleep-inducing effects, but is likely not a prudent long-term strategy given that chronic marijuana use can lead to the development of tolerance and eventual increase in sleep-disturbances or even symptoms of withdrawal manifested in the inability to sleep without marijuana [53].

The current study also found more frequent alcohol use at the between-person level (i.e. greater proportion of days) was associated with *less* perceived negative impact of sleep on daily functioning. This finding is curious but may be confounded by the amount of alcohol used per drinking occasion. Indeed, the linear model showed that, at the between-person level, those who drink more per occasion reported poorer perceived sleep quality, on average. This latter finding aligns with evidence that heavy chronic alcohol use has salient harmful effects on sleep health [13]. Taken together, these somewhat contradictory findings highlight the need for more nuanced assessment of alcohol use frequency, quantity, and timing in relation to sleep onset as well as the potential value in objective measures of sleep health in future studies.

Applied implications

In this study, participants reported marijuana use on 37% of days (either on its own or in conjunction with alcohol), and this raises the questions of whether marijuana use days are associated with *improved* perceived sleep health or simply lessening sleep-related withdrawal symptoms related to dependence on days that marijuana is not used. It is not clear to what degree young adults differentiate sleep onset from sleep quality, nor to what degree young adults appropriately describe next day functioning as due to "sleep quality" or factors like a hangover (in the case of alcohol). Regardless, in brief interventions that aim to elicit personally relevant reasons to change (e.g. motivational interviewing [54]), someone hoping to improve sleep quality (i.e. their value or goal) could receive feedback about ways in which their current substance use (i.e. the status quo) contributes to what they are experiencing. It is possible that improving sleep health through effective interventions for insomnia could lead to reductions in substance use, or that changing substance use behaviors could improve perceived sleep quality. Putting issues like sleep health and substance use into a larger context can highlight clinical opportunities and potential starting points for behavior change.

Given the high rates of alcohol and marijuana use, and increasing prevalence of SAM use among young adults [32], applied strategies may entail community-level prevention messaging around short- and long-term effects of these substances on sleep health. While young adults are often willing to accept the risks of substance use, demonstrable evidence for the impact these substances can have on sleep may be a motivating factor for decreasing use or to not use in risky ways such as combining alcohol and marijuana (relative to marijuana-only and non-substance use days). Indeed, psychoeducation regarding substance use and sleep health may be beneficial to both of these critical health domains.

Limitations and future directions

Alongside the strengths of collecting daily-level data across five 14-day bursts, several limitations should be considered. This study sampled young adults who use alcohol and marijuana, so findings may not generalize to infrequent users or to young adults with diagnosable sleep disorders. Moreover, assessments relied on participants' subjective self-reports, which are typically reliable/valid for substance use and sleep behaviors [55, 56], but due to recall and social desirability biases may not be as accurate as objective measures. Indeed, replication studies using additional daily-level sleep measures [57] and more detailed quantitative estimates of sleep issues (rather than dichotomous) would strengthen the confidence in the present results

[58]. Moreover, marijuana effects were estimated using participants' subjective reports of marijuana experiences (i.e. how high they felt), which precludes dose–response interpretations that may be of interest in future studies examining synergistic effects of marijuana and alcohol. Relatedly, a more in-depth examination of marijuana administration method and THC content is warranted, as well as direct comparisons of medicinal vs. recreational use. We included time spent in bed as a covariate in the models but did not have a specific measure of time spent *asleep*. The analytic models also did not account for timing of substance use in relation to sleep, which may be an important future direction when examining the effects of SAM use on sleep health [22]. An additional future direction not currently examined is young adults' motives for use on a given occasion. For example, if substances were used for social or enhancement reasons, the effects of use on sleep may be different than if substances were used specifically to facilitate sleep or to alleviate pain. Different strains and/or concentrations of marijuana may have varying effects on sleep [59], which was not currently explored in this study as it was beyond the scope. Relatedly, current analyses did not control for use of other substances such as caffeine, nicotine, or sleep medication. Future studies may further increase our understanding of the effects of substance use on insomnia by separating out the unique indices of insomnia (e.g. falling asleep vs. staying asleep). This may be prudent as alcohol and marijuana may decrease sleep onset but increase nighttime wakefulness or early awakening as the effects wear-off throughout the night.

Pertaining to the sample characteristics, the study used a community sample of young adults who reported recent simultaneous alcohol and marijuana use at screening, and data presented herein indicate the sample was a relatively heavy marijuana using sample. Participants were recruited in a state where recreational marijuana use is legal for those 21 or older (at baseline 65.04% of the sample were 21 or older), so findings may not generalize to other states. Similarly, the sample demographics (e.g. race/ethnicity) approximately matched the census data from the counties in Washington State where data were collected, but more diverse samples are needed to fully understand the scope of substance use on sleep health (e.g. samples with greater racial/ethnic diversity, different age groups). Future work may also consider the nature of participants' work schedules as those working at night or with variable work hours may have more sporadic sleep health patterns and could be more at risk for using substances to aid with sleep given disruptions to circadian rhythm. Finally, an inherent limitation to all daily-sampling studies is that participants were aware that they would be asked to report their behaviors during the duration of the study, which could have influenced their behaviors.

Conclusion

Using intensive longitudinal data collection, this is the first study to our knowledge that has examined daily-level effects of SAM use on indices of perceived sleep health. We found evidence that compared to non-substance-use days, young adults reported poorer perceived sleep health when they used alcohol, better perceived sleep health when they used marijuana, and mixed evidence when they engaged in SAM use (i.e. fewer perceived symptoms of insomnia, but poorer perceived next day functioning attributed to sleep). Pertaining to linear associations, young adults reported poorer perceived sleep quality and more perceived negative impact of sleep on functioning when they had consumed relatively more alcohol, but better perceived sleep quality and fewer perceived symptoms of insomnia when they reported relatively stronger effects from marijuana. However, between-person estimates indicated adverse effects of marijuana use on sleep health: Participants who reported stronger effects of marijuana use, on average, reported significantly poorer perceived sleep quality and more perceived symptoms of insomnia. Interaction effects specified to examine whether linear associations were moderated by combined alcohol and marijuana use revealed only that the adverse association between alcohol use and next day functioning was weakened on days marijuana was used in combination with alcohol. Taken together, these findings provide additional evidence for daily-level effects of alcohol and marijuana use on perceived sleep health and address an important literature gap regarding potential adverse effects of SAM use.

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None declared.

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