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Daily-level associations between sleep duration and next-day alcohol and cannabis craving and use in young adults

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Abstract

Study Objectives: To examine the effects of sleep duration on next-day alcohol and cannabis craving and use among young adults.

Method: A community sample of young adults who reported recent simultaneous alcohol and cannabis use at screening (N=409; M_{age}=21.61; 50.9% female) completed twice daily surveys (morning and afternoon) for five 14-day sampling bursts (i.e., 70 days total). Daily measurements included sleep duration, alcohol and cannabis craving, and alcohol and cannabis use (i.e., number of drinks, hours high). Multilevel models enabled examining associations between sleep duration and substance use/craving at three distinct levels: daily-level, burst-level, and person-level.

Results: At the day-level, sleep duration was inversely associated with craving for both alcohol and cannabis: Stronger craving was reported on mornings and afternoons after relatively shorter sleep duration. At the burst-level, sleep duration was inversely associated with morning and afternoon alcohol craving indicating stronger alcohol craving, but not cannabis craving, during two-week periods when young adults have accumulated shorter sleep duration. Pertaining to alcohol and cannabis use, no daily-level effects were found, but the burst-level effect showed that participants engaged in greater alcohol use during two-week bursts with shorter sleep duration.

Conclusions: Based on a non-clinical sample of young adults reporting substance use, results suggest shorter sleep duration may be a modifiable risk factor as it pertains to substance use and cravings. Results highlight day-level effects of shorter sleep duration on substance use cravings and adverse effects of cumulative sleep deficit on alcohol use.

Keywords

Marijuana; Sleep deficit; Drinking; Substance use; Craving

The high prevalence and risky patterns of alcohol and cannabis use among young adults (i.e., ages 18 to 25) represent major public health concerns. U.S. national data provides estimates that 64.7% of young adults engaged in past-month alcohol use and 26.8% engaged in past-month cannabis use (Schulenberg et al., 2021). Preventing substance use among

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young adults is crucial given continued brain development during this period (Somerville, 2016), and the well-documented adverse effects of alcohol and cannabis use on the developing brain (e.g., Meruelo et al., 2017). Moreover, substance use behaviors during this developmental period are particularly concerning as longitudinal evidence suggests lifestyle behaviors (both healthy and risky) persist and may even increase into adulthood (Burdette et al., 2017; Lawrence et al., 2017). Thus, identifying etiological factors that contribute to or correlate with substance use enables prevention efforts to target modifiable risk factors.

Sleep is a central component of health and wellbeing, but relative to other age groups, young adults have the poorest sleep health, which is a multidimensional construct comprising adequate duration, appropriate timing, subjective satisfaction, high efficiency, and sustained alertness during the day (Buysse, 2014). U.S. national data indicates over 20% of young adults struggle with falling and staying asleep (Grandner et al., 2012), and among college students, 62% meet the criteria for ‘poor sleep’ (Becker et al., 2018). Despite expert recommendations that adults should get between 7–9 hours of sleep per night to promote optimal health (Watson et al., 2015), U.S. national estimates show that 32.2% of those 18–24 years old and 37.9% of those 25–34 years old get less than seven hours of sleep, on average (CDC, 2021).

Although all indices of sleep health are crucial, duration is a modifiable behavior that may be reflected in other dimensions of sleep health (e.g., satisfaction, alertness), and effects of sleep duration on other aspects of health may be particularly salient. Inadequate sleep duration has numerous adverse health implications (e.g., cardiovascular, mental, metabolic), and there is increasing evidence of a link between sleep duration and substance use behaviors. National epidemiological data shows a clear association between shorter sleep duration and 12-month prevalence of alcohol and other drug disorders (Geoffroy et al., 2020). Specific to young adults, cross-sectional studies report associations between shorter sleep duration and heavier alcohol use (Chaput et al., 2012) and cannabis use (Conroy et al., 2016; Winiger, Hitchcock, et al., 2021). Prospective research also shows that shorter sleep duration predicts greater alcohol use and related problems among young adults across a period of several years (Wong et al., 2015). Notably, existing literature has scantly examined proximal associations between sleep duration and substance use.

When modeling more proximal associations between substance use and various dimensions of sleep health, numerous studies have examined sleep as an outcome of substance use behaviors. Indeed, recent studies have examined daily-level effects of alcohol and cannabis on indices of sleep on the night following use (e.g., Goodhines et al., 2019; Graupensperger, Fairlie, et al., 2021; Lydon-Staley et al., 2016; Miller et al., 2021), but few studies, to our knowledge, have examined sleep duration as a prospective risk factor for next-day substance use. One recent daily process study of young adults with clinical levels of insomnia found participants drank more heavily on days following better sleep efficiency (i.e., per self-report but not for actigraphy measured) and greater total sleep duration (Miller et al., 2021), but this association has not been demonstrated in a more general sample of young adults (i.e., without specific focus on clinical insomnia).

Although daily-level effects of sleep on alcohol and cannabis use and cravings are under-explored, the theoretical rationale for anticipating this directional effect can be gleaned from studies on sleep and cravings among people recovering from drug addiction. One daily-diary study found evidence that indices of poorer subjective sleep quality, measured in terms of deepness of sleep, related to stronger next-day cravings among adults in treatment for nonmedical opiate use (Lydon-Staley et al., 2017). Subsequent research has evinced the temporality of this association by confirming that perceived sleep quality prospectively predicted next-day cravings more than cravings negatively impacted perceived sleep quality among a sample of individuals recovering from various substance use disorders, including alcohol and cannabis use disorders (Freeman & Gottfredson, 2018). In this paper, Freeman and Gottfredson describe a process in which inadequate sleep duration may lead to ego depletion (i.e., depletion of limited cognitive resources that leads to impaired self-regulation; Baumeister et al., 1998) that may increase cravings and, potentially, use of substances. That is, building on findings that inadequate sleep can cause ego depletion (Barber & Munz, 2011), and that ego depletion is linked to limited self-regulatory capacity related to substance use (Christiansen et al., 2012), there is theoretical precedence for anticipating sleep duration may relate to next-day alcohol and cannabis craving and potentially use. However, the limited research in this domain has focused on clinical samples that are in active recovery, and associations between sleep duration and next-day alcohol/cannabis craving and use among a non-clinical community sample of young adults remain untested.

Current Study

Building on cross-sectional evidence that sleep relates to alcohol and cannabis use behaviors, the current study entailed secondary analyses of longitudinal twice-daily data (five 14-day bursts) to examine effects of sleep duration at the daily level. Informed by recent studies among individuals in active substance use recovery programs, we anticipated that alcohol and cannabis cravings and use would be higher on days following shorter sleep duration. Moreover, the behavioral impacts of shorter sleep duration may occur over a period in which inadequate sleep duration accumulates, which is known as cumulative sleep deficit (Taskar & Hirshkowitz, 2003). To provide a deeper examination of potential effects of sleep on alcohol and cannabis cravings and use, we also examined associations at the burst-level (two-week periods) as well as the person-level. We hypothesized that alcohol/cannabis use and cravings would be higher during bursts with relatively shorter sleep duration and, at the person level, that young adults who generally sleep fewer hours would report stronger cravings for alcohol and cannabis and would report greater use of these substances. Thus, we tested the associations between sleep duration and substance use/cravings at three separate levels of analysis (i.e., daily-level, burst-level, and person-level) to determine whether effects of sleep may be more salient at a given level, and therefore may suggest varied prevention strategies. Further, we tested sleep effects on both morning and afternoon craving, recognizing that craving may vary throughout the day, and effects of sleep on craving may be stronger in the more proximal morning surveys.

Method

Participants and Procedures

A community sample of young adults was recruited for a larger longitudinal daily study to investigate various research questions pertaining to substance use (Fairlie et al., 2021; Lee et al., 2020). To be eligible, participants must have been 18–25 years old, reported at least one past-month occasion of simultaneous alcohol and cannabis use, reported drinking alcohol 3+ times in the past month, and been living within 60 miles of the study office in Seattle, WA. The final sample of young adults who were eligible and enrolled into the study (N = 409; M_{age} = 21.61, SD = 2.17; 50.9% female) completed an in-person session with a member of the research team during which they verified their age with photo identification, completed informed consent, and received a 30-minute training on aspects of the daily survey and measures (e.g., discussed what constitutes a ‘standard drink’). 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 received 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, 25.2% reported working full-time and 40.8% reported working part-time. Baseline scores on the Pittsburgh Sleep Quality Index (Buysse et al., 1989) indicated that 67% of the sample met the cutoff for poor sleep (i.e., scores >5), which is slightly above some estimated prevalence rates for young adults that tend to be between 50% and 65% (e.g., Becker et al., 2018; Fatima et al., 2016), though this could reflect the current eligibility criterion of using alcohol and cannabis (Kenney et al., 2012). Baseline scores on the Alcohol Use Disorders Identification Test (Saunders et al., 1993) indicated 10% of the sample were classified as hazardous/harmful drinkers, and 7% were classified as likely having moderate to severe alcohol use disorder. Finally, baseline scores on the Cannabis Use Disorders Identification Test – Revised (Adamson et al., 2010) indicated that 23% of the sample were classified as having hazardous cannabis use and 46% as having possible cannabis use disorder, and 4.4% of participants indicated they had a medical recommendation to use cannabis.

Participants were asked to complete two daily surveys – morning and afternoon – for five 14-day bursts that were separated by four months (i.e., 70 days total across 16 months). A sixth burst was also collected, but was disrupted by the COVID-19 pandemic and therefore excluded given changes to young adults’ substance use behaviors during this time (e.g., Graupensperger et al., 2021) as well as changes in sleep patterns (Cox & Olatunji, 2021). Participants had two 3-hour survey windows each day. In Burst 1, the morning window was from 9am to 12pm and the afternoon window was from 3pm to 6pm. In Bursts 2–5, the 3-hour survey windows had flexibility such that participants were able to specify a morning start of 8am, 9am, or 10am and an afternoon start time of 2pm, 3pm, or 4pm. Text-message reminders were sent 30-minutes prior to the close of each survey window if the participant had not yet completed the survey. Central to the present study, morning surveys asked participants to retrospectively report alcohol and cannabis use on the prior day and indices of sleep for the past night. Craving was asked in the morning and afternoon. Afternoon surveys included the substance use items from the morning survey if the participant had

missed the morning survey. Models included all study days, including days in which alcohol or cannabis were used exclusively, as well as days in which both substances were used. Participants were compensated $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 approval was obtained, and no adverse events were reported.

Measures

Sleep duration (i.e., measured in number of hours with 15-minute intervals) was calculated using two items assessed in the morning survey asking participants the time they went to bed on the previous night and the time they got out of bed on the current day. We note that sleep duration, as currently operationalized, reflects time spent in bed, which is an imperfect proxy for time spent asleep, though previous studies have shown moderate correlations between time in bed and objectively measured time spent asleep in a young adult sample (Lauderdale et al., 2008). Morning surveys also assessed substance use behaviors from the previous day: (a) “Did you drink any alcohol yesterday?” and (b) “Did you use marijuana yesterday?” 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 cannabis, they were asked “How many total hours were you high?” which, at the daily level, has shown strong criterion validity in these data with strong associations with estimates of quantity, such as grams used or number of hits (Calhoun et al., n.d.). A 0 was recorded if participants did not report any marijuana use.[1] Alcohol and cannabis cravings were asked in both morning and afternoon surveys using items “Right now, how strong is your desire to…(drink alcohol)/(use marijuana)?” Craving was assessed using response options 0 = *No desire* to 8 = *Strong desire*.

Analyses

The aims of this study required multilevel analyses to disentangle data at three levels: the *person* level to examine between-person effects of sleep and substance use and craving (Level 3), the *burst* level to examine effects of cumulative sleep deficit at each two-week burst (Level 2), and the *daily* level to examine how sleep on the previous night relates to substance use and craving on the subsequent day (Level 1). To isolate the unique associations at each level, sleep duration was grand-mean centered at the person level, person-mean-centered at the burst level, and burst-mean-centered at the daily level (Brincks et al., 2017; Enders & Tofighi, 2007; Wang & Maxwell, 2015). Day number within burst as well as burst number variables were included at Levels 1 and 2, respectively, to account for any trends in predictors or outcomes over time.

Reports of alcohol and cannabis craving were positively skewed with a large proportion of responses at the lowest end of the scale (e.g., no desire to drink alcohol), but are nevertheless continuous integer variables rather than count variables. Thus, multilevel gamma regression

[1]The item asking about hours spent high was asked on all days marijuana use was reported, while other items (e.g., grams used) were only asked on days when certain methods of use were reported (e.g., smoking or vaping). As such, we report hours high rather than grams used to maximize the number of useable days.

models with log-link functions were fit for alcohol and cannabis cravings reported in both the morning and afternoon (i.e., four separate models). Consistent with previous substance use craving research with outcome variables reflecting a gamma distribution (e.g., Grow et al., 2015), regression coefficients are exponentiated to facilitate interpretation. Iterative model fitting procedures indicated that craving models with random intercepts for each participant and burst had the best fit to the data, while adding a random slope for sleep duration either did not significantly improve fit or produced convergence errors.

Alcohol and cannabis use outcomes were also positively skewed but measured on a count scale. As such, we modeled alcohol and cannabis use outcomes using negative binomial regressions specified to account for overdispersion of non-use days. In models with count outcomes, coefficients are exponentiated to yield count ratios (CR) that are interpreted similar to odds ratios (i.e., CRs above 1 indicate a positive association and CRs below 1 indicate an inverse association). We removed four participants who did not use alcohol on any day of the study period and 25 participants who did not use cannabis on any day of the study period from the respective models. Iterative model fitting procedures indicated models with random intercepts for each participant and burst and with random slopes for sleep duration at the day-level had the best fit to the data.

All models controlled for birth sex, age at baseline, college student status at baseline, race/ethnicity, burst number, day number within burst, day of the week, whether the participant worked or went to school on the current day, and whether the participant had to work or go to school on the following day. Craving models also controlled for person-mean proportion of drinking days or cannabis use days, depending on the outcome variable, to statistically account for cravings being stronger among those who use more frequently. Use models also controlled for use of the other substance (i.e., alcohol/cannabis) at the person-, burst-, and daily-levels given that co-use is common among this age group, and particularly the present sample given they were screened on the criterion of simultaneous use of cannabis and alcohol within the month prior to screener. Multilevel models were fit using maximum likelihood estimation in R using the ‘glmmTMB’ package (Brooks et al., 2017).

Results

Shown in Table 1, response rates throughout the five bursts ranged from 79.2% to 88.8%, indicating strong fidelity to daily survey protocols. Percentage of missing surveys was significantly correlated with between-person level cannabis use ($r = .21$, $p < .001$) and cannabis craving (Morning: $r = .14$, $p = .006$; Afternoon: $r = .13$, $p = .009$), but was notably uncorrelated with sleep duration and alcohol outcomes. Despite these missingness patterns, multilevel modeling is highly flexible when handling missing responses and it is argued that all participants should be retained in longitudinal studies when missingness is minimal (Enders, 2011; Kwok et al., 2008). Additional descriptive statistics shown in Table 1 include sample and person-level means and intraclass correlation coefficients (ICC) that estimate the amount of variability attributed to between-person differences relative to within-person fluctuations (at the burst and/or daily levels).

Craving Models

Models examining associations between sleep and alcohol craving are shown in Table 2. As it pertains to morning alcohol craving, sleep duration had a significant inverse association at all three levels of analysis. At the person level, those who typically slept fewer hours tended to report stronger morning alcohol craving, on average. At the burst level, morning alcohol craving was stronger during two-week periods in which participants reported relatively fewer hours of sleep (relative to person-means). Finally, at the daily level, participants reported relatively stronger morning alcohol craving following nights of fewer hours of sleep (relative to burst means). For afternoon reports of alcohol craving, the effect of sleep was significant at the burst and daily levels; participants reported stronger afternoon alcohol craving during two-week periods in which they slept fewer hours, relative to person means, and stronger afternoon alcohol craving on days following relatively shorter sleep duration. Morning alcohol craving was stronger on days participants did not have to work or go to school. Moreover, for both morning and afternoon alcohol craving, participants reported stronger craving on days in which participants did not have work or school the next day.

Associations between sleep and cannabis craving are also reported in Table 2. Sleep duration had a significant inverse association with both morning and afternoon cannabis craving at the daily level only; participants reported relatively stronger cannabis craving on mornings and afternoons following nights with shorter sleep duration. Morning–but not afternoon–cannabis craving was stronger on days in which participants did not have work or school.

Alcohol and Cannabis Use Models

Models estimating associations between sleep and alcohol/cannabis use are shown in Table 3. As it pertains to alcohol use, an inverse association between use and sleep was found at the burst level, indicating that alcohol use was greater during two-week periods in which participants reported relatively fewer hours of sleep. The associations at the person and daily levels were not significant. Sleep duration and cannabis use were not significantly associated at any of the three analytic levels. Both alcohol and cannabis use were lower on days participants had to work or go to school, as well as on days in which participants had to work or go to school on the following day. At the daily-level only, cannabis use was related to more alcohol use, and alcohol use was related to more cannabis use, in respective models.

Discussion

To further our understanding of the links between sleep and substance use behaviors, we used longitudinal daily data from a community sample of young adults who used both alcohol and cannabis to examine person-, burst-, and daily-level effects of sleep duration on alcohol and cannabis use and cravings. Consistent with our hypotheses and previous studies among individuals in substance use recovery (Freeman & Gottfredson, 2018; Lydon-Staley et al., 2017), results generally indicated that shorter sleep duration may play an important role on young adults' alcohol and cannabis use and cravings, even when controlling for person-level and daily-level covariates (e.g., day of week, work or school commitments). However, there were notable patterns regarding the level at which these effects existed.

Morning alcohol craving was related to sleep duration at all three levels of analysis, suggesting that shorter sleep duration has (a) an immediate effect on stronger next-morning alcohol craving, (b) a cumulative effect across a two-week burst whereby morning alcohol craving was stronger during periods of cumulative sleep deficit, and (c) a person-level effect showing young adults who typically get less sleep report stronger morning alcohol craving. It is particularly noteworthy that variability in morning alcohol craving was significantly related to sleep duration at all three levels of analysis, considering the multilevel models estimate all three effects simultaneously. Additional studies are needed to further disentangle whether person-level effects reflect cumulative sleep deficit or rather stable between-person effects reflective of shared risk factors of substance use and inadequate sleep. For example, a recent study found a common genetic predisposition between short sleep duration and substance use behaviors (Winiger, Ellingson, et al., 2021).

In contrast to the significant associations between sleep duration and morning alcohol craving at all three levels of analysis, fewer significant associations were found for *afternoon* alcohol craving. Sleep duration was significantly related to afternoon alcohol craving at the burst and daily levels, but not at the person level, indicating that inadequate sleep may not only increase afternoon cravings on the following day, but also that periods of inadequate sleep (i.e., cumulative sleep deficit) may increase young adults' proclivity for alcohol use reported in the afternoon.

Conversely, morning and afternoon cannabis craving were only associated with sleep duration at the daily level, suggesting that cannabis craving was stronger on days following a night of inadequate sleep duration. This finding may indicate that, in contrast to alcohol craving, cumulative sleep deficits at the burst level were not significantly related to increased cannabis craving, at least not above and beyond the daily-level effects of shorter sleep duration.

For both alcohol and cannabis cravings, results showed slightly stronger effects of sleep duration on morning cravings compared to afternoon cravings, which warrants consideration. Relative to morning reports of craving, afternoon craving is less proximal to the previous night's sleep episode and may be more sensitive to other occurrences throughout the day, such as stress, negative affect (Miranda et al., 2019), or the presence of substance-related cues (Ramirez & Miranda, 2014), all of which may weaken or confound the effects of sleep duration.

Alongside alcohol and cannabis cravings, we examined effects of sleep duration on level of alcohol and cannabis use. Across both alcohol and cannabis use models, only one significant effect of sleep duration was found. A significant burst-level effect of sleep duration on alcohol use indicated young adults engaged in greater alcohol use during two-week periods with relatively shorter sleep duration. This finding highlights the important consideration for cumulative sleep deficit, as it pertains to substance use engagement. One possible explanation of the findings is put forward by ego depletion theory (Baumeister et al., 1998), which posits that individuals have a limited pool of cognitive resources, and that self-control becomes impaired when resources are depleted. Regarding substance use, lab-based studies have demonstrated that tasks designed to facilitate ego depletion lead to increased ad-lib

alcohol consumption (Christiansen et al., 2012). Sleep deprivation has also been proposed to lead to ego depletion and was offered as explanation for an inverse relationship between sleep quality and next-day cravings as mediated by self-reported willpower (Freeman & Gottfredson, 2018). Despite the possibility of sleep deficit leading to ego depletion and increased substance use in the current study, we are unable to determine the directionality of the association between sleep duration and substance use at the burst level (i.e., greater substance use may be contributing to less sleep in 2-week bursts). Whereas person-level effects were in the anticipated direction, though non-significant, hypotheses regarding daily-level effects of shorter sleep duration on alcohol and cannabis use were not supported.

When evaluating the stronger evidence of effects of sleep duration on craving, rather than actual use, sample characteristics should be considered. The present study examined a non-clinical sample of young adults who may have been able to resist urges to use alcohol or cannabis on a given day, despite cravings to use. To this end, it is possible that many young adults' substance use decisions were more heavily influenced by external factors (e.g., availability, social context, conflicting responsibilities) and less influenced by internal fluctuations in sleep duration, despite increased craving. Therefore, it remains possible that cumulative sleep deficit and associated increases in craving could eventually lead to greater alcohol or cannabis consumption on days for which external factors increase the likelihood of substance use, which may in part explain the inverse relationship between sleep duration and alcohol use observed at the burst-level. These considerations may also pertain to the general pattern of findings that sleep duration was more strongly associated with alcohol use and craving than cannabis use and craving. The lack of burst- and person-level associations between sleep duration and cannabis craving may suggest that typical sleep duration has more shared risk factors with alcohol than cannabis craving. Moreover, our data show that morning and daytime cannabis craving is generally stronger than morning and daytime alcohol craving, resulting in variability of cannabis use/craving being more responsive to external factors and situations, whereas alcohol use/craving being more directly related to sleep at burst- and person-levels. The sample was also at greater risk for disordered cannabis use than disordered alcohol use (per baseline assessments of CUDIT and AUDIT), so it is possible that cannabis use was generally high across study days, irrespective of sleep, while alcohol use was more reactive to sleep duration.

Future directions within this line of research may seek to better clarify the mediating mechanisms through which sleep relates to substance use and cravings. Daily-level stress may represent one possible mechanism of interest, as it is possible that poor sleep facilitates greater next-day stress (e.g., Sin et al., 2017; Van Laethem et al., 2015), and heightened stress could in turn increase young adults' desire for and/or use of alcohol and cannabis (e.g., Buckner et al., 2016; Miranda et al., 2019; Sinha et al., 2009). Additional physiological and cognitive responses to poor sleep – both acute and cumulative – such as tiredness, irritability, self-regulation, and even mental health symptomology (e.g., depression, anxiety) could also partially bridge an association between sleep and risk of substance use and craving. Thus, the findings from the current study represent a critical first step in this research line, but additional in-depth studies to identify potential mechanisms are prudent.

Applied Implications

The study findings carry important applied implications. Given the association between sleep duration and substance use cravings at the daily level, and associations between sleep duration and alcohol use at the burst level, sleep may represent a modifiable risk behavior with a need for clear psychoeducational messages to encourage adequate sleep among young adults. Further, previous studies have demonstrated that young adults are interested in receiving feedback regarding sleep and substance use (Fucito et al., 2015). Our findings suggest potential utility in developing scalable, mobile programs that could provide personalized feedback based on daily reports such that young adults are able to track and visualize their own patterns between sleep, craving, and substance use across days and weeks. We also acknowledge that short sleep duration may be unavoidable in certain situations (e.g., work schedules) or for certain people. To that end, assessments of sleep duration and quality could also trigger targeted prevention strategies for individuals whose sleep profiles may put them at greater risk of substance misuse. Given the person-level shared risk factors for poor sleep and substance use, inquiring about sleep behaviors in general screenings may identify a need for deeper inquisition into young adults' substance use behaviors, or exploring how the individuals' sleep and substance use behaviors may coincide– especially given that asking about sleep behaviors poses low-risk of eliciting a defensive response.

Limitations

Alongside the strengths of the longitudinal daily-level study, several limitations warrant consideration when interpreting the results and planning next-steps in this line of inquiry. We sampled young adults who screened into the larger parent study based on simultaneous alcohol and cannabis use, so findings may not generalize to other young adult samples (e.g., those who use alcohol but not marijuana). Similarly, we included no sleep-based screening criteria for this study and although 67% of the sample met the threshold for poor sleep at baseline, results may not generalize to young adult samples with clinical sleep disorders. Survey items relied on participants' self-reports of time in bed and substance use/cravings, which are typically valid (Simons et al., 2015; Zinkhan et al., 2014), but and social desirability biases may not be as accurate as objective measures. We used hours high as the operationalization of cannabis use, and although sensitivity analyses using participants' subjective reports of how high they were on the previous day did not alter results, future work may explore whether alternative indices of use may differentially relate to sleep. Ambulatory assessment of sleep and substance use behaviors may be warranted (e.g., Miller et al., 2021), especially as it pertains to hours of total sleep as opposed to time spent in bed, which was used here as a proxy for sleep duration. Related to measuring sleep, the current study focused on only one aspect of sleep health. To better understand relations between sleep and substance use, future studies could examine other indices of sleep health such as efficiency, timing, wakefulness, and disturbances, assuming there is reasonable rationale for expecting these sleep indices to relate to substance use and craving.

A potential future direction is young adults' motives for alcohol and cannabis use on a given occasion. For example, if substances were used on a given day for social reasons irrespective of sleep, the effects of sleep duration on use may be different than if substances were

used specifically to facilitate sleep (e.g., Goodhines et al., 2019) or to alleviate unpleasant feelings related to sleep deprivation. Relatedly, current analyses did not control for use of other substances such as caffeine, nicotine, stimulants, or sleep medication. In future work, use of other substances should be further explored. Finally, whereas the daily-level effects entail a distinct temporal aspect of sleep duration on substance use and cravings, the temporality of effects is difficult to tease apart when examining burst- and person-level effects. Despite the challenges, future studies should be designed specifically to examine effects of cumulative sleep deficits on substance use behaviors, such as modeling the progressive accumulation of sleep deficit alongside substance use behaviors.

Conclusion

Adding to a robust literature investigating alcohol and cannabis use associations with sleep quality and duration, the current study is among the first to examine the daily-level effects of sleep on next-day alcohol and cannabis use cravings and use. Analyses conducted at three levels allowed for critical disaggregation of effects including examination of effects of sleep on next-day craving and use. In sum, the findings suggest that sleep duration may be an important risk factor for alcohol and cannabis cravings and potentially modifiable by a range of prevention and intervention strategies. With further replication, the study findings may reflect important information of interest to a wide range of young adults that could potentially be presented as psychoeducation or as personalized feedback.

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Table 1.

Descriptive statistics for key study variables.

	Number of Daily Responses (% of possible days)	Mean Across All Observations (SD)	Between-Person Mean (SD)	Range of Between-Person Means	Intraclass Correlation Coefficient[b]
Sleep Duration (in hours)	23,107 (80.7%)	7.97 (0.69)	7.96 (0.69)	3.80 – 9.75	0.12
Morning Alcohol Craving	22,683 (79.2%)	0.52 (1.29)	0.53 (0.79)	0.00 – 7.23	0.30
Afternoon Alcohol Craving	22,797 (79.6%)	1.12 (1.85)	1.13 (1.08)	0.00 – 7.30	0.30
Morning Cannabis Craving	22,696 (79.3%)	1.18 (2.03)	1.25 (1.53)	0.00 – 8.00	0.52
Afternoon Cannabis Craving	22,803 (79.6%)	1.60 (2.30)	1.67 (1.66)	0.00 – 7.94	0.48
Any Alcohol Use (0=No; 1=Yes)[a]	25,435 (88.8%)	0.37 (0.48)	0.37 (0.21)	0.00 – 1.00	0.17
Any Cannabis Use (0=No; 1=Yes)[a]	25,369 (88.6%)	0.39 (0.48)	0.39 (0.32)	0.00 – 1.00	0.43
Number of Drinks[a]	25,429 (88.8%)	1.35 (2.58)	1.39 (1.11)	0.00 – 6.63	0.18
Hours High (Cannabis)[a]	23,455 (81.9%)	1.14 (2.08)	1.18 (1.50)	0.00 – 11.30	0.51

Note:

[a]Reports of previous day's alcohol and cannabis use were asked in the morning and, if the morning survey was missed, these items were asked in the afternoon. Non-use days include "0" for drinks and hours high.

[b]Intraclass correlation coefficients estimate the amount of variability due to between-person differences relative to within-person fluctuations (i.e., burst and/or daily levels).

Table 2.

Multilevel gamma log-link regression models assessing associations between sleep indices and next-day alcohol/cannabis cravings (N = 409).

	Morning Alcohol Craving	Afternoon Alcohol Craving	Morning Cannabis Craving	Afternoon Cannabis Craving
	e^b [95% CI]	e^b [95% CI]	e^b [95% CI]	e^b [95% CI]
Person-Level (Level 3)				
Birth Sex (0=Male; 1=Female)	0.965 [0.900, 1.035]	0.955 [0.879, 1.039]	0.946 [0.865, 1.033]	0.937 [0.861, 1.020]
Baseline Age	0.989 [0.968, 1.011]	0.991 [0.966, 1.018]	0.999 [0.972, 1.026]	1.000 [0.974, 1.026]
College Student (0=No; 1=Yes)	1.013 [0.921, 1.113]	1.024 [0.913, 1.147]	1.030 [0.914, 1.160]	1.009 [0.900, 1.130]
Race/Ethnicity (ref = White/Caucasian)				
Asian/Asian American	0.992 [0.896, 1.099]	0.920 [0.814, 1.040]	0.949 [0.836, 1.078]	0.917 [0.813, 1.034]
Other non-Hispanic	0.992 [0.905, 1.087]	0.920 [0.824, 1.027]	0.961 [0.857, 1.079]	0.922 [0.827, 1.029]
Hispanic	0.962 [0.871, 1.063]	0.903 [0.802, 1.018]	0.960 [0.846, 1.09]	0.912 [0.809, 1.028]
Person-Mean Proportion of Drinking Days (gmc)	1.254 [1.054, 1.494] *	2.529 [2.050, 3.119] ***		
Person-Mean Proportion of Cannabis Use Days (gmc)			2.829 [2.466, 3.246] ***	3.573 [3.135, 4.071] ***
Person-Mean Sleep Duration (gmc)	0.937 [0.889, 0.988] **	0.962 [0.903, 1.025]	0.974 [0.912, 1.040]	1.029 [0.966, 1.096]
Burst-Level (Level 2)				
Burst Number	0.994 [0.984, 1.003]	1.005 [0.993, 1.017]	0.989 [0.978, 1.000]	0.996 [0.984, 1.009]
Burst-Mean Sleep Duration (pmc)	0.970 [0.948, 0.993] **	0.965 [0.937, 0.994] **	0.983 [0.957, 1.010]	1.010 [0.979, 1.042]
Day-Level (Level 1)				
Day Number within Burst	1.001 [1.000, 1.003]	1.001 [0.999, 1.004]	0.999 [0.997, 1.001]	1.001 [0.998, 1.003]
Day of Week (ref. = Monday)				
Tuesday	1.021 [0.999, 1.044]	1.055 [1.023, 1.087] ***	1.020 [0.996, 1.045]	0.999 [0.971, 1.028]
Wednesday	1.038 [1.015, 1.061] **	1.106 [1.073, 1.141] ***	1.008 [0.984, 1.033]	1.021 [0.992, 1.052]
Thursday	1.074 [1.051, 1.099] ***	1.112 [1.078, 1.147] ***	1.023 [0.998, 1.049]	1.024 [0.994, 1.055]
Friday	1.132 [1.102, 1.162] ***	1.284 [1.236, 1.334] ***	1.070 [1.039, 1.102] ***	1.082 [1.044, 1.122] ***
Saturday	1.081 [1.051, 1.111] ***	1.186 [1.140, 1.235] ***	1.064 [1.031, 1.097] ***	1.054 [1.014, 1.095] **
Sunday	1.014 [0.988, 1.041]	1.031 [0.994, 1.069]	1.036 [1.006, 1.066] *	1.035 [1.000, 1.072]
Work or School on this Day (0=No; 1=Yes) (pmc)	0.974 [0.955, 0.994] **	0.987 [0.959, 1.015]	0.963 [0.942, 0.984] ***	0.993 [0.966, 1.020]
Work or School Tomorrow (0=No; 1=Yes) (pmc)	0.964 [0.945, 0.983] ***	0.963 [0.931, 0.996] *	0.980 [0.959, 1.002]	0.978 [0.947, 1.011]

	Morning Alcohol Craving	Afternoon Alcohol Craving	Morning Cannabis Craving	Afternoon Cannabis Craving
	e^b [95% CI]	e^b [95% CI]	e^b [95% CI]	e^b [95% CI]
Last Night Sleep Duration (bmc)	0.990 [0.986, 0.995] ***	0.993 [0.986, 0.999] *	0.986 [0.981, 0.991] ***	0.993 [0.987, 0.999] *

Note. Gmc = grand mean centered. Pmc = person mean centered. Bmc = burst mean centered. e^b = exponentiated beta in which values greater than 1 indicate positive associations and values less than 1 indicated negative/inverse associations. Models are fit with random intercepts for each participant and for each burst.

* $p<.05$;

** $p<.01$;

*** $p<.001$.

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Table 3.

Multilevel negative binomial models estimating associations between sleep and next-day alcohol/cannabis use.

	Alcohol Use (*n* = 405)	**Cannabis Use (*n* = 384)**
	Count Ratio [95% CI]	**Count Ratio [95% CI]**
Person-Level (Level 3)		
Birth Sex (0=Male; 1=Female)	0.983 [0.798, 1.212]	0.529 [0.369, 0.759]***
Baseline Age	1.034 [0.970, 1.103]	0.994 [0.889, 1.113]
College Student (0=No; 1=Yes)	1.018 [0.769, 1.348]	0.898 [0.550, 1.464]
Race/Ethnicity (ref = White/Caucasian)		
Asian/Asian American	0.628 [0.467, 0.845]***	0.491 [0.287, 0.840]**
Other non-Hispanic	0.764 [0.583, 1.002]	1.244 [0.773, 2.003]
Hispanic	1.130 [0.842, 1.516]	1.427 [0.867, 2.350]
Person-Mean Hours High (gmc)	1.079 [0.983, 1.184]	---
Person-Mean Number of Drinks	---	1.097 [0.920, 1.308]
Person-Mean Sleep Duration (gmc)	0.939 [0.800, 1.103]	0.882 [0.677, 1.151]
Burst-Level (Level 2)		
Burst Number	0.925 [0.896, 0.955]***	0.879 [0.845, 0.915]***
Burst-Mean Hours High (pmc)	0.978 [0.918, 1.042]	---
Burst-Mean Number of Drinks (pmc)	---	0.969 [0.902, 1.042]
Burst-Mean Sleep Duration (pmc)	0.913 [0.841, 0.990]*	1.036 [0.939, 1.142]
Day-Level (Level 1)		
Day Number within Burst	0.997 [0.986, 1.008]	0.996 [0.989, 1.002]
Day of Week (ref. = Monday)		
Tuesday	1.128 [0.990, 1.286]	0.925 [0.854, 1.001]
Wednesday	1.309 [1.150, 1.491]***	1.007 [0.930, 1.090]
Thursday	1.571 [1.381, 1.787]***	1.021 [0.943, 1.106]
Friday	2.775 [2.397, 3.213]***	1.218 [1.113, 1.334]***
Saturday	2.614 [2.253, 3.033]***	1.281 [1.169, 1.404]***
Sunday	1.154 [0.998, 1.334]	1.087 [0.998, 1.185]
Work or School on this Day (0=No; 1=Yes) (pmc)	0.845 [0.765, 0.933]***	0.879 [0.826, 0.936]***
Work or School Tomorrow (0=No; 1=Yes) (pmc)	0.724 [0.656, 0.800]***	0.934 [0.878, 0.995]*

	Alcohol Use (*n* = 405)	Cannabis Use (*n* = 384)
	Count Ratio [95% CI]	**Count Ratio [95% CI]**
Hours High (bmc)	1.049 [1.018, 1.082]**	---
Number of Drinks (bmc)	---	1.020 [1.008, 1.031]***
Last Night Sleep Duration (bmc)	0.992 [0.966, 1.019]	1.016 [0.988, 1.044]

Note. Models excluded participants that did not report any alcohol/cannabis use days across the entire study period for their respective models. Gmc = grand mean centered. Pmc = person mean centered. Bmc = burst mean centered. Models are fit with random intercepts for each participant and for each burst, and random slopes for sleep duration at the day level.