SMOKE, SIP, SLEEP, REPEAT: INVESTIGATING DAILY-LEVEL BIDIRECTIONAL RELATIONSHIPS BETWEEN SEPARATE AND SIMULTANEOUS ALCOHOL-CANNABIS USE AND SLEEP

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Abstract

Sleep problems are common among young adults, and alcohol and cannabis are known to impact sleep. Given the high prevalence of simultaneous alcohol-cannabis use in this population, there is a need to clarify the mixed findings in existing research regarding the combined effects of alcohol and cannabis use on sleep. This study used daily diary methodology to examine daily relationships between simultaneous use (versus cannabis-only, alcohol-only, and no use) and key sleep indices (i.e., subjective sleep quality, sleep duration, and bedtime), exploring the moderating role of substance use problem severity. Young adults (N=151; 64% female; M_{age} = 22.07) completed daily morning surveys in a smartphone app assessing prior-day alcohol and cannabis use, bedtime, wake time, and subjective sleep quality. Participants also completed measures of alcohol and cannabis problem severity at baseline. Multilevel models (with days nested within participants) indicated that participants reported worse sleep on alcohol-only use days relative to simultaneous use and no-use days, while cannabis-only use was associated with better sleep relative to no use. Participants reported similar subjective sleep quality and sleep duration on cannabis-only and simultaneous use days. Further, alcohol problem severity moderated associations between substance use and sleep. Specifically, individuals with greater alcohol problem severity experienced poorer sleep on alcohol-only days relative to simultaneous use days, whereas those with lower alcohol problem severity reported poorer sleep on simultaneous use days compared to cannabis-only days. Reciprocal models examining the impacts of sleep variables on next-day likelihood of simultaneous or single substance use did not reveal any significant main effects. These findings provide insight into the daily-level relationships between alcohol and cannabis co-use and sleep health, highlighting the need for tailored sleep interventions based on substance use patterns and problem severity.

Keywords: cannabis; alcohol; simultaneous use; co-use; sleep; ecological momentary assessment

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1. Introduction

Alcohol and cannabis are the most used drugs in Canada, with 76% (23.7 million) of Canadians reporting past-year alcohol use and 21% (6.4 million) reporting past-year cannabis use as of 2019 (Government of Canada, 2021). Prevalence of alcohol and cannabis use is particularly elevated among young adults, with 84% and 45% of adults aged 20 to 24 reporting past-year alcohol and cannabis use, respectively (Government of Canada, 2021). Among those who use both alcohol and cannabis, simultaneous use (i.e. co-use of both substances close in time or with overlapping effects) is customary and is associated with greater quantity and frequency of consumption of both substances, as well as increased substance-related consequences (e.g. blackouts, risky driving, and school-related consequences; Brière et al., 2011; Lee et al., 2022; Metrik et al., 2018; Subbaraman & Kerr, 2015). Indeed, 87% of young adults are familiar with the term "cross-faded," a colloquialism referring to the compound effects of using alcohol and cannabis at the same time (Patrick & Lee, 2018). Given the high prevalence of—and increased consequences associated with—simultaneous use, it is important to study factors associated with simultaneous use, particularly among the young adults who commonly engage in such use.

Research indicates that those who engage in simultaneous alcohol-cannabis use are a heterogeneous group, with varying reasons for engaging in simultaneous use. According to motivational models of substance use, individuals are motivated to consume substances such as alcohol based on judgments of whether the positive effects of drinking will be greater than those of abstaining (Cox & Klinger, 1988). Such judgments are influenced by factors such as past experiences with alcohol, current emotional state, life circumstances, and the anticipated benefits (Cox & Klinger, 1988). Since the introduction of the initial motivational model of alcohol, motivational models have subsequently been applied to describe various motives for use of variety of substances (Barber et al., 2016; Cooper, 1994; Simons et al., 1998). Common motives for simultaneous cannabis and alcohol use include the desire to conform with peers, preference for the combined intoxication effects of cannabis and alcohol, perceived calming or anxiety-reducing benefits of simultaneous use, and wanting to partake in simultaneous use as part of a social or celebratory event (Patrick et al., 2018). Preliminary evidence indicates some people are motivated to use cannabis and alcohol simultaneously to improve sleep outcomes, as well (Patrick et al., 2018; Waddell et al., 2023). This is unsurprising, as cannabis and alcohol have each long been individually used as sleep aids. Between 50% and 70% of those who use cannabis recreationally report using cannabis to improve sleep (Babson & Bonn-Miller, 2014), and use of cannabis is associated with the belief that cannabis improves sleep (Winiger et al., 2021). Likewise, approximately 18% of the general population within the United States reports using alcohol as a sleep aid (Johnson et al., 1998), and use of alcohol as a sleep aid is associated with higher estimated alcohol use for sleep among the general population (Graupensperger et al., 2023). Despite what these trends suggest, it is unclear whether cannabis and alcohol—used together or separately—actually improve sleep outcomes. Below I will review the literature on the relationship between use of each substance and sleep before covering the effects of simultaneous alcohol-cannabis use on sleep.

1.1. Cannabis Use and Sleep

In general, cannabis is associated with subjective improvements in sleep (i.e., greater self-reported sleep quality; Babson & Bonn-Miller, 2014; Tervo-Clemmens et al., 2023). Pharmacological research suggests that cannabis may improve sleep by modulating the endocannabinoid system, leading to the release of neurotransmitters such as serotonin, which promotes relaxation and contributes to sleep initiation and maintenance (Babson et al., 2017;

Piomelli, 2003; Russo, 2011; Shannon et al., 2019). Additionally, cannabinoids such as tetrahydrocannabinol (THC) have been shown to reduce sympathetic nervous system activity, potentially aiding in inducing sleep by reducing physiological arousal (Gorzalka et al., 2008). However, some research indicates heavy cannabis use produces the opposite effect of occasional use (Angarita et al., 2016), with those who use cannabis heavily reporting greater rates of insomnia and poorer sleep quality than the general population (Angarita et al., 2016; Conroy et al., 2016; Pacek et al., 2017). The relationship between cannabis use and sleep onset latency—that is, the duration of time from “lights out” to sleep—likewise differs by frequency of use, with occasional cannabis use associated with decreased sleep onset latency but heavy use associated with habituation to this sleep-enhancing effect (Babson et al., 2017; Shannon et al., 2019; Shrivastava et al., 2014). Research concerning the relationship between cannabis use and sleep duration is unclear, with some research indicating greater total sleep time among those who use cannabis recreationally and medicinally (Campbell et al., 2020; Goodhines et al., 2019a), other studies yielding opposite findings (Pacek et al., 2017), and yet others reporting an increased likelihood of both relatively short and long—as compared to average—sleep durations among those who use cannabis (Gonzales et al., 2023). While research has established that a later bedtime corresponds to lower total sleep time, no research to date has clarified the relationship between cannabis use and bedtime (Snitzman et al., 2023b).

Notably, a considerable proportion of individuals who attempt to discontinue cannabis following heavy use report experiencing difficulty falling asleep, strange dreams, and worse sleep quality lasting up to several weeks into the withdrawal period (Bolla et al., 2008; Budney et al., 2004; Copersino et al., 2006); indeed, sleep difficulty is listed as a symptom of cannabis withdrawal in the latest version of the Diagnostic and Statistical Manual of Mental Disorders

(DSM-5-TR; American Psychiatric Association, 2022). This increase in sleep disturbance following attempts to quit or mitigate use can in turn promote relapse among those attempting to reduce or quit using cannabis (Babson & Bonn-Miller, 2014). This withdrawal-relapse cycle may explain why heavy users report using cannabis to improve sleep despite limited sleep gains associated with heavy usage; rather than directly improving sleep, continued use may prevent the adverse sleep symptoms associated with withdrawal (Budney et al., 2004).

Complicating these patterns is the fact that dosage matters, yet few studies control for quantity of cannabis consumed or frequency of consumption within a day. Recent research has revealed a non-linear relationship between frequency of daily cannabis use (i.e. number of times cannabis is used in a day) and sleep duration, with moderate frequencies of cannabis use associated with longer total sleep time than infrequent and frequent daily use (Muzumdar et al., 2023). The same study revealed a similar relationship between mean patterns of use and sleep duration, such that individuals who typically used cannabis at a moderate daily frequency experienced the longest average sleep durations compared to those with light and heavy patterns of use (Muzumdar et al., 2023). These findings suggest a "Goldilocks zone" of daily cannabis use frequency, with moderate within-day frequency of use associated with the longest total sleep times. However, this study did not control for mode of use (e.g. smoking versus consumption of edible cannabis products) nor quantity of cannabis (e.g. grams of flower or mg of THC) consumed; as such, these results should be interpreted cautiously. Additionally, the direction of the abovementioned associations is unclear, in that it is unknown to what extent these associations are attributable to the impact of cannabis use on sleep versus the impact of sleep on cannabis use (with poorer sleep perhaps motivating heavier cannabis use). In summary, we know that cannabis tends to be associated with sleep-enhancing effects when used occasionally, but it is linked with sleep problems when used on a heavy and problematic basis. Beyond these high-level associations, however, much is unclear.

1.2. Alcohol Use and Sleep

Like cannabis, alcohol appears to produce different effects on sleep depending on extent of use. On the one hand, alcohol is a central nervous system depressant, promoting sleep by enhancing the inhibitory effects of neurotransmitters such as gamma-aminobutyric acid (GABA), leading to sedation and relaxation (Brower, 2003; Ebrahim et al., 2013). Additionally, alcohol increases the activity of adenosine, a neurotransmitter which promotes sleepiness and regulates sleep-wake cycles, thereby facilitating sleep onset (Ebrahim et al., 2013). On the other hand, problematic alcohol use is associated with elevated rates of insomnia, with research indicating that 36–91% of heavy and problematic alcohol users report sleep disturbances compared to ~10–30% of the general population (Chakravorty et al., 2016; LeBlanc et al., 2009; Liu et al., 2021; Singareddy et al., 2012; Stein & Friedmann, 2005). Indeed, while occasional alcohol use reduces sleep onset latency, heavy and problematic alcohol use is associated with increased sleep onset latency (Angarita et al., 2016; Ebrahim et al., 2013; Koob & Colrain, 2020). Likewise, average nightly sleep duration is reduced among those who use alcohol heavily as compared to occasionally (Chakravorty et al., 2016; Park et al., 2015), with tolerance evident after only six days of continuous use (Roehrs & Roth, 2018). Among those who use alcohol heavily, sleep disturbance is most strongly pronounced during periods of withdrawal, with some sleep disturbance persisting up to 2 years into abstinence (Chakravorty et al., 2016; Stein & Friedmann, 2005). This creates a negative reinforcement loop whereby those who use alcohol heavily may be at risk of relapse following attempted abstinence because they turn to alcohol to improve sleep in the short term (Brower, 2003; Chakravorty et al., 2016; Smith et al., 2014).

Further, irrespective of extent of use, alcohol use (vs. non-use) is associated with worsened perceived sleep quality (Lydon et al., 2016). Also, daily diary data indicates that alcohol use is associated with later bedtimes across the week compared to non-use across use patterns (Fucito et al., 2018; Van Reen et al., 2016). Quantity of alcohol consumed appears to have a unique effect on sleep, with daily-level associations indicating greater alcohol consumption is associated with poorer subjective sleep quality and shorter sleep duration (Goodhines et al., 2019a; Lydon et al., 2016; Muzumdar et al., 2023).

In summary, both alcohol and cannabis use can improve sleep for those who use such substances occasionally; however, these substances' sleep-inducing effects decrease with extent of use. This may be explained by heavy use leading to the development of tolerance, or the diminished response to a drug after its repeated administration, which necessitates higher doses to achieve the desired effect (Smart et al., 1983). This development of tolerance alongside the increase in sleep disturbance during withdrawal impedes attempts to quit or reduce use of each substance, as those who use each substance heavily experience poorer sleep overall and require greater dosages over time to induce sleep (Babson & Bonn-Miller, 2014; Chakravorty et al., 2016). Alternatively, the correlation between heavy alcohol and cannabis use and poor sleep may be due to pre-existing sleep issues prompting individuals to use these substances as a sleep aids. Longitudinal studies are thus necessary to determine the directionality of these relationships.

1.3. Need for Intensive Longitudinal Designs to Study the Links Between Cannabis, Alcohol, and Sleep

Mixed results in research on the associations of alcohol and cannabis use with sleep highlight the importance of intensive longitudinal research methods involving repeated data collection close in time to substance use behavior (e.g., daily diary studies). Intensive longitudinal designs are essential for studying the complex relationships between cannabis use, alcohol use, and sleep due to their ability to capture the reciprocal and individualized nature of these interactions. As reviewed above, both cannabis and alcohol, whether used individually or concurrently, have been documented to influence key sleep parameters, including onset, duration, and quality. However, these effects vary widely between individuals, fluctuating based on factors like tolerance, dependence, and the quantity and frequency of substance use. For example, while those who use alcohol and cannabis heavily and problematically may generally report poorer sleep quality due to substance use disorders, their sleep may appear comparatively better on days they use substances, likely due to the exacerbation of sleep disturbances during withdrawal periods (Snitzman et al., 2023b). Daily diary methods allow for the identification of such within-person associations, enabling the examination of sleep variations as influenced by day-to-day changes in substance use, while controlling for between-person factors such as each individual's history of substance use and sleep patterns. In other words, by repeatedly assessing cannabis use and sleep outcomes within individuals for a prespecified period, daily diary paradigms allow for the disaggregation of state- and trait-level associations (see Bolger & Laurenceau, 2013).

Further, intensive longitudinal designs such as daily diary studies are relatively more robust to recall bias (that is, the tendency for integrity of recall to deteriorate as a function of time between use and reporting), whereas cross-sectional and less intensive longitudinal studies frequently involve retrospective recall of substance use and sleep over weeks to months (Collins et al., 1985; Ekholm, 2004; Gmel & Daeppen, 2007). To this end, intensive longitudinal designs have the benefit of greater accuracy of self-reported substance use and sleep, which increases the validity of findings.

The importance of examining directionality in the relationship between substance use and sleep further necessitates the use of intensive longitudinal designs. These designs are uniquely equipped to investigate to what extent sleep disturbances prompt substance use as a coping strategy versus the degree to which substance use precipitates sleep disruptions. Longitudinal research has the advantage of allowing for the investigation of directionality by allowing researchers to observe changes in variables over time and establish temporal precedence, which helps determine whether variables of interest precede or predict changes in other variables (Bolger & Laurenceau, 2013; Rogosa et al., 1982). Such temporal sequencing aids in identifying the ways in which such variables impact one another over time, offering insights into the causal pathways and potential feedback loops that exist between these variables. Indeed, some intensive longitudinal studies examining the effects of single-substance alcohol and cannabis use on sleep have found evidence that alcohol and cannabis can negatively impact sleep, which in turn can motivate craving and likelihood of using alcohol and cannabis as a sleep aid (e.g., Graupensperger et al., 2022; Sancho-Domingo et al., 2025). However, relatively few intensive longitudinal studies have examined the impacts of simultaneous alcohol and cannabis use on sleep.

1.4. Simultaneous Alcohol and Cannabis Use and Sleep

To date, only four studies have examined the daily-level impacts of simultaneous alcohol and cannabis use on sleep outcomes (i.e., Graupensperger et al., 2021; Sznitman et al., 2023a; Sznitman et al., 2023b; Wycoff, Miller, & Trull, 2024). One daily diary study in a university student sample revealed that participants reported shorter sleep onset latency and longer sleep duration following nights of separate and simultaneous alcohol and cannabis use, compared to abstinent nights (i.e. "no-use"; Sznitman et al., 2023b). However, this study also found that nights involving alcohol-only use were associated with more nightly awakenings than no-use and simultaneous use nights, while nights involving cannabis-only use were linked to fewer early awakenings than no-use and simultaneous use nights (Sznitman et al., 2023b). Another daily diary study by the same research team observed that individuals who use cannabis to cope with anxiety reported better sleep quality after simultaneous use and cannabis-only use compared to no-use and alcohol-only use, with cannabis-only use associated with the best sleep quality (Sznitman et al., 2023a). Additionally, Graupensperger and colleagues (2021) found that compared to abstinent days, participants reported worse perceived sleep quality on days when they consumed alcohol alone, better perceived sleep quality when they consumed cannabis alone, and conflicting evidence regarding simultaneous use. Specifically, participants reported both poorer perceived sleep health and fewer symptoms of insomnia following simultaneous compared to no-use days (Graupensperger et al., 2021). Finally, Wycoff and colleagues (2024) found that participants reported worse sleep quality following alcohol use, and that while cannabis-only use did not impact sleep outcomes, cannabis attenuated alcohol's negative impact on sleep quality during simultaneous use.

Taken together, these studies suggest a null or positive association between cannabis-only use and sleep, a negative association between alcohol-only use and sleep, and a complex relationship between simultaneous use and sleep. One possible explanation for these trends is that cannabis use positively impacts sleep—at least with respect to total sleep time and perceived sleep quality—and drives the sleep-promoting effects of simultaneous use when they are observed, whereas alcohol use explains the negative consequences of simultaneous use on sleep. From this perspective, differing findings with respect to the impact of simultaneous use on sleep make sense and may be attributable to differing ratios of alcohol-cannabis intake in simultaneous use between samples.

Surprisingly, little research to date has explored bidirectional relationships between simultaneous alcohol and cannabis use and sleep, despite research suggesting an association between sleep disturbances and increased substance use and craving (Graupensperger et al., 2022; Nguyen-Louie et al., 2018). New research has found that persistent poor sleep predicts increased alcohol and cannabis use and consequences over time among emerging adults (Troxel et al., 2022). Only one intensive longitudinal study to date (published after the current analyses were preregistered) has examined both the association between simultaneous use and same day sleep and the association between sleep and next day simultaneous use (Wycoff, Miller, & Trull, 2024). This study found that longer sleep duration predicted greater next-day alcohol craving and cannabis use likelihood; however, sleep quality did not predict next-day cannabis or alcohol craving or likelihood of use at the daily level (Wycoff, Miller, & Trull, 2024).

Though the available intensive longitudinal studies represent important contributions to our understanding of the associations between simultaneous use and sleep, none fully controls for the specific forms and quantities of both substances used. Specifically, while Sznitman and colleagues (2023) controlled for some forms of cannabis (flower vs. edible), they did not include a standard metric of quantity. Though Wycoff and colleagues (2024) utilized a sophisticated "daily high" measure, they did not include a standard metric of cannabis consumed nor control for form of cannabis or route of cannabis administration. This is a critical gap for three reasons. First, quantity of each substance consumed will invariably influence outcomes, as indicated by research suggesting nonlinear relationships between amount of alcohol and cannabis consumed and their respective effects on sleep (Muzumdar et al., 2023). Second, preliminary research indicates use of multiple forms of cannabis (e.g. oil and flower) may be associated with heightened risk of substance-use-related consequences (Swan et al., 2021). Finally, different routes of cannabis administration are associated with distinct psychoactive effects due to variations in the pharmacokinetics and bioavailability of cannabinoids (Giroud et al., 2015). Inhalation methods such as smoking and vaping typically result in rapid onset of effects due to direct absorption into the bloodstream through the lungs, leading to quicker onset of psychoactive effects (Giroud et al., 2015; Russo, 2011). Conversely, oral ingestion (i.e. consuming edibles) results in slower onset, but potentially longer-lasting effects, due to the delayed absorption of cannabinoids through the gastrointestinal system (Giroud et al., 2015). Differences in time course of effects across routes of administration may result in different effects on sleep onset and duration.

Finally, none of the existing intensive longitudinal studies on the relationship between simultaneous use and sleep examine individual differences in this relationship as a function of the severity of alcohol and cannabis use problems. As previously discussed, the association between simultaneous use and sleep may differ for those who are heavier or more dependent users, making it important to examine individual differences in use as a moderator. In summary, the variability in the abovementioned intensive longitudinal findings may be attributable to multiple factors, including individual differences in alcohol and cannabis use patterns, lack of control for quantity of alcohol and cannabis consumed, and differences in onset latency, peak intensity, and duration of effects associated with various forms of cannabis use.

1.5. The Present Study

The present study addresses these gaps in the existing literature by analyzing the daily-level bidirectional relationships between simultaneous alcohol-cannabis use and key sleep outcomes, including bedtime, sleep duration, and subjective sleep quality, while controlling for quantities of alcohol and cannabis and form of cannabis used, as well as examining the moderating role of severity of alcohol and cannabis problems. Drawing from prior ecological momentary assessment (EMA) research suggesting a general sleep-promoting effect of cannabis (Graupensperger et al., 2021; Sznitman et al., 2023a), I hypothesized that participants would report the best sleep outcomes on days when they used only cannabis relative to days when they engaged in no substance use or simultaneous alcohol and cannabis use. Conversely, given EMA findings indicating a negative relationship between alcohol-only use and sleep (Graupensperger et al., 2021; Sznitman et al., 2023a), I expected that days involving alcohol-only use would be associated with the poorest sleep outcomes relative to no substance use or simultaneous alcohol and cannabis use. With respect to bidirectional relationships, I expected that poorer sleep nights would predict increased likelihood of next-day separate and simultaneous alcohol-cannabis use, given that individuals may be motivated to use substances to aid next-night sleep; however, given the lack of prior research on how sleep indices predict next-day simultaneous use at the time of preregistration (the Wycoff, Miller, & Trull, 2024 paper was not published until after hypotheses were pre-registered), analyses examining how poor sleep relates to separate versus simultaneous alcohol-cannabis use were treated as exploratory. I additionally hypothesized that individuals who use alcohol and cannabis heavily and problematically would exhibit poorer sleep on average over the course of the 21-day study period (compared to individuals who use alcohol and/or cannabis occasionally), with individuals who use alcohol heavily and problematically experiencing the poorest sleep overall. With respect to moderation, I examined how degree of problematic use severity moderated the within-person differences in sleep between simultaneous use versus single-substance use days. Given the lack of prior studies investigating the role of problematic use severity in day-level relationships between substance use and sleep, such analyses were treated as exploratory.

2. Method

2.1. Participants and Recruitment

This analysis utilizes baseline electronic daily diary data from a broader longitudinal Ecological Momentary Assessment (EMA) study examining simultaneous alcohol-cannabis use among young adults (Wardell et al., 2024). Though the larger study included 6- and 12-month follow-up EMAs, I analyzed only data from the baseline EMA since this data collection period immediately followed assessment of the AUDIT and CUDIT-R, two primary moderators in this study. Ethics approval for the broader study was granted by the ethics review boards at York University and the Centre for Addiction and Mental Health (CAMH) in Toronto, Canada (Wardell et al., 2024; York REB #2021-158, CAMH REB #076-2017). Hypotheses and analyses were preregistered on OSF on July 5, 2024 and will be made available at the date of paper publication.

Participants (N = 151) were young adults (64% female; M_{age} = 22.07, SD = 2.10) living in Ontario, Canada who were of legal age to purchase both cannabis and alcohol and who reported co-using alcohol and cannabis. A comprehensive demographic background of participants is available in Table 1. Participants were recruited via online ads as well as posters distributed across university campuses and various community locations. N = 177 participants were initially enrolled in the study. At the baseline assessment, n = 9 participants were excluded (n = 2 failed to meet cannabis/alcohol inclusion criteria, n = 3 were unable to verify Ontario residency, and n = 4 encountered technical issues preventing participation). Throughout the EMA period, one participant was removed due to very poor survey compliance and lack of responsiveness to contact attempts by the research team. After completing the EMA period, EMA data from *n* = 16 additional participants were excluded for poor survey compliance (i.e. completion of fewer than 10% of the prompted surveys).

Inclusion criteria for the broader study were: (i) being between the ages of 19 and 25; (ii) consuming alcohol and cannabis, each at a minimum frequency of once per week over the past month; (iii) having at least two instances of simultaneous alcohol and cannabis use in the past month; and (iv) possession of a smartphone compatible with Android or iOS. Exclusion criteria were: (i) using any substances other than cannabis, alcohol, or nicotine on a regular (i.e., monthly of more frequent) basis; (ii) undergoing current treatment for or attempting to cut down on cannabis or alcohol use; (iii) having a severe mental illness (for example, psychosis or mania) or a neurodevelopmental disorder; or (iv) using cannabis solely for medicinal purposes, as indicated by self-report.

2.2. Procedure

2.2.1. Baseline Assessment. Individuals interested in participating in the study completed an online screening survey to determine eligibility. Those deemed eligible were invited to partake in a baseline assessment. Baseline assessments were conducted over a period extending from December 2019 to August 2022, and took place in person (before the COVID-19 pandemic) or via secure videoconferencing platform (during the COVID-19 pandemic). During the baseline appointment, participants first provided informed consent, and then downloaded the EMA application (MetricWire) onto their phones. Participants received training on the EMA procedure and were shown visual instructional materials detailing how to accurately report their alcohol intake (in standard drink units) and their cannabis flower use (in grams). Following the training, participants completed an online questionnaire that captured demographic data and information related to alcohol and cannabis use. For their involvement in the baseline assessment, participants were compensated with a $40 gift card.

2.2.2. Daily Assessments. Participants commenced the Ecological Momentary Assessment (EMA) period on the day after the baseline assessment. Throughout the EMA period, participants completed multiple smartphone surveys each day for 21 days, including a daily morning survey, two randomly timed surveys, and event-contingent surveys completed during substance use episodes. The present analyses utilized data from the daily morning surveys as they captured total consumption of alcohol and cannabis on a day-to-day basis as well as key sleep indices from the night before (see EMA Measures below). Participants were instructed to complete the daily morning survey upon waking each morning, and the surveys were accessible in the app each day from 7:00 am to 2:00 pm, during which participants received multiple reminders to complete them. For their participation in the EMA phase, participants were compensated with gift cards ranging from $45 to $115, with bonuses awarded for higher levels of compliance.

2.3. Baseline Measures

Given that the larger study from which this data originates encompasses numerous aims and measures, not all of which are pertinent to the current analysis, only the measures relevant to this investigation are described below.

2.3.1. Alcohol Measures. To assess for problematic alcohol use, participants completed the Alcohol Use Disorders Identification Test (AUDIT; Saunders et al., 1993), a 10-item screening instrument used to detect heavy and harmful patterns of alcohol consumption over the past six months. The AUDIT is scored on a scale from 0 to 40, with a score of 8 considered indicative of problematic drinking and scores of 15 or more suggesting a higher likelihood of alcohol dependence. This tool has shown good internal consistency in past research (i.e., Cronbach's α = .80–.90; Reinert & Allen, 2002). A cutoff score of 8 was used to establish problematic drinking in this study for the purpose of reporting descriptive statistics.

2.3.2. Cannabis Measures. To assess extent and severity of cannabis use problems, participants were administered the Cannabis Use Disorder Identification Test–Revised (CUDIT-R; Adamson et al., 2010), an eight-item screening tool designed to detect hazardous cannabis use over the past six months. Responses are indicated using a 5-point Likert-type scale ranging from 0 to 4, with scores of eight or above considered indicative of hazardous cannabis use and scores of 12 or above suggesting likelihood of a cannabis use disorder (CUD; Adamson et al., 2010). The CUDIT-R has shown excellent internal consistency in past research (i.e., Cronbach's α = .91; Adamson et al., 2010). A cutoff score of 8 was used to establish problematic cannabis use in this study for the purpose of reporting descriptive statistics. Participants also completed the Daily Sessions, Frequency, Age of Onset, and Quantity of Cannabis Use Inventory (DFAQ-CU; Cuttler & Spradlin, 2017). The DFAQ-CU is a comprehensive measure designed to capture various dimensions of cannabis consumption including frequency of use (ranging from not at all to multiple times per day), forms of cannabis used, typical quantity of cannabis flower consumed (measured in grams per session, per day, and per week), and number of daily cannabis use sessions.

2.4. EMA Measures

2.4.1. Alcohol Measures. In each daily morning survey, participants were asked to report whether they had used any alcohol or drugs the previous day. Participants who endorsed using alcohol the day prior were subsequently asked to indicate how many standard alcoholic drinks they had consumed the day prior. To assist in accurately reporting their consumption, participants had the option to refer to a visual standard drink conversion guide while answering these questions.

2.4.2. Cannabis Measures. Participants who endorsed consuming cannabis the previous day were asked to indicate their method(s) of cannabis administration (i.e., smoking, vaporizing, ingesting, or other methods) along with the forms of cannabis products used (i.e., cannabis flower, referred to as "marijuana," concentrates, edibles, cannabis beverages, or other forms), with response options adapted from the DFAQ-CU. For those who reported using cannabis flower the previous day, the survey requested information on the total grams consumed that day, along with a link to an illustration showing different amounts of cannabis flower. For those who reported using cannabis concentrates the previous day, the survey requested information on number of hits of cannabis concentrate consumed that day. For those who reported consuming edibles and/or cannabis beverages the previous day, the survey requested information on number of edible servings and cannabis beverages consumed that day, respectively.

2.4.3. Sleep Measures. At the beginning of each daily morning survey, participants were asked what time they went to sleep the previous night and what time they woke up that morning. Bedtime was reported on a 1–7 scale whereby each scale value except the upper and lower bounds of the scale was associated with a 1-hour range in bedtime (0 = *before 9pm*, 1 = *9pm–9:59pm*, 2 = *10pm–10:59pm*, 3 = *11pm–11:59pm*, 4 = *12am–12:59am*, 5 = *1am–1:59am*, 6 = *2am–2:59am*, 7 = *3am or later*). Wake time was reported similarly, with response options ranging from 0 = *before 6am* to 8 = *1pm or later*. Participants' nightly total sleep time was determined by calculating number of hours between the midpoints of the sleep and wake time ranges indicated by participants in each daily morning survey. The outer categories were treated as one-hour ranges for the purpose of assigning midpoints (e.g., *before 9pm* = 8:30pm; *3am or* *later* = 3:30am). Sleep quality was assessed using an item adapted from the Single-Item Sleep Quality Scale "*How would you rate your overall sleep quality last night? Consider how many hours you got, how well you fell and stayed asleep, and how refreshing your sleep was*," with response options ranging from 1 = *Terrible* to 5 = *Excellent* (Snyder et al., 2018).

2.5. Data Analysis

To examine the hypothesized day-level relationships between simultaneous use versus single substance use or no use and sleep indices, I specified a set of multilevel models wherein days (level 1) were nested within participants (level 2). I created three separate models for each of the sleep outcome variables (i.e., bedtime, total sleep time, and sleep quality). The independent variable, daily substance use, was represented as a set of three dummy-coded variables entered at level 1, each comparing simultaneous use days (reference category) with no use, alcohol-only use, and cannabis-only use days, respectively. At level 2, person-level means of each dummy variable were entered, representing the proportion of alcohol-only, cannabis-only, and no-use days relative to simultaneous use days for a given participant. In post-hoc analyses, I reran each model with no-use days at the reference category in order to examine differences in sleep outcomes between alcohol- and cannabis-only use days relative to no use days. The moderators, severity of alcohol and cannabis use problems, were operationalized using baseline AUDIT and CUDIT-R scores, respectively, which were entered at level 2. Exploratory moderation effects were evaluated by examining cross-level interactions between the dummy-coded substance use independent variables (level 1) and the problematic use moderators (i.e., AUDIT and CUDIT-R scores; level 2). Significant interactions were probed by examining the day-level associations between type of day (i.e., single-substance or no use vs. simultaneous use) and sleep outcomes conditioned on high and low values of AUDIT and CUDIT-R scores (one standard deviation above and below the sample means, respectively).

Additionally, in order to assess whether differences in quantities of alcohol and cannabis and forms of cannabis consumed on simultaneous use versus single substance use days were driving any observed sleep differences across these days, I conducted follow-up multilevel analyses comparing sleep indices on simultaneous use days vs. alcohol-only days controlling for number of standard drinks at level 1 (in models limited to days on which alcohol use occurred), and conducted analyses comparing sleep on simultaneous use days vs. cannabis-only days controlling for grams of cannabis flower, number of edible and cannabis beverage servings, and number of cannabis concentrate hits used at level 1 (in models limited to days on which cannabis use occurred).

To explore reverse directionality in the relationships between simultaneous use and sleep, I specified two multinomial logistic regression models examining how night-level sleep indices (as independent variables) relate to likelihood of engaging in simultaneous use relative to single substance or no use (dependent variable). In the first of these models, simultaneous use was specified as the reference category; in the second, no-use was specified as the reference category to examine differences between single-substance use and no-use. All sleep indices (i.e., subjective sleep quality, sleep duration, and bedtime) were included as predictors in each model. For these models, substance use variables were lagged by a day so that previous night sleep data reported on a given daily morning survey was specified as a predictor of substance use later in that day, as reported in the next-day daily morning survey. For this reason, there was one fewer day in these analyses for each participant.

All multilevel models specified a level 1 (i.e., day-level) covariate of weekend (Friday–Sunday, coded as 1) versus weekday (Monday–Thursday, coded as 0). Level 2 (i.e., person-level) covariates of age and sex assigned at birth were also included in all models. All level 1 variables were person-mean centered, such that a given observation on a variable for a participant on a given day represents the extent to which that observation differs from that person's average across all days on that variable. Person-level means of all level 1 variables were entered on level 2 to disaggregate within- and between-person variance in these variables. All level 2 variables were grand mean centered. Random intercepts were estimated in all models. To determine whether to include random slopes in each model, I compared model fit for models including random slopes for each level 1 association with models with all fixed slopes. Only random slopes models which were associated with a lower Bayes Information Criterion (BIC) relative to the fixed slope model were retained. Fixed slopes were employed for the models in which type of use day (i.e., simultaneous versus single substance use) was specified as the outcome because random slope models are challenging to estimate with a multicategorical outcome.

Missing data were addressed using the Maximum Likelihood (ML) approach, which utilizes all available data to estimate model parameters and retains participants with partially missing data (i.e., missing data on some days) in the analyses rather than using listwise deletion. Within my main sleep outcome models, I retained $n = 150$ participants after excluding one participant who didn't report their sex. Within my secondary sleep outcome models controlling for cannabis form and quantity, I retained $n = 131$ participants after excluding those who did not report any cannabis use (single- or simultaneous) over the course of the EMA period and one participant who didn't report their sex. Within my secondary sleep outcome models controlling for standard drink quantity, I retained $n = 126$ participants after excluding those who did not report any alcohol use (single or simultaneous) over the course of the EMA period and one participant who didn't report their sex. Within my main substance use type outcome models, I retained $n = 148$ participants after excluding one participant who didn't report their sex and an additional participant who did not provide at least two consecutive daily surveys.

3. Results

3.1. Descriptive Statistics

The average completion rate of daily morning surveys was 89.12%. Across all completed daily morning surveys within the 21-day EMA study period, participants reported 429 (15.18%) simultaneous alcohol-cannabis use days, 712 (25.19%) cannabis-only use days, 243 (8.60%) alcohol-only use days, and 1442 (51.03%) no-use days. The proportion of missing surveys was not significantly correlated with person-level mean number of daily surveys that were no-use days or simultaneous use days, nor with person-level mean sleep quality, sleep duration, grams of cannabis flower, concentrate hits, edible and beverage servings, sex, or CUDIT-R score. The proportion of missing surveys was significantly correlated with person-level proportions of daily surveys that were alcohol-only days, $r(150) = -0.19$, $p = .019$, cannabis-only days, $r(150) = 0.21$, $p = .011$, and daily surveys representing weekend days, $r(150) = -0.45$, $p = <.001$, as well as person-level mean bedtime, $r(150) = 0.33$, $p = <.001$, age in years, $r(150) = -0.16$, $p = .044$, and CUDIT-R score, $r(150) = 0.18$, $p = .031$. Tables 1 and 2 present additional descriptive data on variables assessed at the person- and daily levels, respectively.

3.2. Multilevel Models with Sleep Indices as Outcome Variables

3.2.1. Subjective Sleep Quality. In the main subjective sleep quality model with simultaneous use as the reference category, there were no significant interactions between problematic use (operationalized as participants' AUDIT and CUDIT-R scores at baseline) and day type (all $p > .05$), so the model was trimmed of all interaction terms and rerun. The results of the trimmed model are shown in Table 3. Results revealed that participants tended to report significantly worse sleep quality on days during which they did not engage in alcohol or cannabis use (b = -0.14, SE = 0.05, p = .010), as well as on days during which they engaged in alcohol-only use (b = -0.28, SE = 0.07, p = <.001), compared to days during which they used both alcohol and cannabis. There was no significant difference in subjective sleep quality on cannabis-only use days relative to simultaneous use days. Additionally, there were no significant main effects of AUDIT or CUDIT-R scores on subjective sleep quality (see Table 3).

Given the significant difference in subjective sleep quality on alcohol-only use days relative to simultaneous use days, I ran a post-hoc model controlling for quantity of alcohol (number of standard drinks) when examining the difference between alcohol-only and simultaneous use days with alcohol-only days as a reference category. There were no significant interactions between problematic use and day type (all $p > .05$), so the model was trimmed of all interaction terms and rerun. The full results of the final trimmed model are shown in Table 4. This model confirmed that the better sleep quality reported on simultaneous use days relative to alcohol-only days still held when controlling for alcohol quantity, b = 0.39, SE = 0.13, p = .003, and interestingly, that number of standard drinks did not significantly predict subjective sleep quality, b = -0.01, SE = 0.01, p = .623. Additionally, this model revealed a significant between-person association, b = 0.40, SE = 0.18, p = .030, such that individuals who engaged in simultaneous use on a relatively greater proportion of alcohol use days reported better sleep quality on average across days than those who engaged in simultaneous use on a smaller proportion of alcohol use days (see Table 4).

I next ran a post-hoc model with no-use days as the reference category to observe whether alcohol- and cannabis-only days differed from no-use days in their associations with subjective sleep quality. In this model, there were no significant interactions between problematic use and day type (all $p > .05$), so the model was trimmed of all interaction terms and rerun. The results of the trimmed model are shown in Table 5. Results revealed that participants tended to report better sleep quality on days during which they engaged in cannabis-only use compared to days during which they used neither alcohol nor cannabis, $b = 0.17$, $SE = 0.05$, $p = <.001$. Conversely, participants tended to report worse sleep quality on days they consumed only alcohol relative to days they used neither alcohol nor cannabis, $b = -0.14$, $SE = 0.06$, $p = .026$. Additionally, this model also revealed a significant between-person association, $b = 0.56$, $SE = 0.20$, $p = .005$, such that participants who engaged in cannabis-only use compared to no-use on a relatively greater proportion of days reported better sleep quality on average across days than those who engaged in cannabis-only use compared to no-use on a smaller proportion of days (See Table 5).

3.2.2. Sleep Duration. In the main model with simultaneous use as the reference category, only one interaction between problematic use and day type was significant (for alcohol-only use days x AUDIT), so the model was trimmed of all other interaction terms and rerun. The results of the trimmed model are shown in Table 3. While there was no significant difference in sleep duration on cannabis-only use days relative to simultaneous use days, results revealed that alcohol-only use was associated with shorter sleep duration relative to simultaneous use, $b = -0.35$, $SE = 0.14$, $p = .012$. However, this effect was qualified by a significant cross-level interaction between alcohol-only use days and AUDIT scores, $b = -0.06$, $SE = 0.02$, $p = .015$. Probing this interaction revealed that for individuals with high AUDIT scores, there was a significant association between alcohol-only use (relative to simultaneous use) and shorter sleep duration, *b* = -0.61, *SE* = 0.16, *p* = <.001, and that there was no significant relationship between alcohol-only use (relative to simultaneous use) and shorter sleep duration among individuals with low AUDIT scores, *b* = -0.09, *SE* = 0.18, *p* = .636 (see Figure 1). There were also significant covariate associations for weekend versus weekday (level 1) and participant sex (level 2), such that participants slept for longer on weekends relative to weekdays, and that female participants had longer total sleep times on average relative to male participants (see Table 3). There were no significant main effects of AUDIT or CUDIT-R scores on sleep duration.

Given the significant difference in sleep duration on alcohol-only use days relative to simultaneous use days, I ran a post-hoc model controlling for quantity of alcohol (number of standard drinks) on alcohol-only and simultaneous use days with alcohol-only days as the reference category. There were no significant interactions between problematic use and day type (all *p* > .05), so the model was trimmed of all interaction terms and rerun. The full results of the final trimmed model are shown in Table 4. This model confirmed the effect of simultaneous use days relative to alcohol-only days on sleep duration still held when controlling for alcohol quantity, *b* = 0.53, *SE* = 0.17, *p* = .002, though number of standard drinks also emerged as a significant negative predictor of sleep duration, *b* = -0.10, *SE* = 0.03, *p* = <.001. Additionally, this model revealed a significant between-person association between tendency to drink larger quantities of alcohol on average across alcohol days and shorter sleep duration overall across days, *b* = -0.17, *SE* = 0.02, *p* = .007 (see Table 4).

In the post-hoc sleep duration model with no-use as the reference category, there were no significant interactions between problematic use and day type (all *p* > .05), so the model was trimmed of all interaction terms and rerun. The results of the trimmed model are shown in Table

5. Results revealed that alcohol-only use was associated with shorter sleep duration relative to no-use, *b* = -0.34, *SE* = 0.12, *p* = .004. There was no significant difference in sleep duration on cannabis-only use days relative to no-use days. Results also revealed a significant between-person association of proportion of cannabis-only use vs. no-use days on sleep duration, *b* = 0.79, *SE* = 0.33, *p* = .018, such that participants who tended to engage in cannabis-only use compared to no-use on a relatively greater proportion of days slept for longer on average than those who tended to engage in cannabis-only use compared to no-use on a relatively smaller proportion of days (see Table 5).

3.2.3. Bedtime. In the main model with simultaneous use as the reference category, two interactions between problematic alcohol use and day type were significant (for no-use days x AUDIT and alcohol-only use days x AUDIT), so the model was trimmed of all other interaction terms and rerun. When this trimmed model was run, the interaction between no-use days and AUDIT scores became nonsignificant (*p* = .11); accordingly, the model was further trimmed to only include the remaining significant interaction between alcohol-only use days and AUDIT scores. The results of the final trimmed model are shown in Table 3. Results revealed that participants tended to go to bed earlier on days during which they did not engage in alcohol or cannabis use (*b* = -0.14, *SE* = 0.05, *p* = .010), as well as days during which they engaged in cannabis-only use (*b* = -0.28, *SE* = 0.07, *p* = <.001), compared to days during which they used both alcohol and cannabis. Additionally, while there was no significant difference in bedtime on alcohol-only use days relative to simultaneous use days, there was a significant cross-level interaction between alcohol-only use days (vs. simultaneous use days) and AUDIT scores, *b* = 0.04, *SE* = 0.02, *p* = .026. Probing this interaction revealed no significant conditional associations of alcohol-only use day with bedtime at high (*b* = 0.19, *SE* = 0.13, *p* = .142) nor low (*b* = -1.86, *SE* = 0.15, *p* = .203) levels of the AUDIT; however, the direction of these nonsignificant associations changed from positive to negative at high and low levels of the AUDIT, respectively (see Figure 2). There were also significant covariate associations for weekend versus weekday and participant sex, such that participants went to bed later on weekends relative to weekdays over the course of the 21-day EMA period, and that female participants went to bed earlier than male participants, on average (see Table 3). There were no significant main effects of AUDIT or CUDIT-R scores on bedtime.

I ran two post-hoc models to explore these results further. Given the significant difference in bedtime on cannabis-only use days relative to simultaneous use days, I first ran a post-hoc model controlling for quantity and form of cannabis use on cannabis-only and simultaneous use days with cannabis-only days as a reference category. Only one interaction between problematic alcohol use and day type was significant (for simultaneous use days x AUDIT), so the model was trimmed of all other interaction terms and rerun. The full results of the final trimmed model are shown in Table 6. This model confirmed that individuals go to bed later on days where they engage in simultaneous alcohol and cannabis use relative to cannabis-only use, over and above the effects of amount of cannabis consumed, *b* = 0.33, *SE* = 0.09, *p* = <.001; however, greater grams of cannabis flower used also emerged as a significant predictor of later bedtime, *b* = 0.24, *SE* = 0.09, *p* = .007. Interestingly, in this model the effect of simultaneous use relative to cannabis-only use on bedtime was qualified by a significant cross-level interaction between simultaneous use days and AUDIT scores, *b* = -0.04, *SE* = 0.01, *p* = .007. Probing this interaction revealed a significant conditional association of simultaneous use day (vs. cannabis-only use day) with later bedtime at low levels of the AUDIT, *b* = 0.50, *SE* = 0.13, *p* = <.001, but not high levels of the AUDIT, *b* = 0.16, *SE* = 0.12, *p* = .196 (see Figure 3).

Next, I ran a second post-hoc model controlling for number of standard drinks on alcohol-only and simultaneous use days with alcohol-only days as a reference category. Only one interaction between problematic alcohol use and day type was significant (for simultaneous use days x AUDIT), so the model was trimmed of all other interaction terms and rerun. The full results of the final trimmed model are shown in Table 4. This model confirmed that the significant cross-level interaction between simultaneous use days (vs. alcohol-only use days) and AUDIT scores held when controlling for number of standard drinks, $b = -0.09$, $SE = 0.02$, $p = <.001$; however, greater number of standard drinks also emerged as a significant predictor of later bedtime, $b = 0.17$, $SE = 0.02$, $p = <.001$. Probing this interaction revealed a significant conditional association of simultaneous use day (versus alcohol-only use day) with earlier bedtime at high levels of the AUDIT, $b = -0.63$, $SE = 0.17$, $p = <.001$, but not low levels of the AUDIT, $b = 0.28$, $SE = 0.17$, $p = .106$ (see Figure 4). This pattern observed when controlling for drinks differs from that observed in the main model, in which probing this interaction revealed no significant associations at high nor low levels of the AUDIT.

In the post-hoc bedtime model with no-use as the reference category, only one interaction between problematic use and day type was significant (for simultaneous use days x AUDIT), so the model was trimmed of all other interaction terms and rerun. The results of the trimmed model are shown in Table 4. Results revealed that participants tended to go to bed later on days during which they engaged in alcohol-only use compared to days during which they used neither alcohol nor cannabis, $b = 0.38$, $SE = 0.10$, $p = <.001$. There was no significant difference in bedtime on cannabis-only use days relative to no-use days.

3.3. Multilevel Models with Substance Use Day Type as Outcome Variables

The results of the main model examining the reverse associations, with sleep indices predicting use day type (with simultaneous use as the reference category) are shown in Table 7. Previous-night subjective sleep quality, sleep duration, and bedtime reported in the morning did not predict likelihood of engaging in no-use, cannabis-only use, or alcohol-only use versus simultaneous use later that day. Participants with higher CUDIT-R scores were less likely overall across days to engage in no-use and alcohol-only use relative to simultaneous use, and were more likely to engage in cannabis-only use relative to simultaneous use. Participants with higher AUDIT scores were less likely overall across days to engage in cannabis-only use relative to simultaneous use. With respect to covariates, participants were less likely to engage in no-use, alcohol-only use days, and cannabis-only use days relative to simultaneous use days on weekends relative to weekdays. There was also a significant covariate association for participant sex on cannabis-only use days (vs. simultaneous use days), such that female participants were more likely to engage in cannabis-only use versus simultaneous use overall across days (see Table 7).

The results of the post-hoc model with no-use as the reference category are shown in Table 8. There were no signification associations between the sleep predictors (i.e., subjective sleep quality, sleep duration, and bedtime) and any of the dummy-coded day type outcome variables. However, results revealed significant between-person relationships between the tendency to report greater subjective sleep quality on average across days and likelihood of engaging in cannabis-only days relative to no-use days, as well as between-person tendency to experience longer sleep duration on average across days and likelihood of engaging in cannabis-only days relative to no-use days (see Table 8). These findings indicate that participants who reported better and longer sleep on average over the course of the study were more likely to engage in cannabis use days relative to no-use days.

4. Discussion

Given the high prevalence of simultaneous alcohol-cannabis use among young adults, there is a need to clarify the mixed findings in existing research regarding the combined effects of alcohol and cannabis use on sleep. The present study used daily diary methodology to examine daily-level relationships between single and simultaneous alcohol and cannabis use and key sleep indices (i.e., subjective sleep quality, sleep duration, and bedtime). This study contributes to the small literature of EMA studies on this topic and meaningfully extends upon previous EMA studies by examining the moderating roles of problematic alcohol and cannabis use and controlling for alcohol and cannabis quantity (in number of standard drinks and grams of cannabis flower, edible/cannabis beverage servings, and concentrate hits). Additionally, this study was one of the first to examine and report reciprocal relationships between sleep indices and next-day simultaneous alcohol and cannabis use. Results revealed that alcohol-only use days were associated with worse sleep outcomes than simultaneous use days, but no significant differences in sleep emerged between cannabis-only and simultaneous use days, although some of these associations were moderated by severity of alcohol problems. However, evidence did not support an association between poor sleep and increased likelihood of engaging in single-substance or simultaneous use the next day.

4.1. Sleep Outcomes on Single-Substance and No-Use Days Versus Simultaneous Use Days

Given prior research broadly suggesting sleep-promoting properties of cannabis (Babson & Bonn-Miller, 2014; Tervo-Clemmens et al., 2023) and sleep-impairing effects of alcohol (Lydon et al., 2016; Van Reen et al., 2016), it was hypothesized that participants would experience better sleep on cannabis-only use days relative to simultaneous use days. This hypothesis was largely unsupported; participants reported similar subjective sleep quality and sleep durations on cannabis-only and simultaneous use days, with no significant differences between these two types of days. This held even when controlling for cannabis quantity, although greater cannabis quantity also predicted earlier bedtimes. This general lack of evidence for better sleep on nights following cannabis-only use compared to simultaneous use is inconsistent with the EMA literature to date. Across two studies, Sznitman and colleagues found that cannabis-only use was associated with better subjective sleep quality and fewer early awakenings than simultaneous use (2023a; 2023b), and Graupensperger and colleagues found that cannabis-only use was associated with better subjective sleep quality than simultaneous use (2021). These discrepant findings may be attributable to methodological differences across studies, such as variations in cannabis quantities and forms used, which were not consistently reported in prior studies. Our differing results may also stem from our analytical approach of controlling for severity of alcohol and cannabis use problems, which only one of these prior studies addressed (Sznitman et al., 2023b).

Consistent with literature linking alcohol use with poor sleep outcomes (Goodhines et al., 2019a; Fucito et al., 2018; Lydon et al., 2016; Muzumdar et al., 2023), it was hypothesized that participants would experience worse sleep on alcohol-only use days relative to simultaneous use and no-use days. This hypothesis was supported. Echoing findings by Graupensperger and colleagues (2021), Sznitman and colleagues (2023a), and Wycoff and colleagues (2024), participants reported significantly worse sleep quality on alcohol-only use days compared to days of simultaneous use or no use, and this relationship held even when controlling for the quantity of alcohol consumed. Additionally, alcohol-only use was associated with shorter sleep duration compared to simultaneous use and no-use days. These findings suggest that while alcohol use generally impairs sleep quality and duration, such effects are mitigated when cannabis is used simultaneously. This pattern might reflect cannabis's potential to counteract some of alcohol's sleep-disrupting properties, potentially through inducing relaxation or by reducing alcohol-induced sleep disturbances. Finally, while there was no significant difference in bedtime on alcohol-only use days compared to simultaneous use days, alcohol-only use days were associated with later bedtimes compared to no-use days. Greater number of standard drinks also emerged as a significant predictor of later bedtime. The lack of difference in bedtime between alcohol-only and simultaneous days may be due to the context of alcohol use; young adults tend to engage in both alcohol-only and simultaneous use in social settings that involve staying up late, such as parties and bars (Farrelly et al., 2025; Gunn et al., 2021; Jackson et al., 2021).

Contrary to hypotheses, there were no significant main effects of severity of alcohol and/or cannabis use problems on subjective sleep quality, sleep duration, or bedtime. This indicates that participants' level of problematic alcohol or cannabis use as measured by these scores did not affect average levels of these sleep indices aggregated across all days in the study. However, the study did observe significant interactions involving alcohol use severity (as measured by the AUDIT). In the model evaluating bedtime on simultaneous use days relative to cannabis-only use days, there was an interaction between simultaneous use days and severity of alcohol problems such that participants with low—but not high—alcohol problem severity went to bed later on average on simultaneous use days relative to cannabis-only use days. For individuals with low alcohol problem severity, later bedtime during simultaneous use may reflect recreational patterns of alcohol use, where alcohol is primarily consumed alongside cannabis during social gatherings that extend later into the night (Farrelly et al., 2025; Gunn et al., 2021;

Jackson et al., 2021). Conversely, individuals scoring higher in alcohol problem severity may engage in alcohol consumption more frequently across various contexts, combining alcohol with cannabis even in settings where they maintain their typical bedtime (e.g., at home). However, this explanation remains speculative, and future research should assess the contextual factors associated with different substance use patterns.

Conversely, when examining alcohol-only use relative to simultaneous use, participants with high—but not low— alcohol problem severity went to bed earlier on simultaneous use days (when controlling for amount of alcohol consumed) and reported a longer sleep duration on simultaneous use days (see Figures 4 and 1, respectively). These findings may reflect an attempt by individuals with problematic alcohol use patterns to mitigate the sleep-disrupting effects of heavy alcohol use through use of cannabis as a sleep aid. Further, this pattern suggests that individuals with greater alcohol problem severity experience more disturbed sleep when drinking alcohol alone, and that cannabis use may potentially offset this negative effect for them. This aligns with the existing literature, which demonstrates that heavy alcohol use and alcohol dependence are particularly detrimental to sleep compared to occasional or non-problematic use (Angarita et al., 2016; Chakravorty et al., 2016).

4.2. Sleep Predicting Subsequent Simultaneous Use

Reciprocal models examining the impacts of sleep variables on next-day use patterns did not reveal any unique main effects. Specifically, previous-night subjective sleep quality, sleep duration, and bedtime reported in the morning did not predict likelihood of engaging in no-use, cannabis-only use, or alcohol-only use versus simultaneous use later that day, nor did they predict likelihood of engaging in cannabis-only or alcohol-only use relative to no-use. This suggests that poor sleep does not directly lead to a higher likelihood of next-day substance use.

These findings are inconsistent with literature suggesting that sleep can impact next-day substance use choices. For example, poor sleep predicts drinking to cope with stress, which is associated with alcohol use disorder (Digdon & Landry, 2011). It is possible that among the young adult sample in this study, substances were used more for entertainment and social connection purposes than coping motives (Kuntsche et al., 2005; Lee, Neighbors, & Woods, 2007). Additionally, this was not a sample selected for sleep disturbances, so associations between poor sleep and using substances to cope may be stronger among individuals with clinically significant sleep impairment. Finally, shorter sleep duration and poorer sleep quality may predominantly influence substance cravings over actual use behaviors (Graupensperger et al., 2022; Wycoff et al., 2024), such that individuals might experience stronger urges to use alcohol and cannabis following poor sleep but still exercise self-control over their actual consumption decisions (Graupensperger et al., 2022).

At the between-person level, participants who reported better subjective sleep quality and longer sleep duration on average were more likely to engage in cannabis-only use compared to no-use days. This finding aligns with the day-level associations between cannabis use and improved sleep quality and duration compared to no-use (discussed below), and suggests a between-person correlation between positive sleep experiences overall and more frequent use of cannabis. However, the direction of this between-person relationship remains unclear. It's uncertain whether greater cannabis use promotes better sleep, better sleep encourages more frequent cannabis use, or if a third variable associated with both outcomes is driving this association.

4.3. Single-Substance Versus No-Use

Results from models comparing cannabis-only use with no-use indicated that cannabis-only use was associated with better subjective sleep quality compared to no substance use at the daily level; that is, participants reported significantly better sleep on days when they engaged in cannabis-only use than on days when they used neither alcohol nor cannabis. There was also a significant between-person association suggesting that individuals who engaged in cannabis-only use on a greater proportion of days reported better sleep quality on average compared to those who did so less frequently. Additionally, cannabis-only use was linked to longer average sleep durations compared to no-use, although there was no significant difference in bedtime on cannabis-only days compared to no-use days. These results support a positive association between cannabis use and sleep quality and duration, suggesting potential sleep-enhancing effects of cannabis consistent with much of the literature to date (e.g., Babson & Bonn-Miller, 2014; Campbell et al., 2020; Goodhines et al., 2019a Tervo-Clemmens et al., 2023).

Results from models comparing alcohol-only use with no-use indicated that alcohol-only use was associated with poorer sleep outcomes compared to no substance use at the daily level. Specifically, participants reported worse subjective sleep quality on days they consumed only alcohol relative to days with no alcohol or cannabis use. Additionally, alcohol-only use was associated with shorter sleep duration compared to no-use. The study also found that participants tended to go to bed later on alcohol-only days compared to no-use days. These results suggest that alcohol consumption negatively impacts sleep quality, duration, and bedtime, supporting previously-reported adverse effects of alcohol on sleep when used in isolation (e.g., Fucito et al., 2018; Goodhines et al., 2019a; Lydon et al., 2016; Muzumdar et al., 2023; Van Reen et al., 2016).

4.4. Limitations

There were some important limitations to this study. First, all sleep data were self-report. Relying solely on self-report metrics means that I could not control for participant error in estimating bedtime and wake time in each daily morning survey. Indeed, some research suggests that subjective sleep quality ratings do not cleanly map onto objective sleep metrics (see Cudney et al., 2022). Additionally, the use of one-hour ranges for measuring bedtime and wake time lacked precision and likely resulted in important detail being lost. Future research should incorporate the use of biometric technology such as wearable devices to more precisely capture objective sleep indices such as bedtime, sleep duration, sleep-onset latency, and nightly awakenings, as well as examine how these measures map onto participant's ratings of subjective sleep quality (see Smith et al., 2018). Future studies should also measure sleep and wake time at the minute-level rather than using time ranges in order to maximise precision.

Second, this study's measurement of cannabis quantity had notable limitations. By operationalizing cannabis quantity as grams of cannabis flower, number of edibles and/or beverages, and concentrate hits consumed, I did not directly measure the concentrations of delta-9-tetrahydrocannabinol (THC) and other sleep-relevant cannabinoids. This is problematic because it is these compounds, rather than the overall quantity of cannabis, that are thought to influence sleep. Further, cannabis users may titrate dosage based on THC potency (e.g., by rolling smaller joints with higher-potency cannabis; Freeman et al., 2014), making overall quantity of cannabis a potentially misleading measure of intoxication. Future research should directly measure THC, cannabidiol (CBD), and other relevant cannabinoids to more accurately assess the relationship between cannabis constituents and sleep outcomes while accounting for the wide variability in potency across cannabis products (Coelho et al., 2025).

Another limitation to this study is that I did not measure sleep-specific motivation for substance use. Counterintuitively, use of alcohol and/or cannabis as sleep aids has been associated with worse sleep outcomes than non-sleep-aid use, with sleep aid use being associated with lower sleep satisfaction and shorter sleep duration compared to non-sleep-aid use (Goodhines et al., 2019a; Goodhines et al., 2019b; Meneo et al., 2023). Additionally, some research suggests that long-term use of cannabis as a sleep aid is associated with cannabis dependence, with intended sleep benefits disappearing after one year of consistent use (Goodhines et al., 2022). Future research would benefit from controlling for sleep aid use as well as examining whether simultaneous use as a sleep aid is associated with different sleep outcomes than simultaneous use associated with other motives.

Finally, I did not assess for sleep disorders in the sample. This is a significant limitation as I cannot determine what proportion of participants may have been experiencing clinical sleep problems, potentially confounding results. Given that cannabis and alcohol are often used to self-medicate sleep problems, understanding the prevalence of sleep disorders in the sample would provide important context for interpreting the findings. Future research would benefit from comprehensive sleep disorder screening to better understand how pre-existing sleep conditions might moderate the relationships between substance use and sleep outcomes.

4.5. Conclusion and Clinical Implications

Alcohol and cannabis are the most commonly used substances in Canada, particularly among young adults, where simultaneous use is prevalent. This study found that simultaneous use of alcohol and cannabis resulted in better subjective sleep quality compared to alcohol-only use, suggesting that cannabis may mitigate the negative effects of alcohol on sleep. However, simultaneous use was linked to later bedtimes compared to cannabis-only use, indicating potential disruptions in sleep patterns on simultaneous use nights. Cannabis-only use was associated with improved sleep quality and longer sleep duration compared to no-use, highlighting its potential sleep-enhancing effects. Conversely, alcohol-only use was linked to poorer sleep quality, shorter sleep duration, and later bedtimes compared to no-use, underscoring its detrimental impact on sleep.

The study’s findings that alcohol problem severity moderated simultaneous use’s associations with sleep represent an important contribution to the literature. Individuals with lower alcohol problem severity scores tended to have later bedtimes on simultaneous use days compared to cannabis-only days, possibly reflecting recreational use patterns. Those with higher alcohol problem severity scores reported earlier bedtimes and longer sleep duration on simultaneous use days compared to alcohol-only days, suggesting a potential attempt to mitigate alcohol’s sleep-disrupting effects through cannabis use. These findings emphasize the need for healthcare providers to consider patients’ substance use patterns to tailor recommendations. For patients with higher alcohol problem severity scores using cannabis as a sleep aid, underlying patterns of problematic alcohol use should be addressed. For those with lower alcohol problem severity scores engaging in simultaneous use, education on maintaining consistent sleep schedules may be beneficial. Future intervention research is needed to evaluate the efficacy and feasibility of tailored sleep interventions based on individual substance use patterns and problem severity.

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Tables

Table 1. Person-level descriptive statistics

	n	%
Sex		
Female	96	63.58
Male	54	35.76
Prefer not to respond	1	0.66
Gender		
Woman	57	37.75
Man	90	59.60
Non-binary	5	3.31
Transgender	2	1.32
Race/ethnicity		
White	94	62.25
Asian	24	15.89
East Indian	15	9.93
Black	13	8.61
Middle Eastern	6	3.97
Pacific Islander	2	1.32
Indigenous/Native North American	1	0.66
Other	6	3.97
Annual household income		
Below $49,000	80	52.98
$50,000–$99,999	45	29.80
$100,000–$199,999	12	7.94
Above $200,000	12	7.94
AUDIT met threshold for hazardous use	67	44.37
CUDIT-R met threshold for hazardous use	92	60.93
	M (*SD*)	Range
Age	22.08 (2.10)	18–26
AUDIT score	8.06 (4.70)	2–27
CUDIT-R score	10.17 (5.60)	2–32
Person-level mean number of no-use days	9.55 (6.31)	0–21
Person-level mean number of alcohol-only use days	1.61 (2.31)	0–21
Person-level mean number of cannabis-only use days	4.74 (5.02)	0–21
Person-level mean number of simultaneous use days	2.84 (3.35)	0–21
Person-level mean number of standard drinks consumed across all alcohol use days	3.53 (2.22)	0.75–12.75
Person-level mean grams of cannabis flower used across all cannabis use days	0.40 (0.53)	0–3.03
Person-level mean number of concentrate hits used across all cannabis use days	1.18 (2.44)	0–12
Person-level mean number of edible/beverage servings consumed across all cannabis use days	0.28 (0.55)	0–2.85

Note. Descriptives provided were calculated using all $N = 151$ participants and data from all available days, not limiting to those included in models.

Table 2. Day-level descriptive statistics on variables assessed in daily morning surveys

	n NA	*n*	%
Day of week	0		
Weekday		1623	57.43
Weekend day		1203	42.57
Bedtime	3		
Before 9:00PM		44	1.56
9:00 PM to 9:59 PM		81	2.87
10:00 PM to 10:59 PM		317	11.22
11:00 PM to 11:59 PM		535	18.98
12:00 AM to 12:59 AM		659	23.32
1:00 AM to 1:59 AM		498	17.62
2:00 AM to 2:59 AM		354	12.53
3:00 AM or later		335	11.85
Used cannabis flower (yes)	0	822	29.09
Used cannabis concentrates (yes)	0	253	8.95
Used cannabis edibles (yes)	0	186	6.58
	n NA	*M* (*SD*)	Range
Sleep quality	2	3.44 (0.96)	1–5
Sleep duration (hours)	5	8.22 (1.76)	2–15
Number of standard drinks consumed	3	0.85 (2.06)	0–17
Number of grams of cannabis flower used	4	0.21 (0.55)	0–5.3
Number of concentrate hits used	1	0.58 (2.42)	0–31
Number of edible/beverage servings consumed	1	0.11 (0.52)	0–6

Note. *n* NA = number of missing values. Descriptives provided were calculated using data from all available days ($n = 2826$), not limiting to those included in models. Extreme outliers on several variables (standard drinks, concentrate hites, edible/beverage servings) were winsorized by replacing them with a value one point higher than the next-highest value.

Table 3. Final multilevel models examining sleep outcomes as a function of day type with simultaneous use days as the reference category

	Subjective sleep quality[a]			Sleep Duration[b]			Bedtime[c]		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Intercept	**3.43**	**0.04**	**<.001**	**8.21**	**0.07**	**<.001**	**4.26**	**0.10**	**<.001**
Level 1									
No-use (vs. simultaneous use)	**-0.14**	**0.05**	**.010**	-0.04	0.10	.716	**-0.34**	**0.08**	**<.001**
Alcohol-only use (vs. simultaneous use)	**-0.28**	**0.07**	**<.001**	**-0.35**	**0.14**	**.012**	0.00	0.11	.980
Cannabis-only use (vs. simultaneous use)	0.03	0.06	.596	-0.11	0.11	.307	**-0.30**	**0.08**	**<.001**
Weekend vs. weekday	-0.01	0.03	.687	**0.12**	**0.06**	**.043**	**0.22**	**0.05**	**<.001**
Level 2									
Proportion of no-use days vs. simultaneous use days	-0.41	0.28	.145	-0.45	0.46	.335	**1.25**	**0.61**	**.042**
Proportion of alcohol-only use vs. simultaneous use days	-0.14	0.51	.782	0.41	0.85	.625	0.36	1.11	.747
Proportion of cannabis-only use vs. simultaneous use days	0.15	0.34	.649	0.34	0.56	.540	0.96	0.73	.192
Proportion of weekend vs. weekday	1.00	0.92	.286	-0.59	1.57	.706	-3.10	1.89	.103
AUDIT	0.00	0.01	.690	-0.03	0.02	.079	0.00	0.02	.931
CUDIT-R	-0.01	0.01	.245	0.02	0.02	.253	0.03	0.02	.242
Age	0.00	0.02	.944	-0.01	0.04	.708	-0.08	0.05	.107
Sex – female (vs. male)	-0.13	0.09	.157	**0.37**	**0.16**	**.019**	**-0.41**	**0.21**	**.048**
Cross-level interactions									
Alcohol-only use x AUDIT	–	–	–	**-0.06**	**0.02**	**.015**	**0.04**	**0.02**	**.026**

Random effects	Variance	*SD*	Variance	*SD*	Variance	*SD*
Random intercept	0.25	0.50	0.66	0.81	1.29	1.13

Note. AUDIT = Alcohol Use Disorders Identification Test (Saunders et al., 1993); CUDIT-R = Cannabis Use Disorder Identification Test–Revised (Adamson et al., 2010). Statistically significant effects (at an alpha level of .05) are bolded. All level 1 independent variables were person-mean centered; at level 2, age, sex, AUDIT and CUDIT-R scores, and the person-level means of the substance use day type dummy variables and day of week dummy variable were grand-mean centered. Each sleep outcome variable (i.e., subjective sleep quality, sleep duration, and bedtime) was examined in a separate model. After excluding rows that were missing data on one or more model variables, the models included 150 participants and 2804 participant days in the subjective sleep quality and bedtime models, and 150 participants and 2803 participant days in the sleep duration model.

[a] Including the random slopes for the set of dummy-coded day type variables (ΔBIC = +18.9) and the weekend versus weekday indicator (ΔBIC = +11.9) did not improve model fit. Thus, the final model included only a random intercept with fixed slopes. After excluding rows that were missing data on one or more model variables, the model included 150 participants and 2804 participant days.

[b] Including the random slopes for the set of dummy-coded day type variables (ΔBIC = +21) and the weekend versus weekday indicator (ΔBIC = +11) did not improve model fit. Thus, the final model included only a random intercept with fixed slopes. After excluding rows that were missing data on one or more model variables, the model included 150 participants and 2803 participant days.

[c] Including the random slopes for the set of dummy-coded day type variables (ΔBIC = +11.6) and the weekend versus weekday indicator (ΔBIC = +4.2) did not improve model fit. Thus, the final model included only a random intercept with fixed slopes. After excluding rows that were missing data on one or more model variables, the model included 150 participants and 2804 participant days.

Table 4. Final multilevel models examining sleep outcomes as a function of day type and controlling for alcohol quantity with alcohol-only use days as the reference category

	Subjective sleep quality			Sleep Duration			Bedtime		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Intercept	**3.40**	**0.06**	**<.001**	**8.12**	**0.11**	**<.001**	**4.48**	**0.13**	**<.001**
Level 1									
Simultaneous use vs. alcohol-only use [ref.]	**0.39**	**0.13**	**.003**	**0.53**	**0.17**	**.002**	-0.17	0.12	.160
Standard drinks	-0.01	0.01	.623	**-0.10**	**0.03**	**<.001**	**0.17**	**0.02**	**<.001**
Weekend vs. weekday	-0.11	0.07	.134	0.16	0.13	.225	0.08	0.10	.416
Level 2									
Proportion of simultaneous use days vs. alcohol-only use days	**0.40**	**0.18**	**.030**	0.55	0.36	.125	-0.58	0.38	.136
Standard drinks	-0.05	0.03	.126	**-0.17**	**0.06**	**.007**	0.08	0.07	.247
Proportion of weekend vs. weekday	0.40	0.22	.069	0.78	0.43	.071	0.09	0.45	.834
AUDIT	0.01	0.01	.366	0.00	0.03	.993	-0.04	0.03	.206
CUDIT-R	-0.00	0.01	.783	0.03	0.03	.337	0.04	0.03	.182
Age	-0.00	0.03	.862	-0.05	0.06	.355	-0.12	0.06	.059
Sex – female (vs. male)	-0.16	0.12	.183	0.36	0.24	.146	-0.35	0.27	.198
Cross-level interactions									
Simultaneous use x AUDIT	–	–	–	–	–	–	**-0.09**	**0.02**	**<.001**
Random effects	Variance		*SD*	Variance		*SD*	Variance		*SD*
Random intercept	0.25		0.50	0.98		0.99	1.55		1.24
Random slope for the simultaneous use type dummy variable	0.40		0.63	–		–	–		–

Note. AUDIT = Alcohol Use Disorders Identification Test (Saunders et al., 1993); CUDIT-R = Cannabis Use Disorder Identification Test–Revised (Adamson et al., 2010). Statistically significant effects (at an alpha level of .05) are bolded. All level 1 independent variables were person-mean centered; at level 2, age, sex, AUDIT and CUDIT-R scores, and the person-level means of standard drinks, the simultaneous use day type dummy variable, and day of week dummy variable were grand-mean centered. Each sleep outcome variable (i.e., subjective sleep quality, sleep duration, and bedtime) was examined in a separate model. After excluding rows that were missing data on one or more model variables, the model included 126 participants and 670 participant days in the subjective sleep quality model, and 126 participants and 669 participant days in the sleep duration and bedtime models.

Table 5. Final multilevel models examining sleep outcomes as a function of day type with no-use days as the reference category

	Subjective sleep quality[a]			Sleep Duration[b]			Bedtime[c]		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Intercept	**3.43**	**0.04**	**<.001**	**8.21**	**0.07**	**<.001**	**4.26**	**0.10**	**<.001**
Level 1									
Simultaneous use vs. no-use [ref.]	**0.14**	**0.05**	**.010**	0.05	0.10	.631	**0.37**	**0.08**	**<.001**
Alcohol-only use vs. no-use [ref.]	**-0.14**	**0.06**	**.026**	**-0.34**	**0.12**	**.004**	**0.36**	**0.09**	**<.001**
Cannabis-only use vs. no-use [ref.]	**0.17**	**0.05**	**<.001**	-0.07	0.09	.462	0.04	0.08	.589
Weekend vs. weekday	-0.01	0.03	.687	**0.13**	**0.06**	**.035**	**0.21**	**0.05**	**<.001**
Level 2									
Proportion of simultaneous use days vs. no-use days	0.41	0.28	.145	0.45	0.46	.335	**-1.25**	**0.61**	**.042**
Proportion of alcohol-only use vs. no-use days	0.27	0.42	.526	0.86	0.70	.218	-0.89	0.92	.337
Proportion of cannabis-only use vs. no-use days	**0.56**	**0.20**	**.005**	**0.79**	**0.33**	**.018**	-0.29	0.43	.507
Proportion of weekend vs. weekday	0.99	0.92	.287	-0.59	1.57	.706	-3.10	1.89	.103
AUDIT	0.00	0.01	.689	-0.03	0.02	.078	-0.00	0.02	.931
CUDIT-R	-0.01	0.01	.245	0.02	0.02	.254	0.03	0.02	.241
Age	0.00	0.02	.944	-0.01	0.04	.709	-0.08	0.05	.107
Sex – female (vs. male)	-0.13	0.09	.157	**0.37**	**0.16**	**.019**	**-0.41**	**0.21**	**.048**
Cross-level interactions									
Simultaneous use x AUDIT	–	–	–	–	–	–	**-0.04**	**0.01**	**.007**
Random effects	Variance	*SD*		Variance	*SD*		Variance	*SD*	
Random intercept	0.25	0.50		0.66	0.81		1.29	1.13	

Note. AUDIT = Alcohol Use Disorders Identification Test (Saunders et al., 1993); CUDIT-R = Cannabis Use Disorder Identification Test–Revised (Adamson et al., 2010). Statistically significant effects (at an alpha level of .05) are bolded. All level 1 independent variables were person-mean centered; at level 2, age, sex, AUDIT and CUDIT-R scores, and the person-level means of the substance use day type dummy variables and day of week dummy variable were grand-mean centered. Each sleep outcome variable (i.e., subjective sleep quality, sleep duration, and bedtime) was examined in a separate model. After excluding rows that were missing data on one or more model variables, the model included 126 participants and 670 participant days in the subjective sleep quality model, and 126 participants and 669 participant days in the sleep duration and bedtime models.

[a] Including the random slopes for the set of dummy-coded day type variables (ΔBIC = +5.9) and the weekend versus weekday indicator (ΔBIC = +11.9) did not improve model fit. Thus, the final model included only a random intercept with fixed slopes.
[b] Including the random slopes for the set of dummy-coded day type variables (ΔBIC = +7) and the weekend versus weekday indicator (ΔBIC = +11) did not improve model fit. Thus, the final model included only a random intercept with fixed slopes.
[c] Including the random slopes for the set of dummy-coded day type variables (ΔBIC = +3.2) and the weekend versus weekday indicator (ΔBIC = +4.2) did not improve model fit. Thus, the final model included only a random intercept with fixed slopes.

Table 6. Final multilevel models examining sleep outcomes as a function of day type and controlling for cannabis form and quantity with cannabis-only use days as the reference category

	Subjective sleep quality			Sleep Duration			Bedtime		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Intercept	**3.55**	**0.05**	**<.001**	**8.34**	**1.02**	**<.001**	**4.24**	**0.12**	**<.001**
Level 1									
Simultaneous use vs. cannabis-only use [ref.]	-0.01	0.06	.808	0.14	0.12	.230	**0.33**	**0.09**	**<.001**
Cannabis flower in grams	0.06	0.06	.267	-0.17	0.12	.141	**0.24**	**0.09**	**.007**
Cannabis concentrate hits	0.01	0.01	.224	0.01	0.02	.722	0.01	0.01	.604
Edible and cannabis beverage servings	0.02	0.04	.559	-0.06	0.08	.470	0.11	0.06	.072
Weekend vs. weekday	-0.06	0.05	.205	0.16	0.10	.105	0.10	0.08	.200
Level 2									
Proportion of simultaneous use days vs. cannabis-only use days	-0.12	0.18	.522	0.02	0.34	.961	-0.42	0.38	.266
Cannabis flower in grams	0.12	0.11	.288	-0.29	0.20	.159	-0.45	0.23	.055
Cannabis concentrate hits	**0.05**	**0.22**	**.038**	-0.01	0.04	.861	-0.07	0.05	.156
Edible and cannabis beverage servings	-0.04	0.10	.668	-0.19	0.19	.307	0.31	0.21	.141
Proportion of weekend vs. weekday	-0.03	0.25	.899	-0.00	0.47	.999	-0.06	0.49	.906
AUDIT	-0.00	0.01	.943	-0.03	0.03	.317	0.00	0.03	.930
CUDIT-R	-0.01	0.01	.581	0.04	0.02	.051	0.02	0.03	.399
Age	0.00	0.03	.989	-0.01	0.05	.913	**-0.13**	**0.05**	**.022**
Sex – female (vs. male)	-0.08	0.12	.487	**0.62**	**0.21**	**.005**	**-0.92**	**0.24**	**<.001**
Cross-level interactions									

Simultaneous use x AUDIT	–	–	–	**0.07**	**0.02**	**.005**	**-0.04**	**0.02**	**.047**
Random effects	Variance	*SD*		Variance	*SD*		Variance	*SD*	
Random intercept	0.26	0.51		0.87	0.93		1.37	1.17	

Note. AUDIT = Alcohol Use Disorders Identification Test (Saunders et al., 1993); CUDIT-R = Cannabis Use Disorder Identification Test–Revised (Adamson et al., 2010). Statistically significant effects (at an alpha level of .05) are bolded. All level 1 independent variables were person-mean centered; at level 2, age, sex, AUDIT and CUDIT-R scores, and the person-level means of grams of cannabis flower, cannabis concentrate hits, edible and beverage servings, the simultaneous use day type dummy variable, and day of week dummy variable were grand-mean centered. Each sleep outcome variable (i.e., subjective sleep quality, sleep duration, and bedtime) was examined in a separate model. After excluding rows that were missing data on one or more model variables, the models included 131 participants and 1140 participant days in the subjective sleep quality and bedtime models, and 131 participants and 1139 participant days in the sleep duration and bedtime model.

Table 7. Final multilevel model examining day type as a function of sleep indices with simultaneous use days as the reference category

	No-use vs. simultaneous use [ref.]			Alcohol-only use vs. simultaneous use [ref.]			Cannabis-only use vs. simultaneous use [ref.]		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Level 1									
Subjective sleep quality	-0.07	0.09	.426	-0.10	0.12	.392	-0.03	0.10	.789
Sleep duration	-0.01	0.06	.850	-0.04	0.08	.604	-0.05	0.06	-435
Bedtime	-0.04	0.07	.591	-0.02	0.10	.862	-0.01	0.07	.932
Weekend vs. weekday	**-1.09**	**0.14**	**<.001**	**-0.61**	**0.19**	**.001**	**-0.99**	**0.15**	**<.001**
Level 2									
Subjective sleep quality	-0.32	0.30	.249	-0.33	0.33	.320	0.41	0.29	.158
Sleep duration	-0.31	0.19	.099	-0.05	0.20	.794	0.19	0.18	.279
Bedtime	0.18	0.15	.244	0.05	0.16	.776	0.23	0.15	.125
Proportion of weekend vs. weekday	-0.64	1.87	.734	0.07	2.29	.977	2.07	1.82	.257
AUDIT	-0.05	0.04	.205	0.05	0.04	.196	**-0.11**	**0.04**	**.002**
CUDIT-R	**-0.19**	**0.03**	**<.001**	**-0.19**	**0.04**	**<.001**	**0.09**	**0.03**	**.010**
Age	-0.03	0.07	.689	0.04	0.08	.569	-0.02	0.07	.790
Sex – female (vs. male)	0.14	0.33	.661	0.14	0.35	.694	**0.70**	**0.32**	**.031**
Random effects	Variance		*SD*	Variance		*SD*	Variance		*SD*
Random intercept	2.24		0.42	1.52		0.44	1.72		0.38

Note. AUDIT = Alcohol Use Disorders Identification Test (Saunders et al., 1993); CUDIT-R = Cannabis Use Disorder Identification Test–Revised (Adamson et al., 2010). Statistically significant effects (at an alpha level of .05) are bolded. All level 1 independent variables were person-mean centered; at level 2, age, sex, AUDIT and CUDIT-R scores, and the person-level means of the sleep variables and day of week dummy variable were grand-mean centered. Including random slopes for the sleep predictor variables and the weekend versus weekday indicator resulted in a nonconvergent model. Thus, the final model included only a random intercept with fixed slopes. After excluding rows that were missing data on one or more model variables, the model included 148 participants and 2478 participant days.

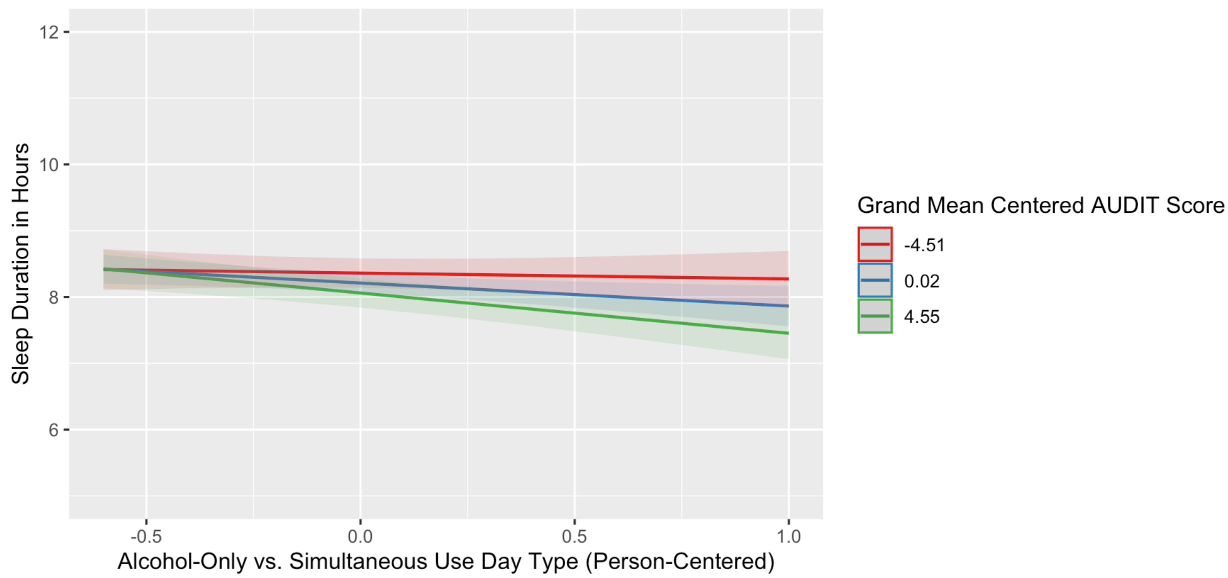
Table 8. Final multilevel models examining day type as a function of sleep indices with no-use days as the reference category

	Simultaneous use vs. no-use [ref.]			Alcohol-only use vs. no-use [ref.]			Cannabis-only use vs. no-use [ref.]		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Level 1									
Subjective sleep quality	0.08	0.09	.390	-0.03	0.10	.742	0.04	0.08	.588
Sleep duration	0.02	0.06	.805	-0.03	0.07	.687	-0.04	0.05	.502
Bedtime	0.04	0.07	.615	0.02	0.07	.843	0.03	0.07	.657
Weekend vs. weekday	**1.12**	**0.15**	**<.001**	**0.41**	**0.16**	**.011**	0.06	0.13	.663
Level 2									
Subjective sleep quality	0.41	0.33	.214	-0.04	0.29	.882	**0.71**	**0.33**	**.031**
Sleep duration	0.27	0.20	.188	0.12	0.19	.508	**0.49**	**0.21**	**.020**
Bedtime	-0.16	0.17	.328	-0.13	0.14	.366	0.11	0.17	.543
Proportion of weekend vs. weekday	-0.44	2.08	.834	-0.39	2.15	.858	2.78	1.99	.162
AUDIT	0.06	0.04	.138	**0.09**	**0.03**	**.013**	-0.08	0.04	.062
CUDIT-R	**0.18**	**0.04**	**<.001**	-0.03	0.03	.418	**0.26**	**0.04**	**<.001**
Age	0.03	0.08	.696	0.09	0.07	.190	0.01	0.08	.915
Sex – female (vs. male)	-0.18	0.35	.620	-0.07	0.31	.817	0.66	0.38	.082
Random effects	Variance		*SD*	Variance		*SD*	Variance		*SD*
Random intercept	2.55		0.51	1.34		0.36	3.04		0.57

Note. AUDIT = Alcohol Use Disorders Identification Test (Saunders et al., 1993); CUDIT-R = Cannabis Use Disorder Identification Test–Revised (Adamson et al., 2010). Statistically significant effects (at an alpha level of .05) are bolded. All level 1 independent variables were person-mean centered; at level 2, age, sex, AUDIT and CUDIT-R scores, and the person-level means of the sleep variables and day of week dummy variable were grand-mean centered. Including random slopes for the sleep outcome variables and the weekend versus weekday indicator resulted in a nonconvergent model. Thus, the final model included only a random intercept with fixed slopes. After excluding rows that were missing data on one or more model variables, the model included 148 participants and 2478 participant days.

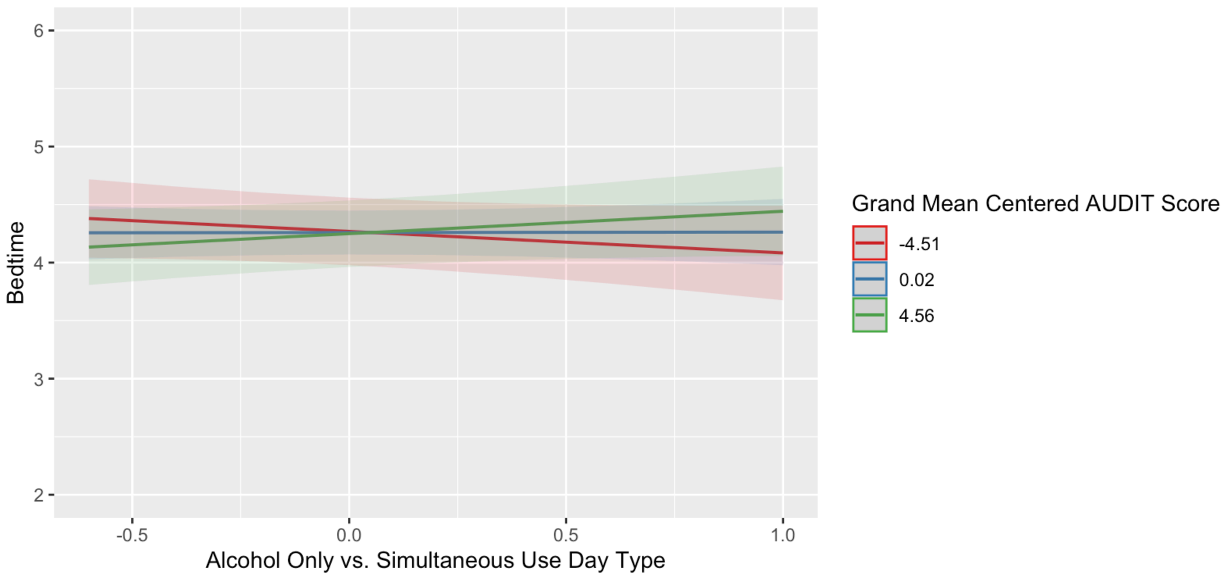
Figures

Figure 1. Cross-level interaction between alcohol-only (vs. simultaneous) use days and AUDIT scores on sleep duration in main model



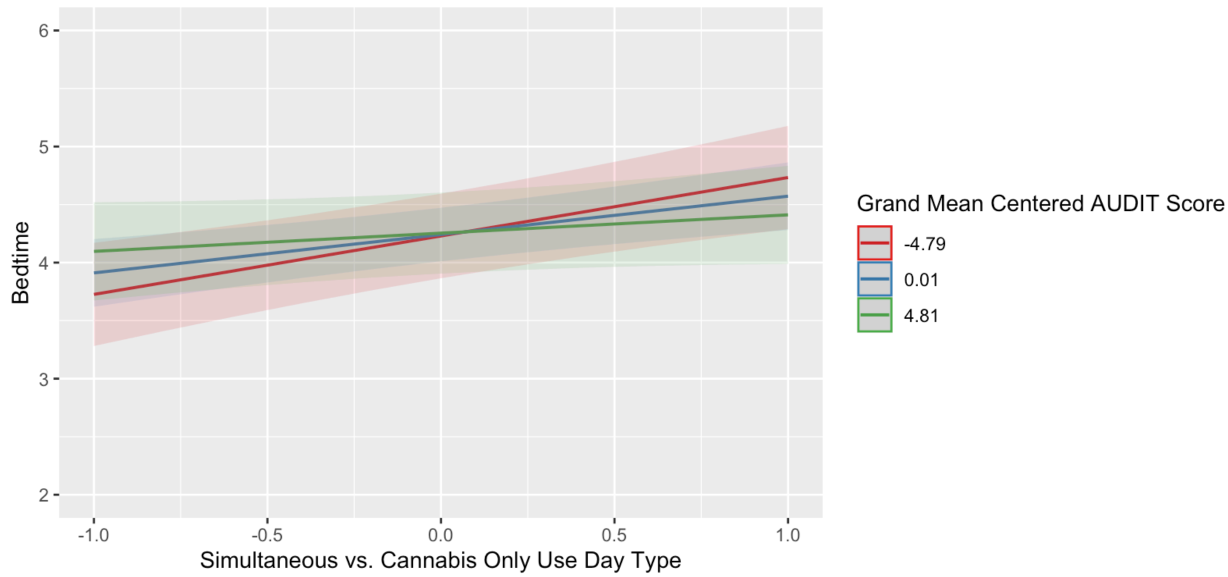
Note. The x-axis shows the person-mean-centered dummy coded day type variables. Positive values on the x-axis represent alcohol-only use days and negative values represent simultaneous use days. The y-axis covers 2 standard deviations above and below the sleep duration mean. The red line represents one standard deviation below the mean Alcohol Use Disorders Identification Test (AUDIT) score, the blue line represents the mean AUDIT score, and the green line represents one standard deviation above the mean AUDIT score. Error bars show the 95% confidence interval.

Figure 2. Cross-level interaction between alcohol-only (vs. simultaneous) use days and AUDIT scores on bedtime in main model



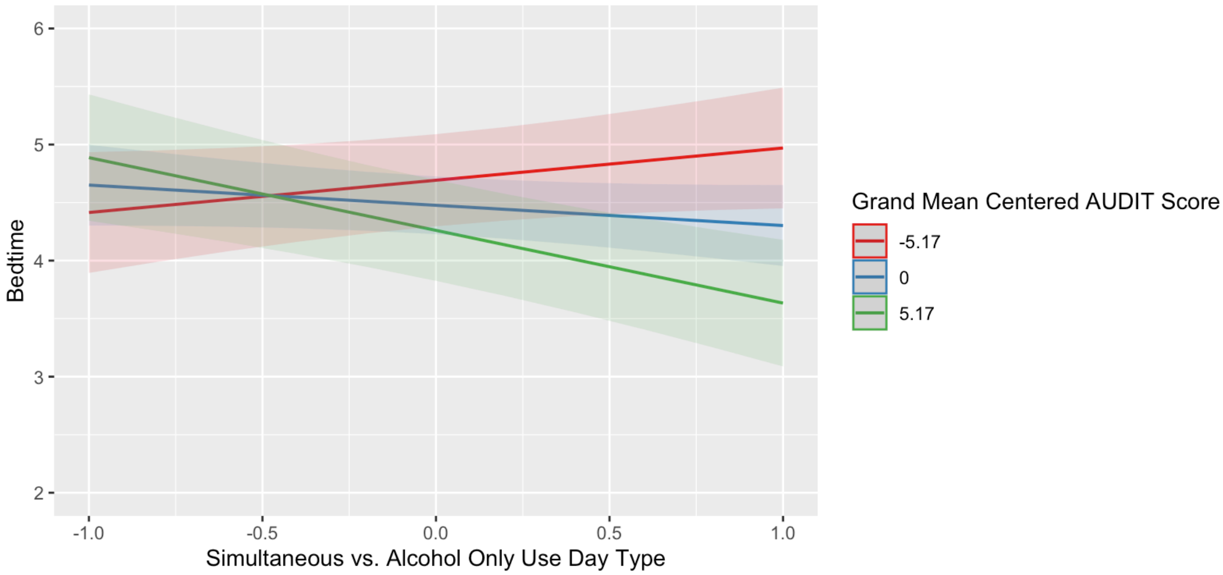
Note. The x-axis shows the person-mean-centered dummy coded day type variables. Positive values on the x-axis represent alcohol-only use days and negative values represent simultaneous use days. Values on the y-axis represent the 1–7 categorical bedtime scale, with each scale value except the upper and lower bounds of the scale associated with a 1-hour range in bedtime (0 = *before 9pm*, 1 = *9pm–9:59pm*, 2 = *10pm–10:59pm*, 3 = *11pm–11:59pm*, 4 = *12am–12:59am*, 5 = *1am–1:59am*, 6 = *2am–2:59am*, 7 = *3am or later*). The y-axis covers 2 standard deviations above and below the bedtime mean. The red line represents one standard deviation below the mean Alcohol Use Disorders Identification Test (AUDIT) score, the blue line represents the mean AUDIT score, and the green line represents one standard deviation above the mean AUDIT score. Error bars show the 95% confidence interval.

Figure 3. Cross-level interaction between simultaneous (vs. cannabis-only) use days and AUDIT scores on bedtime in post-hoc model controlling for cannabis quantity and form



Note. The x-axis shows the person-mean-centered dummy coded day type variables. Positive values on the x-axis represent simultaneous use days and negative values represent cannabis-only use days. Values on the y-axis represent the 1–7 categorical bedtime scale, with each scale value except the upper and lower bounds of the scale associated with a 1-hour range in bedtime (0 = *before 9pm*, 1 = *9pm–9:59pm*, 2 = *10pm–10:59pm*, 3 = *11pm–11:59pm*, 4 = *12am–12:59am*, 5 = *1am–1:59am*, 6 = *2am–2:59am*, 7 = *3am or later*). The y-axis covers 2 standard deviations above and below the bedtime mean. The red line represents one standard deviation below the mean Alcohol Use Disorders Identification Test (AUDIT) score, the blue line represents the mean AUDIT score, and the green line represents one standard deviation above the mean AUDIT score. Error bars show the 95% confidence interval.

Figure 4. Cross-level interaction between simultaneous (vs. alcohol-only) use days and AUDIT scores on bedtime in post-hoc model controlling for alcohol quantity



Note. The x-axis shows the person-mean-centered dummy coded day type variables. Positive values on the x-axis represent simultaneous use days and negative values represent alcohol-only use days. Values on the y-axis represent the 1–7 categorical bedtime scale, with each scale value except the upper and lower bounds of the scale associated with a 1-hour range in bedtime (0 = *before 9pm*, 1 = *9pm–9:59pm*, 2 = *10pm–10:59pm*, 3 = *11pm–11:59pm*, 4 = *12am–12:59am*, 5 = *1am–1:59am*, 6 = *2am–2:59am*, 7 = *3am or later*). The y-axis covers 2 standard deviations above and below the bedtime mean. The red line represents one standard deviation below the mean Alcohol Use Disorders Identification Test (AUDIT) score, the blue line represents the mean AUDIT score, and the green line represents one standard deviation above the mean AUDIT score. Error bars show the 95% confidence interval.