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# Cannabis Sleep Aid Use in Daily College Life: An Intensive Longitudinal Assessment Approach

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## Abstract

**Objective:** Emerging evidence suggests that college cannabis sleep aid use may increase vulnerability to diurnal impairment, despite proximal sleep-related benefits. In contrast, relatively little is known about proximal precipitants of cannabis sleep aid use in daily college life. The identification of modifiable, situational intervention points preceding cannabis sleep aid use in daily college life is critical to accelerate the development of college harm reduction efforts. This 14-night mixed methods study tested temporal associations of THC-based cannabis sleep aid use with cognitive arousal-based precipitants (consistent with cognitive theory of insomnia) and sleep outcomes. **Method:** Daily diary (pre-sleep and waking) and actigraphy data were collected from  $n = 81$  college students across 14 nights. Eligible participants ( $M_{age} = 19.96$  [ $SD = 1.18$ ]; 65% women [100% cisgender]; 72% White) reported at least bimonthly THC-based cannabis use for sleep aid. **Results:** Multilevel models demonstrated that cognitive pre-sleep arousal did not predict cannabis sleep aid use day-to-day over and above individual average arousal levels. In turn, nights of cannabis sleep aid were associated with (a) improved same-night subjective sleep efficiency and (b) shorter next-night objective wake-time after sleep onset and sleep duration, after controlling for general daily-level cannabis use quantity. Mediation models indicated that associations of cognitive pre-sleep arousal with same-night sleep were not explained by cannabis sleep aid use. **Conclusions:** Pre-sleep arousal does not appear to predict cannabis use for sleep aid in daily college life, which in turn demonstrates potential proximal sleep-related benefits. Continued research is needed exploring modifiable within-person precipitants to inform ongoing harm reduction efforts.

Cannabis Sleep Aid Use in Daily College Life: An Intensive  
Longitudinal Assessment Approach

by

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Dissertation

Submitted in partial fulfillment of the requirements for the degree of Doctorate of Philosophy in

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## Cannabis Sleep Aid Use in Daily College Life: An Intensive Longitudinal Assessment Approach

Cannabis sleep aid use among college students is prevalent and associated with sleep- and substance-related consequences. In a recent study, 44% of cannabis-using college students reported using cannabis to help sleep (Drazdowski et al., 2019). Cannabis sleep aid use may not achieve the intended function of improving same-night sleep quality (despite improved sleep maintenance and increased duration) or insomnia symptom severity over time, but instead may increase vulnerability to diurnal impairment such as next-day fatigue and substance use consequences over time (Drazdowski et al., 2019; Goodhines, Gellis, Ansell, et al., 2019). Ongoing research characterizing situational precipitants of cannabis sleep aid use in daily college life is critical to identify potential within-person intervention targets and ultimately inform clinical practice to mitigate adverse outcomes.

### **College Sleep Problems and Cannabis Use**

College-attending emerging adults represent a distinct developmental population (Arnett, 2016) at elevated risk for both sleep problems and cannabis use. In a large study of U.S. college students, 27% rated their sleep as poor quality, 43% endorsed difficulty falling asleep, and 40% reported sub-optimal sleep efficiency (Becker, Jarrett, et al., 2018). College sleep problems are associated with substantial short-term consequences (e.g., academic impairment, depressed mood, and suicidal ideation; Becker, Dvorsky, et al., 2018; Chen & Chen, 2019), as well as long-term consequences (e.g., cardiovascular and metabolic disease risk, neurocognitive dysfunction, and all-cause mortality; for a review, see Grandner, 2020).

Parallel to sleep problems, college-attending emerging adults endorse greater cannabis use compared to both adolescents and non-college peers (SAMHSA, 2020a). Cannabis remains



the most commonly used illicit drug (SAMHSA, 2020a), with prevalence, frequency, and acceptability continuing to rise among college students (Schulenberg, 2020; SAMHSA, 2020b). College cannabis use has demonstrated short-term harms such as impaired academic functioning (Arria et al., 2015), interpersonal functioning, daytime fatigue, and driving under the influence (Pearson et al., 2017), even among occasional or time-limited users (Arria et al., 2016).

### ***College Cannabis Sleep Aid Use***

This novel combination of sleep and cannabis risk factors may predispose college students to self-medicate their sleep problems with cannabis. College cannabis use has been associated with sleep problems and negative cannabis and alcohol consequences (Drazdowski et al., 2019; Goodhines, Gellis, Kim, et al., 2019). These results indicate that cannabis sleep aid may not improve sleep, instead potentially increasing susceptibility to psychosocial consequences of substance use over time (despite consistent levels of substance use). Further, a recent daily diary study found that cannabis sleep aid use predicted higher next-day daytime fatigue within-person (but not cannabis-related psychosocial consequences; controlling for daily cannabis frequency), despite null associations with sleep quality/latency and proximal improvements to sleep maintenance/duration (Goodhines, Gellis, Ansell, et al., 2019). Collectively, these emerging findings demonstrate the potential for adverse sleep- and substance-related outcomes of cannabis use *specifically for sleep aid*, consistent with a host of previous research documenting substance use consequences novel to specific use motives (for a review, see Cooper et al., 2016).

### **Feed-Forward Model of Sleep-Cannabis Associations**

Models of self-medication for sleep (e.g., Brower, 2003) outline a feed-forward process by which substance use and sleep problems exacerbate reciprocally over time. Specifically, sleep

problems prompt self-medication (with THC-based cannabis, for example) which inadvertently maintains or worsens sleep problems due to toxic effects on sleep-related brain systems (for a review, see Kesner & Lovinger, 2020). Over time, self-medication behavior increases to compensate for substance tolerance and ongoing sleep problems, ultimately increasing risk for substance use and then associated consequences. Indeed, while some studies found that pre-sleep cannabis administration resulted in shorter sleep onset latency and improved sleep maintenance, other studies observed residual daytime fatigue, habituation implicating increased dosing over time, and post-cessation rebound insomnia (Babson et al., 2017). Although Brower's (2003) reciprocal influences model was originally developed for alcohol use disorder, it has been supported among sub-clinical populations of cannabis/alcohol-using college students (for example, cannabis/alcohol sleep aid use was associated with increased negative drinking consequences over two months; Goodhines, Gellis, Kim, et al., 2019).

### ***Cognitive Pre-sleep Arousal as a Situational Precipitant of Cannabis Sleep Aid Use***

Brower's model of reciprocal sleep-substance associations (Brower, 2003) may be amended to additionally consider situational (that is, varying within person) precipitants of sleep aid use beyond global sleep problems. Cognitive theory of insomnia (Harvey, 2002) posits that sleep aid use (i.e., safety-seeking behavior; Clark, 1999) is precipitated by cognitive arousal before bed. Compared to healthy sleepers, poor sleepers have demonstrated higher rates of cognitive pre-sleep arousal on average (e.g., worry about falling asleep and/or other problems; Ong et al., 2011). The integration of cognitive insomnia theory and Brower's reciprocal influences model suggests a risk mechanism by which situational, arousal-based precipitants increase the likelihood of sleep aid use, which then leads to exacerbated sleep and substance use problems. Indeed, college students reporting self-medication for sleep aid are characterized by

significantly greater pre-sleep arousal compared to non-using peers (Goodhines, Gellis, Kim, et al., 2019). However, inferences regarding directionality of arousal-sleep aid associations remain speculative, necessitating intensive longitudinal methods to clarify temporal associations within individuals.

### **Literature Gaps**

Four key gaps remain in the developing empirical support for theorized sleep-cannabis associations. First, little research has examined *modifiable within-person precipitants* of cannabis sleep aid use in daily life, which may be critical to inform targeted harm reduction efforts. Second, although experimental findings have characterized cannabis-sleep associations on average, investigation of *within-person outcomes* of cannabis sleep aid use for same-night sleep in the natural college environment remains limited and requires replication. Third, continued empirical work is needed to investigate the *potential within-person risk mechanism* by which cognitive pre-sleep arousal precipitates cannabis sleep aid use, subsequently impacting sleep. Lastly, research is needed to examine precipitants and outcomes of *THC-based cannabis* use for sleep aid specifically (versus cannabidiol [CBD], a non-psychoactive constituent of Cannabis sativa; World Health Organization, 2017). This distinction of THC-based cannabis is critical given potentially differential sleep-related expectancies and consequences, which remain to be fully explicated in the literature (for a review, see Pauli et al., 2020).

### **Current Study**

The identification of situational, arousal-based intervention points preceding THC-based cannabis sleep aid use in daily college life is critical to inform targeted college sleep health and substance use prevention and intervention. This novel mixed-methods 14-day daily diary study (pre-sleep and waking surveys) with wrist-worn actigraphy was designed to achieve three aims

(see Figure 1 for conceptual model of Aims 1-3) remedying aforementioned literature gaps. **Aim 1** investigated directional associations of cognitive pre-sleep arousal with cannabis sleep aid use. It was hypothesized that nights of greater cognitive pre-sleep arousal would be associated with greater likelihood of same-night cannabis sleep aid use within person. **Aim 2** investigated directional associations of cannabis sleep aid use with same-night sleep (diary/subjective and actigraphy/objective, controlling for general cannabis quantity). It was hypothesized that nights of cannabis sleep aid use would be associated with subjective improvements to same-night sleep (increased sleep duration and efficiency, reduced wake-time after sleep onset) within person, consistent with previous research reviewed herein. Notably, current analyses of actigraphy-assessed (objective) sleep outcomes remain exploratory, including consistency with aforementioned subjective impressions of sleep impact. Lastly, **Aim 3** investigated a directional risk pathway involving cannabis sleep aid use potentially underlying associations of cognitive pre-sleep arousal (Aim 1 predictor) with proximal sleep (Aim 2 outcomes). It was hypothesized that cannabis sleep aid use would mediate within-person associations of cognitive pre-sleep arousal with same-night sleep outcomes (as outlined in Aim 2). This project addressed methodological limitations of prior studies by: (a) using both pre-sleep and waking surveys to identify precipitants and outcomes of cannabis sleep aid use day-to-day; (b) using concurrent actigraphy to address the subjective, retrospective nature of sleep reports; and (c) explicating effects of THC-based cannabis (versus CBD-exclusive products).

## Method

### Participants

Participants were 81 undergraduate college students ( $M_{\text{age}} = 19.96$  [ $SD = 1.18$ , range = 18-22]; 65% women and 35% men [100% cisgender]) during the Spring 2021 academic

semester. Participants were 72% White, 12% Bi/Multiracial, 7% Asian, 4% Black or African American, 1% self-reported “Other”, 0% American Indian/Alaska Native or Native Hawaiian/Pacific Islander, and 4% did not disclose, and 12% were Hispanic/Latinx. Students were *eligible* to participate if they met the following inclusion criteria: (a) full-time undergraduate college student, due to observed differences in substance use (Johnston et al., 2015) and sleep behaviors (Oswalt & Wyatt, 2014) relative to part-time and graduate students; (b) aged 18-25 years, consistent with typical college age range (Arnett, 2016; National Center for Education Statistics, 2016), during which sleep needs/behaviors are relatively homogenous due to predictable developmental change (Hirshkowitz et al., 2015); (c) English-speaking and therefore able to complete surveys; and (d) endorse THC-based cannabis sleep aid use at least twice monthly throughout the past 3 months (i.e., demonstrated pattern of current use). Students were *not eligible* to participate if they met the following exclusion criteria: (a) daily THC-based cannabis use (i.e., risky/hazardous; Casajuaana et al., 2016) or self-reported history of treatment for cannabis use disorder; (b) cannabis prescribed by a physician (i.e., not self-medication behavior); (c) consumption of exclusively CBD-based products for sleep aid (e.g., CBD oils or edibles); (d) sleep medications prescribed by a physician, which tends to indicate more severe sleep impairment (Goodhines, Gellis, Ansell, et al., 2019); and (e) positive screen for sleep apnea (i.e., sum scores  $\geq 15$  on the 8-item Sleep Apnea subscale of the SLEEP-50 questionnaire [diagnosis not assessed]; Spoormaker et al., 2005) given 21% prevalence among young adults (McArdle et al., 2020) and potential confounding impact on sleep and fatigue outcomes assessed. Recreational cannabis use was legalized on March 31, 2021 (New York State Senate, 2021), falling *within* the assessment period of  $n = 17$  (20%) current participants and *before* the assessment period of  $n = 4$  (5%) participants ( $n = 175$  observations occurred on or after the date

of legalization), necessitating analytic control given previous findings of increased cannabis use across state-level recreational legalization (Bae & Kerr, 2020; Barker & Moreno, 2021). Notably, no inclusion or exclusion criteria were implemented regarding cannabis administration method or strain in attempts to capture a normative cross-section of college cannabis sleep aid use occurring naturally in daily life.

Students were recruited from: (a) undergraduate psychology courses; (b) an undergraduate psychology research pool; (c) physical and virtual (i.e., Instagram) advertising fliers; (d) a previous research sample of alcohol and cannabis-using college students (Goodhines, Gellis, Ansell, et al., 2019); and (e) peer-based snowball sampling. For participant compensation, all students were provided course credit (maximum 3 points) or monetary (maximum \$40; informed by past studies with similar methods/samples, such as Fucito et al., 2018; Sheehan & Lau-Barraco, 2019) compensation scaled according to number of study nights completed. Diverse techniques that have demonstrated effectiveness (based on the excellent adherence rate of 95% among the full sample from a recent 14-day diary study; Goodhines, Gellis, Ansell, et al., 2019) were utilized to support participant adherence, including: (a) discussing adherence-optimization with a small preliminary focus group; (b) providing individualized training on study protocols and problem-solving barriers at the initial participant meeting; (c) using participants' preferred method of communication; and (d) sending surveys at the same time each day with reminders as needed. Completion rates were 94% for both bedtime ( $n = 1,068$ ) and waking ( $n = 1,065$ ) surveys (out of possible  $N = 1,134$ ). Participants provided an average of 14 nights of diaries ( $M_{\text{nights}} = 13.84$  [ $SD = 0.56$ ]; range = 11-14) and 13 nights of actigraphy data (available for  $n = 80$  [99%];  $M_{\text{nights}} = 13.43$  [ $SD = 2.00$ ]; range = 2-14).

## **Procedure**

Eligible participants attended a 30-minute video conference to provide electronic informed consent, receive instructions for daily survey and actigraphy protocols, and clarify any questions. Directly following the video conference, participants completed an online baseline survey assessing diverse health behaviors (such as sleep and substance use) and picked up an actigraphy device from the lab. Beginning that evening directly following the video conference, participants were sent a secure web-link for a 2-minute “bedtime survey” (delivered at a time of their choosing) and a 5-minute “waking survey” (delivered at 6:00 a.m. for all participants) every night for 15 nights, via preferred method of email or text. This twice-daily assessment approach was necessary to capture risk mechanisms of interest, which involve the impact of pre-sleep experiences (reported in-the-moment directly before sleep initiation) on subsequent sleep and diurnal functioning (reported retrospectively upon waking). Although survey distribution times were determined strategically to conservatively capture bedtime and waking times, students were instructed to complete the surveys “directly before sleep” and within one hour of getting up (per standardized sleep monitoring recommendations; Carney et al., 2012), respectively. Participants wore the actigraphy device on their non-dominant wrist throughout the 15-night assessment period. The first night’s surveys (i.e., bedtime and waking surveys) and actigraphy data were conservatively dropped from analyses to allow for potential first-night measurement effect (e.g., McCall & McCall, 2012; although see null findings from Jean-Louis et al., 1997), resulting in 14 nights of data for each participant. The 14-night timeframe is consistent with recommendations for daily sleep assessment (Buysse et al., 2006; Gunthert & Wenze, 2012) and is sufficient to observe cannabis sleep aid use considering a frequency of use 1–2 nights per week in a previous study of college students (Goodhines, Gellis, Kim, et al., 2019).

## **Measures**

### ***Baseline Survey***

**Psychosocial Characteristics.** Participants reported sex assigned at birth (0 = *female*, 1 = *male*), gender, age, race, ethnicity, and country of birth (PhenX Toolkit, Ver. 23), as well as personal history of positive COVID-19 test results (consistent with Vidot et al., 2021). The DSM-5 Self-Rated Cross-Cutting Symptom Measure-Adult (Narrow et al., 2013; retrieved from PhenX Toolkit, Ver. 23) assessed the severity/frequency of depression (2 items) and anxiety (3 items) symptoms over the past 2 weeks (response options on a 5-point Likert scale ranging from 0 = *None/Not at all* to 4 = *Severe/Nearly every day*). Consistent with the recommended threshold of  $\geq 2$  on any individual item, depression and anxiety symptoms were coded dichotomously (0 = *None/Slight symptoms*; 1 = *Mild to severe symptoms*). Additionally, cannabis legalization was included as a within-person covariate (0 = *survey administered before March 31, 2021*, 1 = *survey administered thereafter*) consistent with recent studies similarly collecting data across legalization events (e.g., Alley et al., 2020).

**Sleep.** The 19-item Pittsburgh Sleep Quality Index (Buysse et al., 1989) comprehensively measured both quantitative (e.g., sleep duration, weekly frequency of waking after sleep onset) and subjective (e.g., sleep quality rating) aspects of sleep. Global index scores  $\geq 5$  (possible range = 0-21) indicate significant sleep disturbance (Buysse et al., 1989). The following parameters were considered for analysis: Sleep Duration (hours) and Sleep Efficiency (%). All sleep variables were treated as continuous scores for analysis. This measure has demonstrated good test-retest reliability and construct validity (Backhaus et al., 2002) and is therefore recommended as a standard measure of sleep (Buysse et al., 2006).

**Cannabis.** A 60-day Timeline Follow-Back (Sobell & Sobell, 1992) adapted for cannabis use and online administration (consistent with Pedersen et al., 2012) assessed past-2-month (a)



frequency of cannabis use days (possible range = 0-60) and (b) average number of cannabis uses on using days. Participants were provided with a definition of cannabis and asked to report only THC-based cannabis use (i.e., not CBD-exclusive products) for all surveys in this study to account for differential effects on sleep-related outcomes (Babson et al., 2017; Kuhathasan et al., 2019). A cannabis “use” was defined as “one occasion where you smoked one joint, bowl, pipe, bong, vaporizer, etc. within one time period” (consistent with "joints" as defined in Pedersen et al., 2012). To optimize data quality, participants reviewed instructions virtually with research staff and confirmed understanding of aforementioned definitions prior to entering data.

***Cannabis sleep aid.*** One item assessed past-month frequency of cannabis use to help sleep (consistent with Goodhines et al., 2020). Responses were on a Likert scale ranging from 2 (*2 to 3 times*) to 7 (*Every day*), consistent with eligibility criteria of at least bimonthly cannabis use in the current study. Continuous scores were used for analyses.

### ***Bedtime Surveys***

Participants were instructed: “The bedtime surveys arrive at your preferred time so that they are there waiting for you when you go to bed. Please complete them directly before sleep in the evening.” Over three quarters of observations (76%;  $n=774$  of 1012 with complete multivariate data) reflect that the bedtime survey was completed within 1 hour of self-reported attempted sleep initiation.

***Pre-Sleep Arousal.*** One item assessed cognitive pre-sleep arousal (“Do thoughts keep running through your mind?”; adapted from the Pre-Sleep Arousal Scale, Nicassio et al., 1985; consistent with Russell et al., 2016). The selected item was the highest loading item from the cognitive factors of the larger pre-sleep arousal construct (Nicassio et al., 1985).

**Cannabis Intoxication.** One item assessed current high (“How high do you feel right now?”; Padovano & Miranda, 2018) on a Likert scale ranging from 0 (*Not at all*) to 10 (*Extremely*) to statistically control for intoxication and potential associated reporting errors in ancillary analysis.

**Depression and Anxiety Symptoms.** Depression and anxiety symptoms over the past 24 hours were assessed via 4-item Positive and Negative Affect Schedule (Bagozzi, 1993), consistent with previous college daily diary studies (e.g., Armeli et al., 2015), given possible daily-level associations with college cannabis use (Patrick et al., 2016). Average scores for depression and anxiety symptom subscales (Cronbach’s  $\alpha = .82$  and  $.80$  respectively among all daily observations) were used for ancillary analyses. While outside the scope of the current study, bivariate correlations with main study variables and other daily health behaviors may be found in Supplementary Table 1.

### ***Waking Surveys***

**Cannabis Use.** The previous day’s cannabis use was assessed, including timing, quantity (grams; Prince et al., 2018), and motives (Simons et al., 1998) including sleep (consistent with Goodhines, Gellis, Ansell, et al., 2019). Participants were provided with a visual guide to assist with cannabis quantification, and practiced quantification of their personal cannabis administration practices virtually with research staff at the baseline appointment to promote accuracy and consistency of reporting. Daily number of cannabis uses and quantity (grams) were treated as continuous variables for analysis.

***Cannabis sleep aid.*** Cannabis sleep aid use was defined as THC-based cannabis consumed *with the intention to help sleep* (vs. other motives, such as relaxation; consistent with Goodhines, Gellis, Ansell, et al., 2019; Goodhines, Gellis, Kim, et al., 2019). Daily cannabis

sleep aid was treated as a dichotomized variable (yes/no) and total daily cannabis sleep aid quantity (grams) was treated as a continuous variable for analysis.

**Sleep.** the Core Consensus Sleep Diary (Carney et al., 2012) solicited subjective reports of previous night sleep and present waking experiences, including: Wake-Time After Sleep Onset (minutes), Sleep Duration (hours), and Sleep Efficiency (possible range = 0-100%; calculated from reported sleep/wake and bed/rise times). Additional subjective variables assessed for exploratory ancillary analyses include: Poor Sleep Quality (possible range = 1-5), Sleep Onset Latency (minutes), and Daytime Fatigue (possible range = 1-5). All sleep/fatigue variables were treated as continuous scores for analysis.

**Health Behaviors.** Other diverse health behaviors potentially contextualizing college sleep were assessed, including napping (Ye et al., 2015), exercise (Kovacevic et al., 2018), alcohol (Sznitman et al., 2021), caffeine (Clark & Landolt, 2017), tobacco (Boehm et al., 2016), prescription medications (for review, see Taylor et al., 2014), stimulant misuse (Clegg-Kraynok et al., 2011), over-the-counter sleep aids (During & Kushida, 2019), technology use (Rosen et al., 2016), and environmental noise (Meng et al., 2020) before bed and during the night. While outside the scope of the current study, bivariate correlations with main study variables may be found in Supplementary Table S1.

### ***Actigraphy***

Actigraphy data was collected using the Actiwatch-2 (Philips, 2019), which is the most used actigraphy device for research of adult sleep (Conley et al., 2019). Data was scored using Philips Respironics Actiwatch Spectrum Plus™ software (Philips, 2019). Specifically, sleep/wake status during the major sleep period was determined for each 30-sec epoch using a validated algorithm, and errors/artifacts were identified by cross-referencing with participant

subjective reports (consistent with recommendations from Ancoli-Israel et al., 2015; Grandner & Rosenberger, 2019). Objective sleep outcomes included: sleep duration (total time between sleep initiation and waking), wake time after sleep onset (% epochs scored as awake between bed and wake time), and sleep efficiency (% epochs scored as sleep between bed and wake time).

Actigraphy-assessed sleep onset latency was omitted herein given limited ability to detect the time an individual *tries* to fall asleep (for review, see Scott et al., 2020). Selected sleep outcomes are shown to be validly and reliably assessed via combined self-report and actigraphy (Buysse et al., 2006; Mantua et al., 2016; Williams et al., 2018).

### **Data Analytic Strategy**

Descriptive statistics and bivariate correlations among all study variables were conducted in *SPSS*, Version 23 (IBM Corp., 2018).

### ***Main Analysis***

Multilevel models were estimated in *Mplus* (Muthén & Muthén, 1998-2017) given the hierarchical nature of the data (i.e., repeated observations nested within each participant) and integration of multilevel modeling and path analysis (Kline, 2016). Level 2 was defined by participants and Level 1 was defined by days, allowing for sufficiently-powered directional modelling of within-person change across time (disaggregated from and controlling for between-person effects). A first-order autoregressive covariance structure was used to account for autocorrelation in repeated measures, allowing residuals from proximal measurements to be more similar. Random effects at Level 2 (i.e., extent to which people differ from the group average) allowed for unique regression equations, and random effects at Level 1 (i.e., extent to which individual data points vary from predicted values) captured residual measurement error.

Unconditional models and Intraclass Correlation Coefficients (ICC) were calculated to estimate percentage of variance due to between-person (vs. within-person) differences.

Maximum likelihood parameter estimation with robust standard errors (Graham et al., 2003) was used for Aims 1-2 to address any non-normally distributed continuous outcome variables, and to include all available data in main analyses regardless of any missing data. Proportion reduction in variance was calculated to measure local effect size of daily predictors (Raudenbush & Bryk, 2002), including pre-sleep arousal for Aim 1 and cannabis sleep aid for Aim 2. Difference in residual variance from models with and without sleep aid use predictors (but all the same covariates) was calculated and divided by the latter. For models finding significant within-person effects (e.g., the Level 1 effect of cannabis sleep aid use on same-night sleep efficiency), models were tested in the inverse direction (e.g., the Level 1 effect of within-person sleep efficiency on next-day cannabis sleep aid use) with the same covariates to test reversed directionality of the association.

**Aim 1: Arousal-based Precipitants of Cannabis Sleep Aid Use.** First, one multilevel model assessed the predictive ability of cognitive pre-sleep arousal with subsequent cannabis sleep aid use (yes/no). The unconditional model demonstrated within-person variability in cannabis sleep aid use (ICC = .35) across the 14-day study period. This model included the following covariates: (a) male sex, age, and White race (fixed effects at Level 2) due to associations with college cannabis use (LaBrie et al., 2009) and sleep (Galambos et al., 2013; Taylor & Bramoweth, 2010); (b) a dichotomized weekend variable (Friday and Saturday evenings, as informed by exploratory analyses of day-of-week effects; fixed effect at level 1) to account for weekend effects observed in cannabis use (e.g., Bravo et al., 2017); and (c) time-lagged within-person predictors to establish a directional temporal sequence within the model

(Wickham & Knee, 2013) and consistent with previous multilevel modelling of cannabis use and psychosocial outcomes (e.g., Ansell et al., 2015).

**Aim 2: Sleep and Substance Use Outcomes of Cannabis Sleep Aid Use.** Second, separate multilevel models assessed whether cannabis sleep aid use (yes/no) predicted same-night sleep (sleep duration, wake time after sleep onset, and sleep efficiency) across daily diary (subjective) and actigraphy (objective; to address the subjective, retrospective nature of sleep diary data) assessments. Unconditional models demonstrated within-person variability in all sleep outcomes (ICCs = .06-.31) across the 14-day study period. All models included the following covariates: (a) male sex, age, and White race (fixed effects at Level 2) due to associations with college cannabis use (LaBrie et al., 2009) and sleep (Galambos et al., 2013; Taylor & Bramoweth, 2010); (b) a dichotomized weekend variable (determined via exploratory analyses of day-of-week effects; fixed effect at level 1) to account for weekend effects observed in cannabis use (e.g., Bravo et al., 2017); (c) daily cannabis use quantity to explicate effects of cannabis sleep aid use over and above general cannabis use (consistent with Goodhines, Gellis, Ansell, et al., 2019); and (d) time-lagged within-person predictors to establish a directional temporal sequence within the model (Wickham & Knee, 2013).

**Aim 3: Cannabis Sleep Aid Use as Mediator of Arousal-Consequence Relationships.** Third, multilevel structural equation models assessed whether cannabis sleep aid use mediated associations of cognitive pre-sleep arousal with same-night sleep (subjective and objective) within-person (1-1-1 mediation). Significance of mediation (calculated as the coefficient of *a* path multiplied by that of *b* path) was assessed via asymmetrical 95% confidence intervals using Bayes estimation (per recommendations from Muthén & Muthén, 1998-2017). Covariates were modeled for *a* and *b* paths consistent with aforementioned main effects models (Aims 1 and 2).

### ***Power Analysis***

Power calculation software for multilevel modeling (PINT; Snijders & Bosker, 1993) estimated required sample sizes for a multilevel model to detect a within-person effect on a time-varying variable after accounting for covariates. Assuming small within-group and between-group covariance (0.10), a residual variance of .90, and an intercept variance of 0.10, data from 81 participants for 14 nights was sufficiently powered ( $> .80$ ) to detect both *a* and *b* indirect paths of the proposed mediation model for a conservative small effect size (.10) at the .05 level.

### ***Ancillary Analyses***

Three sets of ancillary analyses were conducted. First, ancillary analyses replicated main models for Aims 1 (*a* path) and 2 (*b* path) additionally covarying for other contextual environmental and psychosocial factors potentially influencing cannabis and sleep behaviors as informed by correlation analyses, including daily depressed affect, anxious affect, alcohol quantity, cannabis quantity, tobacco use, over-the-counter medication use for sleep aid, cannabis intoxication at the time of evening survey completion, and status of state-level recreational cannabis legality at time of survey completion. Second, although cannabis sleep aid use is defined herein as cannabis consumed with the intention to help sleep, cannabis may impact sleep regardless of motive. Ancillary analyses therefore replicated Aim 2 (*b* path) main analyses to explore within-person effects of general cannabis use (i.e., for sleep or any other motive) on same-night sleep. Third, ancillary analyses explored within-person association of cannabis sleep aid use with supplemental subjective sleep outcomes (same-night sleep quality and sleep onset latency; Aim 2), as well as next-day fatigue and general cannabis quantity (grams).

## **Results**

### **Descriptive Analyses**

Sample descriptive statistics and correlations of all study variables (both baseline and average daily) are presented in Table 1. On average at baseline (as shown in Table 1, top panel), participants reported using cannabis for sleep aid 2-4 times per week over the past month ( $M = 4.60$  [ $SD = 1.51$ ]). Over the past 2 months, participants reported using cannabis slightly over half of days ( $M = 33.59$  [ $SD = 16.26$ ]) at 1-2 uses per using day ( $M = 1.68$  [ $SD = 0.76$ ]). On average at baseline, 62% of students reported poor global sleep quality ( $M = 6.75$  [ $SD = 2.73$ ]), reflecting a 7-hour sleep duration ( $M = 7.37$  hours [ $SD = 1.30$ ]) and 82% sleep efficiency ( $M = 82.18$  [ $SD = 12.30$ ]). Clinically-relevant symptoms were endorsed by 43% for depression and 64% for anxiety.

Cannabis use and sleep across the 14-day diary period were largely consistent with baseline reports (as shown in Table 1, bottom panel). Participants reported using cannabis for sleep aid on 4 of 14 days ( $M = 4.21$  days [ $SD = 4.14$ ]) on average. On average, participants reported using cannabis slightly over half of days ( $M = 8.49$  days [ $SD = 4.18$ ]) at roughly 1 use ( $M = 1.21$  uses [ $SD = 0.93$ ]) and slightly more than half a gram ( $M = 0.68$  grams [ $SD = 0.57$ ]) per using day. Participants reported minimal/slight cognitive pre-sleep arousal on average across days ( $M = 1.65$  [ $SD = 0.61$ ]). On average across the 14-day diary period, students reported 8-minute wake-time after sleep onset ( $M = 7.55$  [ $SD = 7.96$ ]), 7-8 hour sleep duration ( $M = 7.65$  [ $SD = 1.05$ ]), and 83% sleep efficiency ( $M = 83.20$  [ $SD = 7.74$ ]). Both self-reported (subjective) and actigraphy-measured (objective) sleep parameters are presented in Table 2, demonstrating approximate equivalency of sleep duration and efficiency in this nonclinical college sample (with documented discrepancies favoring objective assessment historically noted in clinical insomnia samples; Rezaie et al., 2018). In contrast, actigraphy-assessed wake-time after sleep onset ( $M = 43.71$  [ $SD = 12.12$ ]) was greater than subjective reports.



As shown in Table 1, frequencies of cannabis sleep aid use at baseline (i.e., past-month) and across the 14-day diary period were significantly positively correlated ( $r = .41, p < .001$ ). Neither baseline nor average daily cannabis sleep aid use frequency was correlated with any baseline demographics assessed ( $r_s = -.16-.22, p_s = .05-.94$ ). Number of cannabis sleep aid use nights (0-14) was correlated significantly with cognitive pre-sleep arousal on average ( $r = .32, p = .003$ ), but not with sleep variables ( $r_s = -.10-.16, p_s = .19-.61$ ). Average daily cannabis sleep aid use was also positively associated with average cannabis use frequency ( $r = .59, p < .001$ ) and quantity (i.e., number of uses [ $r = .24, p = .03$ ] but not grams [ $r = .01, p = .97$ ]). Positive history of COVID-19 was not significantly correlated with the majority of baseline or daily variables ( $p_s > .05$ ), with the exception of average daily cognitive pre-sleep arousal ( $r = -.25, p = .03$ ) possibly attributable to COVID-related anxiety (for a review, see Becker, 2021), and was thus omitted from Table 1 for simplicity of presentation.

## **Main Analyses**

### ***Aim 1: Arousal-based Precipitants of Cannabis Sleep Aid Use***

Results of multilevel model assessing whether cannabis sleep aid use (yes/no) was predicted by cognitive pre-sleep arousal are reported in Table 3. Cognitive pre-sleep arousal predictors accounted for a 7% proportion reduction in residual variance. Nights of cannabis use for sleep aid were not significantly predicted by same-night or previous-night cognitive pre-sleep arousal ( $\gamma = -0.11 [SE = 0.13], p = .40, OR = 0.90, 95\% CI [0.67, 1.13]$ ;  $\gamma = 0.07 [SE = 0.11], p = .51, OR = 1.08, 95\% CI [0.84, 1.31]$ ) over and above individual mean of the respective predictor (i.e., between-person effect;  $\gamma = 1.45 [SE = 0.38], p < .001, OR = 4.26, 95\% CI [1.13, 7.39]$ ) after controlling for male sex, age, and White race (Level 2), study days, and weekend (Level 1).

The significant weekend (versus weekday) covariate effect in Aim 1 multilevel model suggests that cannabis sleep aid use is more likely to occur on weekdays.

***Aim 2: Sleep and Substance Use Outcomes of Cannabis Sleep Aid Use***

Results of separate multilevel models assessing whether cannabis sleep aid use (yes/no) predicted subsequent same-night sleep (i.e., sleep duration, wake-time after sleep onset, and sleep efficiency) are presented in Table 4. Cannabis sleep aid predictors accounted for proportion reduction in residual variance ranging from 0-3% across outcomes, except for a 2% increase observed for objective wake-time after sleep onset. Nights of cannabis sleep aid use significantly predicted improved same-night sleep efficiency ( $\gamma = 2.87$  [ $SE = 1.42$ ],  $p = .04$ ) within individuals after controlling for covariates. Inverse within-person findings indicated that neither previous-night nor time-lagged (two nights previous) sleep efficiency was associated with subsequent cannabis sleep aid use ( $ps = .16-.73$ ); thus, cannabis sleep aid use was associated with subsequent sleep efficiency, but not vice versa. In contrast, nights of cannabis sleep aid use were *not* associated with any change in same-night sleep duration ( $\gamma = 0.32$  [ $SE = 0.20$ ],  $p = .12$ ) or wake-time after sleep onset ( $\gamma = -1.50$  [ $SE = 2.13$ ],  $p = .48$ ) within individuals.

Regarding actigraphy-assessed sleep outcomes, nights of cannabis sleep aid were not associated with same-night sleep efficiency ( $\gamma = -0.78$  [ $SE = 1.15$ ],  $p = .50$ ), but were associated with shorter next-night (lagged) total sleep duration ( $\gamma = -0.35$  [ $SE = 0.16$ ],  $p = .03$ ; inverse nonsignificant,  $ps = .42-.81$ ) and wake-time after sleep onset ( $\gamma = -10.10$  [ $SE = 3.47$ ],  $p = .004$ ; inverse nonsignificant,  $ps = .19-.47$ ).

***Aim 3: Cannabis Sleep Aid Use as Mediator of Arousal-Consequence Relationships***

Results of multilevel structural equation models assessing whether daily cannabis sleep aid use mediated within-person associations of cognitive pre-sleep arousal with same-night sleep

outcomes are presented in Table 5. No indirect associations of cognitive pre-sleep arousal with sleep outcomes (same-night sleep duration, wake-time after sleep onset, and sleep efficiency) were significantly mediated by cannabis sleep aid use ( $ps = .65-.74$ ). Similarly, no associations of cognitive pre-sleep arousal with actigraphy-assessed sleep outcomes were significantly mediated by cannabis sleep aid use ( $ps = .72-.82$ ).

### **Ancillary Analyses**

First, ancillary analyses demonstrated that the pattern of significance for Level 1 pre-sleep arousal effects on cannabis sleep aid use (Aim 1) did not change after additionally controlling for within- and between-person depressed affect, anxious affect, cannabis quantity, alcohol quantity, tobacco use, over-the-counter sleep aid use, or cannabis intoxication at the time of evening survey completion (all with lagged effects), or cannabis legalization in separate ancillary models. Pattern of significance for Level 1 cannabis sleep aid effects on same-night sleep (Aim 2) did not change after additionally controlling for within- and between-person depressed affect (except effect on same-night sleep efficiency becomes marginal;  $\gamma = 2.73$  [ $SE = 1.53$ ],  $p = .07$ ), anxious affect, alcohol quantity, tobacco use, over-the-counter sleep aid use (all with lagged effects), or cannabis legalization in separate ancillary models. Second, ancillary analyses assessing variability of within-person sleep attributable to general cannabis quantity demonstrated no significant impact of cannabis quantity on same-night sleep in day-to-day college life (Aim 2). Third, exploratory ancillary analyses demonstrated non-significant effects of cannabis sleep aid on same-night subjective sleep quality and sleep onset latency (Aim 2), or next-day fatigue or cannabis quantity.

### **Discussion**

This 14-night mixed methods study used diary and actigraphy data to test temporal associations of cannabis sleep aid use with a cognitive pre-sleep arousal precipitant and same-night sleep outcomes. Cannabis sleep aid use was correlated with general cannabis use, but not sleep problems (consistent with Goodhines, Gellis, Ansell, et al., 2019; Goodhines, Gellis, Kim, et al., 2019). Given substantial correlation between cannabis use for sleep aid and general cannabis use quantity (consistent with previous research correlating cannabis use to a multitude of motives; e.g., Buckner et al., 2019), main analyses exploring outcomes of cannabis sleep aid use controlled for daily-level cannabis quantity to explicate patterns of within-person consequences unique to the self-medication behavior specifically. Multilevel analysis revealed that cognitive pre-sleep arousal did not predict cannabis sleep aid use within individuals over and above individual averages. Nights of cannabis sleep aid use, in turn, were associated with improved same-night subjective sleep efficiency compared to individual averages (notably without next-day “hangover” fatigue effect or increased cannabis use), as well as shorter objective next-night wake-time after sleep onset and sleep duration.

### **Aim 1: Arousal-based Precipitants of Cannabis Sleep Aid Use**

Counter to hypotheses, nights of cannabis sleep aid use were not significantly predicted by cognitive pre-sleep arousal day-to-day, over and above individual averages (see Table 2). There are several possible explanations for this unexpected finding. First, arousal-sleep aid associations may exist at the between-person level, consistent with the current significant bivariate correlation of average cognitive pre-sleep arousal with cannabis sleep aid use. That is, on average among the entire sample, students with greater cognitive pre-sleep arousal are more likely to use cannabis for sleep aid, but this arousal does not necessarily function as a contextual precipitant within-person. This hypothesis is further supported by significant Level 2 effects in

the Aim 1 multilevel model, although replication with larger samples is warranted to clarify individual level differences. Second, it is possible that decisions to use cannabis for sleep aid are proximally informed by contextual variables outside the scope of the current assessment.

Qualitative work may help clarify perceived motivations for self-medicating with cannabis for sleep, and continued research into sleep-related cannabis expectancies (e.g., Altman et al., 2019; Goodhines et al., 2020; Winiger et al., 2021) may further clarify contextual informants of individual decision-making. Third, detection of variability in cognitive pre-sleep arousal domains may have been precluded by the current single-item subjective assessment approach (see Future Directions below). These results require replication and may inform future research to continue characterizing pre-sleep arousal experiences potentially informing cannabis sleep aid use.

## **Aim 2: Sleep and Substance Use Outcomes of Cannabis Sleep Aid Use**

Overall, results highlight potential benefits to same-night subjective sleep efficiency, as well as shorter next-night objective sleep duration and wake-time after sleep onset, after controlling for general daily-level cannabis quantity.

### ***Subjective Sleep Outcomes***

The within-person finding that nights of cannabis sleep aid use (over and above general cannabis use quantity) were associated with same-night improvements to individual sleep efficiency (i.e., percentage of time spent asleep while in bed) is novel to the literature. While previous literature has demonstrated negative cannabis-sleep efficiency correlations on average (Winiger et al., 2021) consistent with correlational trends reported herein, current within-person findings highlight the potential distinct patterns occurring at the individual level day-to-day. That is, although individuals who use cannabis more frequently may have worse sleep efficiency on average (as in Winiger et al., 2021), using cannabis for sleep aid may alleviate this problem in

the short-term, reinforcing ongoing use. This reinforcement may likewise explain the *marginal* benefits to same-night subjective sleep quality observed in ancillary analysis following cannabis sleep aid use, necessitating future replication. Notably, these benefits are novel to sleep-related cannabis motives in this sample, as evidenced by nonsignificant within-person associations of general cannabis quantity with same-night sleep. Current findings thus highlight the critical need to disaggregate within- from between-person trends when investigating the impacts of cannabis use specifically for sleep aid in daily college life, and require replication moving forward.

In contrast, nights of cannabis sleep aid use were *not* associated with changes to same-night sleep duration, or wake-time after sleep onset, within individuals in the current sample after controlling for general cannabis quantity. Null findings related to same-night sleep duration are consistent with a previous study of college cannabis sleep aid use (Goodhines, Gellis, Ansell, et al., 2019), suggesting that cannabis sleep aid use is potentially an effective safety behavior protecting against individual variability in these sleep parameters (however, note that this counterfactual is technically unknowable given current naturalistic design; for a conceptual review, see Collins et al., 2004). Mixed findings related to same-night wake-time after sleep onset (that is, current null results versus benefits observed in Goodhines, Gellis, Ansell, et al., 2019) may be explained by key sample differences. Because this sample is comprised strictly of students who regularly use cannabis for sleep aid, the current null effects may be novel to this specific subgroup of college students (despite relatively comparable baseline sleep characteristics). For example, given regular cannabis use for sleep aid, participants may be habituated to the hypothesized impacts on wake-time after sleep onset and next-day daytime fatigue. This hypothesis is further supported by the observed underestimation of wake-time after sleep onset (relative to actigraphy; consistent with previous studies of young adult sleep, such as

Thurman et al., 2018), potentially suggestive of differential sensitivity or limited subjective saliency of nocturnal wakings. That is, individuals may only recollect substantial or salient awakenings, not brief episodes of subtle wrist movements detected by actigraphy. Taken in consideration of positive impacts to same-night sleep efficiency, results suggest some limited benefit to subjective same-night sleep without notable impact on next-day fatigue (per ancillary analysis herein) for students regularly using cannabis for sleep aid.

### ***Objective Sleep Outcomes***

Main analyses of actigraphy-assessed sleep demonstrate that nights of cannabis sleep aid use were associated with shorter total sleep duration and wake-time after sleep onset the *following* night (that is, a lagged effect) after controlling for general cannabis use quantity, but not sleep efficiency. Discrepant cannabis-sleep findings between subjective and objective sleep measurements may be attributable to aforementioned subjective under-estimation of wake-time after sleep onset. Actigraphy analyses suggest that, while cannabis use for sleep aid may not impact sleep duration the same night, it instead restricts sleep duration the following day. This may be consistent with known rebound insomnia resulting from over-the-counter sleep aids (Culpepper & Wingertzahn, 2015), such that same-night over-compensation of accrued homeostatic debt results in reduced sleep need the following night. Such day-to-day variability in sleep duration may preclude establishment of sleep timing regularity across days, necessitating future research investigating sleep regularity (as in Phillips et al., 2017) as a potential consequence of cannabis sleep aid use. Likewise, while cannabis use for sleep aid may not impact wake-time after sleep onset the same night, reductions are observed the following night. One possible explanation is that predictable same-night impacts of pre-sleep cannabis use on sleep staging (i.e., REM suppression; Babson et al., 2017) may in turn impact sleep staging the

following night, such as compensatory deeper sleep and reduced nocturnal waking. However, continued research utilizing polysomnographic sleep assessment is needed to investigate such claims to impacts on sleep staging in the naturalistic college environment (see Future Directions below). In sum, results suggest that the distinction between subjective and objective measurement of sleep occurring in the naturalistic college environment is critical to clarifying the proximal within-person impacts of cannabis sleep aid use in daily life.

### **Aim 3: Cannabis Sleep Aid Use as Mediator of Arousal-Consequence Relationships**

Regarding mediation (Aim 3;  $c'$  path), associations of cognitive pre-sleep arousal with sleep outcomes were not explained by cannabis sleep aid use within individuals. Regarding direct effects ( $c$  path), although nights of greater cognitive pre-sleep arousal were associated with longer objective sleep duration within individuals after accounting for all other paths in the model, this association was not significantly mediated by cannabis sleep aid use ( $c'$  path). Null mediation suggests that cannabis sleep aid use is perhaps not effective in mitigating the direct impact of pre-sleep arousal on subsequent sleep. No sleep outcomes were directly predicted by pre-sleep arousal after controlling for all other pathways in the models. Potential explanations for null associations, as well as proposals for future research, are reviewed herein (see Aims 1 and 2 above).

### **Clinical Implications**

Findings of this study may inform individualized intervention for college cannabis and sleep behaviors. By highlighting potential mixed outcomes resulting from sleep aid, results support the promotion of healthy sleep behaviors among college cannabis users. Cognitive behavioral therapy has demonstrated strong and consistent evidence for improving college sleep (for a review, see Friedrich & Schlarb, 2017) and cannabis use (for a review, see Winters et al.,



2021). Endorsement of cannabis sleep aid use in college healthcare settings may present a “teachable moment” (Lawson & Flocke, 2009) to collaboratively weigh subjective benefits/consequences to increase motivation for behavior change (for a review, see Calomarde-Gómez et al., 2021) and harm reduction (e.g., using lesser quantities earlier in the evening; for a review, see Kruger et al., 2021). This behavior change intervention might be achieved clinically by expanding the substance-specific sleep hygiene recommendations already present within existing sleep health interventions (as in a historical integrated college sleep-alcohol intervention; Fucito et al., 2015). Emphasis on sleep-related intervention is likewise supported by recent work demonstrating efficacy of CBT-I for college insomnia regardless of cannabis use (Miller et al., 2021). Intervention effectiveness may also be supported by peer interventionists, given that shared cultural backgrounds theoretically facilitate greater perceived credibility, understanding, and empathy relative to healthcare providers (for a review, see MacArthur et al., 2016).

Results may additionally inform prevention and harm reduction efforts at the community and policy levels within the context of rapidly-changing cannabis legislation (Hammond et al., 2020) and decreasing perceived harmfulness among college students (Schulenberg, 2020). Results may inform campus-wide harm reduction (for a review, see Logan & Marlatt, 2010), including primary prevention for individuals who abstain from cannabis and secondary prevention targeting individuals who use cannabis (Wotring et al., 2019). In addition to substance use and sleep problems, campus healthcare and counseling services may screen specifically for sleep aid use behavior to identify at-risk students (for behavioral health screening recommendations in university primary care, see Shepardson & Funderburk, 2014). More globally, health psychology research may inform recommendations for systemic harm reduction

via regulatory policy regarding cannabis prescription and marketing (such as Devylder et al., 2021; Fischer et al., 2020) specifically as a sleep aid. Prevention, intervention, and policy development efforts should consider the role of systemic inequities and cultural variability, which can inform disparities in both sleep health (for a review, see Billings et al., 2021) and cannabis accessibility and consequences (e.g., racial disparities in possession arrests; Gunadi & Shi, 2022; Sheehan et al., 2021).

### **Strengths and Limitations**

This study benefited from four key methodological strengths related to the intensive longitudinal design. First, within-person findings are an incremental contribution to limited research in this area, as disaggregation of within-person fluctuations around individual averages eliminated the potential confound of sample-level trends and allowed for directional modeling of day-to-day relationships. By repeatedly sampling participant responses in daily life within the natural environment, findings are directly generalizable to the daily lives of college students. Second, the inclusion of actigraphy serves as a valid objective measure of sleep (Grandner & Rosenberger, 2019) given known discrepancies in perceived reports of sleep parameters (Rezaie et al., 2018; Thurman et al., 2018). Second, novel event-level assessment capturing pre-sleep experiences in this study enabled the identification of in-the-moment subjective perceptions of arousal directly before attempts to initiate sleep, representing an advantage over historical attempts to solicit retrospective recall upon waking. Feasibility of this twice-daily assessment approach is evidenced by the exceptional response rates of 95% for both bedtime and waking surveys, thereby supporting the continued pursuit of more complex event-level designs for comprehensive assessment of pre-sleep experiences and event-level cannabis sleep aid use. Third, inclusion of actigraphy in this study represents an incremental strength over previous

iterations (Goodhines, Gellis, Ansell, et al., 2019) because cannabis sleep aid may have differential impacts on subjective versus objective sleep experiences. Fourth, the preliminary attempt at cannabis quantification (guided by recommendations from Prince et al., 2018) provides preliminary data on naturalistic dosing of self-administered cannabis sleep aid presents an incremental addition to the literature. Despite known limitations to accuracy given lack of standardization in naturalistic administration practices (Cuttler & Spradlin, 2017; Prince et al., 2018), this data may inform future research into characterizing this self-medication behavior. Overall, these strengths contribute to the rapidly developing literature on within-person cannabis-sleep literature, informing future methodological approaches to optimize participant reporting and generalizability of findings.

Findings should be interpreted within the context of some limitations. First, data was drawn from a predominantly White and female sample from a private New York State university, requiring replication for assessment of generalizability to more heterogeneous college samples. Second, daily pre-sleep arousal and cannabis use for sleep aid were assessed via single-item, dichotomous responses in efforts to minimize participant burden and maximize response rates; however, this single-item measure may have limited construct validity. Third, subjective assessments are vulnerable to self-reporting errors (e.g., memory impairment due to cannabis use; Broyd et al., 2016) and/or sleep deprivation (Krause et al., 2017). Subjective self-reporting of cannabis quantity specifically is limited by demonstrated inaccuracies in estimation (Prince et al., 2018), differential experiences across administration methods, strains, and prior experiences (MacCallum & Russo, 2018). In the current study, these concerns are somewhat mitigated by the concurrent use of objective sleep assessment, as well as statistical control for cannabis intoxication in ancillary analyses. Fourth, although sleep parameters examined in this study have

been demonstrated to be validly assessed via combined actigraphy and self-reports, a remaining limitation is that actigraphy cannot distinguish sleep staging (Mantua et al., 2016) potentially impacted by pre-sleep cannabis use (Babson et al., 2017). Fifth, the lack of control group in this observational study inhibits assessment of relative impact of cannabis sleep aid use; however, this limitation is mitigated by the fact that each participant statistically served as their own reference in within-person analyses (i.e., cannabis-using nights vs. non-using nights within the same individual). Lastly, it is unclear if New York State legislation on cannabis use influenced results (but see Ancillary Analyses). Limited emerging evidence suggests that state-level recreational legalization may not significantly impact college students' cannabis use frequency (Jones et al., 2018); however, potential changes in associated psychosocial cannabis-related consequences (such as social-interpersonal or occupational-academic problems, impaired control and risk behaviors, and dependence symptoms; Simons et al., 2012) require ongoing examination.

### **Future Directions**

Results of this study may inform future research into cannabis sleep aid use behavior. First, continued efforts characterizing the phenomenon of self-medication with cannabis for sleep aid are needed, including: (a) age of cannabis use onset given possible risk conferral for executive functioning (Gorey et al., 2019) and dependence symptoms (Rioux et al., 2018); (b) qualitative characterization of motives and expectancies; (c) characterization of cannabis sleep aid use patterns (e.g., dose, administration method, daily timing of use) and strain, given documented preference for indica (versus sativa) for relative sedative effect among samples of community adults (Pearce et al., 2014; Sholler et al., 2021) and sleep-disturbed medicinal cannabis users (Belendiuk et al., 2015); (d) latent class analysis to clarify distinct cannabis sleep

aid use patterns among college students; (e) replication in larger samples to explore potential moderators, such as depression and anxiety symptoms, insomnia symptom severity, sleep-related cannabis expectancies, and differential weekday effects; and (f) measurement burst designs (i.e., multiple periods of daily assessment; Stawski et al., 2015) to clarify short-term cannabis-sleep associations controlling for semester-level variability in sleep deficit/need (e.g., mid-term exams; Liguori et al., 2011) and cannabis use (e.g., 4/20 or university sports events; Buckner et al., 2018). Second, generalizability of current findings should be assessed across diverse developmental, sociodemographic, and clinical populations. Replication across various US states is also needed to ascertain potential differing results across recreational cannabis legality (Goodman et al., 2020) and geographic region (SAMHSA, 2021). Third, replication of current findings is needed using between-person and controlled designs to test the relative impact of the cannabis sleep-aid use (vs. no use and/or recreational use not for sleep aid) on same-night sleep and next-day fatigue and cannabis use. Fourth, polysomnography (for a review, see Conley et al., 2019) may be used to explore effects of cannabis sleep aid use on subsequent sleep staging and associated novel functional outcomes, such as susceptibility to diurnal functional impairment (for a review, see Babson et al., 2017). Related to objective assessment methods, ambulatory assessments of physiological arousal (such as electro-dermal activity or heart rate variability; Salgado & Kingo, 2020) may facilitate more comprehensive characterization of the pre-sleep experience without substantially impacting participant burden. Fifth, additional research using event-level designs should investigate concurrent/simultaneous substance use for the manipulation of both sleep and wake states (e.g., cannabis to sleep and nicotine to wake up), possible interactive effects of polysubstance use, and potential moderating effects of other substance use motives (e.g., coping). Finally, current findings may inform the development of

functional models of self-medication behavior for sleep, as well as targeted prevention and intervention research efforts.

### **Summary**

Results of this 14-day mixed methods study (diary and actigraphy data) of college students endorsing regular cannabis use for sleep aid highlight mixed support for the potential sleep-related benefits of this self-medication behavior (over and above general cannabis use quantity) within individuals day-to-day (notably without next-day “hangover” fatigue effect or increased cannabis use), but offer limited support for pre-sleep arousal as a contextual precipitant. As such, continued research is needed to further capture and clarify precipitants of cannabis use for sleep aid in daily college life. Current findings may inform sleep-related intervention development to mitigate potential feed-forward harms to cannabis use frequency and downstream consequences over time.

Table 1

Means (and Standard Deviations) and Bivariate Correlation Coefficients of Study Variables

Variables	<i>M (SD)</i> or %	<i>r</i>																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Baseline (possible range)																				
1. Past-Month Cannabis Sleep Aid Frequency (2-7)	4.60 (1.51)	—																		
2. Male Sex (1 vs. 0)	35%	-.01	—																	
3. Age (18-25)	19.96 (1.18)	.15	-.01	—																
4. White Race (1 vs. 0)	72%	.02	-.04	-.13	—															
5. Hispanic/Latinx Ethnicity (1 vs. 0)	12%	-.16	.05	.01	-.16	—														
6. Sleep Duration (hours) <sup>a</sup>	7.37 (1.30)	-.07	-.01	.07	<b>.23</b>	-.04	—													
7. Sleep Efficiency (0-100%) <sup>a</sup>	82.18 (12.30)	-.05	-.01	-.13	.12	-.04	<b>.63</b>	—												
8. Frequency of Cannabis Use Days (0-60) <sup>b</sup>	33.59 (16.26)	<b>.68</b>	.01	.06	.14	<b>-.30</b>	.03	.15	—											
9. Average Number of Cannabis Uses on Using Days <sup>b</sup>	1.68 (0.76)	.12	.03	.01	<b>-.23</b>	-.06	<b>-.25</b>	-.09	<b>.24</b>	—										
Daily (possible range)																				
10. Number Cannabis Sleep Aid Days (0-14)	4.21 (4.14)	<b>.41</b>	-.04	.22	-.14	.12	.07	.04	<b>.36</b>	.00	—									
11. Cognitive Pre-Sleep Arousal (1-5)	1.65 (0.61)	.20	-.18	-.11	-.08	-.15	-.15	-.09	.09	-.04	<b>.32</b>	—								
12. Poor Subjective Sleep Quality (1-5)	2.53 (0.50)	-.01	<b>.23</b>	.08	.08	-.12	<b>-.34</b>	<b>-.32</b>	.07	.16	-.07	-.02	—							
13. Sleep Onset Latency (minutes)	20.71 (15.27)	.06	.07	.04	.01	.01	-.04	-.21	.01	<b>.28</b>	.16	.19	<b>.31</b>	—						
14. Wake-Time After Sleep Onset (minutes)	7.55 (7.96)	.08	<b>-.25</b>	.16	-.07	-.16	<b>-.23</b>	<b>-.26</b>	.05	.00	.10	.14	.16	.14	—					
15. Sleep Duration (hours)	7.65 (1.05)	.02	-.09	.05	<b>.28</b>	.05	<b>.58</b>	.22	.10	<b>-.32</b>	.07	-.26	-.41	-.23	-.20	—				
16. Sleep Efficiency (0-100%)	83.20 (7.74)	-.10	.17	-.08	<b>.24</b>	-.06	<b>.28</b>	<b>.25</b>	.10	-.22	-.11	-.20	<b>-.23</b>	-.45	<b>-.28</b>	<b>.48</b>	—			
17. Daytime Fatigue (1-5)	2.33 (0.70)	.08	-.02	-.17	.13	<b>-.23</b>	-.11	-.05	.07	.17	-.06	.44	<b>.30</b>	.26	-.10	<b>-.30</b>	-.20	—		
18. Frequency of Cannabis Use Days (0-14)	8.49 (4.18)	<b>.51</b>	-.02	.13	-.14	-.14	.06	.07	<b>.63</b>	.19	<b>.59</b>	.29	-.05	.06	.15	-.02	-.11	-.02	—	
19. Average Number of Cannabis Uses on Using Days	1.21 (0.93)	<b>.36</b>	.13	-.02	-.14	-.10	.03	.07	<b>.54</b>	<b>.49</b>	<b>.24</b>	.21	-.01	.20	.13	-.10	-.05	.10	<b>.70</b>	—
20. Average Cannabis Quantity (grams) on Using Days	0.68 (0.57)	.05	<b>.33</b>	-.08	-.15	.10	.08	-.09	.02	<b>.30</b>	.01	-.13	-.04	.21	-.17	.12	.01	.01	.12	<b>.45</b>

Note.  $N = 81$ . Pearson's correlation coefficients are reported for two continuous variables; Spearman's coefficients ( $r_s$ ) are reported for continuous and dichotomous variables; Phi coefficients ( $r_\phi$ ) are reported for two dichotomous variables. <sup>a</sup>Variable assessed via Pittsburgh Sleep Quality Index (past-month timeframe; single items, excepting computed Sleep Efficiency), which notably does not solicit typical wake-time after sleep onset. <sup>b</sup>Variable assessed via 60-day Timeline Follow-Back; a cannabis "use" was defined for participants as "one occasion where you smoked one joint, bowl, pipe, bong, vaporizer, etc. within one time period." Significant correlation coefficients at  $p < .05$  are highlighted in bold font.

Table 2

*Daily Diary (Subjective) and Actigraphy (Objective) Sleep Parameters across Study Nights*

	Data Type	<i>n</i>	Mean	Min	Max	<i>SD</i>
Total Sleep Time (hrs)	Subjective	81	7.65	5.39	10.12	1.05
	Actigraphy	80	6.98	5.26	9.74	0.85
Sleep Efficiency (%)	Subjective	81	83.20	54.14	54.14	7.74
	Actigraphy	80	82.04	71.89	90.06	4.03
Wake Time After	Subjective	81	7.55	0.00	35.13	7.96
Sleep Onset (mins)	Actigraphy	80	43.71	19.82	81.68	12.12

*Note.* *SD* = standard deviation. Subjective data available for  $N=81$  (100%) participants ( $M_{\text{nights}}=13.84$  [ $SD=0.56$ ]; range=11-14). Actigraphy data available for  $n=80$  (99%) participants ( $M_{\text{nights}}=13.43$  [ $SD=2.00$ ]; range=2-14). Actigraphy-assessed sleep onset latency was omitted herein given limited ability to detect the time an individual *tries* to fall asleep (for review, see Scott et al., 2020).



Table 3

*Aim 1. Multilevel Model Investigating Cognitive Pre-Sleep Arousal as a Precipitant of Same-Night Cannabis Sleep Aid Use*

Fixed Effects	Cannabis Sleep Aid (yes/no)	
	Estimate (SE)	OR (95% CI)
Level 2 (Between-Person)		
Cognitive Pre-Sleep Arousal	1.45 (0.38)***	4.26 (1.13, 7.39)
Male Sex	0.22 (0.58)	1.25 (-0.16, 2.66)
Age	0.52 (0.23)*	1.68 (0.91, 2.44)
White Race	-0.37 (0.59)	0.69 (-0.10, 1.48)
Level 1 (Within-Person)		
<b>Cognitive Pre-Sleep Arousal</b>	<b>-0.11 (0.13)</b>	<b>0.90 (0.67, 1.13)</b>
<b>Cognitive Pre-Sleep Arousal (lagged)</b>	<b>0.07 (0.11)</b>	<b>1.08 (0.84, 1.31)</b>
Study Days	-0.26 (0.22)	1.81 (0.01, 3.62)
Weekend (versus Weekday)	-0.43 (0.22)*	0.65 (0.43, 1.00)

*Note.*  $N=81$ . Weekend covariate includes Friday and Saturday evenings. Lagged predictors represent effects on cannabis sleep aid outcomes the following night. Level 1 pre-sleep arousal effects are highlighted in bold font. Random effects omitted for simplicity of presentation.

\* $p<.05$ . \*\* $p<.01$ . \*\*\* $p<.001$ .

Table 4

*Aim 2. Multilevel Models Investigating Daily Diary (Subjective) and Actigraphy (Objective) Sleep Outcomes of Cannabis Sleep Aid Use*

	Same-Night Sleep Duration		Same-Night Wake-time After Sleep Onset		Same-Night Sleep Efficiency	
	(Hours)		(Minutes)		(0-100%)	
	<u>Diary</u>	<u>Actigraphy</u>	<u>Diary</u>	<u>Actigraphy</u>	<u>Diary</u>	<u>Actigraphy</u>
	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
Level 2 (Between-Person)						
Cannabis Sleep Aid Use (yes/no)	0.29 (0.41)	0.55 (0.37)	1.89 (4.01)	3.49 (5.21)	-0.84 (3.76)	-1.91 (1.71)
Male Sex	-0.20 (0.30)	-0.46 (0.24)	-2.19 (2.91)	1.37 (4.97)	4.63 (2.16)*	-0.67 (1.45)
Age	0.11 (0.10)	0.14 (0.09)	0.16 (0.99)	-2.54 (1.55)	-0.53 (0.98)	0.15 (0.44)
White Race	0.81 (0.29)**	0.54 (0.24)*	0.86 (2.67)	1.76 (2.96)	3.85 (2.55)	0.87 (1.28)
Cannabis Quantity	0.13 (0.32)	0.02 (0.25)	-1.89 (2.21)	-1.76 (3.45)	-0.46 (2.24)	-0.37 (1.37)
Level 1 (Within-Person)						
<b>Cannabis Sleep Aid Use (yes/no)</b>	<b>0.32 (0.20)</b>	<b>0.24 (0.18)</b>	<b>-1.50 (2.13)</b>	<b>1.21 (2.82)</b>	<b>2.87 (1.42)*</b>	<b>-0.78 (1.15)</b>
<b>Cannabis Sleep Aid Use (Lagged)</b>	<b>-0.02 (0.22)</b>	<b>-0.35 (0.16)*</b>	<b>-1.28 (3.18)</b>	<b>-10.10 (3.47)**</b>	<b>-1.31 (1.18)</b>	<b>-0.23 (0.97)</b>
Study Days	0.16 (0.11)	-0.18 (0.10)	2.90 (1.58)	0.02 (2.46)	-1.44 (0.80)	-1.59 (0.70)*
Weekend (versus Weekday)	0.14 (0.17)	0.19 (0.17)	1.57 (2.13)	1.56 (2.70)	0.22 (0.99)	0.98 (1.08)
Cannabis Quantity	0.02 (0.13)	-0.01 (0.14)	-0.21 (1.54)	4.99 (2.15)*	-1.34 (0.85)	-0.03 (0.88)
Cannabis Quantity (Lagged)	0.09 (0.12)	0.13 (0.13)	-0.76 (1.06)	-0.24 (1.63)	0.24 (0.76)	0.16 (0.83)

*Note.*  $N=80-81$ . Level 1 cannabis sleep aid (yes/no) effects are highlighted in bold font. Random effects omitted for simplicity of presentation. Lagged predictors represent effects on (a) duration, wake-time after sleep onset, and sleep efficiency the following day.

\* $p<.05$ . \*\* $p<.01$ . \*\*\* $p<.001$ .

Table 5

*Aim 3. Multilevel Models Testing Cannabis Sleep Aid Use as a Mediator (M) Underlying Associations of Cognitive Pre-Sleep Arousal (X) with Same-Night Daily Diary (Subjective) and Actigraphy (Objective) Sleep (Y)*

Same-Night Sleep Outcome	Diary				Actigraphy			
	Path A $\gamma$ (95% CI)	Path B $\gamma$ (95% CI)	Path C $\gamma$ (95% CI)	Path C' $\gamma$ (95% CI)	Path A $\gamma$ (95% CI)	Path B $\gamma$ (95% CI)	Path C $\gamma$ (95% CI)	Path C' $\gamma$ (95% CI)
Sleep Duration	-0.01 (-0.06, 0.03)	0.26 (-0.06, 0.64)	-0.15 (-0.35, 0.08)	-0.00 (-0.03, 0.01)	-0.01 (-0.07, 0.04)	0.24 (-0.12, 0.53)	<b>0.17 (0.00, 0.36)</b>	-0.00 (-0.03, 0.01)
Wake-time After Sleep Onset	-0.01 (-0.06, 0.04)	-0.01 (-0.06, 0.04)	-0.01 (-0.06, 0.04)	-0.01 (-0.06, 0.04)	-0.01 (-0.07, 0.03)	2.91 (-4.47, 10.43)	3.42 (-0.67, 7.07)	-0.01 (-0.39, 0.17)
Sleep Efficiency	-0.01 (-0.06, 0.04)	<b>2.62 (0.39, 5.12)</b>	-0.86 (-2.03, 0.35)	-0.02 (-0.21, 0.10)	-0.01 (-0.07, 0.04)	-0.92 (-3.09, 1.21)	-0.40 (-1.62, 0.73)	0.00 (-0.07, 0.12)

*Note.*  $N=80-81$ . A total of 6 Level 1 mediation (1-1-1) models were analyzed (see Figure 1 for companion conceptual model): separate models were conducted for cannabis sleep aid use (yes/no) as the mediator (M) between cognitive pre-sleep arousal variables (independent variable or X) and same-night subjective (3) and objective (3) sleep outcomes (dependent variable or Y). Path A (X→M): direct Level 1 association of cognitive pre-sleep arousal (X) with cannabis sleep aid (M). Path B (M→Y): direct Level 1 association of cannabis sleep aid (M) on same-night sleep (Y), controlling for cognitive pre-sleep arousal. Path C (X→Y): direct Level 1 association of cognitive pre-sleep arousal (X) with same-night sleep outcomes (Y), controlling for cannabis sleep aid. Path C' (X→M→Y): indirect Level 1 association of cognitive pre-sleep arousal (X) with same-night sleep outcomes (Y), mediated by cannabis sleep aid (M).  $\gamma$ =estimated effect. 95% CI=asymmetrical confidence intervals based on Bayes estimation. Significant effects at  $p<.05$  are highlighted in bold font.

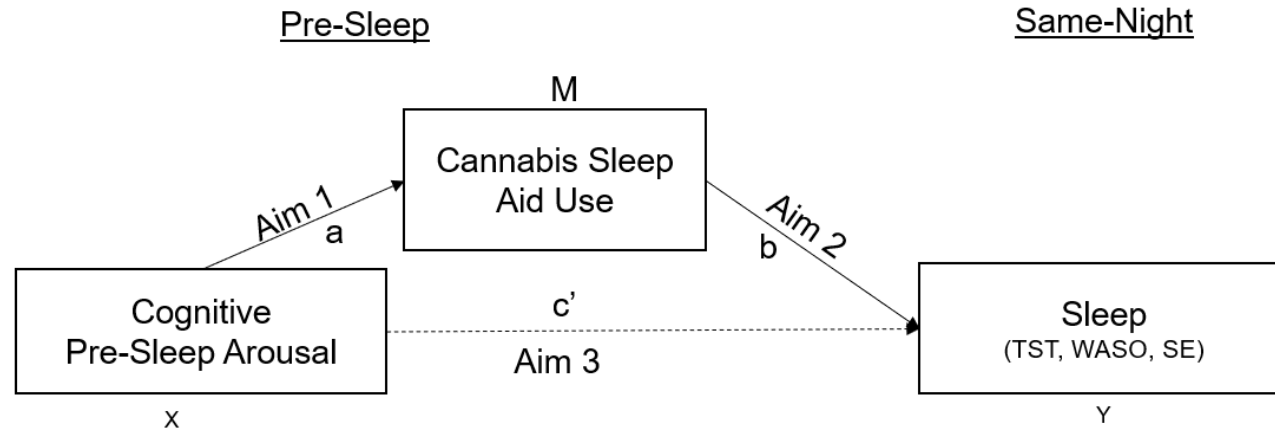
Table S1

Supplemental: Means (and Standard Deviations) of Main Study Variables with Other Contextual Variables Outside Scope of Main Study

Daily Variables (possible range)	<i>M</i> ( <i>SD</i> ) or %	<i>r</i>																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Number Cannabis Sleep Aid Days (0-14)	4.21 (4.14)	—																				
2. Cognitive Pre-Sleep Arousal (1-5)	1.65 (0.61)	<b>.32</b>	—																			
3. Poor Subjective Sleep Quality (1-5)	2.53 (0.50)	-.07	-.02	—																		
4. Sleep Onset Latency (minutes)	20.71 (15.27)	.16	.19	<b>.31</b>	—																	
5. Wake-Time After Sleep Onset (minutes)	18.80 (22.79)	-.07	-.15	.03	.06	—																
6. Sleep Duration (hours)	7.65 (1.05)	.07	<b>.26</b>	<b>-.41</b>	<b>-.23</b>	-.17	—															
7. Sleep Efficiency (0-100%)	83.20 (7.74)	-.11	-.20	<b>-.23</b>	<b>-.45</b>	-.12	<b>.48</b>	—														
8. Daytime Fatigue (1-5)	2.33 (0.70)	-.06	<b>.44</b>	<b>.30</b>	<b>.26</b>	<b>-.23</b>	<b>-.30</b>	-.20	—													
9. Nap Duration (minutes)	13.19 (16.75)	-.13	.03	.06	.11	-.06	-.18	-.16	<b>.22</b>	—												
10. Exercise (0-1)	0.21 (0.24)	-.07	-.11	-.03	-.20	-.16	-.06	.17	-.10	-.06	—											
11. Alcohol Quantity (count)	1.13 (1.32)	<b>-.25</b>	-.22	.18	-.15	-.10	.09	<b>.24</b>	-.02	.13	.01	—										
12. Caffeine Quantity (count)	0.62 (0.67)	.13	-.03	.06	-.00	-.19	.05	.02	.04	-.01	-.07	.16	—									
13. Tobacco Uses (count)	0.47 (1.43)	-.19	-.10	.17	.06	-.12	-.07	-.01	.04	.09	-.04	<b>.23</b>	.08	—								
14. Prescription Medications (0-1) <sup>a</sup>	0.21 (0.38)	.19	.05	-.02	.05	-.01	.04	-.12	-.13	<b>.27</b>	-.13	-.09	.17	-.10	—							
15. Stimulant Misuse (0-1) <sup>b</sup>	0.01 (0.07)	-.14	.14	-.03	.12	-.03	-.06	-.04	-.05	-.06	-.08	-.02	-.08	.11	-.06	—						
16. Over the Counter Sleep Aids (0-1) <sup>c</sup>	0.04 (0.12)	<b>-.25</b>	.06	.04	.12	-.04	-.11	<b>-.26</b>	.09	<b>.36</b>	.06	.04	-.05	.17	.14	-.02	—					
17. Depression Symptoms (1-5)	1.50 (0.56)	<b>.28</b>	<b>.74</b>	.02	.04	-.11	<b>-.23</b>	-.15	<b>.39</b>	.17	-.12	<b>-.26</b>	-.05	-.08	<b>.23</b>	.11	.01	—				
18. Anxiety Symptoms (1-5)	1.52 (0.60)	.20	<b>.73</b>	-.02	.03	-.11	-.20	-.07	<b>.39</b>	.07	-.13	<b>-.22</b>	.01	-.12	.16	.22	-.07	<b>.77</b>	—			
19. Tech use at bedtime (0-1)	0.81 (0.23)	.13	.08	-.07	-.11	<b>-.25</b>	.02	.12	.01	-.03	.08	-.14	.09	.06	.15	-.04	.01	.18	<b>.22</b>	—		
20. Tech use at nighttime waking (0-1)	0.14 (0.18)	.03	.11	.02	-.05	.04	.02	-.04	.03	.15	.05	-.02	.01	.06	.16	-.09	-.02	<b>.23</b>	.12	<b>.28</b>	—	
21. Noise at bedtime (0-1)	0.11 (0.15)	.12	.11	.03	<b>.46</b>	.02	.02	-.14	<b>.26</b>	<b>.25</b>	-.16	-.19	.10	-.03	.04	-.07	.14	.08	.07	<b>.23</b>	.19	—
22. Noise at nighttime waking (0-1)	0.10 (0.16)	.06	.04	.03	<b>.26</b>	-.01	.21	-.10	.18	<b>.29</b>	<b>-.24</b>	-.13	.18	.04	<b>.28</b>	-.06	.11	.07	.14	.17	<b>.28</b>	<b>.60</b>

Note. *N* = 81. Pearson's correlation coefficients are reported for continuous variables averaged across 14 days (unless otherwise specified). <sup>a</sup>Prescription medications were endorsed by *n*=23 (28% of sample), including SSRIs (Amitriptyline, Bupropion, Duloxetine, Escitalopram, Fluoxetine, Lamotrigine, Sertraline, Venlafaxine), ADHD medications (Adderall XR, Guanfacine), birth control (e.g., Enskyce, Kariva, Yaz), antibiotics (e.g., Doxycycline, Metronidazole), and others (Accutane, Levothyroxine, Metformin, Spironolactone). <sup>b</sup>Non-prescription stimulant misuse was endorsed by *n*=3 (4% of sample; e.g., Adderall, Concerta). <sup>c</sup>Over the counter sleep aids were endorsed by *n*=14 (17% of sample), including melatonin, antihistamines (Benadryl), and cold medicines (e.g., Nyquil, Mucinex).

Significant correlation coefficients at *p* < .05 are highlighted in bold font.



*Figure 1.* Conceptual model for Aims 1-3, including timepoint of assessment (e.g., pre-sleep assessment and subsequent same-night sleep). TST = total sleep time. WASO = wake-time after sleep onset. SE = sleep efficiency.

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