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Prospective Associations between Sleep Disturbances and Cannabis Use among Veterans: A Behavioral Economic Approach

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Abstract

Background: Veterans often use cannabis for sleep despite limited evidence of its efficacy. Moreover, how sleep disturbances impact cannabis use longitudinally is unclear. We applied a behavioral economic framework to examine whether sleep disturbances and cannabis demand (i.e., relative value) were related risk-factors for future cannabis use and problems.

Methods: Veterans deployed post-9/11/2001 who reported past 6-month cannabis use at baseline (n=126) completed surveys on their sleep disturbances, demand via the Marijuana Purchase Task (MPT), and cannabis use. Mediation analyses using Hayes' PROCESS Macro and zero-inflated negative binomial models tested indirect effects of baseline sleep disturbances on 12-month cannabis use frequency, quantity, and problems via 6-month cannabis demand (i.e., intensity, O_{max}, P_{max}, and breakpoint).

Results: Only O_{max} (i.e., maximum expenditure for cannabis) was a significant mediator for 12-month cannabis use quantity and problems when examined concurrently with other demand indices after controlling for covariates. Intensity (i.e., purchase at zero cost) was a significant mediator for 12-month cannabis use frequency when examined concurrently with other demand indices in models controlling for lifetime cannabis use, but not past 30-day use at baseline.

Conclusion: Cannabis demand, specifically intensity and $O_{max,}$ may help to identify Veterans with sleep disturbances who are at increased risk for escalating their cannabis use. Subsequent research should assess the extent that sleep disturbances impact cannabis demand in the context of withdrawal, which will inform novel prevention and intervention strategies geared toward reducing negative cannabis-related outcomes among Veterans.

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Keywords

Marijuana Purchase Task; sleep behaviors; cannabis demand; marijuana; mechanism

1. Introduction

Sleep is a critical physiological process, yet Veterans commonly report sleep disturbances including, but not limited to: difficulties falling asleep, insufficient sleep durations, increased wake after sleep onset (i.e., time spent awake after sleep onset prior to final awakening), poor sleep efficiency (i.e., percent of time in bed spent asleep) and subjective quality, and daytime dysfunction[1–4]. Moreover, sleep disturbances are considerably more prevalent among Veteran than civilian populations[4–7], and epidemiologic data indicates that International Classification of Diseases (ICD-9-CM) insomnia diagnoses among Veterans increased 372% from 2005 to 2014[8]. Sleep disturbances impair neurobiological functioning[9, 10], increase the likelihood of future substance use[11, 12], and elevate relapse risk for Veterans following cannabis use treatment[13]. Veterans may be at disproportionately higher risk because sleep disturbances are a common transdiagnostic symptom of the most prevalent mental health disorders (i.e., posttraumatic stress disorder [PTSD] and major depressive disorder) among Iraq and Afghanistan Veterans[14–16]. Thus, more research is needed to identify both the causes and consequences of sleep disturbances.

Veterans frequently use cannabis for sleep[17] and perceive it is a low-risk alternative to prescription medications[18] despite equivocal evidence supporting its therapeutic efficacy[19–21]. In fact, one study found that using cannabis specifically as a means of managing sleep disturbances was the dominant factor linking two psychiatric conditions with cannabis use, cannabis problems, and cannabis use disorder (CUD) among Veterans[22]. Likewise, Veterans' CUD prevalence increased over 50% from 2002–2009[23], and recent epidemiologic findings indicated that almost 12% of Veterans reported past 6-month cannabis use[24]. Further, extant research from civilian populations shows that sleep disturbances were associated with hazardous cannabis use, cannabis problems, and CUD symptoms[25, 26]. Thus, a deeper understanding of how sleep disturbances impact subsequent cannabis use will inform novel strategies geared towards reducing Veterans' CUD risk.

Current models posit reciprocal relations between sleep and substance use, including cannabis[27]. Initially, sleep disturbances precipitate using cannabis use for sleep and may improve certain sleep behaviors in the short-term (e.g., shorter time to sleep onset)[28–32]. However, individuals develop tolerance to cannabis' somnolent effects, thus necessitating greater amounts of cannabis for sleep promotion, ultimately impairing other sleep components (e.g., rapid eye movement [REM] sleep and slow-wave-sleep [SWS]) over time[19, 33]. As such, cannabis use in the context of sleep is often characterized as negatively reinforcing and coping-oriented in nature[13, 34, 35]. Yet, mechanisms linking sleep disturbances and problematic cannabis use are understudied and may point to salient targets for tailored interventions[36].

1.1. Cannabis Demand as a Mechanism Linking Sleep and Cannabis Use

Behavioral economic theory, which originated from operant learning approaches and integrates aspects of psychology and economics[37, 38], may help to extend prior research and clarify links between sleep and cannabis use. Specifically, behavioral economics posits that a reinforcers relative value (i.e., demand) is a key factor in understanding substance use behaviors[39, 40]. Cannabis demand quantifies the relationship between cannabis consumption and cost across escalating prices using commodity purchase tasks[41, 42]. Observed demand indices include intensity (i.e., consumption at zero cost), $O_{\max}$ (i.e., maximum expenditure on cannabis), $P_{\max}$ (i.e., price associated with maximum expenditure), and breakpoint (i.e., price at which consumption is suppressed to zero). Recent reviews and meta analyses provide evidence that elevated demand is consistently related to cannabis frequency, quantity, and severity outcomes[43–45]. Given the widespread perception that cannabis improves sleep[46, 47], and evidence indicating that cannabis can initially decrease the time to sleep onset[28–31], individuals with sleep disturbances may inordinately value cannabis that reinforces continued use. Experimentally-induced sleep deprivation can shift preferences for immediate reward (i.e., delay discounting)[48], which is conceptually and empirically related to demand[38]. Moreover, brain regions (e.g., prefrontal cortex, striatum) that are adversely impacted by sleep disturbances (for reviews see[10, 49]) also influence decision-making and alcohol and cannabis demand in the laboratory[50, 51]. Thus, despite theoretical relations between sleep disturbances and cannabis demand, to our knowledge no published studies have examined these constructs as related risk-factors. Moreover, determining cannabis' reinforcing value among Veterans with sleep disturbances has direct implications for prevention and intervention efforts.

1.2. Present Study

The present study aimed to address a notable gap in the sleep-cannabis literature by prospectively examining mechanisms linking sleep disturbances and cannabis use indices among a sample of Veterans who used cannabis ranging from infrequent to current daily use. Prior longitudinal research has infrequently tested mechanisms underlying sleep disturbances and cannabis use, frequently enrolled adolescents and young adults from civilian populations, and often used singular cannabis use assessments (e.g.,[52–55]). Thus, the present study used three waves of observational data to extend prior research by examining whether cannabis demand mediated the link between sleep disturbances and cannabis use frequency, quantity, and problems among Veterans. We hypothesized that baseline sleep disturbances would be positively associated with 6-month cannabis demand, which, in turn, would be positively associated with 12-month cannabis use frequency, quantity and problems.

2. Materials and methods

2.1. Participants and procedure

Data for this secondary analysis came from a longitudinal study assessing cannabis use and related problems in Veterans (N = 361) who had returned from serving in Operation Enduring Freedom, Operation Iraqi Freedom, or Operation New Dawn (OEF/OIF/OND)[56]. Participants who reported lifetime cannabis use were recruited from a Veteran's Health

Administration (VHA) facility in the Northeast region of the United States (for full eligibility criteria and recruitment methods see[56]). Following initial telephone screening, eligible participants completed a baseline visit. Written informed consent was followed by a structured clinical interview and self-report assessments. Participants completed follow-up appointments 6 and 12 months later. This study focused on a subset of participants who reported any cannabis use in the past 180 days at baseline or 6-months, completed the cannabis demand measure at the 6-month assessment, and completed the 12-month assessment ($n = 127$). The study was approved by the University and local VHA institutional review boards. Participants received \$50 per visit and a \$50 bonus payment for completing all three study visits.

2.2. Measures

2.2.1 Sociodemographic questionnaire—Participants reported on their age, sex, race, and ethnicity, which was verified through VHA medical records, and annual household income.

2.2.2 Baseline sleep disturbances—Participants completed the Pittsburgh Sleep Quality Index (PSQI)[57]. This widely used measure of past-month sleep disturbance and quality (e.g., duration, latency) contains 19 items (e.g., "*How would you rate your overall sleep quality?"*) that generates seven component scores (e.g., *sleep disturbances* and *sleep latency*) on a 0 (no difficulty) to 3 (severe difficulty) scale. The seven component scores were summed to create a global "sleep disturbance" score ranging from 0–21. Higher scores indicate more sleep disturbances; scores > 5 indicate poor sleep quality[57]. The PSQI has been previously validated among Veterans[58] and demonstrated good internal consistency in the present study ($\alpha = .74$).

2.2.3 Behavioral economic demand—The Marijuana Purchase Task (MPT)[59] quantified cannabis demand at the 6-month assessment. The MPT includes a standardized instructional vignette describing a hypothetical situation where participants indicated how many hits of cannabis they would purchase in a typical day over the past month evaluated across 22 escalating prices ranging from \$0–10 in ascending order (see full instructions in Supplemental Materials). Intensity, O_{max}, P_{max}, and breakpoint were calculated from raw MPT data by hand using established formulae[60].

2.2.4 Cannabis use indices—At baseline, a single-item assessed *"How many times in your life have you used marijuana or hashish?"* with response options of "1–10 times", "11–50 times", "51–100 times", or "over 100 times." Participants completed three assessments concerning cannabis use frequency, quantity and problems at the 12-month follow-up appointment. The Timeline Follow Back[61] covered the 180 days prior to the visit and evaluated past 30-day cannabis use frequency operationalized as the percentage of days that any cannabis was consumed. A single-item assessed weekly cannabis use quantity during the past month on a 12-point scale ranging from *"Never used regularly"* to *"More than 1 ounce"* in common 1/16th to 1/8th increments. The Marijuana Problems Scale (MPS)[62] assessed past 90-day cannabis-related problems, which contains 22-items on a 3-point scale (i.e., *"no problem", "minor problem",* or *"serious problem"*). The sum of minor and serious problems was used in the present study for a total count of cannabis problems. The MPS has strong internal consistency[62, 63] that was excellent in this sample (α = .85).

2.3. Statistical approach

2.3.1. Preliminary analyses—One participant with missing data for lifetime cannabis use at baseline was excluded in the analyses leaving the final analytic sample at n = 126. In cross-sectional demand research, participants are typically removed from analyses for violating performance assumptions (e.g., bounce; frequent price-to-price increases in consumption) and are required to report at least two continuous price points to generate elasticity[60, 64]. However, elasticity was not derived in this study to retain participants who reported zero, or constant (i.e., invariant purchasing across escalating price), cannabis demand. The final analytic sample included participants with one reversal (n = 3), zero cannabis demand at 6-months (n = 22), constant demand (n = 6), and demand for cannabis only at zero cost (n = 13). Procedures for cleaning raw MPT data followed established recommendations[60]. Minimal outliers (i.e., Z score > 3.29) were detected (80/2772 data points; 2.9%) and all were determined to be legitimate high-magnitude values that were recoded to one unit higher than the greatest, nonextreme value[65].

Study variables were examined for normality and were transformed as necessary to reduce skew. O_{max} was positively skewed and square root transformed, which brought skew to acceptable levels. Two extreme values for cannabis-related problems were recoded to one unit higher than the greatest, nonextreme value[65]. Next, bivariate correlations were tested among sociodemographic characteristics, baseline PSQI sleep disturbances, lifetime cannabis use frequency at baseline, 6-month MPT demand indices, and 12-month cannabis use frequency, quantity, and problems.

2.3.2 Prospective mediation analyses—We used the PROCESS macro[66] in SPSS version 27 (SPSS Inc, Chicago, Illinois) to test whether 6-month cannabis demand (i.e., intensity, O_{max}, P_{max}, and breakpoint) mediated the relation between baseline PSQI sleep disturbances and 12-month cannabis use frequency and quantity. The 12-month cannabis problems outcome was a positively skewed count variable with excessive zeroes[67]. For models with this dependent variable, we tested zero-inflated negative binomial (ZINB) regressions[a] in Mplus Version 8.1 (Muthén & Muthén, 1998–2018) to determine whether 6-month cannabis demand mediated the relation between baseline PSQI sleep disturbances and 12-month cannabis problems. Covariates retained in the primary analyses included statistically significant (p<.05) sociodemographic variables from bivariate correlations. Since all participants in the present study reported cannabis use at the baseline and/or 6-month assessment(s), mediation analyses adjusted for lifetime cannabis use frequency. The parent study was observational in nature and designed to establish the temporal precedence of constructs of interest rather than to manipulate variables that can be targeted in future interventions. Thus, mediation analyses did not control for baseline cannabis demand.

[a]ZINB models contain two concurrent procedures: (1) a zero-inflated model ascertaining the log-odds of an observation being zero, or beyond what is expected from a negative binomial distribution, and (2) a negative binomial model that can also incorporate zero values. For simplicity, results are presented from the negative binomial models. Estimates from the zero-inflated process of the models are not of central interest and are thus not reported or discussed.

Mediation models concurrently estimated the effect(s) of baseline PSQI on each 12-month cannabis use outcome, controlling for covariates (*c*-path); baseline PSQI on each 6-month demand index, controlling for covariates (*a*-paths); and baseline PSQI (c'-path) and 6-month demand indices (*b*-path) on 12-month cannabis outcomes, controlling for covariates. The product of coefficients for the *a*- and *b*-paths are used to generate indirect effects, which characterize how the relation between baseline PSQI and each 12-month cannabis use outcome is influenced by 6-month demand indices. Following established recommendations[68], 10,000 bootstrapped estimates were used to compute 95% bias-corrected confidence intervals (CI) for the indirect effects. Indirect effects with confidence intervals that do not contain the value zero are statistically significant[66], regardless of the total effect's statistical significance[68, 69].

3. Results

3.1. Preliminary analyses

The present sample was primarily male (93.7%), White (75.4%) and Non-Hispanic/Latinx (85.7%). At baseline, all participants reported at least one sleep disturbance and approximately 18% of the sample (n=23) screened positive for poor sleep quality (i.e., PSQI scores >5). Participants reported using cannabis between 51–100 times, on average, in their lifetime, and in the month prior to the 12-month assessment, participants reported, on average, using cannabis on approximately 36% of days and consuming between 1/16th and 1/8th ounces of cannabis per week. Further, participants reported approximately two cannabis-related problems in the three months prior to the 12-month assessment, on average (Table 1).

Correlations among variables (Table 2) revealed that annual household income was associated with 12-month cannabis use quantity ($r = -.20$, $p < .05$). No other sociodemographic variables were significantly associated with 12-month cannabis use indices (ps ≥ .24). Lifetime cannabis use frequency at baseline was associated with 12-month cannabis use frequency, quantity, and problems (rs ≥ .33, $p < .01$). Baseline PSQI sleep disturbances were significantly associated with 6-month intensity and O_{max} (rs ≥ .18, ps < .05), and 12-month cannabis use quantity ($r = .20$, $p<.05$), but not frequency or problems (ps ≥ .065). All 6-month MPT demand indices were significantly associated with 12-month cannabis use frequency and quantity (rs ≥ .22, $p < .05$). Intensity, O_{max}, and breakpoint were significantly, positively associated with 12-month cannabis problems (rs ≥ .20, $p < .05$).

3.2. Prospective mediation analyses

3.2.1. Sleep disturbances, behavioral economic demand, and cannabis use frequency—The total effect (c) of baseline PSQI sleep disturbances on 12-month cannabis use frequency was statistically significant (Table 3). Lifetime cannabis use frequency was associated with 6-month intensity ($B = 10.10$, $SE = 2.45$, $p < .001$) and O_{max} ($B = 0.83$, $SE = 0.26$, $p = .002$), but not P_{max} or breakpoint (ps ≥ .051). The indirect effect of baseline sleep disturbances on 12-month cannabis use frequency through 6-month intensity, but not O_{max},

P_{max} or breakpoint, was statistically significant and accounted for 30% of the total effect (Figure 1, Panel A).

3.2.2. Sleep disturbances, behavioral economic demand, and cannabis use quantity—

The total effect (c) of baseline PSQI sleep disturbances on 12-month cannabis use quantity was statistically significant (Table 3). Lifetime cannabis use frequency was associated with 6-month intensity ($B = 9.34$, $SE = 2.39$, $p < .001$) and O_{max} ($B = 0.80$, $SE = 0.27$, $p = .003$), but not P_{max} or breakpoint ($ps \geq .051$). Likewise, annual household income was associated with 6-month intensity ($B = -8.32$, $SE = 2.48$, $p = .001$), but not O_{max}, P_{max} or breakpoint ($ps \geq .40$). The indirect effect of baseline sleep disturbances on 12-month cannabis use quantity through 6-month O_{max}, but not intensity, P_{max} or breakpoint, was statistically significant and accounted for 50% of the total effect (Figure 1, Panel B).

3.2.3. Sleep disturbances, behavioral economic demand, and cannabis-related problems—

The total effect (c) of baseline PSQI sleep disturbances on 12-month cannabis problems was not statistically significant (Table 3). Lifetime cannabis use frequency at baseline was associated with 6-month intensity ($B = 0.99$, $SE = 0.17$, $p < .001$), O_{max} ($B = 0.82$, $SE = 0.21$, $p < .001$), and breakpoint ($B = 0.06$, $SE = 0.03$, $p = .019$), but not P_{max} ($p = .195$). The indirect effect of baseline sleep disturbances on 12-month cannabis-related problems through 6-month O_{max}, but not intensity, P_{max} or breakpoint, was statistically significant (Figure 1, Panel C).

3.2.4. Ancillary analyses—

Three *post hoc* mediation models were tested to more stringently examine changes in cannabis use frequency, quantity, and problems over time by controlling for baseline levels of each cannabis outcome variable rather than lifetime cannabis use frequency (see Supplemental Materials). The indirect effect of 6-month O_{max} remained statistically significant in models predicting 12-month cannabis use quantity and problems, whereas the indirect effect of 6-month intensity was no longer statistically significant in the model predicting cannabis use frequency.

4. Discussion

The present study aimed to address an important literature gap by applying a behavioral economic framework to investigate mechanisms linking sleep disturbances and cannabis outcomes. Study results replicated and extended the literature in two notable ways. Specifically, this is the first study to demonstrate that sleep disturbances and cannabis demand are related risk-factors for future cannabis involvement. Further, although results were slightly less robust when controlling for baseline levels of each 12-month cannabis outcome, this study provides initial evidence that cannabis' reinforcing value (i.e., demand) helps to explain why sleep disturbances confer risk for future cannabis use frequency, quantity, and problems in Veterans.

Consistent with prior reviews and meta-analytic findings[43–45], intensity and O_{max} had the strongest associations with cannabis use outcomes in the present study. Notably, *post hoc* analyses indicated that sleep disturbances remained indirectly associated with 12-month cannabis use quantity and problems via O_{max} even when controlling for baseline levels of each dependent variable. These results underscore the importance of intensity and O_{max} in understanding individual differences in decision-making and risk for future cannabis use. Given the near ubiquitous belief that cannabis improves sleep[17, 46, 47], coupled with some indication that cannabis can reduce sleep onset latency[28–32], Veterans with sleep disturbances may be willing to allocate more resources for cannabis. Further, as tolerance to cannabis' soporific effects increases over time[70], greater quantities of cannabis are necessary to facilitate sleep that may increase cannabis' reinforcing value. Thus, intensity and O_{max} may be optimal ways to identify individuals with sleep disturbances who are at increased risk for escalating their cannabis use over time.

Interestingly, sleep disturbances were not directly related to cannabis problems in the present study. However, sleep disturbances were indirectly related to cannabis problems via O_{max}, which indicates that individuals with more sleep disturbances may report greater overall monetary expenditures for obtaining cannabis that increase risk for problems over time. Moreover, results linking sleep disturbances and problems aligns with prior findings linking insomnia symptoms to hazardous cannabis use, cannabis-related problems, and CUD symptoms in college student samples[25, 26]. Future prospective research is needed to clarify whether individual differences factors (e.g., using cannabis for medical versus recreational reasons) moderate the extent to which sleep disturbances confer risk for cannabis-related problems. It is also possible that current measures do not comprehensively capture consequences perceived as negative and attributable to cannabis use by this population (e.g., poor medication adherence) given that many participants endorsed no problems at the 12-month assessment.

Equally important, prior longitudinal studies examining different sleep disturbances and subsequent cannabis use outcomes often focused on adolescent and young adult populations[11, 25, 53, 54]. However, one study of older Veterans entering residential treatment for PTSD found that smaller reductions in hyperarousal symptoms during treatment, which includes sleep disturbances, were associated with greater cannabis use frequency four months later[71]. In a recent study examining how sleep disturbances affected self-guided quit attempts among Veterans with CUD, more sleep disturbances resulted in smaller reductions in cannabis use over six months[72]. The present study extended these findings among a sample of primarily middle-aged Veterans who reported a range of cannabis use and sleep disturbances. Altogether, individuals with sleep disturbances can become more reliant on cannabis to sleep that increases its relative value, which, in turn, may result in greater cannabis use frequency, quantity, and problems over time.

Study results have germane clinical implications when considering ongoing cannabis legalization and Veterans' widespread perceptions that cannabis improves sleep[17] and is a safe alternative to prescription medications[18]. Increased access to evidence-based treatments and accurate information regarding cannabis' short-term therapeutic benefits (e.g., reduced sleep onset latency) and longer-term potential harms (e.g., impairments in REM sleep and SWS) are imperative[19, 20]. One small pilot study with Veterans demonstrated that a technology-assisted Cognitive Behavioral Therapy for Insomnia (CBT-I) intervention reduced cannabis use and improved sleep quality[73]. However, additional research with larger sample sizes is needed to determine the effectiveness of CBT-I interventions for Veterans with sleep disturbances and who self-medicate with cannabis. Moreover, integrating CBT-I with components that facilitate self-monitoring of cannabis and sleep patterns (e.g., via daily diaries), paired with personalized feedback of objective sleep behaviors (e.g., sleep efficiency via actigraphy), may diminish perceptions that cannabis improves sleep and potentially decrease cannabis demand.

4.1. Strengths and Limitations

Strengths of the present study include being the first to empirically test prospective pathways from sleep disturbances to cannabis demand to multiple cannabis use indices among Veterans that enabled us to disentangle the temporal ordering of relations between variables. Additionally, retaining only participants who endorsed cannabis use at the baseline and/or 6-month assessment in the analyses, statistically controlling for lifetime cannabis use, and using bias-corrected bootstrapped confidence intervals to test the significance of indirect effects enhanced methodologic rigor. The use of behavioral economic constructs (i.e., demand) was also a strength because it captured an objective, and multifaceted, assessment of cannabis reinforcement.

Several limitations should also be considered. First, true of all observational research, causal conclusions are limited and study findings may not generalize to female Veterans or Veterans from diverse racial and ethnic backgrounds as the sample was predominantly male and White. Further, while we used a widely-used and reliable sleep disturbance measure that has been previously validated among Veterans[58], this study did not include objective sleep assessments (e.g., SWS, REM sleep). Accordingly, it is unclear how other sleep components not captured via self-report are related to cannabis demand and cannabis use outcomes that warrants future investigation. Moreover, the present study did not assess use of specific modes or cannabinoid composition. More detailed assessments may have provided granularity in terms of cannabis quantity across different cannabis formulations, cannabinoid concentrations, and route of administration, yet psychometric concerns of existing cannabis quantity measures persist[74, 75]. Additionally, given the timeframes between assessments we were unable to test how sleep disturbances over shorter time periods (e.g., days) acutely, and dynamically affected cannabis demand in relation to cannabis outcomes.

Another important consideration is the MPT instructional set[42]. Recent work on the MPT suggests that cannabis grams and typical cannabis quality are more valid vignette elements than cannabis hits and average quality specified in the present study[76]. Future research should examine variations in cannabis demand among Veterans that may be attributed to differences across instructional set. Further, methodological considerations (e.g., reduced sample size) precluded deriving elasticity as certain demand patterns (e.g., zero, low, constant) are not amenable to generating demand curves[60, 64]. Accordingly, it is unclear whether sleep disturbances affect elasticity of cannabis demand.

4.2. Conclusions and Future Directions

Behavioral economic cannabis demand may be an important factor in understanding risk for future cannabis use among Veterans with sleep disturbances. To provide a more comprehensive understanding of the sleep-cannabis association, future research should examine cannabis demand in the context of other potential mechanisms (e.g., impulsivity domains), developmentally-distinct age ranges, study designs with shorter (e.g., ecological momentary assessment) and longer (e.g., years) assessment periods, and participants from diverse backgrounds. Moreover, given increasing CUD rates among Veterans, another important future direction will be to determine how sleep disturbances following cannabis withdrawal impact cannabis' reinforcing value and whether cannabis demand may serve as a salient indicator of who may be more likely to return to cannabis use following a quit attempt.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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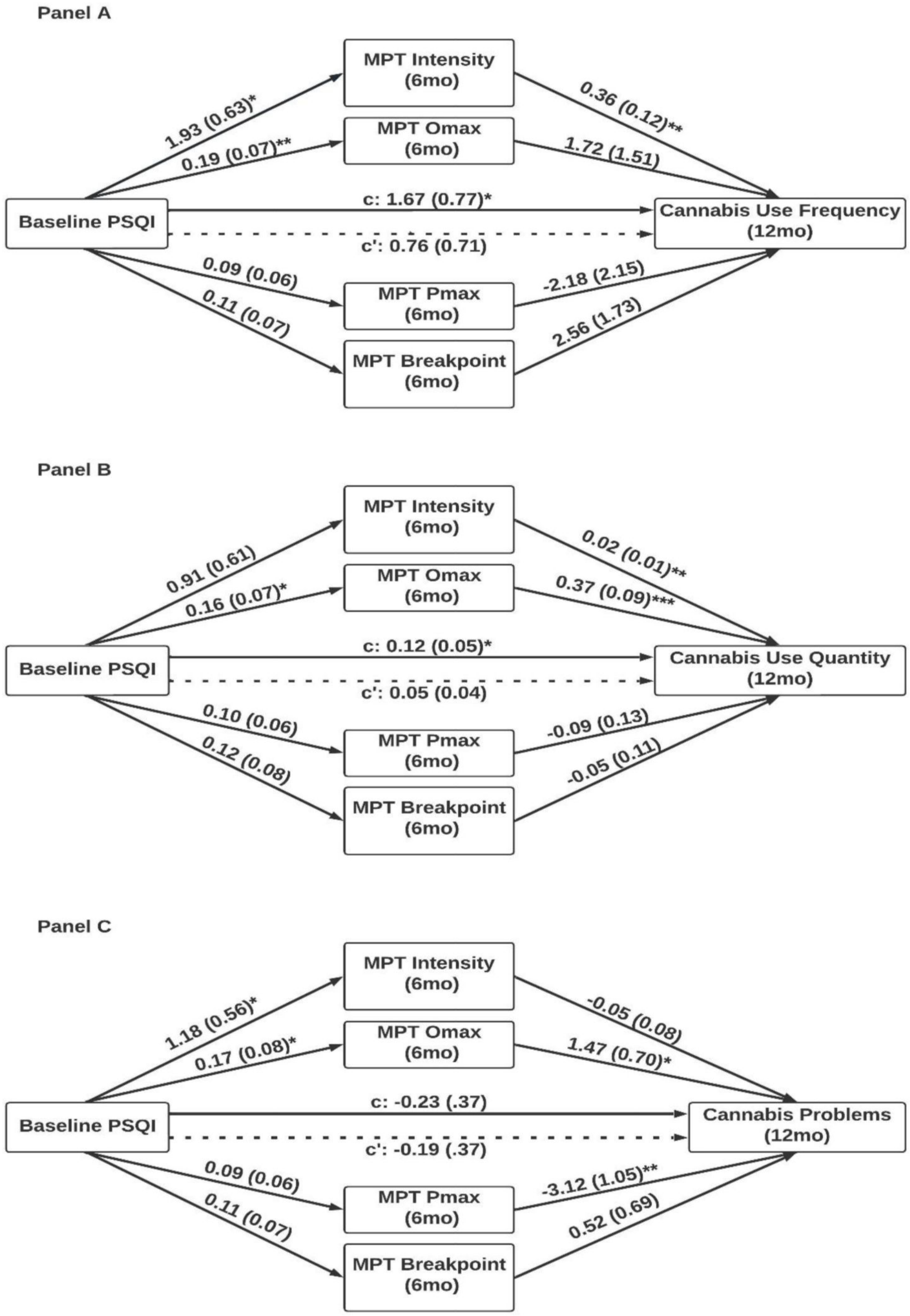

Figure 1.

Mediation analyses of the relation between PSQI sleep disturbances and cannabis use frequency, n=126 (**Panel A**), quantity, n=124(**Panel B**), and problems, n=124 (**Panel C**). Parameter estimates (SE) are unstandardized. C = Total effect, C' = direct effect, All models controlled for lifetime cannabis use frequency; the model predicting cannabis use quantity also controlled for baseline annual household income.

*p<.05; **p<.01; ***p<.001

Table 1.

Sample Descriptive Statistics

(N = 126)	*M (SD)*, sample range	%
Baseline		
Age (in years)	*31.19 (8.02),* 22 – 61	-
Sex, *n* (% Male)	-	118 (93.7)
Race, *n* (%)		
American Indian / Alaskan Native	-	1 (0.8)
Asian American	-	3 (2.4)
Black / African American	-	7 (5.6)
Multiracial	-	6 (4.8)
Other	-	12 (9.5)
White	-	95 (75.4)
Not reported	-	2 (1.6)
Ethnicity, *n* (%)		
Hispanic/Latinx	-	18 (14.3)
Annual Household Income[a]		
$19,999 or less	-	26 (20.6)
$20,000 – 39,999	-	44 (34.9)
$40,000 – 59,999	-	28 (22.2)
$60,000 or higher	-	28 (22.2)
Frequency of lifetime cannabis use, *n* (%)		
1 – 10 times	-	14 (11.1)
11 – 50 times	-	20 (15.9)
51 – 100 times	-	10 (7.9)
100 or more times	-	82 (65.1)
Past-month % cannabis use days	*37.65 (43.92), 0 – 100*	-
MPS total score[b]	*2.13 (3.18),* 0 – 15	-
Past-month avg. cannabis use quantity per week, *n* (%)		
1/16th ounce or less	-	70 (55.6)
1/8th ounce	-	18 (14.3)
1/4th – 1/2 ounce	-	26 (20.6)
More than ½ ounce	-	12 (9.5)
PSQI Global Score[c]	*9.87 (4.26),* 1 – 20	-
6-month Cannabis Demand		
MPT – O_{max}[a]	*20.38 (49.88),* 0 – 273	-
MPT – P_{max}[a]	*1.94 (2.72),* 0 – 10	-
MPT – Breakpoint[a]	*3.13 (3.56),* 0 – 10	-
MPT – Intensity	*21.58 (32.20),* 0 – 99	-
12-month Cannabis Use		

(N = 126)	*M (SD)*, sample range	%
Past-month % cannabis use days	*36.01 (42.17)*, 0 – 100	-
MPS total score[b,d]	*1.70 (2.52)*, 0 – 10	-
Past-month avg. cannabis use quantity per week, *n* (%)[d]		
1/16th ounce or less	-	80 (64.5)
1/8th ounce	-	15 (12.1)
1/4th – 1/2 ounce	-	22 (17.7)
More than ½ ounce	-	7 (5.6)

Notes:

[a]values are in USD;

[b]Marijuana Problem Scale winsorized for outliers, full possible range is 0–22;

[c]Full possible range of Pittsburgh Sleep Quality Index is 0–21;

[d]based on n=124

Table 2.

Bivariate correlation matrix for sociodemographic, sleep, demand, and cannabis use indices

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
Baseline																
1. Sex[a]	--															
2. Age	.01	--														
3. Race[b]	.17†	−.08	--													
4. Ethnicity[c]	−.11	−.05	.36**	--												
5. Annual Household Income	.11	.28**	−.09	.07	--											
6. Lifetime cannabis use freq.	.07	.10	.19*	.10	−.05	--										
7. Cannabis freq.[d]	−.16	−.16	.07	.10	−.21*	.45**	--									
8. Cannabis quantity	−.10	−.20*	.08	.01	−.23**	.37**	.72**	--								
9. Cannabis problems[e]	−.05	−.03	−.05	−.21*	−.10	.29**	.26**	.29**	--							
10. PSQI Global Score	.02	.12	−.08	−.03	−.15	−.01	.17	.13	.10	--						
Six-month																
11. O_{max}[f,g]	.09	.11	.06	.12	−.14	.26**	.46**	.46**	.04	.24**	--					
12. P_{max}[g]	.12	.25**	.04	.12	.04	.10	.18*	.12	−.10	.15	.64**	--				
13. Breakpoint[g]	.12	.20*	.09	.14	−.01	.17†	.34**	.22*	−.04	.14	.72**	.85**	--			
14. Intensity[g]	−.05	−.10	.10	−.05	−.33**	.34**	.48**	.53**	.11	.18*	.58**	.15	.32**	--		
Twelve-month																
15. Cannabis freq.[d]	−.03	−.02	.09	.10	−.15	.48**	.69**	.56**	.17	.17	.47**	.22*	.35**	.53**	--	
16. Cannabis quantity[h]	−.10	−.04	<.01	−.03	−.20*	.39**	.62**	.70**	.25**	.20*	.58**	.22*	.33**	.59**	.76**	--
17. Cannabis problems[e,h]	.05	.03	.10	.11	−.04	.33**	.34**	.35**	.44**	.01	.32**	.02	.20*	.31**	.31**	.38**

Notes:

† p<.07

* p<.05

** p<.01

[a] 0=Female, 1=Male

[b] Participants were categorized as “White” vs. “Non-White/Multiracial” for correlational analyses, 0=Non-White/Multiracial, 1=White

[c] 0=Hispanic/Latinx, 1=Not Hispanic/Latinx

[d] Past-month percentage of days using cannabis based on Timeline Followback

[e] MPS winsorized for outliers

[f] Square root transformed

[g] Marijuana Purchase Task

[h] correlations based on n=124

Table 3.

Total, Direct and Indirect Effects of Baseline Sleep Disturbances (PSQI) on Cannabis Use Frequency, Quantity, and Problems via MPT Demand Indices

Dependent variable:	**Cannabis Use Frequency**		**Cannabis Use Quantity**		**Cannabis Problems**	
	Parameter Estimate (SE)	**95% CI [Lower, Upper]**	**Parameter Estimate**	**95% CI [Lower, Upper]**	**Parameter Estimate**	**95% CI [Lower, Upper]**
Total effect	**1.67 (0.77)**	**0.15, 3.19**	**0.12 (0.05)**	**0.01, 0.22**	−0.23 (0.37)	−0.89, 0.60
Multiple mediators						
Total indirect effect	**0.92 (0.40)**	**0.21, 1.79**	**0.06 (0.03)**	**0.005, 0.14**	−0.05 (0.14)	−0.35, 0.22
MPT Intensity	**0.50 (0.33)**	**0.02, 1.27**	0.02 (0.02)	−0.004, 0.07	−0.06 (0.11)	−0.43, 0.04
MPT O_{max}	0.33 (0.31)	−0.28, 0.98	**0.06 (0.04)**	**0.005, 0.14**	**0.24 (.17)**	**0.03, 0.72**
MPT P_{max}	−0.20 (0.32)	−0.96, 0.37	−0.01 (0.02)	−0.05, 0.03	−0.29 (0.23)	−0.84, 0.08
MPT Breakpoint	0.29 (0.33)	−0.23, 1.07	−0.01 (0.02)	−0.05, 0.02	0.06 (0.11)	−0.11, 0.31
Direct effect	0.76 (0.71)	−0.66, 2.17	0.05 (0.04)	−0.03, 0.14	−0.19 (0.37)	−0.87, 0.64
Covariates						
Lifetime cannabis use	**12.74 (2.87)**	**7.05, 18.43**	**0.49 (0.18)**	**0.14, 0.84**	**0.49 (0.21)**	**0.16, 0.96**
Household income	–	–	−0.08 (0.18)	−0.44, 0.29	–	–

Notes: Parameter estimates are unstandardized. Parameter estimates and 95% bias-corrected CIs for the total indirect effect and mediators were computed from 10,000 bootstrapped samples. The cannabis problems variable was winsorized for two outlying values. MPT O_{max} was square-root transformed. Models with Cannabis Use Quantity and Cannabis Problems based on n=124. Only models predicting 12-month cannabis use frequency and problems covaried for annual household income based on results from preliminary analyses.