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RESEARCH ARTICLE

Longitudinal associations between insomnia, cannabis use and stress among US veterans

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Summary

Insomnia is highly prevalent among military veterans, with rates nearly double that of civilian populations. Insomnia typically co-occurs with other psychological problems, including substance use (e.g. cannabis) and perceived stress. Much of the research focused on insomnia, stress and cannabis use explores cannabis as a sleep aid and a mechanism for stress relief. However, recent theoretical and empirical evidence suggests a dynamic interplay between insomnia, cannabis use and perceived stress, yet few longitudinal studies exist. Using a sample of 1105 post-9/11 veterans assessed over four time points across 12 months, we used latent difference score modelling to examine proportional change between insomnia, perceived stress and cannabis use. Results revealed a complex interplay between all three constructs. In particular, we show that higher prior levels of insomnia are associated with greater increases in perceived stress, and greater prior levels of stress are associated with greater increases in cannabis use. Perhaps more importantly, our results also point to cannabis use as a catalyst for greater increases in both stress and insomnia severity. Our results suggest there may be both benefits and costs of cannabis use among veterans. Specifically, for veterans who experience chronic sleep problems, perceived stress may become overwhelming, and the benefit of stress reduction from increased cannabis use may come at the cost of increasing insomnia symptomology.

KEYWORDS
cannabis use disorder, dynamic change, military, sleep problems, substance use disorder, trauma

1 | INTRODUCTION

Insomnia, a behavioural sleep disorder characterized by dissatisfaction with quality or quantity of sleep, difficulty initiating or maintaining sleep, or waking up earlier than desired, is linked to various psychological and physical health problems (American Psychiatric Association, 2013). United States military veterans are particularly vulnerable to sleep problems, likely due to irregular sleep schedules established during active duty, combat-related stress, and co-occurring mental health problems that persist or emerge after returning from deployment (Hughes et al., 2018; Troxel et al., 2015). In a recent observational study of post-9/11 veterans enrolled in the Veterans Health Administration (VA), 57% met criteria for insomnia (Colvonen et al., 2020), nearly double the prevalence reported in civilian samples (Morin et al., 2019; Olfson et al., 2018). In a large nationally representative sample of veterans recruited outside the VA, over 11% of veterans screened positive for clinical insomnia, with 26% screening positive for subclinical insomnia (Byrne et al., 2021). Insomnia often co-occurs with substance use (including cannabis use) and perceived stress, and these co-occurring problems are especially prevalent among veterans (Babson et al., 2017; Babson & Bonn-Miller, 2014; Davis et al., 2022; Yurasek et al., 2017).

The leading framework for understanding insomnia is the 3P behavioural model (Spielman & Glovinsky, 1991). The 3P behavioural model is an extension of the diathesis-stress model (McKeever & Huff, 2003) and provides a framework for understanding insomnia through three sequential sets of factors: predisposing factors (pre-existing vulnerabilities for insomnia like genetic factors or early childhood experiences); precipitating factors (responses to stressors that impinge on sleep, such as increased hyperarousal); and perpetuating factors (actions taken to compensate for sleep loss that may make insomnia worse, such as using cannabis to help fall asleep at night; for review, see Hughes et al., 2018). However, the 3P behavioural model conceptualizes insomnia as a consequence (outcome) of stress. Thus, this unidirectional emphasis fails to consider how insomnia might also be a catalyst (predictor) of stress or problematic behaviours.

Recently, Hughes et al. (2018) introduced an integrated theoretical model that takes a more holistic and dynamic view of insomnia, with a particular focus on veterans. The model expands on the essential components of the 3P behavioural model by outlining potential mechanisms linking insomnia with psychosocial stress and behaviour. In this integrated model of insomnia, Hughes and colleagues highlight the cyclical nature of insomnia among veterans. For example, they note that stressful events (both military- and non-military-related) can lead to a cascade of effects involving cognitive appraisal mechanisms, whereby the perceived severity of the stressor and its negative outcomes become increasingly heightened. This heightened *perceived stress* is posited to lead to one (or more) behavioural responses such as irregular sleep (e.g. insomnia) or self-medication for sleep problems (e.g. the use of substances such as cannabis to sleep). However, unlike existing theories such as 3P that assume unidirectional, linear pathways from stress (or stressors) to insomnia, Hughes' integrated model proposes a dynamic interplay in which insomnia symptomology, stressors and behavioural health factors influence one another through bidirectional and self-perpetuating processes.

1.1 | The multifaceted relationship between insomnia and cannabis use

Cannabis use and sleep problems, such as insomnia, have a complex, dynamic relationship – with some research noting high rates of cannabis use among those with insomnia and other work noting cannabis products are often used to address sleep problems (including insomnia). For example, in cross-sectional studies with college students, those reporting greater insomnia symptomology had greater odds of hazardous cannabis use and cannabis use disorder (Wong et al., 2019) and greater past-month cannabis problems (Yurasek et al., 2020).

Research investigating the effects of cannabis on sleep has a long history. Contemporary reviews include research dating back to the early 1970s (Babson et al., 2017). The general conclusion from early research on associations between cannabis use and sleep problems is that, while cannabis use may offer acute benefits for one's sleep problems (e.g. shortening the time it takes to fall asleep), long-term use may contribute to worsening sleep problems (Babson et al., 2017). In a recent review, Babson and colleagues concluded that these negative effects, observed among long-term cannabis users, likely resulted for two reasons. First, individuals using cannabis as a sleep aid may find themselves needing increasingly higher doses of cannabis to achieve the desired sleep effect (i.e. tolerance), resulting in greater risk of cannabis-related problems. And second, sleep problems are key features of cannabis withdrawal and may precipitate a relapse episode; those who desire to quit or cut back but find sleep difficult may resume their use of cannabis. Perhaps, however, the biggest motivator for the use of cannabis for sleep and insomnia difficulties is its perceived benefit. For example, in a naturalistic sample of individuals who self-reported using cannabis to cope with insomnia, cannabis use was perceived to help with sleep (Kuhathasan et al., 2021). This also appears to be the case among individuals with mental health problems, as in a recent study of individuals who self-reported using cannabis to cope with insomnia symptoms and comorbid depression and anxiety, cannabis use was perceived to help with sleep (Kuhathasan et al., 2022).

However, recent research in both non-veteran and veteran samples shows mixed support for cannabis as a way to alleviate insomnia symptomology and related sleep problems. For example, a study of non-veterans focused on the effects of the psychoactive ingredient in cannabis (tetrahydrocannabinol; THC) on sleep noted that high levels of THC negatively affect the sleep/wake cycle, which was assessed by brain temperature during a week of THC administration (Perron et al., 2001). Other research has revealed low doses of THC have a mild sedative effect and may decrease the amount of time it takes to fall asleep; however, high doses of THC appear to decrease important rapid eye movement sleep and otherwise suppress sleep cycles (Garcia & Salloum, 2015). Finally, there have been mixed results on the effects of cannabis use on insomnia and sleep quality, suggesting that different cannabinoid concentrations, doses and routes of administration may have differential effects on sleep quality and insomnia symptoms (Ogeil et al., 2015). For example, a recent review reported that chronic cannabis use negatively affects sleep and insomnia symptoms and noted that, while short-term use might help individuals fall asleep faster, some individuals may become tolerant to this effect as they become chronic users (Angarita et al., 2016).

Though there are fewer studies among veterans, similar results have been reported. For example, some research has noted that, among cannabis-dependent veterans attempting to quit, those with poor sleep quality prior to the quit attempt had greater risk for lapse within the first 2 days of the quit attempt (Babson et al., 2013b), and veterans with poor perceived sleep quality had less of a reduction in cannabis use during a self-guided quit attempt (Babson et al., 2013a). As in civilian samples, veterans also believe cannabis is helpful for insomnia. In a longitudinal cohort study of veterans, Metrik and colleagues reported that veterans frequently cited insomnia as reason for cannabis use, and had greater motivation to use cannabis to cope with sleep disturbances; however, these veterans who reported using cannabis to aid with sleep reported increased sleep problems throughout the study (Metrik et al., 2018).

1.2 | The role of perceived stress

Perceived stress is defined as the appraisal that a stressor has exceeded one's ability to cope and thus endangers their well-being (Lazarus, 1985). Recent evidence suggests that the majority of Americans (63%) do not believe they can manage their stress adequately, and many (27%) report feeling so stressed they cannot function most days (*Stress in America 2022: Concerned for the Future, Beset by Inflation*). Further, veterans have some of the highest levels of stress and stress-related problems (Davis et al., 2022). For decades, stress-coping models of addiction have posited that some individuals use substances, namely cannabis, to cope with life stress and to reduce negative affect (Copeland et al., 2001; Green et al., 2003). Research on the association between stress and cannabis use dates to the mid-1980s when adults who used cannabis were interviewed and described its use as an escape or relief from problems, and that it helped ease frustrations and life stressors (Hendin & Haas, 1985). More recent studies have reported similar reasons for use among adolescents, with nearly 20% of high-school seniors reporting use of cannabis for stress-coping purposes. In a recent review of studies addressing the connection between cannabis use and stress, the authors concluded that using cannabis to relieve stress or cope with stressful events may be among the most common reasons for use among heavy users (Hyman & Sinha, 2009).

Unfortunately, research among veteran samples is nascent compared with work among adolescents and broader adult samples. However, prior work indicates that veterans (particularly those presenting with multi-morbid mental health problems) use cannabis to cope with negative affect, regulate emotion and address sleep disturbances (Boden et al., 2013; Metrik et al., 2016). While the associations between cannabis use and stress are still being uncovered, and are at times, unclear, the link between stress and sleep is much clearer. In a sweeping review of literature that included both animal models and human studies, Van Reeth reports stress can have pronounced effects on sleep (including insomnia) and, among individuals who experience chronic stress, such stress may contribute to life-long unstable sleep patterns (Van Reeth et al., 2000).

1.3 | Toward a better, dynamic, understanding of insomnia, cannabis use and stress

As noted above, the associations between insomnia, cannabis use and stress are complex, as there is mixed evidence for the utility of cannabis as a sleep aid. When considering stress, the story becomes even more complex, as stress has robust (negative) associations with sleep, yet much of the evidence implies cannabis use may alleviate stress. Not only do prior studies suggest degrees of bidirectionality between each pairing of these behavioural health problems (insomnia, stress and cannabis use), but initial evidence points to more complex dynamic associations between all three. Unfortunately, methodological limitations of prior research have restricted a more fulsome understanding of the true associations between these constructs. Most existing research is cross-sectional or unidirectional in nature and, even among the longitudinal studies, few have addressed directionality. In their integrated model of insomnia, Hughes et al. (2018) posit dynamic associations between insomnia and behavioural health factors, warranting more longitudinal investigations. The present study aims to empirically test a part of Hughes' integrated model of insomnia by allowing insomnia, cannabis use (frequency) and perceived stress to each be a predictor and an outcome in longitudinal data using a latent difference score modelling approach. Given the lack of consensus on associations between insomnia, cannabis use and perceived stress, we do not propose any specific directional hypotheses; rather, we are allowing our modelling approach to be exploratory.

2 | METHODS

2.1 | Participants and procedures

Veterans were recruited via social media advertisements in February 2020 as part of a survey study of veteran attitudes and health behaviour. Eligibility criteria for the study were: (1) aged 18–40 years; and (2) had separated from the Air Force, Army, Marine Corps or Navy. As recruitment was completed solely online, we implemented several verification checks (see BLIND FOR REVIEW) to ensure, to the best of our ability, that participants were not misrepresenting themselves. Checks included noting if participants completed surveys in an impossibly quick amount of time, utilizing "insider knowledge" military-related questions that needed to be consistent across multiple surveys, and checking to confirm that participants did not complete the survey more than once. The final sample was composed of 1230 veteran participants at baseline. Participants were sent follow-up surveys via email at 6 months ($N = 1025$; 83.3% retention from baseline), 9 months ($N = 1006$; 81.8%), 12 months ($N = 1005$; 81.7%) and 18 months ($N = 976$; 79.3%) after baseline. They received gift cards (ranging from $30 to $50) for completion of baseline and follow-up surveys. The present study uses data from the 6-month follow-up forward as insomnia was not assessed at baseline (analytic sample $N = 1025$). See BLIND FOR REVIEW for more details on participant recruitment, and Table 1 for participant demographics.

2.2 | Measures

2.2.1 | Demographic covariates

Participants self-reported their age, sex and race/ethnicity at baseline. For combat exposure, participants indicated "yes" or "no" for whether they had experienced each of 12 assessed exposures, and received a

TABLE 1 Demographic characteristics

Variable	M (SD) or N (%)
Age (years)	34.5 (3.67)
Sex (male)	1091 (88.7%)
Race/ethnicity	
White	975 (79.3%)
Hispanic/Latino	134 (10.9%)
Black	90 (7.3%)
Asian	13 (1.1%)
Multiracial/other	18 (1.5%)
Combat severity	5.02 (2.35)
PTSD (Time 1)	27.6 (11.9)
Perceived stress (Time 0)	14.6 (6.85)
Perceived stress (Time 1)	14.9 (5.71)
Perceived stress (Time 2)	13.4 (6.44)
Perceived stress (Time 3)	13.5 (6.31)
Perceived stress (Time 4)	13.3 (6.21)
Perceived stress (Time 5)	13.2 (6.33)
Days of cannabis use (past month; Time 0)	1.49 (4.64)
Days of cannabis use (past month; Time 1)	1.45 (4.63)
Days of cannabis use (past month; Time 2)	1.3 (3.81)
Days of cannabis use (past month; Time 3)	1.84 (3.51)
Days of cannabis use (past month; Time 4)	1.86 (4.30)
Days of cannabis use (past month; Time 5)	1.66 (3.58)
ISI score (Time 1)	8.54 (5.10)
ISI score (Time 2)	8.89 (4.78)
ISI score (Time 3)	8.99 (4.78)
ISI score (Time 4)	8.55 (4.57)
ISI score (Time 5)	8.79 (4.68)

Note: Perceived stress range (0–36); cannabis use range (0–30); ISI range (0–28); PTSD range (0–80); combat severity range (0–12).
Abbreviation: ISI, Insomnia Severity Index; PTSD, post-traumatic stress disorder.

combat severity score of 0–12 (Schell & Marshall, 2008). Because insomnia was first assessed at the 6-month follow-up (not at baseline), we also controlled for baseline levels of cannabis use, baseline levels of stress, and baseline post-traumatic stress disorder (PTSD) symptoms using the 20-item PTSD Checklist for DSM-5 (Bovin et al., 2016) given that PTSD is associated with all three constructs (Hicks et al., 2022; Richards et al., 2019).

2.2.2 | Perceived stress

Participants responded to the 10-item Perceived Stress Scale (Cohen & Williamson, 1988) at all waves. Each item asked participants to rank how often they had a specific experience in the past month on a Likert scale from never (0) to very often (5). Example items include "how often have you been upset because of something that happened unexpectedly?" and "how often have you felt nervous or stressed?" A summed score was created for each wave with a range from 0 to 40, and higher scores indicating greater stress (average $\alpha = 0.76$).

2.2.3 | Insomnia

The Insomnia Severity Index (ISI) was used to assess symptoms of insomnia (Bastien et al., 2001) at all waves except baseline. This seven-item measure assessed severity of symptoms, including difficulty falling or staying asleep, sleep problems interfering with daily life, and concern about sleep problems. A summed score was created for each wave with a range from 0 to 28, and higher scores indicated more severe insomnia (average $\alpha = 0.82$).

2.2.4 | Cannabis use

Days of cannabis use was assessed at each wave by asking each participant to indicate how many days they used cannabis in the past 30 days. Participants were asked to consider cannabis that contained THC in all forms (e.g. smoked, edibles) and not cannabidiol (CBD)-only products.

2.3 | Analytic plan

A series of latent difference score models (Grimm et al., 2012) were estimated to address study aims (see Figure 1 for conceptual model). This modelling approach allows for simultaneous examination of constant change (e.g. latent growth models) and proportional change (how do previous levels of one variable relate to subsequent change in another). The latent difference score model does not subtract values from a given time point from a previous time point; rather, it allows for change itself to be the focus of analysis. To do this, we specify latent variable indicators to capture latent change between true scores at two time points, essentially capturing mean change between two time points. This latent change variable can then be used as a predictor or outcome in subsequent model specifications. The latent difference score model provides various levels and types of prediction at the within- and between-person level (see Supplemental Materials for more detailed information). For this study, we focus on the within-person parameter estimated in the model. This parameter is referred to as the *proportional coupling parameter*, which models *changes* in, for example, insomnia at a given time point predicted by the lagged effect of an individual's *level* (trait-like value) of stress symptoms at the prior time point. Here, we provide one lagged example (stress predicting insomnia); however, our model estimates all possible cross-lagged paths between all three constructs. A significant positive effect of this proportional coupling parameter would be interpreted as an individual's *level* of stress at time t is associated with positive *changes* (or, increases) in insomnia from time t to $t + 1$. For example, lower prior levels of stress are associated with smaller,

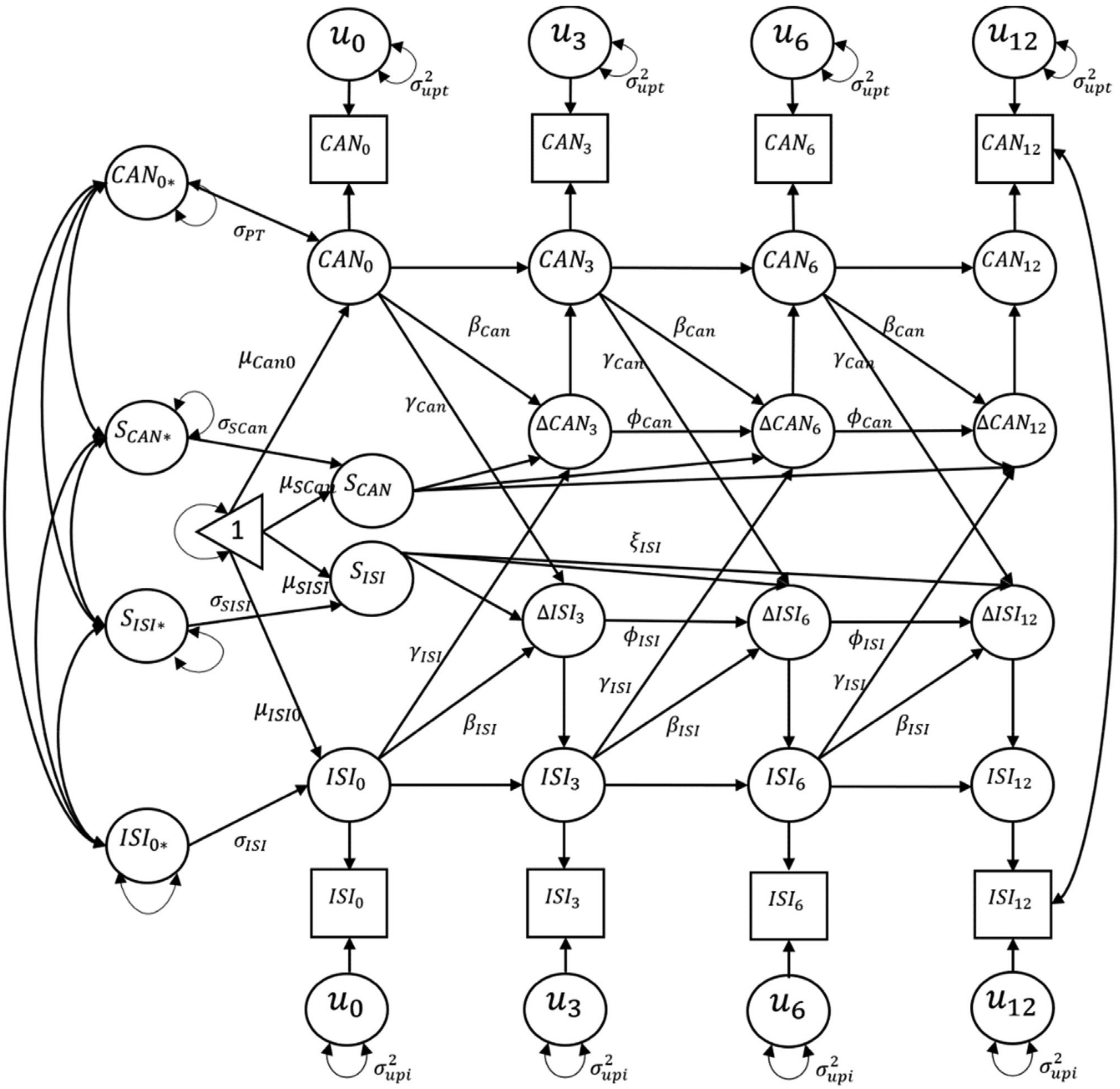

FIGURE 1 Conceptual latent difference score model. Here, we depict only two variables for ease of reading; however, in our final empirical model all three variables of interest (cannabis use, insomnia symptoms, and stress) are included. Between-person effects are captured by correlations between intercepts (ISI_{0*}, CAN_{0*}) and slopes (S_{CAN*}, S_{ISI*}). Latent change variables that are preceded with a Δ represent a change in the construct from time t to $t+1$. Within-construct proportional change is represented by regression coefficients labelled β_{ISI} and β_{CAN}. The within-person proportional coupling parameters are represented by regression coefficients labelled γ_{Can} and γ_{ISI}

but positive subsequent changes in insomnia, and higher prior levels of stress are associated with larger positive subsequent changes in insomnia. As recommended by Grimm et al. (2016), we have constrained each proportional change lag to be equal over time for parsimony. All models controlled for our covariates (outlined above), which were regressed onto each of the intercept and slope factors. Of note, because our model uses maximum likelihood estimation, all models utilize all available data (e.g. individuals are not removed for missing data). Thus, the only missing data from our models are that of covariates, which leaves us with a final sample size of 1105. All analyses were conducted in *Mplus* version 8.6 (Muthén & Muthén, 1998–2017).

3 | RESULTS

Although we are only describing the coupling parameters for our final model in the text below, to be thorough and provide readers with a full picture of how insomnia, stress and cannabis use are associated in our sample, we have developed a thorough supplement of materials.

TABLE 2 Coupling parameters for the final latent difference score model assessing longitudinal associations between insomnia, PTSD and cannabis use

Parameters for LDS model	*B (SE)*
Within construct proportional change	
Level insomnia → changes insomnia	−0.20 (0.06)*
Level stress → changes stress	−0.73 (0.07)*
Level cannabis use → change cannabis use	0.09 (0.02)*
Proportional coupling parameters	
Level insomnia → changes stress	1.02 (0.09)*
Level insomnia → changes cannabis use	−0.37 (0.09)*
Level stress → changes insomnia	0.06 (0.05)
Level stress → changes cannabis use	0.21 (0.07)*
Level cannabis use → changes stress	0.05 (0.04)
Level cannabis use → changes insomnia	0.08 (0.02)*
Initial level and constant change parameters	
Level insomnia	5.58 (0.48)*
Level stress	8.15 (0.61)*
Level cannabis use	1.11 (0.35)*
Change insomnia	0.88 (0.17)*
Change stress	0.64 (0.40)
Change cannabis use	−0.45 (0.20)*
Variance of initial level and constant change parameters	
Level insomnia	9.18 (0.65)*
Level stress	12.9 (1.08)*
Level cannabis use	6.59 (0.47)*
Change insomnia	0.48 (0.19)
Change stress	6.44 (1.15)*
Change cannabis use	0.92 (0.44)*
Model fit criteria	
χ^2	876.0
Df, p	97, $p < 0.01$
CFI	0.94
TLI	0.92
RMSEA	0.07
SRMR	0.05

Abbreviations: CFI, comparative fit index; LDS, latent difference score; RMSEA, root mean square error of approximation; SRMR, standarized root mean square residual; TLI, Tucker Lewis index.
*indicates $p < 0.05$

In these supplemental materials, we describe methods, results and discussion for each univariate, bivariate, as well as a walkthrough of our final, trivariate model, and describe the remaining parameters including between-person parameters (i.e. constant change correlations) and within-construct proportional change parameters.

Table 2 provides coefficients for the coupling parameters and the means and variances of the intercepts and constant change components for each construct in our final model. This model had excellent model fit (Comparative Fit Index (CFI) = 0.94, Root Mean Square Error of Approximation (RMSEA) = 0.07, Standarized Root Mean square Residual (SRMR) = 0.05, $\chi^2 = 876.0$ (97), $p < 0.01$). In terms of *proportional* coupling parameters, greater, prior levels of insomnia (i.e. greater sleep problems) were associated with increases (e.g. positive change) in stress ($\beta = 1.02$). That is, stress increased more rapidly among individuals reporting greater prior insomnia. However, prior levels of insomnia were also associated with greater decreases (e.g. negative change) in cannabis use ($\beta = -0.37$). Thus, individuals tended to use less cannabis use between time points when reporting greater prior levels of insomnia. Results also indicate prior levels of cannabis use were positively associated with subsequent changes in insomnia ($\beta = 0.08$). Thus, insomnia increased more rapidly for individuals reporting greater prior levels of cannabis. Finally, greater prior levels of stress were associated with greater increases (e.g. greater positive change) in cannabis use ($\beta = 0.21$).

We did not note an association between prior levels of stress predicting changes in insomnia or prior levels of cannabis use predicting changes in stress. Thus, stress does not seem to have an influence on insomnia of veterans and, further, stress does not seem to be influenced by prior levels of cannabis use (e.g. cannabis use does not decrease [or increase] stress).

3.1 | Visual depiction of results

To gain a more in-depth understanding, we use visual representations of our final model to explore what happens to insomnia symptoms and stress when we simulate increases in cannabis use (Figure 2). Our figure depicts a hypothetical veteran starting with average levels (i.e. intercept values) of insomnia (score of 5.58), cannabis use (average of 1.2 days per month) and stress (score of 8.15). We then simulate increases in cannabis use by 4 additional days per month at the 9- and 12-month follow-ups. As cannabis use increases to nearly 10 days per month, we see a slow and steady increase in stress (note: the model did not indicate that cannabis use was a significant predictor of changes in stress, this is simply a simulation of what would happen to stress and insomnia given increases in cannabis use over time). Similarly, as cannabis use increases, we see a steady climb in insomnia symptoms. As we simulate cannabis use back down to initial levels, stress continues to increase and ends at an average score of 10.0 at the 18-month follow-up, with insomnia symptoms also continuing to rise, ending at the highest point during the study (score of 7.4).

On the other side of this dynamic process, we visually explored what would happen to cannabis use and stress if we simulated increases in insomnia symptoms on our hypothetical veteran. After we simulated increases in insomnia symptoms through the 12-month follow-up (4 symptom increase per follow-up; Figure 3), cannabis use decreased by very small, modest increments throughout the study. However, for stress, when insomnia symptoms increased from the 9- to 12-month follow-up, stress increased exponentially, even after

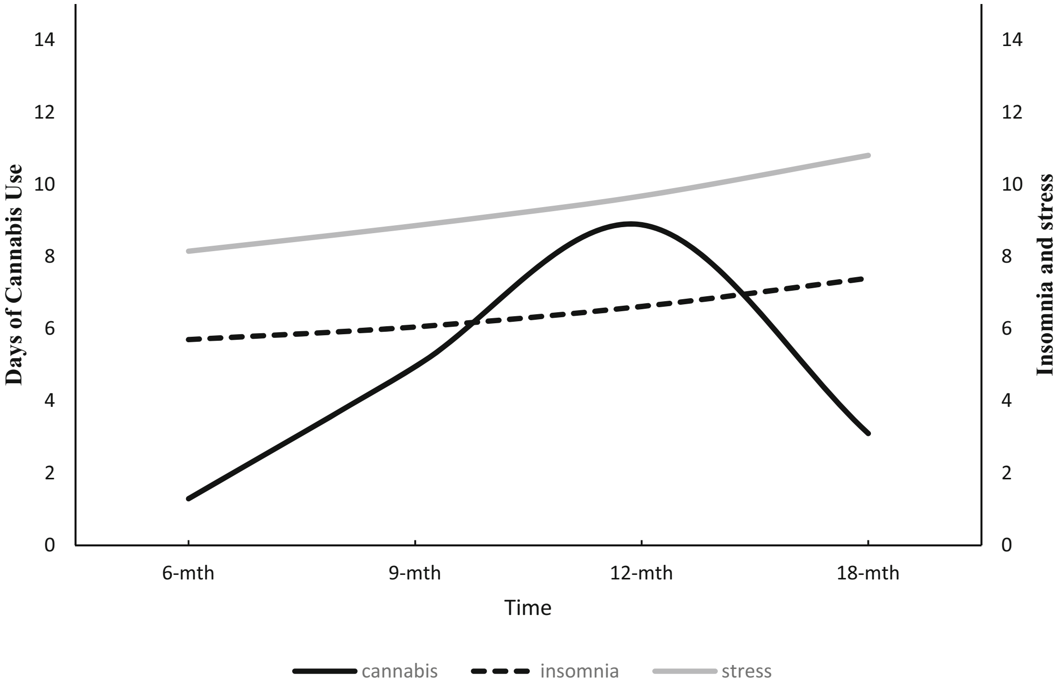

FIGURE 2 This figure portrays the effect of "system shocks" to cannabis use, and its effect on insomnia and stress. Model is based on final model parameters. Predicted trajectories for a hypothetical veteran who begins with average levels of cannabis use, stress and insomnia scores (i.e. intercept values) at 6 months who then experiences an increase in cannabis use at 9 months and 12 months. Following the increase in cannabis use frequency, we see a slow and steady increase in stress from the 6- to 9-month follow-up. We also see a steady increase in insomnia. At 18 months, after cannabis use subsides to average levels, stress and insomnia symptoms do not subside but, rather, they persist

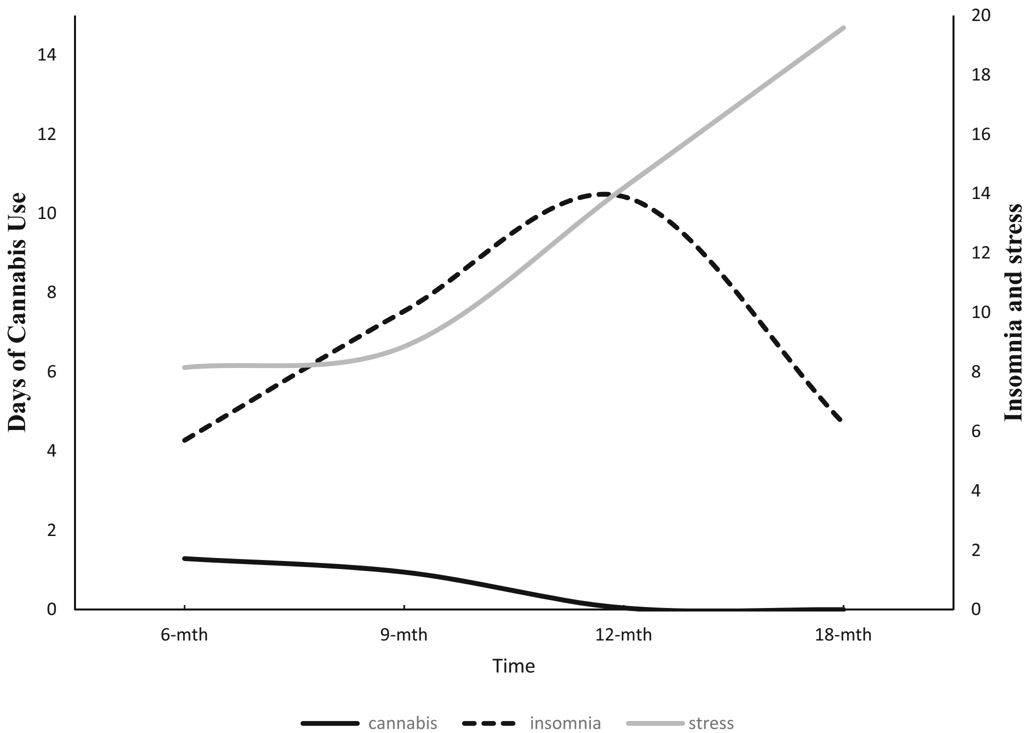

FIGURE 3 This figure portrays the effect of "system shocks" to insomnia symptoms, and its effect on cannabis use and stress. Model is based on final model parameters. Predicted trajectories for a hypothetical veteran who begins with average levels of cannabis use, stress and insomnia scores (i.e. intercept values) at 6 months who then experiences an increase in insomnia at 9 months and 12 months (increases to clinical cut-off levels on the Insomnia Severity Index [ISI]). Following the increase in insomnia, we can see a rapid increase in stress scores and a steady decrease in cannabis use. After insomnia symptoms subside to average levels, stress scores remain high with cannabis use continuing to decrease

insomnia symptoms were simulated back to initial levels, peaking at the 18-month follow-up (score of 19.5).

4 | DISCUSSION

In the present study, we sought to test components of Hughes and colleagues' integrated model of insomnia (Hughes et al., 2018). Hughes posits that sleep problems are both a consequence of stressful life events as well as a catalyst for long-term behavioural health problems. While numerous studies have noted that cannabis is primarily used to relieve stress, others have shown cannabis use, especially heavy or prolonged use, can have detrimental effects on sleep, including greater insomnia symptomology. Similar to prior work, we show continued support for the association between insomnia and stress as well as stress and cannabis use. In particular, we show that higher prior levels of insomnia are associated with greater increases in perceived stress, and greater prior levels of stress are associated with greater increases in cannabis use. Perhaps more importantly, our results also point to cannabis use as a catalyst for greater stress and insomnia severity.

Overall, our results reveal dynamic and nuanced associations between cannabis use, insomnia and stress, consistent with Hughes' integrated model wherein insomnia is both an outcome and predictor of long-term behavioural problems. In particular, two possible aetiological models emerged from our results: an *insomnia-driven model* in which greater insomnia symptomology is a catalyst for some, but not all, negative behavioural health outcomes (i.e. stress and cannabis use); and a *substance-induced model* in which greater use of cannabis is a catalyst for problematic sleep outcomes. Among our sample, in particular, veterans reporting greater prior levels of insomnia are reporting greater *increases* in stress but, also, greater *decreases* in frequency of cannabis use. The idea of an insomnia-driven model has been shown in our prior work focused on longitudinal associations between insomnia, PTSD and alcohol use, with insomnia severity emerging as a catalyst for greater changes in PTSD symptomology but less change in alcohol use (Davis et al., 2022a, 2022b). Thus, our results partially support the idea of an insomnia-driven model and provide continued support for the notion that when individuals experience greater sleep problems, their perceived stress appears to increase. This notion has been empirically supported since the mid-1980s (Healey et al., 1981) when Healy and colleagues noted a significant association between major stressful events and the onset of insomnia. In their study, insomnia sufferers reported a greater incidence of stressful life events during the year preceding the onset of their insomnia. Others have echoed these results, revealing that individuals with high perceived stress have difficulty falling asleep (Friedman et al., 1995). More recent work shows that individuals with insomnia perceive their life to be stressful and, when daytime stress is assessed at the daily level, it is associated with greater difficulty falling asleep, more disturbed sleep, and pre-sleep physiological and cognitive arousal at night (Morin et al., 2003). Interestingly, however, we show that when veterans are experiencing greater problems with sleep, their cannabis use subsequently decreases. Thus, it may be that while insomnia precipitates greater stress, veterans may ultimately realize that cannabis use may not be a useful tool for dealing with insomnia symptomology. These processes are depicted in Figure 2 where we simulate increases in insomnia for a typical, hypothetical, veteran in our study. As noted above, when insomnia severity increases, stress follows suit with an exponential pattern while cannabis use slowly decreases.

However, our results become more nuanced from the perspective of a *substance-induced* model. In particular, when veterans report more frequent cannabis use, we see greater increases in insomnia symptomology. While many perceive cannabis to be a sleep aid, our results suggest frequent use may actually have long-term detrimental effects on sleep. This is in line with recent work assessing sleep among a sample of non-veteran young adults that revealed the psychoactive ingredient in cannabis (THC) is associated with decreased sleep latency (Nicholson et al., 2004), and other work noting the overall amount of nighttime sleep decreases over time among cannabis users, potentially suggesting a tolerance effect (Gorelick et al., 2013). While some have reported that among medicinal cannabis users, sleep latency decreases following cannabis use, others have linked cannabis use with poor sleep quality (Ogeil et al., 2015). Among veterans, a similar story has emerged in the literature: many use medical cannabis as an aid for poor sleep, and yet they often still have high levels of insomnia and sleep problems (Metrik et al., 2016). This is in line with what we display in Figure 1, where we simulate increases in cannabis use and see a steady increase in insomnia symptomology.

However, the complexity does not end here. In addition to cannabis use influencing insomnia, we also see that when perceived stress is high, veterans report greater increases in cannabis use during the course of the study. This result is not that surprising, given a robust literature provides evidence that cannabis users, and especially chronic users, most commonly use cannabis for stress relief. While the research in perceived stress and cannabis use is somewhat robust, some prior work using brain imaging data has revealed alterations in corticolimbic circuits involved in stress and reward regulation among chronic cannabis users (Bolla et al., 2004). While research on the effects of cannabis use on stress responses is ongoing, neuroscientific research indicates chronic cannabis consumption may impact brain development and sensitize individuals to life stressors. This idea has been presented in a theoretical model where stress confers risk for increased cannabis use and, subsequently, heightened use may alter brain stress and reward systems thereby decreasing one's capacity to cope with stress (Kalin et al., 2005; Sinha, 2001; Steckler et al., 2005). While it is impossible to determine if these factors are at play in our study, we note that while cannabis use preceded improvements in perceived stress among veterans in our sample, there may be more complex relations between cannabis use and stress reactivity over the longer-term.

The present study aimed to improve our ability to understand long-term associations between insomnia, cannabis use and perceived stress. Our results suggest there may be both benefits and costs of cannabis use among veterans. Specifically, for veterans who experience chronic sleep problems, perceived stress may become overwhelming and a strong held belief that cannabis use may relieve stress is at the cost of increasing insomnia symptomology. Thus, some veterans may find themselves in an unhealthy perpetuating feedback loop of using cannabis to combat one problem (stress), only to experience worsening of another problem (insomnia). This cycle has been suggested in prior work where individuals using cannabis to sleep appeared to find themselves caught in a cycle of heavier cannabis use to achieve the desired effect, resulting in greater risk of problematic use, and ultimately worsening sleep problems (such as insomnia; Babson et al., 2017). Thus, for veterans looking to improve their sleep or reduce stress, it may be useful to seek out behaviour change interventions, which can consist of formal treatment at a mental health clinic or a less formal treatment option such as utilizing mobile health (mHealth) apps freely available to veterans. For the latter, veterans have access to a wide variety of mHealth apps such as Insomnia Coach (Kuhn et al., 2022), which could help increase access to care for those who will not or cannot receive in-person treatment. Cognitive behavioural therapy for insomnia (CBT-I; Mitchell et al., 2012; Muppavarapu et al., 2020) is the gold-standard psychological treatment for insomnia and contains multiple evidence-based components targeting sleep health, including cognitive restructuring of maladaptive thoughts that impede sleep, relaxation practices to reduce pre-sleep arousal, and addressing problematic behavioural patterns that keep individuals caught in a cycle of insomnia. Though CBT-I has been found to improve insomnia symptoms among veterans and other populations across a number of studies, modifications of CBT-I, in both traditional in-person and group forms and via mHealth apps, are needed that concurrently address sleep problems and cannabis use (Bowyer et al., 2022).

4.1 | Limitations and conclusion

Our results should be interpreted in light of several limitations. Despite our use of longitudinal models that account for dynamic, temporal effects, our study is observational in nature. Therefore, causal inferences cannot be made as clear as they could be in a study with an experimental design (Cook et al., 2002). Measures are self-reported and prior sleep disturbances (during deployment) are unknown. Furthermore, our sample was not representative of all veteran populations and thus results may not generalize to all veterans. Finally, our cannabis use variable is days of cannabis use in the past month. Thus, constructs indicative of more severe cannabis problems such as cannabis-related consequences, cannabis use disorder symptoms or heavy cannabis use (i.e. daily cannabis use) may have differential associations with insomnia and stress. Though we asked veterans to indicate frequency of days they used cannabis with THC in any form, we did not assess quantity of use (e.g. amount used on use days), THC-level of the products used, or method of administration (e.g. edibles, smoked). Such detail will be important to assess in follow-up work. Researchers may wish to replicate or extend our results using more severe cannabis use measures or more frequently collected data, such as with daily diary studies.

In closing, this is the first study to assess the complex, and dynamic, associations between insomnia, cannabis use and stress among American veterans. Unlike prior research, we allowed these constructs to be both catalysts and consequences of change, which is in line with more recent theoretical models of insomnia (Davis et al., 2022; Hughes et al., 2018). While cannabis use is increasingly touted as a progressive and useful stress reliever, our results note some possible, unintended consequences of cannabis use, including worsening insomnia symptomology.

AUTHOR CONTRIBUTIONS

jordan davis: Conceptualization; formal analysis; funding acquisition; methodology; visualization; writing – original draft; writing – review and editing. **John Prindle:** Formal analysis; methodology; validation; visualization; writing – review and editing. **Shaddy Saba:** Conceptualization; methodology; writing – original draft; writing – review and editing. **Carl Castro:** Conceptualization; writing – review and editing. **Liv Canning:** Conceptualization; resources; writing – review and editing. **Angeles Sedano:** Project administration; resources; visualization. **Eric Pedersen:** Funding acquisition; project administration; writing – review and editing. **Justin Hummer:** Writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

Authors report no conflicts of interest.

DATA AVAILABILITY STATEMENT

data are available upon reasonable request and internal review of request by PI.

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SUPPORTING INFORMATION

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