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**LONGITUDINAL PROSPECTIVE RELATIONS BETWEEN CANNABIS
USE AND SUBSTANCE-FREE ACTIVITIES IN A DIVERSE
COMMUNITY SAMPLE OF EMERGING ADULT HEAVY DRINKERS**

Andrew T. Voss

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LONGITUDINAL PROSPECTIVE RELATIONS BETWEEN CANNABIS USE AND
SUBSTANCE-FREE ACTIVITIES IN A DIVERSE COMMUNITY SAMPLE OF EMERGING
ADULT HEAVY DRINKERS

by

Andrew T. Voss

A Dissertation

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Abstract

National drinking and drug use trends suggest emerging adulthood (ages 18-25) is the developmental apex of harmful co-use of alcohol and drugs, with notable recent increases in cannabis use among emerging adults. Many emerging adults naturally begin to reduce harmful alcohol or drug use into their late 20s and 30s, however, a significant subgroup report a developmentally persistent pattern of frequent alcohol and cannabis use. There is evidence that limited access to alternative substance-free reinforcement (SFR) is a risk factor for chronic alcohol and drug misuse, there is a need for longitudinal research that examines changes in patterns of SFR and cannabis use during this developmental window. This study examined baseline associations and dynamic relations between cannabis use and SFR using latent change score modeling over 32-months (five assessment waves) in a community sample of heavy drinking emerging adults (baseline $N = 439$, $M_{\text{age}} = 22.60$, 53.8% female, 47.7% White, 41.3% Black). Cannabis use and depressive symptoms were associated with less access to substance-free rewards at baseline. Participants with less household income, other drug use in the past-month, and more recent heavy drinking days reported more cannabis use at baseline. Cannabis use and SFR showed small decreases over study waves and participants with higher baseline cannabis use showed smaller reductions in cannabis use over time and steeper reductions in SFR. Assigned sex and college status influenced the magnitude of change trajectories of SFR (Female: $\beta = -.09$, $p = .02$ Male: $\beta = -.23$, $p < .001$) and cannabis use (Non college: $\beta = -.12$, $p < .001$; College: $\beta = -.22$, $p < .001$), respectively. Contrary to hypotheses, cannabis use was not prospectively associated with subsequent change in substance-free activity engagement across waves, or vice versa. Overall results are consistent with previous research suggesting that

cannabis use is associated with less access to SFR, but do not suggest a specific prospective association between these two outcomes in emerging adult heavy drinkers.

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Introduction

Behavioral economic (BE) theory suggests that the availability and price of substances compared to substance-free sources of reward (e.g., employment opportunities, recreational activities) is an important contextual variable that interacts with other risk factors commonly implicated in the development of substance misuse (Bickel et al., 2014; MacKillop, 2016). Thus, a focus of BE research is understanding and quantifying reward in the environment to inform prevention and treatment research (Acuff et al., 2019; Correia et al., 2003; Higgins et al., 2004; Lamb & Ginsburg, 2018). Early preclinical experimental studies were the first to demonstrate the impact of environmental changes on drug self-administration (Alexander et al., 1981; Heminway, & Furumoto, 1972; Parker & Radow, 1974). These studies shifted the current paradigm from a focus on simple operant experimental designs which evaluated drug self-administration in isolation, to a focus on important contextual variables (see Gage & Sumnall, 2019). Specifically, these studies demonstrated that rates of drug self-administration are lower in environments that are enriched via access to a variety of drug-free rewards (e.g., food, social reward, exercise). This key finding has since been replicated numerous times (Carroll et al., 2009; Cosgrove & Carroll, 2003; Robison et al., 2018; Venniro et al., 2019).

Studies with humans have extended this literature by evaluating the potential protective effects of substance-free reward on drug use both in the laboratory and in the natural environment. Higgins et al. (2004) conducted an important review of early laboratory studies with human subjects which demonstrated that providing the option of concurrently available monetary rewards can lead to fewer choices to self-administer drugs, even among chronic users (Vuchinich & Tucker, 1988). Importantly, substance-free activities have also been studied in the natural environment. Among college students, increased engagement with prosocial activities

(e.g., community service, academic leadership roles) is negatively associated with heavy drinking episodes (Fenzel, 2005). More time spent on academic activities as well as higher motivation to achieve academic goals is also associated with less drinking frequency over time (Vaughen et al., 2009). Further, increases in substance-free activity engagement have been linked to reductions in substance use similar to reductions observed after a brief motivational intervention (Correia et al., 2005). On a larger scale, after employing systematic efforts to increase access to afterschool and evening activities, and to reduce access to alcohol and other drugs, substance misuse decreased significantly among adolescents in Iceland (Kristjansson et al., 2016).

Substance-free alternative activities are also highly relevant to research on treatment and recovery. Those in recovery from substance abuse typically face the unique challenge of replenishing sources of substance-free reward damaged by the effects of chronic use, such as employment opportunities, financial resources, and personal relationships (Henkel, 2011; Tucker et al., 2016). In fact, more impairment in valued areas associated with substance-free reward (e.g., intimate relationships, vocational functioning) predicts greater severity of posttreatment relapse (Tucker et al., 2016; Vuchinich & Tucker, 1996). Multiple other studies have implicated environmental reward deficits as an important risk factor by demonstrating that deficits in substance-free reward are associated with increased levels of drug use and associated problems (Higgins et al., 2004; Hogarth & Field, 2020; Morris et al., 2017). For example, among college student heavy drinkers, deficits in access to reward were associated with a greater number of alcohol use disorder symptoms (Joyner et al., 2016). This literature has inspired several substance abuse treatments including behavioral activation, contingency management, and occupational incentive-based programs, which have all demonstrated efficacy in reducing

substance use via increasing alternative sources of reward (Daughters et al., 2018; Defulio & Silverman, 2011; Petry et al., 2017). Thus, access to alternative rewards may be an important protective factor against alcohol and drug use as well as an important mechanism of change in recovery (McKay, 2017).

Applied behavioral economic (BE) research suggests that both frequency and resulting enjoyment of activities is important to consider and provides a translational index of reinforcement value (Acuff et al., 2019; Correia et al., 2003). Using this framework, the ratio of substance-related reinforcement to total reinforcement (i.e., substance-related plus substance-free reinforcement) is an important indicator of the relative valuation of alcohol and drugs that may be related to substance problem severity and likelihood of change. Indeed, a greater proportion of substance-related reinforcement has shown consistent positive associations with alcohol use and associated problems in models that control for baseline level of use (Acuff et al., 2018; Morris et al., 2017; Skidmore et al., 2014). Further, Murphy et al. (2019) created a supplement for brief alcohol interventions designed to increase substance-free activity engagement and found that decreases in proportionate reinforcement from alcohol-related activities mediated the effects of treatment on reductions in alcohol use and problems. Other studies suggest greater proportionate substance-related reinforcement predicts poor response to alcohol intervention, and that greater reductions (i.e., increases in substance-free activity engagement) following a motivational intervention predict fewer alcohol related problems and less cannabis use at follow-up among college student heavy drinkers (Murphy et al., 2005; Yurasek et al. 2015).

Although the importance of alternative rewards has been well documented in laboratory research and in treatment studies, less is known about natural trajectories of substance-free activity involvement and relations with substance use over time. Moreover, findings related

specifically to substance-free reinforcement are mixed relative to the more robust associations between proportionate substance-related reinforcement and substance use. Less substance-free reinforcement has been identified as a mediator between socioeconomic disadvantage and greater conduct problems and substance use (Andrabi et al., 2017; Khoddam et al., 2018; Leventhal et al., 2015), suggesting that deficits in substance-free reinforcement are a relevant risk factor. Lee et al. (2018) found this to be a full mediation, in that socioeconomic disadvantage was no longer significantly associated with substance misuse development after accounting for less substance-free reinforcement. Another large longitudinal study with adolescents found that fewer substance-free rewarding activities (e.g., academic activities, sports team involvement) was prospectively associated with more frequent smoking as well as greater odds of initiating cigarette use (Audrain-McGovern et al., 2004; Audrain-McGovern et al., 2011). However, while most studies suggest that substance-free activities may precede changes in substance use, chronic use can result in a blunted neurological response to substance-free reward, which could suggest a reciprocal relationship (Koob & Moal, 2008; Volkow & Morales, 2015). In addition, among emerging adults this relationship is complicated by the fact that alcohol and drug use are highly social activities that can facilitate close social connections (Murphy et al., 2005; Sayette et al., 2012). Some studies suggest that heavy drinking is associated with increased substance-free reinforcement when it comes to certain activity categories, namely, sexual, and social reinforcement (Skidmore & Murphy, 2010). But as noted earlier, other activity categories are negatively associated with drinking (academic activity, volunteer/service activities; Fenzel, 2005; Murphy et al., 2005). In addition, the few studies that have evaluated substance-free activities as a prospective predictor have been conducted with adolescents and primarily focused on cigarette use and most studies which have examined cross-sectional associations have been limited to

alcohol use among college students. Thus, there is a need for more longitudinal studies evaluating substance-free activity changes over time among different high-risk groups as well as studies that evaluate other commonly used drugs.

Emerging Adulthood and Cannabis Use

Emerging adulthood is a particularly high-risk period because it is typically the developmental apex of alcohol and drug use (Lanza et al., 2021; Schulenberg et al., 2020; Terry-McElrath & Patrick, 2018). Emerging adulthood refers to a large age range (e.g., 18-29) and is broadly defined as a unique stage of life characterized by role transitions and identity formation that can facilitate risky drug use (Arnett, 2005;2007). This period is often characterized by increased access to peers who drink or use drugs (Allen et al., 2017; Arria et al., 2008; Doremus-Fitzwater et al., 2010; Sessa, 2005; von Sydow et al., 2002). In addition, the social rewards of substance use are particularly salient during this time and may outweigh consequences (Borsari, & Carey, 2001; Foulkes & Blakemore, 2016). Despite high prevalence rates of drugs and alcohol throughout emerging adulthood, many individuals tend to “age out” of these behaviors as they enter their 30s (Lanza et al., 2021; Patrick et al., 2019a; Prince et al., 2019). However, persistent cannabis use into adulthood is increasingly common (Kosty et al., 2017; Schulenberg et al., 2020) and some studies suggest that in general, cannabis use may peak later than other drug and alcohol use (Compton et al., 2016). Further, while cannabis use does show a gradual decline into adulthood, use is increasing across the lifespan and perception of risk is decreasing (Hasin et al., 2015; Patrick et al., 2021; Schulenberg et al., 2020).

Approximately 1-10 adults in the U.S. report non-medical cannabis use in the past year (Schulenberg et al., 2020). Emerging adults continue to exhibit the highest prevalence rates of any age group, with approximately 4 in 10 reporting use in the past-year and 3 in 10 in the past-

month. In addition to combustible cannabis, other non-traditional uses (e.g., edibles, vaping) are also increasing (Reboussin et al., 2019). Within emerging adulthood, daily cannabis use rates also remain high (Johnston et al., 2020; Schulenberg et al., 2020). Some estimates suggest that as many as 30% of emerging adults who use cannabis frequently may develop a cannabis use disorder (Hasin et al., 2016). Frequent cannabis use is routinely associated with worse academic outcomes (e.g., lower GPA, more skipped classes, higher dropout), as well as lower rates of employment (Allen et al., 2019; Arria et al., 2013; Arria et al., 2015; Martinez et al., 2015; Silins et al., 2014; Suerken et al., 2016; Zhang et al., 2016), and long-term negative psychosocial outcomes (Arria et al., 2016; Blanco et al., 2016).

Cannabis use Among Black Emerging Adults and Emerging Adults without a College Degree

Studies on non-majority subgroups of emerging adults are limited, and two groups, people of color, and non-college attenders, are underrepresented and important to consider due to high likelihood of health and economic disparities in the US. Considering racial/ethnic differences, some studies suggest that cannabis use prevalence is higher among those who identify as Black or African American (Patrick et al., 2021; Wu et al., 2016), which may be due in part to the experience of racial discrimination (Carter et al., 2019; Mays et al., 2007; Pascoe & Smart Richman, 2009). Another study found a greater prevalence of cannabis use disorders among Black individuals compared to other groups (Pacek et al., 2012), but other studies have failed to observe racial differences in cannabis use among emerging adults (Bierhoff et al., 2019; Buckner et al., 2016). Considering college status differences, one study suggested that cannabis use rates are increasing at similar rates for both college and non-college emerging adults (McCabe et al., 2021). This finding is contrary to previous findings which suggest that non-college emerging adults use cannabis at higher rates (Patrick et al., 2016; Schulenberg et al.,

2020). There are even fewer studies evaluating subgroup differences over time. In one relevant study, Patrick et al. (2021) found that while cannabis peaked in early emerging adulthood for White participants, among Black participants, cannabis use peaked at a later age. Further, they found that while cannabis use was lower among college attendees, alcohol use was higher. Numerous other studies have observed differences in alcohol and other substance use between 4-year college students and their non-college peers (Crum et al., 1993; Quinn & Fromme, 2011; Slutske, 2005; Velazquez et al., 2011) but studies with cannabis use are limited. Clearly there is a need for more research understanding predictors of cannabis use trajectories in higher risk emerging adult subgroups that experience economic and health disparities.

Prevalence and Outcomes of Co-Use of Alcohol and Cannabis

Co-use of alcohol and cannabis has increased in recent years during adolescence (Schlitz & Lee, 2018) and emerging adulthood (McCabe et al., 2021). As many as 2 in 10 emerging adults endorsed simultaneous use in the past-year (Terry-McElrath, & Patrick, 2018). Simultaneous use refers to use of both substances concurrently to experience the effects of both simultaneously, whereas co-use is a general term which refers to recent use of both substances, not necessarily at the same time (White et al., 2019). Among emerging adults who use both alcohol and cannabis, simultaneous use is almost twice as common as non-simultaneous co-use (Subbaraman & Kerr, 2015).

In general, emerging adults who use alcohol and cannabis experience more academic, interpersonal, and legal consequences compared to alcohol or cannabis only users (Shillington & Clapp, 2001; Shillington & Clapp, 2006). A review of co-use studies found similar results; co-use was associated with a greater likelihood of reporting significant consequences (e.g., motor vehicle accidents) across studies compared to alcohol or cannabis use alone (Yurasek et al.,

2017). Similarly, co-users report drinking more on cannabis use days (Gunn et al., 2019; Metrik et al., 2018) and more simultaneous use days are associated with more severe and chronic alcohol-related consequences (Copeland et al., 2012; Harrington et al., 2012). In addition, co-users are more likely to experience alcohol or other substance use disorders (Blanco et al., 2016; Weinberger et al., 2016; Yurasek et al., 2017). While co-use outcomes vary somewhat by amount of use (Harrington et al., 2012; Subbaraman et al., 2019), any co-use is typically associated with greater risk for severe outcomes compared to alcohol or cannabis use alone (Yurasek et al., 2017; Subbaraman et al., 2019). In addition, co-use outcomes vary by sex assigned at birth, with males typically reporting more frequent simultaneous use (Patrick et al., 2019b). While it is well established that co-users are at increased risk for a variety of negative outcomes, little is known about predictors of changes over time in this high-risk group and there is a need for more longitudinal studies.

Modifiable Risk Factors for Cannabis Use

Commonly studied risk factors for cannabis use include ADHD (Bierhoff et al., 2019), anxiety, depressive symptoms, and other acute negative emotions (Blanco et al., 2016; Buckner et al., 2007), positive expectancies and beliefs about normative use (Boden et al., 2013; Buckner, 2013; Simons & Carey, 2000; von Sydow et al., 2002), alcohol and other substance use (Bailey et al., 2019; von Sydow et al., 2002), and personality factors such as impulsivity and low conscientiousness (Bailey et al., 2019). As noted previously, emerging adulthood is often characterized by a high co-occurrence of many of these risk factors. Most emerging adults perceive cannabis use as normative during this time (Kilmer et al., 2006; Martens et al., 2006) and use is considered low risk (Johnston et al., 20). Further, emerging adulthood is typically characterized by more frequent impulsive behavior (Bechara, 2005). Depressive and other

mental health symptoms are also common during this time and often co-occur with alcohol and other drug misuse (Blanco et al., 2016; Boden & Fergusson, 2011; Connor et al., 2009; Johnston et al., 2020; Keith et al., 2015; White et al., 2019).

Despite extensive research on the risk factors and high prevalence of cannabis use among emerging adults, more research on evidence-based treatment and prevention is needed (O'Connor et al., 2020). One recent review found only a small number of studies evaluating brief interventions to reduce cannabis use among emerging adults (Halladay et al., 2019), and concluded that effect sizes were small, and that study quality was generally low. To inform cannabis treatment research, there is a need to evaluate potential modifiable protective factors and mechanisms of change in this age group. In addition, since cannabis use frequently co-occurs with symptoms of mental illness and other substance use, which in turn are related to worse treatment outcomes (Greenfield et al., 2012; McCabe et al., 2006; Mojarrad et al., 2014), there is a need for research to continue to examine the impact of these co-occurring modifiable factors and inform treatment approaches (Yurasek et al., 2017).

Cannabis and Substance-Free Activities Among Emerging Adults

Although numerous studies have implicated substance-free alternative reward as a protective factor relevant to problematic substance use broadly, there is a need for more studies examining this association with cannabis use specifically, in light of increasing prevalence rates (Johnston et al., 2020; Reboussin et al., 2019; Schulenberg et al., 2020). The association between cannabis use and substance-free alternative reward may be more nuanced during the emerging adult developmental period, considering high rates of intermittent use, common perceptions that use is widespread and harmless, and the fact that cannabis is generally used in social settings (Buckner, 2013; Hasin et al., 2015; Patrick et al., 2021; Schulenberg et al., 2020). More research

is needed to illuminate substance-free alternatives as a potentially highly relevant and modifiable factor that could inform treatment and prevention efforts.

Several previous studies have examined cannabis use and substance-free activities among emerging adults. One review of studies evaluating physical activity in adolescents and emerging adults who reported using one or more substances indicated that while alcohol was positively associated with physical activity, co-use of alcohol and cannabis was associated with more sedentary behavior (West et al., 2020). However, another study demonstrated a positive relationship between cannabis use and exercise (French et al., 2021). Buckner et al. (2010) found that college students who reported frequent cannabis use spent less time with academic and extracurricular activities. One recent study found that college freshman who reported less alcohol-free reinforcing activities also reported more co-use of alcohol and cannabis (Jun & Fazzino, 2023). Notably, this study did not specify that alcohol-free reinforcing activities also excluded cannabis use. Meshesha et al. (2015) found that heavy drinking students who also reported cannabis use spent less time exercising, studying, and participating in extracurricular activities compared to those who did not report cannabis use. Co-users also reported greater depressive symptoms compared to alcohol only users. Meshesha et al. (2018) replicated these results and found that co-users also endorsed more deficits in access to reward. Further, among college student cannabis users, those with the most negative attitudes towards substance-free experiences used at the highest rates (Simons & Carey, 2000). As noted above, Yurasek et al. (2015) also found that cannabis use was reduced after heavy drinking college student participants received a brief intervention designed to motivate reductions in cannabis use and to increase substance-free reward. Finally, one longitudinal study found that in a small sample of college students who reported non-medical prescription opioid use, 94% also reported regular cannabis

use and 80% reported regular alcohol use. This group spent significantly less time on academic activities and reported less expected enjoyment from a variety of typically enjoyable activities at three waves, over 12-months (Meshesha et al., 2017). Of note, most of these studies included smaller samples and have been comprised primarily of White college students. In addition, existing studies have generally examined associations between cannabis and specific categories of substance-free activities rather than more general associations with substance-free activity participation and enjoyment. Therefore, there is a need to further understand this potentially reciprocal relationship over time (Heinz et al., 2012) and in a more diverse (with respect to ethnicity and college status) community sample of emerging adults.

Current Study

The current study is the first to examine patterns of general substance-free activity engagement and cannabis use among heavy drinking emerging adults using latent change score (LCS) modeling. Latent change is a robust modeling approach that can be used to understand complex individual changes (increases or decreases over time) as well as bivariate reciprocal relationships between variables. We are interested in four primary exploratory aims. First, we aim to examine baseline associations between a general index of substance-free reinforcement (SFR) and past-month cannabis use. Based on previous findings we hypothesize there will be an inverse relationship (Meshesha et al., 2015; West et al., 2020). Second, we explore latent trajectories of cannabis use and substance-free activity reinforcement over five assessment waves. Previous longitudinal findings on trajectories of SFR have primarily evaluated specific activity categories or post-intervention changes among college students (Meshesha et al., 2017; Yurasek et al., 2015). Thus, we have no a priori hypotheses related to the nature of changes over time for SFR. Although studies on subgroups of cannabis users and peak use age are mixed,

studies generally support the assertion that cannabis use reduces with age (Allen et al., 2017; Patrick et al., 2021; Schulenberg et al., 2020). Previous findings suggest that across race-ethnicity groups, use peaks between ages 18-20 followed by a general decline and rates of decline are relatively consistent across college and non-college groups (Patrick et al., 2021). Thus, we hypothesize that cannabis use will show a reduction over time in the full sample. Third, we aim to understand longitudinal prospective relationships between cannabis use and SFR. We used bivariate latent change score modeling to examine if past-month cannabis use is associated with subsequent change in SFR or vice versa. Based on previous work, we expect to find potential bidirectional prospective relationships between these variables (i.e., negative cross-variable coupling effects; Audrain-McGovern et al., 2011; Leventhal et al., 2015; Volkow et al., 2015). However, since no studies have evaluated these variables using longitudinal dynamic modeling, we have no a priori hypotheses related to one being the *leading variable* (i.e., predicting subsequent change in the other).

Finally, we aim to understand the role of important predictors of baseline values and trajectories of outcome variables. Several relevant predictors will be included that are time-varying (i.e., expected to change across study waves) and invariant (i.e., stable, trait-like variables). Specifically, we hypothesize that, depressive symptoms (Boden & Fergusson, 2011; Blanco et al., 2016; Meshesha et al., 2015) and heavy drinking days (Gunn et al., 2019; Vaughn et al., 2009) will show positive relations with cannabis use and negative relations with substance-free activities and effects may vary across study waves. In addition, we expect several relevant invariant predictors may be associated with SFR or cannabis use. Namely, we expect that baseline household income will be positively associated with SFR (Leventhal et al., 2015), whereas baseline other drug use will be negatively associated (Meshesha et al., 2015). We have

no a priori hypotheses related to college status, sex assigned at birth, or race-ethnicity due to previous mixed findings. Nevertheless, it is important to continue to examine potential group differences to inform further treatment and psychosocial outcome research. Specifically, it is important to examine differences among these understudied groups (i.e., Female, Black/African-American, Non-college attenders) who experience health or economic disparities relevant to substance use and other psychosocial outcomes. Based on previous findings we expect race-ethnicity to be potentially relevant to cannabis use levels and trajectories (Patrick et al., 2021; Wu et al., 2016). Further, we expect sex assigned at birth to be relevant to cannabis use (Patrick et al., 2019b; Wu et al., 2016) and SFR (Murphy et al., 2006; 2007). Finally, we expect college status to be relevant to cannabis use based on previous findings (Johnston et al., 2020; Schulenberg et al., 2020) and we aim to examine potential differences in SFR among non-college attenders due to previous studies being limited to college students.

Methods

Participants

Participants were 499 emerging adults (see Table 1) recruited as part of a three-year longitudinal assessment study of heavy drinking among emerging adults during the transition into adulthood (R01AA024930; Minhas et al., 2020)¹. The current study uses data from the baseline, 8, 16, 24, and 32 month follow-up assessments. Across the 5 timepoints, participants

¹See Minhas et al. (2020) for a description of baseline data for the larger study sample.

Table 1. Baseline descriptive data

Note. Means (SDs) are presented for continuous variables, counts (percentages) are presented for categorical/count variables; PHQ-9 = Patient Health Questionnaire, 9-item version.

Variable	<i>N</i> = 439
Age (in years)	22.6 (1.0)
Race (2 largest groups)	
Black	181 (41.3%)
White	209 (47.7%)
Sex	
Female	236 (53.8%)
Male	203 (46.2%)
College Status	
College	277 (63.2%)
Non-College	162 (36.8%)
Past-Month Cannabis Use	
0=None	137 (34.9%)
1=Monthly	119 (25.9%)
2=Weekly	69 (15.1%)
3=Daily	40 (8.9%)
4=Multiple Times Daily	74 (15.1%)
Past-Month Heavy Drinking Days (HDD)	5.2 (4.8)
Income	
<\$15,000	76 (17.2%)
\$15,000-30,000	92 (20.9%)
\$30,000-45,000	76 (17.5%)
\$45,000-60,000	61 (14.0%)
\$60,000-75,000	26 (6.0%)
\$75,000-90,000	31 (7.0%)
>\$90,000	76 (17.4%)
Depressive Symptoms (PHQ-9)	8.0 (5.8)

with adequate data for 3 or more assessments were included in the analysis. This left a sample of 439 participants with viable data for analysis (87.9% retention for analysis of eligible participants). All participants endorsed at least one instance of cannabis use in the past year at baseline. Approximately 37% of participants were recruited from the community and were not 4-year college students or graduates ($n= 162$). The remaining participants were currently attending (39.7%) or had graduated from (60.3%) a 4-year college. Participants were required to be between ages 21.5-24.99 at the time of enrollment and required to endorse at least two past-month heavy drinking episodes (four standard drinks in one sitting for males or three for females). Exclusion criteria were (1) current/past psychosis, and (2) current/past treatment for alcohol use disorder. Approximately 41.3% of participants identified as Black or African American, 47.7% identified as White, and 5.7% identified as multiracial; the remainder identified as one other racial/ethnic group and each remaining group comprised <1% of the sample. See Table 1 for full demographic characteristics of the sample.

Procedures

Participants were recruited through the community (i.e., flyers, online advertisements) and at a large public university via campus-wide emails and screening surveys administered to students enrolled in psychology courses. Enrolled participants filled out counterbalanced surveys every 4-months, beginning with an in-person appointment and alternating between in-person appointments and partial surveys with fewer measures completed remotely². Compensation was \$40 cash for in-person appointments which took approximately 90-minutes, and \$20 for remote partial assessments which took approximately 30-minutes. Participants completed in-person

²All surveys were completed remotely after March 2020, when local COVID-19 lockdown procedures began.

assessments on a desktop computer and were told to complete remote assessments on their phone or computer in a private location. All procedures for the study were approved by the university Institutional Review Board (IRB). Data was collected from 2017-2021 in a state without legalized recreational or medical cannabis and legalization status did not change over the course of the study.

Measures

Substance-Free Activity Participation and Enjoyment (Reinforcement)

Participation in potentially enjoyable substance-free activities (e.g., attending a sporting event, shopping, having a conversation) was measured using the Activity Level Questionnaire (ALQ; Sigmon et al., 2010). The ALQ was designed to assess past-month participation in 36 activities and how much participants enjoyed each activity. The measure was modified to administer each item twice, once for activities that specifically included alcohol or drug use, and once for activities completed when not under the influence of alcohol or drugs (Meshesha et al., 2020). The current study used only items specifying substance-free activities. After selecting frequency of engagement in each activity on a 1-4 scale (*0 times in the past 30 days to more than once a day*), participants indicated how much they enjoyed each activity on a 1-4 scale (*unpleasant or neutral to extremely pleasant*). Frequency and enjoyment ratings were multiplied to create a cross product which reflected Substance-Free Reinforcement (SFR) from each activity. Finally, we created an average SFR value by summing each activity cross product and dividing by the total number of items. SFR values have a range of 1-16. Activity enjoyment and frequency ratings have shown differential associations with substance use in the past (Magidson et al., 2017). Therefore, models were tested with average frequency and enjoyment ratings separately in addition to the reinforcement cross-product. Reinforcement survey measures have

been used extensively in this population with college student and community samples and have demonstrated robust associations with substance use above and beyond depressive symptoms (Acuff et al., 2019; Hallgren et al., 2016; Magidson et al., 2017; Morris et al., 2017). In addition, reinforcement survey measures have demonstrated adequate test-retest reliability and concurrent mixed validity with emerging adult drinkers (Hallgren et al., 2016).

Cannabis Use Days

Past-month cannabis use was assessed using a single-item modified from the Alcohol, Smoking and Substance Involvement Screening Test (ASSIST; W.H.O. ASSIST Working Group, 2002). Participants responded to the item on a 0-4 Likert-type scale to indicate frequency of use over the past month, where: 0 = *None*, 1 = *Monthly*, 2 = *Weekly*, 3 = *Daily*, 4 = *Multiple times daily* (see Table 1). The item did not ask what method participants used to ingest cannabis (e.g., smoked, consumed edibles). The ASSIST has received substantial support for validity and reliability in this population (Humeniuk et al., 2008).

Depressive Symptoms

Depressive symptoms were included in models due to previous associations with cannabis use (Arias et al., 2020) and substance-free activities (Meshesha et al., 2015). Symptoms of depression were measured using the Patient Health Questionnaire, 9-item screening version (PHQ-9; Kroenke et al., 2001). PHQ-9 items assess DSM-5 criteria for major depressive episodes. Participants indicated the extent to which they experienced each symptom on a 4-point scale from 0 (*not at all*) to 3 (*nearly every day*), with total scores ranging from 0-27. The PHQ-9 has demonstrated good specificity and sensitivity (Kroenke et al., 2001) and psychometric properties comparable to lengthier measures (Kroenke et al., 2010).

Alcohol Consumption

Alcohol use was included in models due to previous associations with cannabis use (Gunn et al., 2019; Vaughn et al., 2009) and substance-free activities (Correia et al., 2005; Fenzel, 2005; Joyner et al., 2016). Heavy drinking days (HDD) over the past month were assessed using a single item which asked participants to indicate how many times they had 5/4 drinks in one sitting for males/females per NIAAA guidelines for risky episodic drinking (National Institute on Alcohol Abuse and Alcoholism, 2019).

Income

Household income was included due to previous associations with substance-free activity availability (Lee et al., 2018; Leventhal et al., 2015). Income was evaluated using a single item which asked participants to estimate the yearly income bracket for their household. Income brackets ranged from *less than \$15,000* to *greater than \$90,000*.

Demographics

Race-ethnicity, and college status was included to extend previous mixed findings on potential group differences (Johnston et al., 2020; Schulenberg et al., 2020; Wu et al., 2016). Education level was determined by asking participants the highest level of education they had attained. Participants were then asked if they were currently enrolled in an educational program, the status of their enrollment (e.g., part-time, or full-time), and the type of program (4-year degree, less than 4-year degree, or trade school). Participants who were currently enrolled or had graduated from a 4-year college or university were classified as “college” and all other participants were classified as “non-college”. This distinction was based on previous research indicating that although 4-year college students are at high risk for alcohol and drug use during

the college years, individuals without a college degree are at greater lifetime risk for alcohol and drug use disorders (Quinn & Fromme, 2011; Velazquez et al., 2011). Race-ethnicity was determined by having participants select the race-ethnicity they most identified with from various categorical options (e.g., Black/African ancestry, East Asian ancestry). Other drug use was measured using a single item which asked participants to indicate how many days out of the past 30-days they used various types of illicit drugs and prescription drugs not as prescribed.

Data Analytic Plan

Data screening and analyses was conducted using Mplus version 8 (Muthén & Muthén, 2017). Maximum likelihood estimator with robust standard errors was used due to its ability to handle non-normal and missing data. Data were not transformed or winsorized due to natural ceilings for all variables. We used fit indices recommended by Kline (2015) and cutoffs by Hu and Bentler (1999) to evaluate model fit. Specifically, values associated with excellent fit are a non-significant chi-square, root mean square error of approximation (RMSEA) values less than .05, comparative fit index (CFI) values above .95, and standardized root mean square residual (SRMR) values less than .05.

To address study aims, we used latent change score (LCS) modeling with five waves of data because of its utility in modeling various components of change over time (e.g., linear vs. non-linear, constant vs. proportional), the longitudinal reciprocal relationship between two variables, and the impact of time-varying and invariant predictor variables (Klopack & Wickrama, 2020; Usami et al., 2019). Model selection was guided by the above fit indices as recommended by Usami et al. (2016), with preference given to the RMSEA and the CFI.

To test our primary hypotheses, constraints were removed using a bottom-up approach, where constraints are removed only if model fit is significantly improved (Klopack & Wickrama,

2020). For nested models, a chi-square difference test was used to evaluate significant changes in fit. Based on recommendations by Mulder & Hamaker (2021), the Bayesian information criterion (BIC) was also considered in determining significant changes in fit, with preference given to the lowest BIC (Kass & Raftery et al., 1995), and constraints were only imposed or removed based on relevant empirical reasoning. To evaluate if there is overall change in cannabis use and/or substance-free activities over five waves, an unconstrained model was compared to a model where means are constrained to be the same across waves. If the unconstrained model demonstrates better fit than the constrained model, constraints are deemed untenable, thus suggesting that one or both variables change significantly over time. A similar process was utilized to determine if changes are constant, if fluctuations in cannabis use or substance-free activities are proportional to levels at the previous waves, or if a dual change model fits the data best. The dual change model is a unique feature of latent change score modeling and is a combination of constant and proportional change models. The dual change model allows for proportional change to contribute to interpretation of the constant change component (i.e., slope), thus allowing for examination of general patterns of change as well as the influence of proximal changes across waves.

Next, to evaluate baseline and reciprocal longitudinal relations between substance-free reinforcement (SFR) and cannabis use and vice versa, we compared bivariate models which constrained cross variable couplings (i.e., cross-lagged relationships), to models where couplings are freed to vary one at a time (see Klopck & Wickrama, 2020). For all bivariate models, parameters were estimated between outcome intercepts and constant change components within- and between-variables. The following parameters were fixed to be equal across time: residual variance of SFR and cannabis use, covariance between SFR and cannabis, paths from latent

cannabis to latent change in SFR and latent SFR to change in cannabis, and proportional change of SFR and cannabis use. These constraints are a recommended starting point by Grimm et al. 2012. We also tested models that allowed proportional within-variable change and cross variable couplings to vary to explore potential non-linear change. Finally, predictor variables were included individually in univariate models to determine significance before inclusion in the final model. Parameters were specified to determine if predictors (e.g., depressive symptoms, heavy drinking days, education level) were associated with initial levels of cannabis use or substance-free activities, constant change components, and change at each wave based on hypotheses.

Results

Baseline Descriptive Data

As noted previously, all participants reported past-year cannabis use. Approximately 65% of participants reported past-month cannabis use at baseline and 24% reported daily or multiple times daily use. Frequency distributions across the five waves are displayed in Figure 5. At baseline, participants reported an average of 5.2 ($SD = 4.8$) past-month heavy drinking days (see Table 1). Depressive symptoms were on average in the mild range. Approximately 27% of participants reported at least one instance of other drug use in the past 30-days (range 1-12 days), with cocaine and misuse of stimulant or sedative medications being most common.

Univariate Model Fit Testing

Univariate LCS models were evaluated for cannabis and SFR and fit statistics were compared to identify the most appropriate model among possible options including no change, proportional change, constant change, and dual change models. Fit statistics are presented in Table 2. For both the SFR and cannabis univariate models, the constrained (i.e., no change) model was deemed inadequate, with poor fit indicated by each of the indices. Thus, models

Table 2. Fit indices for univariate models

Note. SFR = substance-free reinforcement, RMSEA = root mean square error of approximation, CFI = comparative fit index, SRMR = standardized root mean square residual, BIC = Bayesian information criterion; *At least one of the variables in this model was not positive definite, χ^2 = chi-square.

	Cannabis			SFR		
	Proportional Change	Constant Change	Dual Change	Proportional Change*	Constant Change	Dual change
RMSEA	.385	.043	.050	.370	.028	.033
CFI	.000	.968	.961	.000	.977	.970
SRMR	.564	.063	.063	2.01	.055	.051
BIC	6949.04	6123.34	6158.72	9588.83	7860.24	7865.37
χ^2	801.39	24.79	26.39	739.9	18.01	18.25
χ^2 p-value	.00	.02	.01	.00	.15	.11

evaluating the nature of change were compared. The constant change model fit the data the best for the SFR model, with each of the fit statistics being in the excellent or acceptable range (Hu & Bentler, 1999). Similar fit statistics were observed for the Cannabis univariate model, with the constant change model representing the best fit compared to the dual and proportional change models³.

Substance-Free Reinforcement Model

The estimated baseline mean for SFR was 4.03 (range 1-16) and the constant change component indicated a significant but small reduction over subsequent timepoints ($\beta = -0.16$, $SE = .03$, $p < .001$; see Figure 4). Non-significant proportional change paths indicated that within-person change did not fluctuate based on the previous level of SFR at each wave. The variance of the true score was significant ($\beta = 1.46$), indicating between person variability of baseline values. Constant change variance was also significant ($p = .036$), indicating between person variance in

³To evaluate non-linear change, allowing for potential effects of the COVID-19 pandemic, models were also tested allowing proportional change pathways to vary across time points. These models demonstrated similarly poor fit on all indices and non-significant estimates and thus were not retained.

change rates. Covariance was non-significant, indicating that initial scores did not influence change rate.

Next, we added hypothesized predictors individually to determine significance before inclusion in a final model. Race-Ethnicity, household income, education level, and past-month heavy drinking days (HDD) were all unrelated to initial levels of SFR or change over time. Sex assigned at birth was positively associated with change over time ($\beta = .10, SE = .04, p = .03$), indicating that being assigned male sex at birth was associated with greater decreases in SFR. Other drug use was negatively associated with baseline SFR levels ($\beta = -.09, SE = .03, p = .03$). Depressive symptoms were also negatively associated with baseline SFR ($\beta = -.05, SE = .01, p = .002$). Depressive symptoms were also included at each time point to evaluate potential time-varying effects. However, depressive symptoms were not associated with subsequent change at any time point beyond baseline. In the final model, depressive symptoms, and other drug use remained negatively associated with baseline SFR and sex assigned at birth remained significantly associated with change over time (see Figure 1).

Cannabis Model

For the univariate Cannabis model, estimated baseline mean Cannabis was 1.43 (see Table 1 for the observed frequency distribution) and the constant change component indicated a significant but small reduction over subsequent timepoints ($\beta = -0.18, SE = .02, p < .001$). The variance of the true score was significant ($\beta = 1.42$), indicating between person variability. Constant change variance was also significant ($p < .001$), indicating between person variance in change rates. Covariance between baseline levels and change component was significant ($\beta = -0.17, SE = .03, p < .001$), indicating initial scores did influence change rate; higher baseline use was associated with less cannabis reduction over time.

Next, predictors were added individually to determine significance before inclusion in a final model. Race-Ethnicity, and sex assigned at birth were not related to initial levels or change in Cannabis use over time. Household income was significantly negatively associated with baseline cannabis use levels ($\beta = -.11, SE = .02, p < .001$). Education level was also significantly negatively associated with baseline cannabis use levels ($\beta = -.31, SE = .06, p < .001$).

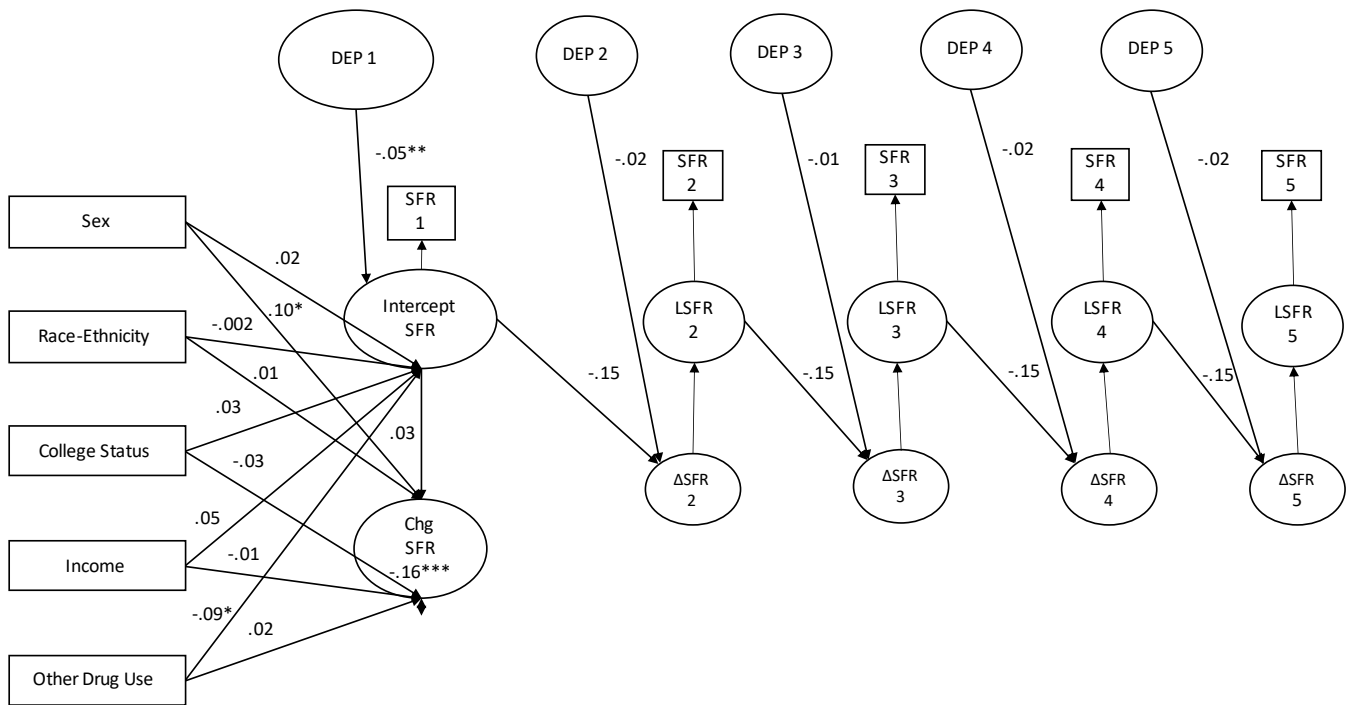


Figure 1. Final univariate SFR model with predictors

Note. DEP = depressive symptoms measured according to the PHQ-9; SFR = substance-free reinforcement; LSFR = latent SFR; Δ SFR = SFR change; Chg SFR = constant change; * = $p < .05$, ** = $p < .01$, *** = $p < .001$; HDD excluded due to non-significance in final model.

In addition, education level was positively associated with the constant change component ($\beta = 0.08$, $SE = .02$, $p = .005$); participants with higher education tended to reduce cannabis use over time to a greater extent compared to those with lower education. Past-month HDD was positively associated with baseline cannabis use ($\beta = .05$, $SE = .002$, $p = .02$) but unrelated to change over time. Other drug use was also significantly positively related to baseline cannabis use, ($\beta = .17$, $SE = .04$, $p < .001$), but was unrelated to change in cannabis use over time. Finally, depressive symptoms were associated with greater cannabis use at baseline ($\beta = .04$, $SE = .009$, $p = .01$) and less decrease in use over time ($\beta = -0.07$, $SE = .006$, $p = .04$). Depressive symptoms and HDD were also included at each wave to evaluate potential time varying effects. Neither depressive symptoms nor HDD were associated with individual change in cannabis use at any wave beyond baseline. When including all predictors in the final model, HDD, education level, other drug use, and income remained associated with baseline cannabis use in the expected directions, and education remained positively related to change over time (see Figure 2).

Bivariate Models

Next, bivariate models were compared to evaluate baseline associations and longitudinal reciprocal relationships between cannabis and SFR. Fit statistics were compared across the baseline model where cross variable coupling was constrained to zero, the cannabis leading model where prior level of cannabis was coupled with subsequent change in SFR, the SFR leading model where prior level of SFR was coupled with subsequent change in cannabis, and the bidirectional model where both coupling parameters were estimated. The baseline model demonstrated good to excellent fit on all indices (see Table 3). However, none of the

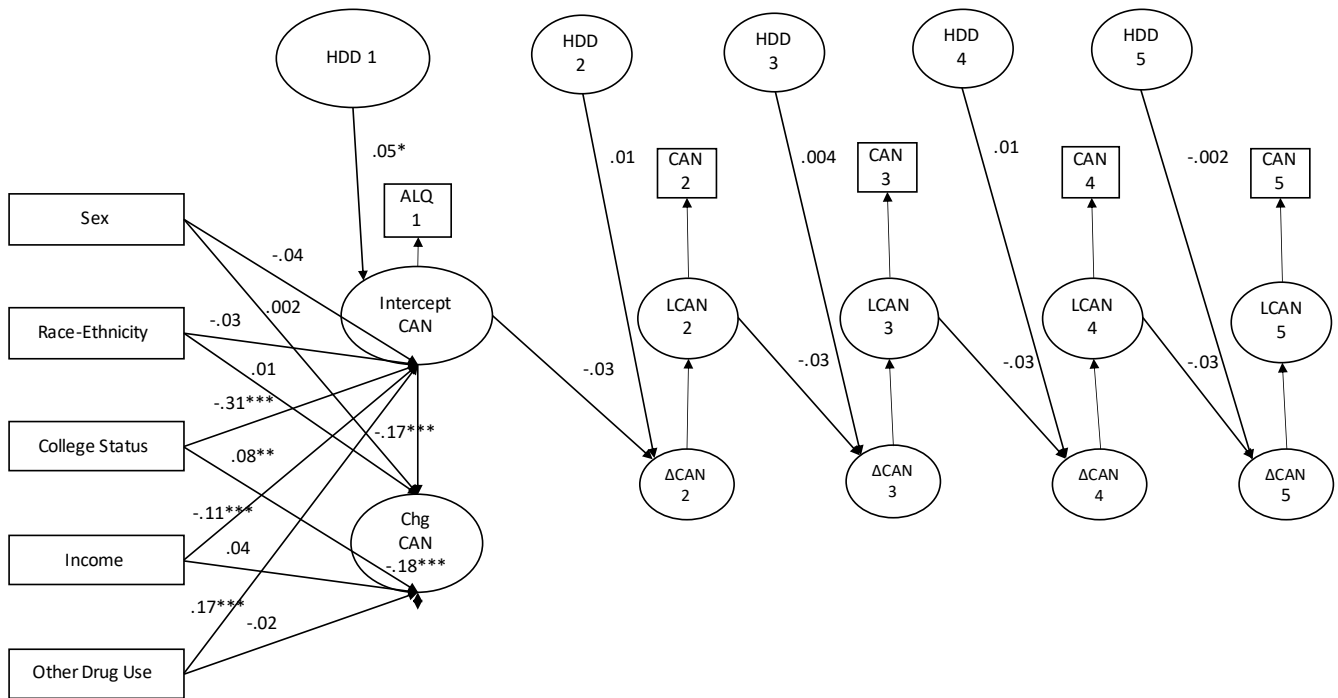


Figure 2. Final univariate cannabis model with predictors

Note. HDD = heavy drinking days; CAN = cannabis; LCAN = latent cannabis; ΔCAN = cannabis change; Chg CAN = constant change; * = $p < .05$, ** = $p < .01$, *** = $p < .001$; depressive symptoms excluded due to non-significance in final model.

Table 3. Fit indices for bivariate models

Note. *df* = degrees of freedom; SFR = substance-free reinforcement, RMSEA = root mean square error of approximation, CFI = comparative fit index, SRMR = standardized root mean square residual, BIC = Bayesian information criterion, χ^2 = chi-square.

	Baseline (<i>df</i> = 48)	Cannabis Leading (<i>df</i> = 47)	SFR Leading (<i>df</i> = 47)	Bidirectional (<i>df</i> = 46)
RMSEA	.026	.026	.027	.027
CFI	.979	.979	.977	.977
SRMR	.054	.053	.055	.054
BIC	14023.85	14028.47	14029.33	14033.81
χ^2	63.46	62.37	63.96	62.64
χ^2 <i>p</i> -value	.07	.07	.05	.05

hypothesized coupling pathways were significant (see Figure 3). SFR levels were not associated with subsequent within-person change in cannabis use at any time points beyond baseline and the same was true for prior cannabis use predicting change in SFR. In addition, none of the models demonstrated significant increases in model fit, evaluated with the chi-square difference test, compared to the baseline model where cross variable couplings were constrained to zero⁴. Covariance between cannabis use and SFR was negative indicating an inverse relationship at baseline ($p < .001$; see Figure 3). Cannabis use at baseline was also positively associated with SFR constant change component, indicating higher cannabis use at baseline was associated with generally steeper decreases in SFR over time. Thus, only baseline cannabis use level predicted change in SFR but subsequent values did not predict change at future waves. Bivariate models were also evaluated which allowed cross variable pathways to vary across times to evaluate if specific waves were associated with subsequent change in the other variable.

⁴Similar results were observed when models were run using the substance-free activity frequency and enjoyment ratings separately (Magidson et al., 2017). Each of these alternative models remained non-significant and demonstrated poorer fit than the SFR cross-product model.

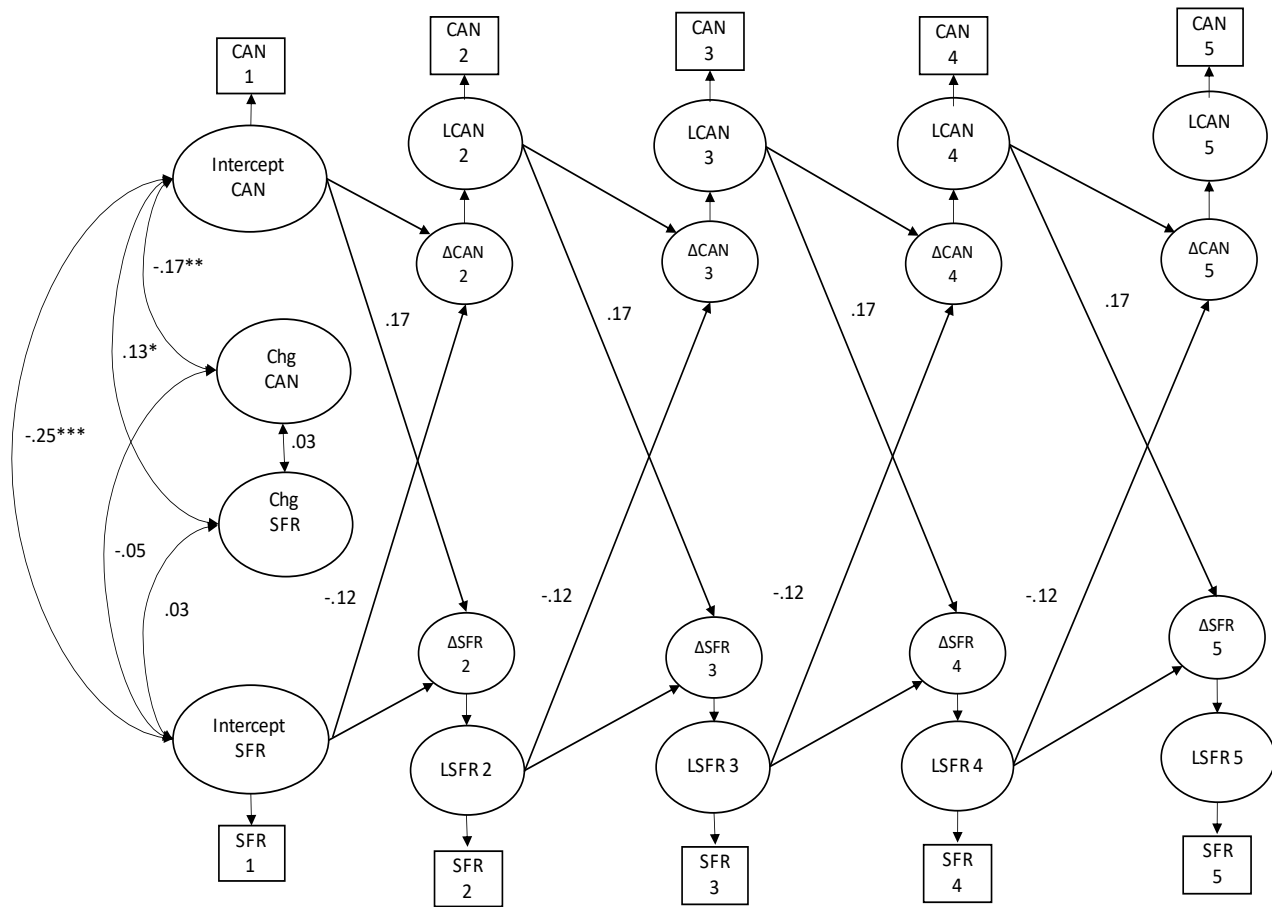


Figure 3. Final bivariate model with bidirectional coupling pathways and baseline associations
 Note. * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

These models yielded similar non-significant results and non-significant changes in fit according to chi-square difference testing⁵.

Multi-Group Bivariate Models

Since sex assigned at birth and college status were significantly associated with constant change components in the final univariate models, multi group models were evaluated using dichotomous demographic variables to further explore potential differences. Two multi-group models were conducted using dummy coded variables to evaluate differences across college status (0 = non-college, 1 = college) and sex assigned at birth (0 = Female, 1 = Male). The sex assigned at birth model indicated similar results to full sample models, namely, SFR constant change remained significant in both groups with differences in magnitude (Female: $\beta = -.09$, $SE = .03$, $p = .02$ Male: $\beta = -.23$, $SE = .04$, $p < .001$; see Figure 4 for mean differences over time), proportional within-variable change pathways remained non-significant, and hypothesized coupling pathways between cannabis and SFR remained non-significant. Similar results were observed for the college status multi-group model with negligible differences observed on all coefficients apart from the cannabis constant change value, which was almost twice as large in the college group compared to non-college participants (Non college: $\beta = -.12$, $SE = .02$, $p < .001$; College: $\beta = -.22$, $SE = .03$, $p < .001$; see Figure 5).

⁵An alternative model was tested based on recommendations by Grimm et al., 2012 and previous findings that changes in alcohol/drug use predicted subsequent change in substance-free activity engagement (Correia et al., 2005). This model estimated pathways between recent change in SFR and subsequent change in cannabis and vice versa. These new pathways were also non-significant at each time point.

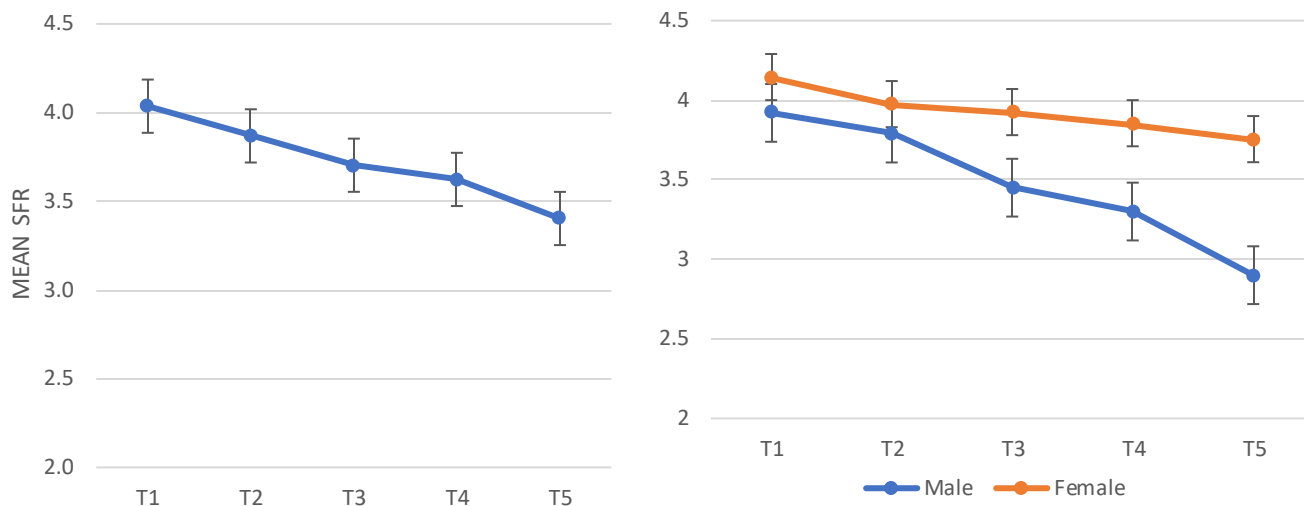


Figure 4. Mean (+/- 1 SE) changes in SFR across time and split by sex assigned at birth. Note. SE = Standard Error. Substance-free reinforcement means in the full sample (left panel) and split by sex assigned at birth (right panel). The right panel is a visual representation of the observed significant association between assigned sex and SFR change rate. The x-axis represents each assessment (T1 = Baseline – T5 = 32-months) and average SFR over the past month is represented by the y-axis.

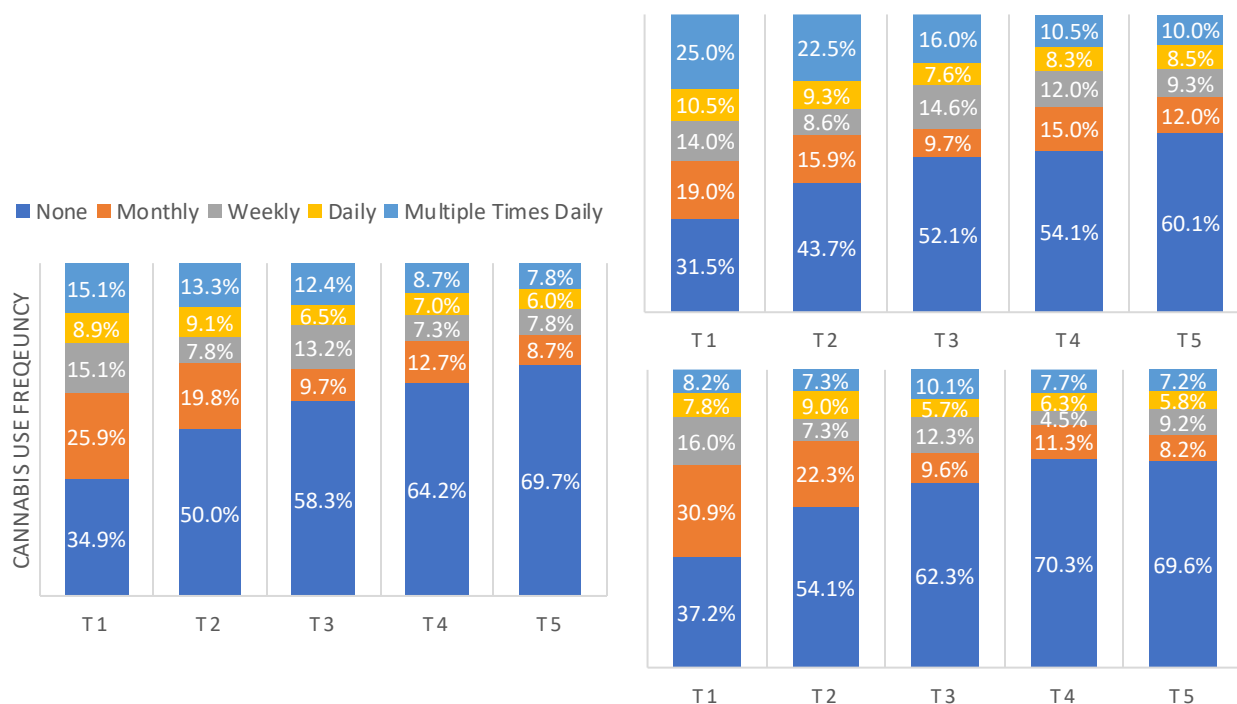


Figure 5. Frequency changes in cannabis use across time and split by college status. Note. Past month cannabis use frequencies in the full sample (left panel) and split by college status (right panel): top right = “non college”, bottom right = “college”. The right panel is a visual representation of the observed significant association between education and cannabis change rate. The x-axis represents each assessment (T1 = Baseline – T5 = 32-months) and frequencies of the past-month cannabis use variable is represented by the y-axis.

Discussion

The current study is the first to explore longitudinal reciprocal relationships between cannabis use and substance-free reinforcement (SFR) using a diverse community sample of emerging adults. The sample was comprised of non-treatment seeking 21–25-year-olds who reported recent heavy drinking and completed five assessments over 32-months. Approximately 65% of the sample reported cannabis use in the past-month and 24% reported daily or multiple times daily use at baseline. The current study provides insight into patterns of cannabis use and SFR and relevant predictors in this high-risk group. The current findings also provide important information for treatment and prevention based on findings of at-risk subgroups and potentially modifiable risk and protective factors.

Cannabis Trajectories and Predictors

Consistent with hypotheses, the current study demonstrated a reduction in cannabis use over time (Hasin et al., 2015; Patrick et al., 2021; Schulenberg et al., 2020). In the full sample, the number of participants reporting no cannabis use in the past month increased from 35% to 70% at the final wave. The magnitude of reduction over time was influenced by education level. Specifically, consistent with previous research, participants who were 4-year college students or graduates at baseline reported less baseline cannabis use and greater reductions in cannabis use over time (Patrick et al., 2016; Schulenberg et al., 2020). The number of participants reporting multiple uses daily was greater in the non-college group compared to college completers across all study waves (see Figure 5) and standardized estimates suggest a nearly twofold decrease in the college group compared to non-college participants. This finding extends previous literature showing higher lifetime risk of developing a substance use disorder among individuals without a 4-year college degree (Quinn & Fromme, 2011; Slutske, 2005; Velazquez et al., 2011).

Nonetheless, the current results suggest that, overall, non-college emerging adults also decrease cannabis use during their early to mid-twenties. These findings suggest that much like with heavy drinking, many emerging adults may naturally “age out” of cannabis use across the third decade of life, and that educational attainment is associated with a more rapid decrease in use (Lanza et al., 2021; Patrick et al., 2019a).

Participants with greater household income reported less past-month cannabis use at baseline. Previous epidemiological data has linked lower income to greater cannabis use frequency and prevalence of cannabis use disorder (Hasin et al., 2015). Cannabis use was also associated with greater depressive symptoms and more heavy drinking days at baseline, consistent with previous findings (Bailey et al., 2019; Blanco et al., 2016; von Sydow et al., 2002). However, neither of these variables were associated with individual changes in cannabis use over time. Although depressive symptoms have been frequently implicated as a relevant risk factor for heavier substance use across age groups (Johnston et al., 2020; Keith et al., 2015; White et al., 2013), this is one of the first studies to replicate this finding in a sample of emerging adults from the community. Further, symptoms of depression were also associated with less access to SFR, suggesting a potentially compounding effect. In addition, previous literature suggests a high co-occurrence of depressive symptoms, heavy drinking, and other drug use (Boden & Fergusson, 2011; Connor et al., 2009) and participants who endorsed greater frequency of other drug use also used cannabis at significantly higher rates at baseline in the current study. Taken together, the current results are consistent with previous findings which suggest that emerging adults who drink heavily and use cannabis likely experience a concurrence of potential risk factors necessary to address in treatment and prevention efforts.

The current study was conducted partially during the COVID-19 pandemic. Although the present analyses did not directly model pandemic effects, all participants completed at least the first two assessments prior to the start of the pandemic and there was no significant change in the trajectory of reductions post pandemic. Recent research on the impact of the COVID pandemic on substance use prevalence and severity is substantial, and yet results are mixed. Some previous findings have suggested that drinking frequency increased during the pandemic among middle aged adults (Vanderbruggen et al., 2020) and colleges students (Jackson et al., 2021), while other severity indices remained stable or decreased. Another large-scale study suggests that daily cannabis use escalated in adults who used cannabis prior to lockdown (van Laar et al., 2020). In a recent review of alcohol use outcomes reported by 128 studies conducted during COVID lockdown, Acuff et al. (2022) found that studies with young adults and individuals who reported more depressive symptoms were more likely to report increases. Multiple reviews evaluating adolescent substance use have suggested relatively stability of use but increases when accompanied with increased symptoms of anxiety and depression (Jones et al., 2021; Layman et al., 2022). There has yet to be a review of the literature on specific impacts among emerging adults and few studies have evaluated cannabis use trends, with one finding no change in frequency during COVID-19 lockdown (Vanderbruggen et al., 2020). However, many studies have had limited follow-ups and qualitative data collected from emerging adults suggests any increases in substance use may have been temporary until individuals could adjust to a “new normal” (Fedorova et al., 2022). Overall, more research is needed to understand potential effects of the COVID-19 pandemic on cannabis use among emerging adults.

Substance-Free Reinforcement Trajectories and Predictors

This was the first study to find that a general measure of substance-free reinforcement decreased over time in a sample of heavy drinking emerging adults. Previous studies have primarily utilized measures of specific categories of activities (Meshesha et al., 2015; 2018) or indices of proportionate substance-related reinforcement (Acuff et al., 2018; Morris et al., 2017; Skidmore et al., 2014) and the majority have been treatment studies or with participants in their early college years (Dennhardt et al., 2015; Murphy et al., 2005), when access to social and extracurricular activities is abundant. Post-college emerging adults and their non-college peers may experience natural decreases in access to enjoyable substance-free activities as they age, accompanied by changes in social relationships, increased work responsibilities, and other role transitions (O'Malley, 2004; Reed et al., 2007). In the full sample, decreases were consistent and relatively small over five assessments (see Figure 4). However, changes can be difficult to quantify using a general reinforcement survey index and more research is needed to further understand trajectories of SFR in this group.

The current observed decreases in SFR prior to and throughout COVID-19 physical distancing lockdown. Analyses did not indicate that reductions varied between pre- and post-pandemic data, indicating that overall change is likely attributable to other factors. Nonetheless, the observed reduction is consistent with other literature on potential reward deprivation during the COVID-19 pandemic lockdown. One relevant study using a large general adult sample in the US, found that heavy drinking episodes, depressive symptoms and coping drinking motives increased during the first 30 days of social distancing, while environmental reward decreased (McPhee et al., 2020). Another recent study on emerging adults' perceptions during pandemic lockdown found greater self-reported experiences of loneliness and negative emotions, less

reported socialization, and greater perceived cannabis use (Bonar et al., 2021). Several other studies have gathered data on the impact of loneliness and isolation during physical distancing requirements and suggest emerging adults may be particularly vulnerable to this impact (Bu et al., 2020; Settersten et al., 2020). Another previously mentioned review suggests that role changes (e.g., having kids at home, job loss) accounted for significant differences in alcohol use outcomes across studies (Acuff et al., 2022), further implicating limited access to SFR as potentially highly relevant broadly to substance use and other psychosocial outcomes.

The current study found differences in the magnitude of changes in SFR over time by assigned sex. Namely, participants assigned male at birth demonstrated greater decreases over time, suggesting that male sex assigned at birth may be a risk factor for lower SFR in the later emerging adulthood years. Previous research on sex differences is limited. Some previous findings suggest that female gender is associated with greater SFR (Murphy et al., 2007), and that college males may experience less social reinforcement from substance-free activities (Murphy et al., 2006), but this is the first study to find a sex difference in trajectories of SFR over time⁶. As discussed above, emerging adulthood is a period of identity formation and role transition that can be challenging to navigate for some (Arnett et al., 2007). Previous research on life course transitions suggests that social expectations for the timing of important role transitions (e.g., becoming a parent, earning an advanced degree, working full-time) differ for women and men (Crockett & Beal, 2012) and delaying these transitions may be more common in men (Andres & Adamuti-Trache, 2008). Thus, one interpretation of the current finding is that participants assigned male in the current sample may still be in a time of transition where they

⁶Acuff et al. (2023) found that prospective associations between behavioral economic indices of demand for alcohol and longitudinal alcohol problems also varied by sex assigned at birth in the current sample.

have yet to identify new sources of alternative substance-free reward via stable adult relationships, fulfilling work, or other sources. However, the current study did not evaluate potential mediators of this effect and did not have an adequate number of sexual and gender minority individuals to do statistical comparisons. This is a significant limitation of the current finding, and further research is needed to understand potential sex and gender identity differences in access to SFR.

Consistent with previous findings, the current study also found that depressive symptoms were associated with lower SFR at baseline (Boden & Fergusson, 2011; Blanco et al., 2016; Meshesha et al., 2015). Average depressive symptoms in the current sample were in the mild range with some variability and depressive symptoms were not associated with individual change in SFR beyond baseline. Future studies should examine this association over time in a treatment seeking sample or sample with higher average depression scores considering previous findings of a longitudinal reciprocal relationship following treatment for adolescent cannabis use disorder (Arias et al., 2020).

Consistent with hypotheses, other drug use was associated with less SFR (Meshesha et al., 2015), however, this association was small and no longer significant when included in the final model. Contrary to previous findings, heavy drinking days were not associated with SFR at baseline. This null finding persisted when comparing models evaluating individual components of SFR based on previous findings where enjoyment ratings but not frequency ratings were related to heavy drinking (Magidson et al., 2017). Notably, previous findings suggest that SFR is particularly relevant to drinking behavior or other substance use following treatment engagement (Dennhardt et al., 2015; Murphy et al., 2005). The current sample was not treatment seeking, which may explain the current null association. Further, some previous findings suggest that

heavy drinking is associated with increased substance-free reinforcement related to specific categories of activities (Sayette et al., 2012; Skidmore & Murphy, 2010). Heavy drinking and other substance use can facilitate social interactions among emerging adults which are often highly rewarding (Borsari, & Carey, 2001; Foulkes & Blakemore, 2016) and can lead to a more expansive social network and potentially more access to rewarding social activities that are substance-free. Additional studies are needed to further understand the nuanced social context of rewarding alternatives to drinking.

Associations between Substance-Free Reinforcement and Cannabis Use

Consistent with previous findings, cross-sectional results demonstrated that cannabis use frequency and SFR were significantly inversely related (Meshesha et al., 2015; West et al., 2020). In the current study, participants with higher cannabis use at baseline also tended to decrease cannabis use less and show greater decreases in SFR over the 32-month follow-up period. This finding is consistent with previous longitudinal findings which suggest that drug use frequency is broadly associated with less access to SFR over time (Khoddam et al., 2018; Leventhal et al., 2015; Meshesha et al., 2017), and extends previous research by focusing specifically on associations with cannabis use in a diverse community sample of emerging adults who report recent heavy drinking.

Contrary to hypotheses, cannabis use was not prospectively associated with within-person change in SFR or vice versa. As noted above, participants with higher baseline cannabis use showed generally steeper decreases in SFR over time but change in SFR and cannabis use did not predict subsequent within-person changes in the other variable across waves. This is the first study to examine these variables using dynamic longitudinal modeling and previous studies examining these associations have been limited to mostly cross-sectional data and between-

subjects findings (Buckner et al., 2010; Meshesha et al., 2015; 2018). The current modeling approach used a robust covariate model and analyses that separately evaluated individual trajectories and between-subjects baseline differences, making it difficult to detect within-person changes beyond existing group differences.

It is important to note that previous research has implicated SFR as a prospective predictor of initiating substance use (Lee et al., 2018), suggesting a potential protective effect among adolescents that is consistent with the inverse baseline association between SFR and cannabis we observed in our sample. Proportionate substance-related reinforcement (relative to total reinforcement) has also shown promise as a prospective mediator of brief alcohol intervention outcomes (Murphy et al., 2019). It is worth noting that proportionate substance-related reinforcement typically has strong associations with alcohol problem severity measures and considerable overlap with frequency measures (Acuff et al., 2018; Morris et al., 2017; Skidmore et al., 2014). The current study evaluated SFR apart from substance-related reinforcement. In addition to the potential for significant overlap with our cannabis use frequency measure, the current reinforcement survey measure was not designed to evaluate cannabis specific activity reinforcement distinct from other substances. Further, the current study sought to continue to evaluate the predictive utility of SFR independent of substance-related reinforcement to extend previous findings. While the current findings suggest that heavy drinkers who use cannabis more frequently at baseline do tend to report lower SFR over time, SFR and cannabis use appear to change relatively independent of one another among non-treatment seeking emerging adults in the community. There are several possible explanations for this null finding.

Notably, the current sample was a non-treatment seeking sample, as previously discussed, studies which have demonstrated robust associations between SFR and substance use have been conducted post-intervention (Murphy et al., 2019; Correia et al., 2005), and it is possible that intervention effects increase change in both. Further, the current data were collected to evaluate naturalistic changes and it is possible that discrete wave to wave changes in cannabis use or SFR were minimal or could have gone undetected due to time between assessments (see limitations below). Further, there are numerous longstanding biological and environmental factors that could influence individual differences in cannabis use and engagement with substance-free activities. The current study accounted for some of these stable factors (i.e., income, sex, race-ethnicity), but it is impossible to fully understand the nature of these factors associated with individual differences. These differences appear to be highly relevant to initial levels of cannabis and SFR as is evident by observed baseline relations and previous robust between-subjects findings. It is plausible that beyond individual stable differences at baseline, the current sample may not have demonstrated sufficient change over the 32-months of the study for incremental change from baseline values to have predictive utility.

In addition, the current data was collected partially over the early stages of COVID-19 pandemic. Although non-linear change models did not suggest that the pandemic impacted SFR or cannabis use trajectories disproportionately compared to pre-pandemic data, this is important contextual information and a limitation for the current findings. COVID physical distance requirements may have been initially disruptive, followed by a period of stability and potentially low engagement with different types of rewarding activities. In fact, while education and income were related to cannabis use in the current data, they were unrelated to SFR, which contradicts previous findings (Lee et al., 2018; Leventhal et al., 2015). This may indicate that regardless of

education or income differences, participants in the current sample experienced difficulties accessing enjoyable substance-free activities. Considered in conjunction with findings of relatively small changes in cannabis consumption during the pandemic among other age groups (Jones et al., 2021; Layman et al., 2022; Vanderbruggen et al., 2020), the current null findings may well be attributed to a general lack of change in this naturalistic study. Further research is needed to understand naturalistic changes apart from COVID-related influences present in the current data.

The current study was also the first to use a general measure of SFR to examine trajectories in this age group and the first to examine specific relations with cannabis use. Specifically, the current study used a reinforcement survey approach with a composite index of average reinforcement (i.e., enjoyment and frequency) from 36 substance-free activities. In a review of methods to measuring SFR, Acuff et al. (2019) discuss the strengths and limitations of reinforcement survey approaches. Although these measures typically have good psychometric properties and consistent associations with substance use broadly, limitations include an overreliance on retrospection, an arbitrary list of pre-selected activities, and a limited categorical frequency rating system. While an-item level analysis of specific types of salient activities was beyond the scope of this study, future research on relevant categories of activities and individual relations with cannabis use outcomes are essential. It is also important to continue to evaluate and understand the role of major life transitions during this time including obtaining a degree, changing jobs, getting married and others which may significantly impact engagement with substance use and the type and quantity of available alternative rewarding activities (Acuff et al., 2022).

Some previous studies have examined specific substance-free activity types including exercise and academic activities (French et al., 2021; Meshesha et al., 2017; West et al., 2020) and have some mixed findings. While specific activity categories such as academic productivity are generally somewhat incompatible with frequent substance use in a college sample, other categories, such as socializing or meeting romantic partners, may be facilitated by use or be unrelated and more research is needed using community samples. Although certain categories of activities are commonly cited in intervention and prevention efforts (e.g., exercise, mood enhancing activities, volunteering, community/religious activities), behavioral treatment research suggests that selecting personalized value-driven activities may also be important (Daughters et al., 2018). Thus, cannabis use may have a varied and inconsistent relationship to many activities for emerging adults. For example, motives for cannabis use tend to vary considerably across situations and emerging adults are more likely to choose cannabis to enhance experiences compared to other drugs or alcohol (Arterberry et al., 2021; Lee et al., 2007). In addition, although cannabis use remains illegal in many states, use is commonly perceived as low risk and socially acceptable (Boden et al., 2013; Buckner, 2013; Schulenberg et al., 2020) and legal consequences for possession have decreased dramatically across states (Plunk et al., 2019). Thus, it may be increasingly common to use cannabis in public settings or immediately prior to engaging in activities inside or outside the home, even in states where cannabis remains illegal. These unique factors complicate the relationship between cannabis use and many types of activities that may have previously been considered somewhat incompatible with use of risky or less socially acceptable substances. Thus, there is a need to continue to evaluate this relationship since we can expect results may vary considerably based on sample characteristics.

Clinical Implications

There are several potential clinical implications of the current results. Namely, heavy drinking emerging adults who use cannabis frequently may be at elevated risk of developmentally persistent cannabis use and have difficulty accessing substance-free sources of alternative reward. This may be particularly true for males who did not attend college and individuals with low income. In addition, greater depressive symptoms, greater frequency of heavy drinking days, and other drug use are relevant potential targets for prevention and intervention in this group. Studies using community samples of emerging adults are scarce and this population may be particularly difficult to access due to low rates of treatment seeking and recruitment and retention challenges. Nonetheless, more studies are essential to continue to examine psychosocial outcomes in this high-risk group. Brief motivational interventions have shown potential for small effect sized reductions in cannabis use among emerging adults (Halladay et al., 2019) and may be particularly accessible for this population and effective due to potential for addressing ambivalence or establishing harm-reduction goals. Further, Bonar et al. (2022) recently conducted a randomized clinical trial to establish efficacy and acceptability of a novel social media-based intervention to reduce cannabis use among emerging adults. The study recruited non-treatment seeking emerging adults who reported recent cannabis use and utilized a novel 8-week motivational interviewing intervention implemented via social media. The intervention received strong support for feasibility and acceptability and initial small effect size reductions in cannabis use as well as co-use of alcohol and cannabis days compared to the control group. Similar targeted treatment and prevention efforts are needed in this group to mitigate high prevalence rates, high concurrence of other risk factors, and low rates of treatment seeking.

Limitations and Future Directions

The current study used a moderately large sample and employed contemporary statistical modeling methods to explore dynamic, bidirectional effects between substance-free activity engagement and cannabis use frequency. The sample was relatively ethnically-racially diverse and contained college students and non-college same-aged peers, indicating increased generalizability. Despite these strengths, the current study was not without limitations. The current sample was recruited based on heavy drinking criteria and thus, it is possible the results would be different with a sample selected based on cannabis use frequency. Future studies may consider investigating these effects in samples selected based on regular cannabis use, and that include more frequent (i.e., daily) cannabis users since previous findings suggest that cannabis and alcohol co-use outcomes can vary by frequency/severity of use (Harrington et al., 2012; Subbaraman et al., 2019). In addition, the current study was limited to a categorical frequency measure of past-month cannabis use and future studies should utilize more robust measures of quantity, frequency, or severity of use.

The current measure of SFR also has limitations as previously discussed, including reliance on retrospection and a limited frequency rating system. Future studies should examine SFR using real-time assessments (e.g., ecological momentary assessment) which would bypass potential issues with retrospection and allow for a thorough examination of relations between specific activity types and cannabis, and important contextual factors such as current mood and social setting. In addition, the current results from univariate models suggest that change trajectories of cannabis and SFR varied significantly between subjects. While the current study evaluated several relevant random effects variables that may account for these differences,

further research is needed using person-centered approaches (e.g., latent profile analysis) to examine subgroup differences over time and predictors of group membership.

Further, the time scale of data in the present study (i.e., 8 months between each assessment) may not be ideal for detecting effects between these aggregate behavioral variables. The current variables collected data from the past month at each wave but likely did not adequately capture fluctuations that could have occurred outside of this window in between assessments. Future research should utilize shorter follow-up periods to detect discrete changes in these variables over time. As discussed above, the current study collected data prior to and throughout the COVID-19 pandemic. Physical distancing requirements likely had a significant impact on participants' cannabis use and ability to access alternative substance-free activities and could explain the observed reductions across study waves. In addition, the current data was collected in a state where medicinal and recreational cannabis use remains illegal. Future research should continue to evaluate cannabis use trends across states with different legalization statuses to improve generalizability. Finally, we cannot infer causation from the associations observed in this naturalistic study.

Conclusion

The results of this study are consistent with previous between-person studies and extend these data by exploring within-person effects over time. Although the current study did not find significant within-person reciprocal relationships between cannabis and SFR, the current findings suggest these variables are associated, and that emerging adult heavy drinkers who use cannabis more frequently report lower levels of SFR over time. Emerging adults assigned male sex at birth and individuals who did not attend college are two groups that warrant further investigation and may face increased risk. Further, the current results implicate several relevant

modifiable treatment and prevention targets including depressive symptoms, and other drug use. Future research should continue to explore these associations in clinical samples, using real-time assessment methods, and using person-centered statistical modeling to further examine subgroup differences over time. The current results should inform future efforts to evaluate the potential impact of key life transitions likely to occur in this critical developmental period.

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Appendix A

IRB Approval Letter



Institutional Review Board
Division of Research and Innovation
Office of Research Compliance
University of Memphis
315 Admin Bldg
Memphis, TN 38152-3370

March 24, 2022

PI Name: James Murphy
Co-Investigators: Samuel Acuff
Advisor and/or Co-PI:
Submission Type: Modification
Title: Behavioral Economic Trajectories of Alcohol Misuse
IRB ID: #4320
Level of Review: Full Board

Approval: March 24, 2022
Expiration: --*

The University of Memphis Institutional Review Board, FWA00006815, has reviewed your submission in accordance with all applicable statuses and regulations as well as ethical principles.

The modification is approved.

Approval of this project is given with the following obligations:

1. This IRB approval for modification has an expiration date, an approved renewal must be in effect to continue the project prior to that date. If approval is not obtained, the human subjects consent form(s) and recruiting material(s) are no longer valid and any research activities involving human subjects must stop.
2. When the project is finished a completion form must be submitted.
3. No change may be made in the approved protocol without prior board approval.
4. Human subjects training is required every 2 years and is to be kept current at citiprogram.org.

**Modifications do not extend the expiration of the original approval*

Thank you,
James P. Whelan, Ph.D.
Institutional Review Board Chair
The University of Memphis