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DOI
10.1016/j.addbeh.2021.107221

Publication date
2022

Document Version
Final published version

Published in
Addictive Behaviors

Addictive Behaviors 128 (2022) 107221

Contents lists available at ScienceDirect

Addictive Behaviors

journal homepage: www.elsevier.com/locate/addictbeh

Cannabis use as a predictor and outcome of positive and negative affect in college students: An ecological momentary assessment study

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ARTICLE INFO

Keywords:
Micro-longitudinal research designs
Cannabis-related problems
Mood
Negative and positive affect
Cannabis use
Positive and negative reinforcement
College students

ABSTRACT

Background: Reinforcement models identify negative affect (NA) and positive affect (PA) to be important momentary determinants and outcomes of cannabis use. Sensitization and allostatic models further suggest that these mood-cannabis associations are stronger among individuals with more cannabis-related problems. Despite this theoretical background and the fact that cannabis is commonly used for its mood-enhancing effects among college students, surprisingly, little is known about the momentary associations between mood and cannabis use in this population.
Aims: To examine the associations between (a) momentary within-person variations in NA (worried, stressed, nervous) and PA (happy, enthusiastic, proud, excited) and intention to use cannabis within the next hour, (b) the within-person variations in time elapsed since last cannabis use, amount used and momentary NA and PA, and (c) to test whether cannabis-related problems moderate the stated associations.
Method: Eighty, more-than-weekly, cannabis using students at the University of Amsterdam reported on cannabis use, NA and PA three times daily for 14 consecutive days. Mixed-effects models were performed to analyze the dataset.
Results: Within-persons, relatively high PA and low NA were associated with a higher likelihood of intending to use cannabis. Within-persons, more recent and greater amounts of cannabis use were associated with relatively high PA. More recent cannabis use was associated with relatively low NA. Cannabis-related problems did not moderate the associations.
Conclusions: While recent cannabis use related to higher PA and lower NA, high PA but low NA preceded use, supporting positive reinforcement rather than negative reinforcement in this college sample of regular cannabis users

1. Introduction

Cannabis use among college students is high and linked to adverse educational and health outcomes (Gunn et al., 2018; Pearson et al., 2017; Schulenberg et al., 2020). Despite this, college students tend to not seek treatment (Buckner et al., 2010; Fernández-Artamendi et al., 2013). Cannabis users commonly use cannabis to relieve negative affect (NA, e.g., stress, depression, anxiety) and to enhance positive affect (PA, e.g., happiness, joy) (Wycoff et al., 2018). Mood fluctuations play an important role in the maintenance of substance use and addiction (Cheetham et al., 2010). To date, little is known of the daily-life within-person relationships between cannabis use and mood in non-treatment seeking populations. We aimed to unravel the natural interplay between within-person fluctuations in cannabis use, PA, and NA in cannabis-using college students and to assess the role of cannabis use problems in these associations.

1.1. Mood, reinforcement and cannabis use

Positive and negative reinforcement are suggested to play different roles in trajectories of cannabis use and related problems. Positive reinforcement relates to cannabis use to enhance PA and is thought to be involved in the relatively early stages of cannabis use experiences (Bresin & Mekawi, 2019). Cannabis intoxication enhances positive

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https://doi.org/10.1016/j.addbeh.2021.107221
Received 6 July 2021; Received in revised form 19 December 2021; Accepted 20 December 2021
Available online 1 January 2022

mood (Matheson et al., 2020) and activates brain areas involved in reward processing, but interestingly, these effects seem less pronounced in heavier users (Mason et al., 2021).

Cannabis use has frequently been found to be driven by negative reinforcement, (Hathaway, 2003; Reilly et al., 1998) and cannabis users report using to cope with depressed mood, stress and anxiety (Bravo et al., 2019; Buckner et al., 2007; De Dios et al., 2010; Hathaway, 2003; Ogbome et al., 2000). Moreover, individuals with psychological vulnerabilities and those who experience uncomfortable psychological states are particularly likely to use cannabis to reduce NA (Baker et al., 2004; McDonald et al., 2003; Metrik et al., 2011).

The relation between mood states and cannabis use is likely dynamic, transient, and variable within individuals. Intoxication from cannabis inhalation roughly peaks after 30 min and can last for a duration of 4 h, depending on the cannabis dose, product, and use history (Noble et al., 2019). Ecological momentary assessments (EMA; Shiffman et al., 2008) can capture these dynamic intra-individual processes.

Despite the prevalence peak of cannabis use during young adulthood (UNODC, 2020), and the fact that a large proportion of these young users will not seek treatment (Buckner et al., 2010; Fernández-Artamendi et al., 2013), most EMA studies of cannabis users have focused on clinical samples (Wycoff et al., 2018). Moreover, the scant evidence from community samples are mixed (Wycoff et al., 2018); NA was higher before cannabis use in a sample of mostly college students (Buckner et al., 2015), but Chakroun et al., (2010) found depressed mood to negatively relate to subsequent cannabis use. Furthermore, two studies reported lower NA (Buckner et al., 2015; Treloar Padovano & Miranda, 2018), one study reported no relation with NA (Buckner, Crosby, & Wonderlich, 2012), and one study reported higher anxiety (Tournier et al., 2003) after cannabis use.

Concerning PA, high PA has been observed both before (Buckner et al., 2015; Chakroun et al., 2010) and after cannabis use (Treloar Padovano & Miranda, 2018). Although, Bucker and colleagues found no association (Buckner et al., 2015).

1.2. The moderating role of cannabis-related problems

Sensitization and allostatic models suggest that within-person associations between mood and cannabis use are clinically relevant dynamic neurobiological processes that underlie cannabis use problems (Koob & Le Moal, 2001; Robinson & Berridge, 2008). From this perspective, it can be expected that NA and PA fluctuations before and after cannabis use are particularly large among cannabis users with more severe cannabis use problems.

To the best of our knowledge, only one EMA study has investigated whether cannabis-related problems interact with momentary mood and cannabis use relations. In a community sample of regular cannabis-using adolescents and young adults, participants with higher cannabis use disorder (CUD) severity reported sharper increases in PA (e.g. stimulation) and sharper decreases in craving following cannabis use relative to those with fewer CUD symptoms (Treloar Padovano & Miranda, 2018).

1.3. The current study

The current study investigates i) whether within-person fluctuations in momentary PA and NA predict intention to use cannabis within the next hour, ii) whether a within-person fluctuation in time elapsed since last cannabis use and amount of cannabis used predicts momentary PA and NA, and iii) whether cannabis-related problems moderate these associations in college students. Currently, the moderating role of CUD on the associations between cannabis use and feelings of stimulation, sedation, tension, craving, and high has been investigated (Treloar Padovano & Miranda, 2018). The current study will expand on this by including additional mood states (PA and NA), a broader measurement of cannabis-related problem severity, and a sample of students exposed to an environment of cannabis decriminalization.

As previously stated, cannabis users report use to increase PA and reduce NA. Based on this background, we hypothesized that when participants experience relatively high PA and NA, they would be more likely to intend to use cannabis within the next hour compared to when they report lower levels of PA and NA (H1). Furthermore, we expected that when relatively little time has passed since last cannabis use and after use of a relatively high quantity of cannabis use, participants would report more PA (H2a), and less NA (H2b), compared to when they reported more hours elapsed and lower quantity used. Based on theoretical (Robinson & Berridge, 2008) and empirical (Treloar Padovano & Miranda, 2018) research related to sensitization to cannabis' acute effect, we expected that the hypothesized associations between PA/NA and cannabis use would be stronger in participants with higher levels of cannabis-related problems (H3).

2. Methods

2.1. Procedure

The study protocol was approved by the ethics committee of the University of Amsterdam. A recruitment notice and study description was posted to first-year psychology students enrolled at the University of Amsterdam. Participants signed up online, completed informed consent, provided contact details, and confirmed they met eligibility criteria: 18+ years of age; smoking cannabis joints at least weekly to ensure cannabis use during the study period and reduce heterogeneity in effects of cannabis intoxication by mode of use. Eligible participants received a link to the online baseline survey. During the subsequent fourteen days, three daily surveys were sent at 11:00, 15:00, and 19:00, which had to be completed within 2 h. Four participants who reported no cannabis use during the study period and 11 participants who completed $\leq$30% of daily surveys were excluded from analyses (Delespaul, 1995) leading to a final sample size of 80 participants. Participants who filled $\geq$80% ($n = 67$) of daily surveys were rewarded with 3 Psychology Research Credits. On average, participants filled in 33.8 daily surveys, were 21 years old (S.D. = 3.14), and were 35% male/65% female.

2.2. Measures

Baseline measures included age and sex (male, female, other). None of the participants entered 'other'). Cannabis use-related problems were assessed with the 8-item Cannabis Use Disorder Identification Test-revised (CUDIT-R; Adamson et al., 2010). CUDIT-R is a reliable measure for identifying at-risk cannabis use among non-treatment seeking college students (Schultz et al., 2019). Items ranged from 0 to 4 and were summed, resulting in total scores between 2 and 25 (Cronbach alpha = 0.74).

For descriptive purposes, duration, frequency and quantity of cannabis use, and cannabis use treatment history were assessed. Alcohol use problems were assessed with the 10-item Alcohol Use Disorder Identification Test-revised (AUDIT; Saunders et al., 1993). Items ranged from 0 to 4 and were summed, resulting in total scores between 2 and 24 (Cronbach alpha = 0.78). General mental health was assessed with the 20-item DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure—Adult (DSM-5 CCSM; American Psychiatric Association, 2013), excluding the substance use items. The DSM-5 CCSM measures severity of a broad range of mental health symptoms during the past 2 weeks and is a viable tool for evaluating psychopathology in non-treatment college students (Bravo et al., 2018). Items ranged from 0 (never) to 4 (always) and were summed, resulting in a total score between 3 and 57, with higher scores indicating worse mental health (Cronbach alpha = 0.88).

Momentary affect assessments: In each EMA survey participants were asked how strongly, in the current moment, they felt the following emotions adopted from the PANAS (Watson et al., 1988): happy, enthusiastic, proud, excited, worried, lonely, stressed, and nervous. Items ranged from 1 (not at all) to 5 (a great deal). Reliability analyses

according to the Generalizability Theory (Goldstein & McDonald, 1988) showed that the loneliness item lowered reliability substantially at the within-person level (between-person reliability with loneliness = 0.97, within-person reliability with loneliness = 0.34). Due to this, the item was excluded before calculating the average PA and NA scores. Reliabilities were excellent at the between-person level (PA = 0.98; NA = 0.97) but lower at the within-person level (PA = 0.62; NA = 0.54).

Momentary cannabis use assessments: In each EMA survey participants were asked whether they intended to use cannabis within the next hour (0 = no, 1 = yes) and whether they had used cannabis since the last EMA survey (0 = no, 1 = yes). Those who confirmed cannabis use since last EMA were asked how long ago they last used cannabis (30-minute interval answer categories, from 0 = 0 min to 16 = >480 min) and how much they had used in grams (participants that did not use were coded as missing).

2.3. Statistical analysis

Normal distribution requirements were confirmed through data visualization, the ladder of powers tests, and residual diagnostics. No outliers were present in this dataset. The xtmelogit stata command (StataCorp, 2011) was used to calculate logistic mixed-effects models that tested H1 and the associations of PA and NA (predictors) with the intention to use cannabis within the next hour (dependent variable). The stata command xtmixed (StataCorp, 2011) ran linear mixed-effects models to test H2a/b and to estimate associations of time elapsed since last cannabis use and grams used (predictors) with PA and NA respectively (dependent variables). The following ICCs based on unconditional models showed substantial variance in the outcome variables occurring within individuals: intention to use cannabis = 0.31; PA = 0.52, NA = 0.39.

Models included both within- and between-person versions of the momentary independent variables. This is important to facilitate inferences about the within-person associations between (1) the momentary fluctuations of PA and NA and intention to use cannabis and (2) fluctuations in time elapsed since last cannabis use and amount used and momentary experiences of NA and PA, while controlling for between-person differences in these associations. Between-person versions of each of the momentary independent variables were created by group-mean centering. Within-person versions of these variables were then created by subtracting the group-mean variable from the raw scores (i.e. within-person mean centered).

As recent use may be associated with mood and intention to use cannabis, we controlled for whether participants had used cannabis since the last EMA in the models predicting intention to use cannabis. Additionally, the following covariates were included in all models: age, sex, whether momentary assessments were on a weekday or weekend, assessment time (morning [referent], afternoon, evening), and a linear study period time trend. Beyond testing the main effect hypotheses, moderation of within-person independent variables of interest by cannabis-use problems was also tested (H3). Listwise deletion of observations with missing values was used.

Random intercept and slope models were estimated using a first-order autoregressive covariance structure to account for autocorrelation in repeated measures. Marginal R^2 was reported to estimate explained variance (Nakagawa, Schielzeth, & O'Hara, 2013). To measure local effect sizes (Raudenbush & Bryk, 2002), the difference in within-person intercept variance between models with and without momentary affect predictors (model predicting intention to use cannabis), and with and without time passed since last use and grams used (models predicting PA and NA) was calculated, with the inclusion of all covariates. The difference was divided by the within-person intercept variance of the models without the within-person measures.

3. Results

3.1. Sample descriptives

On average, participants had used cannabis for 1.6 years (S.D. = 1.25, range 19–37), 3.4 days per week (S.D. = 2.04), 2 g per week (S.D. = 1.86) and reported smoking 1.85 joints on use days (S.D. = 1.19). Two participants had previously received cannabis treatment. The average CUDIT-R was 11.6 (S.D. = 5.13), AUDIT was 8.1 (S.D. = 4.89), and DSM5-CCSM was 15.6 (S.D. = 8.82, see Table 1).

3.2. Descriptive summary of momentary data

Intention to use cannabis within the next hour was reported on 17% (n = 469) of the sampled time points (Table 1). Average PA was 2.22 (S.D. = 0.02), NA was 1.75 (S.D. = 0.01), time since last use was 3.3 h

Table 1
Sample characteristics.

	N	Mean (SD) or n (%)	Range
Socio-demographic background			
Age, mean (S.D.)	80	21.5 (3.14)	19–37
Male, n (%)	80	28 (35.00)	0–1
Health related background			
CUDIT-R, mean (S.D.)	80	11.6 (5.13)	2–25
AUDIT, mean (S.D.)	80	8.1 (4.89)	2–24
DSM-5 CCSM, mean (S.D.)	80	15.6 (8.82)	3–57
Cannabis use history			
Duration of use (years), mean (S.D.)	80	1.6 (1.25)	0–5
Cannabis use days per week, mean (S.D.)	80	3.4 (2.04)	0–7
Grams per week, mean (S.D.)	80	2.0 (1.86)	0.2–10
Joints per use day, mean (S.D.)	80	1.85 (1.19)	0.5–6
Is/was ever in cannabis use treatment, n (%)	80	2 (2.50)	0–1
Daily attributes			
Intention to use cannabis, n (%)	2818	469 (16.64)	0–1
Time past since last cannabis use, mean (S.D.)	803	6.60 (0.20)	0–16
Grams used since last EMA survey, mean (S.D.)	791	0.60 (0.48)	0.2–4
Positive affect, mean (S.D.)	2818	2.22 (0.02)	1–5
Negative affect, mean (S.D.)	2818	1.75 (0.01)	1–5

Note: S.D. = Standard Deviation; EMA = Ecological Momentary Assessment; CUDIT-R = Cannabis Use Disorder Identification Test-revised, AUDIT = Alcohol Use Disorder Identification Test; DSM-5 CCSM = DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure—Adult.

Table 2
Results from mixed effects models predicting intention to use cannabis in the next hour, N = 80.

	Model 1a: main effects only				Model 1b: interactions included			
	OR	P value	95% Conf. Interval		OR	P value	95% Conf. Interval	
Within-person variables								
Within positive affect	**1.721**	**<0.001**	**1.384**	**2.141**	1.571	0.124	0.884	2.794
Within negative affect	**0.761**	**0.021**	**0.604**	**0.959**	0.891	0.701	0.493	1.608
Between-person variables								
Between positive affect	0.882	0.597	0.555	1.404	0.884	0.603	0.556	1.407
Between negative affect	1.866	0.059	0.976	3.566	1.865	0.059	0.976	3.566
Used cannabis since last survey	**1.530**	**0.005**	**1.140**	**2.053**	**1.522**	**0.005**	**1.133**	**2.043**
Age	1.026	0.607	0.931	1.131	1.026	0.606	0.931	1.131
Male	0.915	0.778	0.495	1.693	0.914	0.774	0.494	1.691
Weekend vs. weekday	1.258	0.079	0.973	1.627	1.257	0.081	0.972	1.625
Linear time trend	**0.980**	**0.001**	**0.969**	**0.992**	**0.980**	**0.001**	**0.969**	**0.992**
Afternoon [morning = referent]	**2.931**	**<0.001**	**2.062**	**4.166**	**2.942**	**<0.001**	**2.068**	**4.184**
Evening [morning = referent]	**8.075**	**<0.001**	**5.772**	**11.297**	**8.083**	**<0.001**	**5.776**	**11.311**
CUDIT-R	**1.135**	**<0.001**	**1.072**	**1.202**	**1.133**	**<0.001**	**1.070**	**1.200**
Cross-level variables								
Within positive affect * CUDIT-R					1.007	0.740	0.965	1.051
Within negative affect * CUDIT-R					0.988	0.576	0.947	1.031
Intercept	**0.003**	**<0.001**	**0.0001**	**0.061**	**0.003**	**<0.001**	**0.0001**	**0.062**
Marginal R^2	**0.249**				**0.247**			

Note: OR = Odds Ratio; CUDIT-R = Cannabis Use Disorder Identification Test-revised.

(mean = 6.60, each unit representing a 30 min increment, S.D. = 0.20), and grams of cannabis use was 0.60 (S.D. = 0.48). Non-responses, which became more prevalent as the study progressed (response fatigue), were not found to be related to demographic variables (age, gender), CUDIT-r and AUDIT scores or other baseline measures of cannabis use. However, excluded participants had higher DSM-5 CCSM scores than included participants (25.8 vs. 15.6, p < 0.001), which was controlled for in subsequent sensitivity analyses (see Table S1 and S2).

3.3. Intention to use cannabis & affect (H1)

The model predicting intention to use cannabis in the next hour explained 25% of the variance (Table 2). Participants were more likely to report intention to use cannabis when they reported relatively high PA (OR = 1.721, $p < 0.001$), and relatively low NA (OR = 0.761, $p = 0.021$). Yet, the local effect size for within-person variables of interest (NA and PA) was small (=0.10).

In addition, intention to use cannabis was more likely during the afternoon (OR = 2.931, $p = 0.001$) and evening (OR = 8.075, $p < 0.001$) compared to in the morning, and the likelihood of reporting intention to use cannabis decreased over the course of the study (OR = 0.980, $p = 0.001$), and was more likely among participants who reported use since the last EMA survey (OR = 1.530, $p = 0.005$).

3.4. Positive affect, time since last use & quantity of use (H2a)

The model predicting PA, including participants reporting cannabis use since the last EMA survey, explained 8% of the variance (Table 3, model 1a). PA was higher when participants reported less time since last use (B: −0.012, $p = 0.016$) and when using relatively high quantities of cannabis (B: 0.113, $p = 0.048$). Within-person NA was negatively related to PA (B: −0.267, $p < 0.001$). The local effect size for the within-person variables was small (=0.01).

3.5. Negative affect, time since last use & amount of use (H2b)

The model predicting NA in participants reporting cannabis use since the last EMA survey explained 10% of the variance (Table 3, model 2a). NA was higher when participants reported more time since last use (B: 0.017, $p = 0.005$). Within-person amount used was not associated with NA (p = 0.868). Within-person PA was negatively related to NA (B: −0.271, $p < 0.001$). The local effect size for the within-person variables was small (=0.06). Participants reported higher NA in the afternoon (B: 0.154, $p = 0.010$) and evening (B: 0.173, $p = 0.007$) and lower NA on weekends (B: −0.094, $p = 0.023$).

3.6. Moderation by cannabis-related problems (H3)

Cannabis-related problems related to a higher likelihood of reporting intentions to use cannabis (OR = 1.135, $p < 0.001$), but cannabis-related problems did not moderate the relation between PA and NA and intention to use (Table 2, model 1b). Cannabis-related problems were not related to PA or NA and did not moderate any of the associations between affect, hours passed since last cannabis use, and amount used (Table 3, model 1b and 2b).[1]

4. Discussion

This study aimed to elucidate the dynamic interplay between affect and cannabis use in the daily life of cannabis using college students. With 42.5% scoring 8 or higher on the AUDIT and 35% scoring 13 or higher on the CUDIT-R, a substantial proportion of the sample were at risk for an alcohol or cannabis use disorder and may require treatment (Adamson et al., 2010). Although, less mental health problems were reported in the current sample (DSM-5 CCSM = 15.6) compared to what was previously reported in a general student college population (DSM-5 CCSM = 26.4, also excluding substance use items; Bravo et al., 2018).

Confirming our hypotheses, and echoing previous findings (Buckner et al., 2015; Chakroun et al., 2010). Intentions to use cannabis in the next hour were more likely when PA was relatively high. PA was also higher when less time had elapsed since last use and when students reported using relatively high quantities of cannabis. While NA was lower when less time had passed since last use, unexpectedly, low (not high) NA related to a higher likelihood of reporting intentions to use, and quantity of use was not associated with NA.

Combined, this suggests that use may be maintained by high PA but

[1] The AUDIT and DSM-5 Self-Rated Level 1 Cross-Cutting Symptom score were included for descriptive purposes. In sensitivity analyses we added these variables to the mixed effects models. Their inclusions did not change the main result in any substantial way and thus the more parsimonious models were kept (see supplementary Table S1 and S2.

Table 3
Results from mixed effects models predicting positive and negative affect, N = 80.

	Model 1a: positive affect (main effects only)				Model 1b: positive affect (interaction included)				Model 2a: negative affect (main effects only)				Model 2b:negative affect (interaction included)			
	B	P value	95% Conf. Interval		B	P value	95% Conf. Interval		B	P value	95% Conf. Interval		B	P value	95% Conf. Interval	
Within-person variables																
Within hours past since last cannabis use	**-0.012**	**0.016**	**-0.022**	**-0.002**	**-0.023**	**0.045**	**-0.045**	**0.000**	**0.017**	**0.005**	**0.005**	**0.030**	0.025	0.057	-0.001	0.050
Within grams used	**0.113**	**0.048**	**0.001**	**0.226**	0.377	0.091	-0.060	0.814	0.002	0.868	-0.016	0.020	-0.057	0.093	-0.124	0.010
Model 1a & 1b: within negative affect / Model 2a & 2b: within positive affect	**-0.267**	**< 0.001**	**-0.340**	**-0.194**	**-0.262**	**< 0.001**	**-0.335**	**-0.189**	**-0.271**	**< 0.001**	**-0.342**	**-0.200**	**-0.267**	**< 0.001**	**-0.339**	**-0.196**
Between-person variables																
Between hours past since last cannabis use	-0.006	0.792	-0.050	0.038	-0.006	0.798	-0.049	0.038	-0.037	0.282	-0.106	0.031	-0.037	0.287	-0.105	0.031
Between grams used	0.238	0.402	-0.318	0.794	0.253	0.374	-0.304	0.810	0.021	0.584	-0.054	0.096	0.021	0.575	-0.053	0.096
Model 1a & 1b: Between negative affect / Model 2a & 2b: Between positive affect	-0.099	0.575	-0.445	0.247	-0.090	0.612	-0.437	0.257	-0.039	0.631	-0.200	0.121	-0.037	0.653	-0.198	0.124
Age	-0.031	0.225	-0.081	0.019	-0.031	0.227	-0.081	0.019	-0.021	0.239	-0.056	0.014	-0.021	0.230	-0.056	0.013
Male	0.154	0.346	-0.166	0.473	0.150	0.360	-0.170	0.470	-0.103	0.339	-0.315	0.109	-0.103	0.339	-0.315	0.108
Weekend vs. weekday	-0.072	0.091	-0.156	0.012	-0.073	0.088	-0.157	0.011	**-0.094**	**0.023**	**-0.175**	**-0.013**	**-0.092**	**0.026**	**-0.173**	**-0.011**
Linear time trend	0.003	0.077	-0.0004	0.007	0.003	0.099	-0.001	0.007	0.002	0.227	-0.001	0.006	0.002	0.188	-0.001	0.006
Afternoon [morning = referent]	0.085	0.119	-0.022	0.192	0.086	0.117	-0.021	0.193	**0.154**	**0.010**	**0.037**	**0.272**	**0.155**	**0.010**	**0.038**	**0.272**
Evening [morning = referent]	**0.175**	**0.003**	**0.060**	**0.291**	**0.175**	**0.003**	**0.059**	**0.290**	**0.173**	**0.007**	**0.046**	**0.300**	**0.172**	**0.008**	**0.046**	**0.299**
CUDIT-R	-0.011	0.489	-0.041	0.020	-0.010	0.520	-0.041	0.021	-0.013	0.239	-0.035	0.009	-0.015	0.206	-0.037	0.008
Cross-level variables																
Within hours past * CUDIT-R					0.001	0.298	-0.001	0.002					-0.001	0.498	-0.002	0.001
Within grams used * CUDIT-R					-0.017	0.230	-0.045	0.011					0.004	0.073	0.000	0.008
Intercept	**2.962**	**< 0.001**	**1.411**	**4.513**	**2.933**	**< 0.001**	**1.379**	**4.487**	**2.624**	**< 0.001**	**1.368**	**3.880**	**2.638**	**< 0.001**	**1.379**	**3.897**
Marginal R^2	**0.082**				**0.082**				**0.096**				**0.098**			

Note: CUDIT-R = Cannabis Use Disorder Identification Test-revised.

not high NA in college students who are at risk for cannabis use problems, but with relatively low signs of other mental health problems. In other words, cannabis use to prevent or deal with NA is unlikely to be a strong explanatory factor for cannabis use in this population. NA and likelihood of reporting intentions to use cannabis were both at their highest in the afternoon and evenings, but higher NA was related to a lower likelihood of intending to use cannabis. One explanation is that social contexts (e.g. parties or social gatherings) that are more likely to occur in the afternoon/evening may be driving cannabis use in this population, independent of NA. The current study did not measure social contexts of use but should be a direction for future research. Participants reported using cannabis on 82% of the time points following reports of intention to use, showing a strong relationship between intention to use and actual use.

Potentially, the negative reinforcement model may be more useful for explaining cannabis use in users with longer and more problematic cannabis use histories, rather than the college student sample recruited in the current study who may be more likely to use cannabis within the context of parties and social gatherings (Chakroun et al., 2010; Wycoff et al., 2018). Yet, at least one study among (mainly) college students of which 87% had a CUD, found evidence in support of the negative reinforcement model of cannabis use (Buckner et al., 2015). Multiple factors could contribute to the discrepancies between our and previous studies, including variability in use, severity of cannabis-related problems, mood measures and cannabis legislation. Indeed, severity of cannabis use-related problems appears somewhat lower in the current sample compared to that reported in Buckner et al. (2015). Furthermore, it is important to note that our NA items did not include important depressive emotions such as sadness. Thus, more research is needed to confirm or refute the current findings with a broader set of NA items.

We failed to find evidence for moderations of mood-cannabis relations by cannabis-related problems which is in contrast to findings from a study in weekly young cannabis users with a roughly similar history of cannabis use. Akin to our findings of lower NA and higher PA when less time had passed since last cannabis use, this study found that cannabis was associated with increases in stimulation, sedation, and high, as well as reductions in craving and tension. Yet, in contrast to our findings, this study found that cannabis' positive reinforcing effects were higher with higher CUD severity (Treloar Padovano & Miranda, 2018). Reasons for the discrepancies in findings may be associated with differences in the measurement of cannabis-use problems and how mood was assessed. As far as the authors are aware, ours and this previous study are the only investigations of the potential moderating role of momentary mood and cannabis use. Due to the discrepancies in findings, there is a need for more research in this area.

Regional and cultural differences may also play a role. We did not collect data on race/ethnicity, but our sample included international students (i.e., 22 Dutch, 18 German, 27 from other European countries, 13 outside Europe) and Amsterdam has a long history of liberal cannabis attitudes and policies, which differ from the ruling cannabis policies for participants in other studies. All participants smoked cannabis joints, the homogeneous method of administration being a strength. However, cannabis potency [~16% tetrahydrocannabinol (THC)] is relatively high in the Netherlands (Freeman, Groshkova et al., 2019; Niesink et al., 2015) and while smoking pure cannabis is most popular in the U.S., combining cannabis with tobacco is popular in Europe (Russell et al., 2018). Method and product of use, as well as attitudes towards cannabis use likely impact the association between cannabis and mood.

Other characteristics of cannabis use revealed by our study include a negative time trend for intentions to use. Post-hoc analysis indicated that actual cannabis use also decreased over the course of the study (OR $= 0.985$, $p = 0.004$). Answering questions regarding cannabis use may trigger self-awareness, influencing participants' experiences or responses (Heron & Smyth, 2010; Kramer et al., 2014). Moreover, the intention to use was more likely later in the day, showing that cannabis was mainly used in the evening. NA was lower on weekends akin to the *weekend effect* typically found in college students (Ryan et al., 2010). NA was higher in the afternoon and evening, similar to what has been found in other studies (Murray et al., 2002). Exploring this finding further is beyond the scope of this study, but the experiences of stressful or other negative events may be more common in the afternoon and evening, which in turn may trigger NA (Watson et al., 1999).

5. Limitations

Our EMA assessments were signal-contingent to capture naturally occurring mood fluctuations throughout the day, and as such, we were not able to test whether mood changes from immediately before, to after use. Furthermore, our last daily assessment was sent at 19:00, which may have missed capturing some cannabis using events. Future studies with participant-initiating reporting when they intend to use and later signal-contingent time assessments should be conducted as they may be more sensitive to detect mood responses right after cannabis use.

To prevent fatigue and scale floor effects, daily surveys were kept brief and excluded particularly extreme emotions. This rendered our NA items more related to anxiety than depression or general NA, compared to other similar studies (e.g. Buckner et al., 2015). Given the mixed literature regarding associations between cannabis use and anxiety (Buckner, Crosby, Silgado, & Wonderlich, 2012; Tournier et al., 2003), future research should test a wider range of NA items and study their potential differential association with cannabis use.

Future studies are needed to test if our results generalize to other student populations and jurisdictions. The observed cannabis-affect associations may also depend on the mode of cannabis administration and tetrahydrocannabinol (THC) versus Cannabidiol (CBD) concentrations (Freeman, Petrilli et al., 2019). Despite participants indicating they smoked cannabis joints, we did not include detailed momentary assessments on methods of use and product. A controlled cannabis intoxication study including manipulation by THC/CBD concentration and mode of administration could add essential information to the mechanisms of cannabis use. As of yet, there is only limited evidence that CBD alters THC's effects on mood (Freeman, Petrilli et al., 2019).

We did not measure expectancies, motivation (including medical motivation) or social context of use, which may be important moderating and mediating factors of the relationships between cannabis use and mood (Wycoff et al., 2018). Medical use is probably uncommon in our sample as it is generally associated with older age groups, and compared to other countries the number of registered medical cannabis users is low in the Netherlands (Hazekamp & Heerdink, 2013).

Finally, while this study answers a general call to include momentary questions regarding amount used (Wycoff et al., 2018), the measure may be unreliable (Van der Pol et al., 2013). Since the focus was on within-subject differences, it is, however, expected that any related bias should be minimal; while there may be differences between individuals' visual estimates of a gram of cannabis, the estimates are likely to be similar within the individual.

6. Conclusion

In this sample of weekly cannabis users from a university sample, little evidence was found for the negative reinforcement model, whereas results were in line with positive reinforcement. More research is needed that directly tests whether cannabis use is more driven by PA than NA, including a broader range of affect measures and studying the potential moderating role of methods of use, cannabis product, severity of use and CUD, and cultural factors. If our results replicate, it can have implications for prevention and treatment; among young college students with relatively high CUD risk, cannabis use to deal with NA may have limited value for identifying individuals that need professional help. Identification of treatment needs in college students may need to consider other factors, such as personality traits as previously suggested (Chakroun et al., 2010).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors would like to thank the respondents who shared their experiences through taking part in the survey.

Role of funding source

Nothing declared.

Contributors

S.R. Sznitman conceived and supervised the study, led the writing and the analyses. L. van Rijswijk collected the data and contributed to the writing up of results. J. Cousijn conceived of the study and contributed to writing up the results.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2021.107221.

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