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Attentional bias, craving and cannabis use in an inpatient sample of adolescents and young adults diagnosed with cannabis use disorder: The moderating role of cognitive control

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HIGHLIGHTS

- CUD patients did not show an AB towards cannabis-related words.
- Session-induced cannabis craving was positively related to daily cannabis use, however not to the severity of CUD.
- Cognitive control did not moderate the relationships between AB/craving and the severity of CUD or daily cannabis use.

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ABSTRACT

Motivational processes like attentional bias and craving have been related to substance use. However, results are inconclusive. The present cross-sectional study was designed to replicate and extend previous research by investigating the relationships between attentional bias, craving, cognitive control and (severity of) cannabis use in a sample of inpatient adolescents and young adults (aged 18–30) diagnosed with CUD according to DSM-5. Contrary to expectations, our sample did not show attentional bias for cannabis words, neither did attentional bias correlate with craving, cognitive control or (severity of) cannabis use. In line with our hypotheses, however, increased session-induced craving was correlated to more daily cannabis use and reduced cognitive control. Furthermore, participants who displayed reduced cognitive control used more cannabis per day. A bootstrapped hierarchical regression model showed that, contrary to expectations, cognitive control did not modulate the relationships between attentional bias, craving and cannabis use. This study highlights the unique role of craving in relation to cannabis use and extends previous findings that cognitive control appears to have no moderating role regarding cannabis use disorder. Based on our results, it might well be that the underlying mechanisms of cannabis use disorder differ from those in other substance use disorders.

1. Introduction

Cannabis Use Disorder (CUD) is associated with substantial mental health issues (Levine, Clemenza, Rynn, & Liebermann, 2017; Stinson, Ruan, Pickering, & Grant, 2006), cognitive and social impairments and low rates of long-term abstinence (Chaudard, Septfons, & Chabrol, 2013; Danovitch & Gorelick, 2012). Knowledge of the underlying mechanisms associated with CUD may help to identify new treatment targets and improve treatment outcome.

The incentive sensitisation model of addiction proposes that brain systems involved with incentive motivation, reward and information processing become altered due to repeated substance use (Robinson & Berridge, 2001). This results in hypersensitivity to the rewarding properties of substances. Substance cues become highly salient and may bias behaviour towards substance use in a rather automatic way: increasing craving, grabbing attention and activating approach behaviour (Houben, Schoenmakers, Thush, & Wiers, 2008; Van Deursen, Salemink, Schoenmakers, & Wiers, 2009; Wiers et al., 2007). Cognitive control processes are thought to inhibit the effects of these so-called motivational processes on substance use and appear to be weaker in

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individuals with substance use disorder (SUD) (Grenard et al., 2008; Houben & Wiers, 2009; Peeters et al., 2012), thereby further supporting continued substance use and relapse.

The degree to which attention is drawn to motivationally relevant (substance-related) stimuli as opposed to neutral stimuli is referred to as attentional bias (AB). AB has been the focus of many studies (see Field & Cox, 2008 for a review) and is thought to be an important behavioural marker for SUD (Field, Munafò, & Franken, 2009; Stacy & Wiers, 2010).

Compared to other substances, relatively little is known about the processes underlying CUD. However, emerging evidence suggests the presence of AB and craving in adults with a CUD (Lundahl & Johanson, 2011; Cousijn et al., 2013; Asmaro, Carolan, & Liotti, 2014; Vujanovic, Wardle, Lui, Dias, & Lane, 2016). Furthermore, adult studies suggest a positive relationship between AB and the severity of cannabis use (Cousijn, Watson, et al., 2013; Field, 2005) and between AB and craving (Field, 2005; Field et al., 2009; Field, Mogg, & Bradley, 2004). Although CUD is most common among adolescents and young adults, only a limited number of studies investigated motivational processes in this specific population (see Wiers, Boelema, Nikolaou, & Gladwin, 2015 for a review). Cousijn, Watson, et al. (2013), found evidence for the presence of a moderately sized AB towards cannabis words in heavy cannabis users (aged 18–30) compared to controls. In addition, individuals diagnosed with CUD showed stronger AB than heavy, non-dependent, cannabis users. AB and craving were not related. Using the same methodology and cannabis cues, these results were partially replicated within a sample of adolescent (aged 15–22) outpatients with a CUD (Cousijn, Van Benthum, Van der Schee, & Spijkerman, 2015), showing a small effect size. However, contrary to expectations only craving, but not AB, seemed to be related to cannabis use. Results from a study in young SUD patients (aged 12–18, 68% diagnosed with CUD) showed stronger AB for stimuli representing the primary substance of abuse (van Van Hemel-Ruiter, Wiers, Brook, & Jong, 2016), both in comparison with controls and within the group of CUD patients. Furthermore, they found a positive relationship between AB and the severity of cannabis dependence within CUD patients.

Regarding cognitive control, defined as goal-directed regulation of behaviour that constitutes of different partly overlapping sub-processes, a bidirectional relationship with cannabis use seems plausible. Although long-term cannabis use may impair cognitive control (Crean, Crane, & Mason, 2011), evidence of a reversed relationship appears to be stronger (Cousijn et al., 2014; Cousijn, Watson, et al., 2013; Verdejo-García & Pérez-García, 2007; Wiers et al., 2015); decreased cognitive control might predispose individuals to an increased risk of developing CUD. However, evidence by Cousijn, Watson, et al. (2013), Cousijn et al., 2015) and van Van Hemel-Ruiter et al. (2016) regarding a relationship between cognitive control and (the severity of) cannabis use is not convincing.

Concerning the moderating role of cognitive control on the relationship between biased motivational processes and substance use, results are inconclusive. Theoretical models regarding motivational and controlled processes and the development of addictive behaviors in adolescents (Wiers et al., 2007) suggest that higher cognitive control inhibits the relationship between attentional bias, craving and cannabis use, suggesting a protective role of cognitive control. Indeed, Wiers et al. (2015) conclude that biased motivational processes are likely to contribute to the development of substance-related problems in adolescent and young adult substance users with decreased cognitive control. Nonetheless, Van Hemel-Ruiter, De Jong, Ostafin, and Oldehinkel (2015), Van Hemel-Ruiter et al., 2016) showed that cognitive control did not moderate the relationship between AB and severity of substance use within a group of early adolescent alcohol users and SUD patients. Concerning cannabis use, Cousijn, Watson, et al. (2013) did find evidence of the moderating effect as expected, but only within a group of severe and chronic cannabis users. Surprisingly, additional research within a group of in adolescent (aged 15–22) CUD patients (Cousijn et al., 2015) could not find evidence that cognitive control moderates the relationship between cannabis-oriented motivational processes and cannabis use.

Overall, evidence on the relationships between biased motivational processes and cognitive control in adolescents and young adult cannabis users with is limited and mixed. In addition, we cannot simply assume that the processes underlying cannabis use are the same for different groups of cannabis users, including (inpatient or outpatient) CUD patients. Since criteria of CUD changed since the introduction of DSM-5 previous results regarding the underlying processes of CUD according to DSM-IV cannot be generalized to a group of CUD patients according to DSM-5. The present study was designed to replicate and extend research by investigating the relationships between AB, craving, cognitive control and cannabis use in a group of inpatient CUD patients. To the best of our knowledge, there are no published studies yet that include inpatient adolescents and young adults (aged 18–30) diagnosed with CUD according to DSM-5.

In line with previous studies using similar methodological procedures (Cousijn et al., 2015; Cousijn, Watson, et al., 2013; Van Hemel-Ruiter et al., 2016), we expected AB to be present for cannabis-related cues. Since CUD was the primary diagnosis, we expected AB for cannabis-related cues to be significantly higher than AB for alcohol-related cues. Stronger AB and craving were predicted to be correlated with higher severity of CUD and more units of cannabis use. Although research on the role of cognitive control is inconclusive, we expected decreased cognitive control to be related to more cannabis use. We also expected positive correlations between AB, craving and cognitive control (higher scores indicating decreased cognitive control). Moreover, in line with current theoretical models and previous studies using similar methodological procedures and samples, we hypothesized that cognitive control would moderate the relationship between AB, craving and cannabis use, suggesting a protective role of cognitive control.

2. Methods

2.1. Participants

After giving their informed consent, 65 adolescents and young adults (aged 18–30) diagnosed with CUD according to DSM-5 were included in this study. Participants were recruited from a Dutch inpatient treatment facility for adults and adolescents with SUD (IrisZorg), receiving Community Reinforcement Approach treatment (Meyers & Smith, 1995), a cognitive behavioural treatment that aims to help individuals in finding healthier, more adaptive ways to meet their emotional and social needs than using substances. Intended treatment duration was two months, the first two weeks of hospitalization were focused on detoxification, stabilization, and activation. Participants were all abstinent at the time of testing, however self-reported abstinence duration varied widely (see Table 1 for sample characteristics). A total of 29 participants used prescribed medication, of which 12 used a combination of 2 or more, including antipsychotics (n = 14), psychostimulants (n = 7), benzodiazepines (n = 6), antidepressants (n = 5), antihistamine (n = 3), thiamine (n = 3), disulfiram (n = 2), and hypnotics (n = 2). Potential participants were excluded if they were in a florid psychotic state and/or having suicidal tendencies. The study was approved by The Ethics Committee of the Behavioural Sciences (ECSW), Radboud University Nijmegen. (See Table 2).

2.2. Questionnaires

General questionnaires were used to collect demographic information and data about the onset and nature of cannabis, alcohol and nicotine use. A structured checklist for DSM-5 CUD criteria was used to support the clinical judgement of the physicians.

Section 1 of the Measurements in the Addictions for Triage and Evaluation (MATE: Schippers & Broekman, 2007) was used to quantity

Table 1
Sample characteristics.

	N	Mean	Min.	Max.	SD
Age	65	22.42	18	30	3.23
Female	14	22%	–	–	–
Nicotine use	57	88%			
Days of hospitalization	59	20.61	6	41	7.95
Cannabis use					
Daily cannabis use, 30 days before hospitalization (grams): MATE	64	1.85	0.25	7.5	1.26
Total days of cannabis use, 30 days before hospitalization: MATE	64	26.72	0	30	7
Weekly cannabis use, before hospitalization (grams)	65	11.65	1	70	10.14
Abstinence before test-session (days)	65	18.20	1	52	10.48
Onset age (years)	65	15.92	7	21	2.52
Duration weekly use (years)	65	6.18	1	21	3.87
Assessments during test session					
Total score CUDIT	64	24.41	8	32	5.77
Total score AUDIT	65	10.03	0	34	8.43
Total score FTND	65	4.51	0	8	2.26
Cannabis attentional bias (sec): Cannabis Stroop	65	0.99	−11.53	11.81	4.28
Alcohol attentional bias (sec): Alcohol Stroop	65	0.87	−9.50	17.14	4.46
Craving pre-testing: VAS	65	27.83	0	94	28.63
Craving post testing: VAS	65	28.26	0	100	30.26
Session induced craving cannabis: VAS difference score	65	0.43	−22.00	29.00	8.34
Cognitive control: Classical Stroop interference score	65	35.24	15.43	74.77	12.85

MATE: Measurements in the Addictions for Triage and Evaluation; CUDIT: Cannabis use disorder Identification Test; AUDIT: Alcohol Use Disorder Identification Test; FTND: Fagerstrom Test for Nicotine Dependence; VAS: Visual Analogue Scales.

Table 2
Correlations among parameters of interest.

	1	2	3	4	5
1 Daily cannabis use	–	–			
2 CUDIT-R	–	–			
3 Attentional bias cannabis	0.346	0.842	–		
4 Craving	**0.002****	0.105	0.704	–	
5 Cognitive control	**0.026***	0.704	0.661	**0.041***	–

Note: significant effects are depicted in bold.
* $p < .05$.
** $p < .01$.

cannabis, alcohol and nicotine use 30 days prior to the start of inpatient treatment. The MATE is set up to make a valid and reliable assessment of various patient characteristics.

The revised 8-item Cannabis Use Disorder Identification test-revised (CUDIT-R: Adamson et al., 2010), with total scores ranging from 0 to 32, was used to assess severity of cannabis use and problematic cannabis behaviors. Adamson et al. (2010) found that 91.3% of patients with a diagnosed cannabis use disorder score above 13. The 10-item Alcohol Use Disorder Identification Test (AUDIT: Saunders, Aasland, Babor, de la Fuente, & Grant, 1993), with total scores ranging from 0 to 40, was used to assess severity of alcohol use or hazardous alcohol consumption. A score above 8 is considered to be related to hazardous and harmful drinking. The Fagerström Test for Nicotine Dependence (FTND: Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991), a 6-item questionnaire with total scores ranging from 0 to 10, was used to assess severity of nicotine use and dependence. A score of 6 or higher is considered indicative for severe nicotine dependence.

2.3. Craving

Three separate Visual Analogue Scales (VAS) ranging from 'not at all' to 'very much' were used to measure craving for cannabis, alcohol, and nicotine at the start and end of the test session. Session-induced craving was calculated by subtracting the pre-test score from the post-test score.

2.4. Cannabis and alcohol Stroop

The Dutch cannabis Stroop task (Cousijn, Watson, et al., 2013) was used to measure AB for cannabis-related words. The task consisted of two subtasks that were presented in counterbalanced order. Both subtasks contained a sheet of paper with either 14 cannabis or 14 neutral words (matched for number of syllabi, length and frequency) printed on it four times in different ink colours (red, blue, green and yellow) in random order. Participants had to name the colour of the ink as fast as possible, the total time to complete each subtask was measured with a stopwatch. The Dutch alcohol Stroop task (Cousijn et al., 2015), constructed similarly to the cannabis Stroop, was used to measure AB for alcohol related words. By subtracting the time to complete the neutral subtask from the time to complete the substance subtask a positive score indicated AB for cannabis or alcohol words.

2.5. Classical Stroop

The validated version of the classical Stroop task (Hammes, 1971) was used to measure cognitive control. The task consisted of three subtasks in fixed order. The total time to complete each subtask was measured with a stopwatch. On the first subtask, participants had to read printed words aloud as quickly as possible. The words were printed in black ink, and pertained to four colours (red, blue, green and yellow). On the second subtask participants were asked to name the colour of solid colour patches as quickly as possible. On the third subtask printed words that pertained to the same four colours as before, were printed in an incongruent colour. Participants had to name the colour of the ink as quickly as possible. By subtracting the mean time to complete the first two "congruent" subtasks from the third "incongruent" subtask we calculated an interference score, thought to be a measure of cognitive control: higher scores indicating weaker cognitive control.

2.6. Procedure

All patients meeting the inclusion criteria received an information letter about the study at their first day of hospitalization. After signing the informed consent, general questionnaires, Section 1 of the MATE and a structured checklist for DSM-5 CUD criteria were administered by a physician specialized in addiction. To prevent assessor bias, these data were not accessible before the actual test-session. Due to treatment and patient characteristics (complications related to the process of detoxification, early relapse) the timing of the test-session, which was planned in week two of hospitalization, fluctuated more than anticipated.

During the test-session, which lasted about 45 min, participants first indicated their craving for cannabis, alcohol and nicotine. Next, the substance Stroop tasks were administered in counterbalanced order, always followed by the classical Stroop to control for practice effects. The CUDIT-R, AUDIT and FTND were administered after the Stroop tasks. The test session concluded with a second assessment of craving for cannabis, alcohol and nicotine.

2.7. Statistical analyses

All computations of required sample size and achieved statistical power were based on the conventional alpha level of p = .05 (one-sided). Moreover, in the absence of reliable information on the to-be-expected effect sizes, we powered the study for the conventional assumption of medium-sized effects. Descriptive analyses were executed to describe the study population and the study parameters. Independent one-sample *t*-Tests (testing against zero) were used to investigate whether our sample showed AB towards cannabis stimuli. The current sample size of 65 participants yields excellent statistical power (1-β = 0.99) to detect a medium-sized AB (d = 0.50), but only power of 1-β = 0.48 to detect an AB of small size (d = 0.20). A paired samples *t*-Test was conducted to compare AB scores for cannabis words and AB scores for alcohol words. For this comparison, the sample size also yields excellent power (1-β = 0.99) for detecting a medium-sized difference (d = 0.50), and power of only 1-β = 0.48 for detecting a small difference (1-β = 0.48). Pearson and Spearman's rho (in case of non-normal distributed data) correlations were used to investigate the relationships between AB, session-induced craving, cognitive control and individual differences in CUDIT-R scores and daily cannabis use. For each of these correlations, the current sample size yields sufficient statistical power (1-β = 0.79) for detecting medium-sized correlations (r = 0.30), but only power of 1-β = 0.20 for detecting small correlations (r = 0.10). Finally, since our data failed to meet basic assumptions of regression, we used a 1000 samples bootstrapped hierarchical regression model to investigate whether cognitive control would moderate the relationship between the motivational processes (AB and session-induced craving) and cannabis use. Using CUDIT-R and total units of daily cannabis use as the dependent variables, in three steps the motivational measure, classical Stroop interference score and the interaction term between the motivational measure and classical Stroop interference score were added into the model. For these multiple regression analyses, the current sample size yields very good power (1-ß = 0.87) to detect a medium-sized moderation effect (f^2 = 0.15) of cognitive control (that is, a significant interaction effect). For a small moderation effect (f^2 = 0.02), power was only 1-β = 0.20. Additional exploratory analyses were performed to investigate the potential association of the dependent variables with gender, age and total years of frequent cannabis use, if so the variable was added into the model.

3. Results

3.1. Attentional bias

Within the group of CUD patients, AB did not differ significantly from zero (t(64) = 1.870, p = .66). There was no significant difference between AB for cannabis words (M = 0.992, SD = 4.277) and alcohol words (M = 0.867, SD = 4.458); t(64) = 0.202, p = .841).

3.2. Relationships between attentional bias, session-induced craving, cognitive control and cannabis use

Cannabis AB did not correlate with CUDIT-R scores (rs = 0.025, p = .842) or total grams of daily cannabis use (rs = 0.119, p = .346). Neither did we find a significant relationship between Cannabis AB and AUDIT (rs = 0.086, p = .494), FTND scores (r = 0.079, p = .537), classical Stroop interference score (rs = 0.055, p = .661) and session-induced craving (rs = 0.048, p = .704). Cannabis AB, however, was positively correlated with alcohol AB (rs = 0.350, p = .004).

Although we did not find evidence of a significant relationship between session-induced craving and CUDIT-R scores (rs = 0.203, p = .105), session-induced craving was positively correlated with the total units of daily cannabis use (rs = 0.375, p = .002) and classical Stroop interference score (rs = 0.254, p = .041). The classical Stroop interference score correlated positively with the total units of daily cannabis use (rs = 0.277, p = .026), however not with CUDIT-R scores (rs = 0.048, p = .704).

3.3. Moderating effect of cognitive control on the relationship between motivational processes and cannabis use

Using a 1000 samples bootstrapped regression, we found that cognitive control did not moderate the relationship between AB and CUDIT-R scores (p = .362, SE = 0.029, BCa 95%CI = -0.088, 0.048) or total units of daily cannabis use (p = .868, SE = 0.004, BCa 95%CI = -0.013, 0.007). Neither did we find proof of a moderating effect of cognitive control on the relationship between session-induced craving and the severity of CUD (p = .054, SE = 0.007, BCa95% CI = -0.027, −0.007) or total units of daily cannabis use (p = .050, SE = 0.002, BCa 95%CI = -0.006, 0.001). Since gender, age and total years of frequent cannabis use were not correlated with our dependent variables they were not included in our model.

4. Discussion

This study investigated the relationships between motivational processes, cognitive control and cannabis use in a sample of inpatient adolescents and young adults (aged 18–30) diagnosed with CUD according to DSM-5. Results can be summarized as follows: (1) CUD patients did not show an AB towards cannabis-related words, (2) session-induced cannabis craving was positively related to the total units of daily cannabis use (however not to the severity of CUD), and (3) we could not establish a moderating role for cognitive control on the relationships between the motivational processes and the severity of CUD or daily cannabis use.

Contrary to our expectations, we could not replicate previous findings (Cousijn et al., 2015; Cousijn, Watson, et al., 2013; Van Hemel-Ruiter et al., 2016) regarding the presence of AB for cannabis-related words. However, the aforementioned studies included non-clinical or outpatient cannabis users: differences in motivation, cannabis use, craving, withdrawal and abstinence may have contributed to our results. In addition, inpatient treatment settings tend to lack triggers that have been previously related to AB (Field, Marhe, & Franken, 2014): withdrawal symptoms are managed and drugs cues and opportunities to use are mostly absent. The finding that AB is absent in abstinent patients is in line with previous SUD studies (Field et al., 2014; Noël et al., 2006), whereas some studies even established attentional avoidance of substance cues (Townshend & Duka, 2007; Vollstädt-Klein et al., 2009). In addition, Field, Mogg, Mann, Bennett, and Bradley (2013) indicated subjective craving as a correlate of attentional biases in abstinent alcoholics.

In contrast with previous adult studies and one adolescent study (Cousijn, Goudriaan, & Wiers, 2011, Cousijn, Snoek, & Wiers, 2013; van Van Hemel-Ruiter et al., 2016) we could not establish a relationship between AB and cannabis use or any other parameter, including session-induced craving. Replicating findings by Cousijn, Watson, et al. (2013), Cousijn et al., 2015), session-induced craving however did have a positive relation to daily cannabis use and cognitive control. The latter suggesting that individuals who show more craving have weaker cognitive control, which in itself turned out to be related to more daily cannabis use. Our results suggest that craving, which seems to be associated with more cannabis use in a direct as well as an indirect way, plays a unique role in adolescent and young adult CUD patients. A recent study in a sample of heavy cannabis users aged 18–31 year (Cousijn & van Duijvenvoorde, 2018) supports our findings: craving turned out to be a unique predictor of withdrawal which has been previously related to (future) cannabis dependence (Chung, Martin, Cornelius, & Clark, 2008; Preuss, Watzke, Zimmermann, Wong, & Schmidt, 2010). In our study, craving was measured with a simple VAS within a clinical setting in patients who had been abstinent for 18 days on average. Since craving is likely to be strongest within the environment in which individuals typically use substances, one might expect that our participants experienced less craving in a clinical setting devoid of cannabis cues, compared to out-patient settings (Budney, Moore, Vandrey, & Hughes, 2003; Kouri & Pope, 2000). Hence, it remains to be tested if our results generalize to non-clinical settings and the detoxification stage. There are still only very few studies regarding the role of craving, which prevents drawing strong conclusions.

The hypothesized moderating effect of cognitive control on the relationships between motivational processes (AB and craving) and cannabis use could not be confirmed. Since our study failed to find an AB for cannabis words, this might have contributed to this negative finding although it does not explain why we did not find proof of a moderating role of cognitive control on the relationship between session-induced craving and cannabis use. Whereas previous adolescent studies (Grenard et al., 2008; Thush et al., 2008; Van Hemel-Ruiter, De Jong, Ostafin, & Oldehinkel, 2015; Van Hemel-Ruiter, De Jong, Ostafin, & Wiers, 2015) did confirm a moderating role of cognitive control on the relationship between AB and alcohol use, evidence of a moderating role of cognitive control regarding motivational processes and cannabis use is inconsistent (Cousijn et al., 2015; Cousijn, Snoek, & Wiers, 2013; Cousijn, Watson, et al., 2013; Van Hemel-Ruiter, De Jong, Ostafin, & Wiers, 2015) and limited regarding craving. Since previous and current results could not confirm a moderating role of cognitive control on the relationship between motivational processes like AB and craving and cannabis use, the underlying mechanisms of CUD might be different than for other SUD's. Alternatively, the moderating effect may have been too small to detect with our current sample size. Although our study had good to excellent power for detecting moderate effects, power for detecting small effects was insufficient, limiting the conclusions that can be drawn from our study.

A clear limitation of the current study is the lack of a control group, due to which we could not determine whether craving, AB and cognitive control were actually different or impaired in comparison with controls. However, our design, which was highly similar to previous studies, was sufficient in extending knowledge about the relationships between motivational processes, cognitive control and cannabis use within a sample of inpatient adolescents and young adults with CUD. Although previous studies did find proof for AB using cannabis Stroop tasks (Cane, Sharma, & Albery, 2009; Cousijn et al., 2015; Cousijn, Watson, et al., 2013; Field, 2005), internal reliability is poor (Ataya et al., 2012). Using more direct measures like eye movement monitoring and neural substrates of AB might be more accurate in detecting AB (Field et al., 2014; Field & Christiansen, 2012). Since we did not find a significant correlation between cannabis Stroop and classical Stroop scores we may conclude that potential methodological similarities between these tasks did not account for our results. In our sample CUDIT-R scores were high and showed limited variance ($M = 24.41$, $SD = 5.77$, 8–32) compared to previous studies, which might explain that we did not find any relationships with the parameters of interest. Suggesting that in a sample of inpatient CUD patients, other measurements of cannabis use, like daily cannabis use, are more appropriate in the study of the mechanisms underlying cannabis use problems.

The heterogeneous naturalistic composition of our sample could be considered a strength regarding potential generalization of our results, however, the current design cannot rule out the potential confounding effect of medication use and comorbid (substance use) disorders. Due to the fact that only a limited number of participants used different types of medication, with possible different effects on the Stroop performances, we cannot specify the precise effects on attentional bias and cognitive control. Regarding comorbid substance use, which is quite common among cannabis users (Stinson et al., 2006; Teesson et al., 2012), additional analyses showed that our motivational measures were not related to AUDIT and FTND scores. Therefore suggesting a limited impact of alcohol and nicotine use on our results. Duration of abstinence and the total amount of treatment sessions before assessment varied greatly among participants, which may have accounted for individual differences in AB, craving and cognitive control: abstinence has been previously related to improved cognitive impairments (Schulte et al., 2014) and the absence of drug oriented motivational processes (Field et al., 2013; Noël et al., 2006). The fact that the duration of abstinence was self-reported could also account for less reliable results. Post-hoc analyses, however, indicated that abstinence did not correlate with attentional bias, craving or cognitive control, neither with any of our outcome variables, therefore suggesting a limited impact on our results. Nonetheless, a design with multiple precisely timed assessments over the course of treatment and more objective measurements of cannabis satiation would minimalize the potential effects of abstinence and treatment factors. In addition, compared to controls, it could provide more information about the role of motivational processes, cognitive control and cannabis use in different stages of treatment. This could have potential implications for timing of treatment interventions.

In conclusion, adolescents and young adults with CUD did not show an AB for cannabis words. Only session-induced craving was positively related to the total units of daily cannabis use (however not to the severity of CUD), and this relationship appeared to be independent of cognitive control. Neither could we establish a moderating role for cognitive control on the relationship between AB and cannabis use. Higher session-induced craving was related to less cognitive control whereas less cognitive control was related to more daily cannabis use. Overall our study furthers our understanding of CUD, highlighting an important role for craving.

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Declaration of Competing Interest

None.

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