Running Head: IMPULSIVITY AND CO-USE OF CANNABIS AND ALCOHOL

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Daily associations between cannabis use and alcohol use in young adults: The moderating role of self-report and behavioral measures of impulsivity.

Alexander R. Daros[1,2], Brian J. Pereira[3], Dinat Khan[3], Anthony C. Ruocco[4], Lena C. Quilty[1,5], Jeffrey D. Wardell[2,3,5]

[1]Campbell Family Mental Health Institute, Centre for Addiction and Mental Health
[2]Department of Psychology, York University
[3]Institute for Mental Health Policy Research, Centre for Addiction and Mental Health
[4]Department of Psychology and Clinical Psychological Science, University of Toronto
[5]Department of Psychiatry, University of Toronto

Corresponding Author

Jeffrey D. Wardell, Department of Psychology, York University, 101 Behavioural Sciences Building, 4700 Keele St., Toronto, ON, M3J 1P0, Canada.
Phone: 416-736-2100 ext. 44241
Email: jwardell@yorku.ca

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Abstract

Although impulsivity has been implicated in cannabis and alcohol use, its role in alcohol and cannabis co-use behavior use requires further study. We examined the moderating role of self-report and behavioral measures of impulsivity in the daily-level relationships between cannabis use and both (a) likelihood of same-day alcohol use and (b) number of drinks consumed on the same day. Young adults (N=153) completed a 90-day Timeline Follow Back assessing the amount of cannabis smoked (in grams), other forms of cannabis (e.g., oils, edibles), and number of standard drinks consumed each day. Participants also completed a structured interview of Alcohol and Cannabis Use Disorders (AUD/CUD), and both self-report (UPPS impulsivity scales) and behavioral (behavioral disinhibition and delay discounting) measures of impulsivity. Zero-inflated multilevel modelling revealed that negative urgency, delay discounting, and disinhibition were significant, unique moderators of the daily relationship between cannabis and alcohol consumption, after controlling for AUD/CUD symptoms and other covariates. Specifically, individuals high (but not low) on negative urgency and delay discounting showed a positive association between grams of cannabis used on a given day and same-day number of standard drinks consumed. Contrary to expectations, individuals low on negative urgency and low in disinhibition showed a stronger relationship between grams of cannabis consumed and odds of engaging in any drinking on the same day. Results extend research on moderators of within-person, daily-level associations between cannabis and alcohol use, suggesting that several impulsivity-related constructs may contribute to complementary use of cannabis and alcohol among young adults.

Keywords: marijuana; alcohol; co-use; inhibitory control; delay discounting; negative urgency

Introduction

Alcohol and cannabis are two of the most widely used substances and they are commonly used together. In the U.S. National Alcohol Survey for 2005 and 2010, 11.4% of people reported that they used both alcohol and cannabis in the past year (i.e., co-use), with 7.5% using both substances such that their effects overlapped (i.e., simultaneous use) and another 3.9% using cannabis and alcohol on separate occasions (i.e., concurrent use; Subbaraman & Kerr, 2015). The rate of co-use is higher in young adults, with over half of college students reporting being drunk and high from cannabis at the same time in the past year (Patrick & Lee, 2018). Individuals who report co-use of alcohol and cannabis (and simultaneous use in particular) tend to consume both substances more heavily relative to individuals who use only one of these substances, putting them at a greater risk for developing substance use disorders and negative consequences such as blackouts and occupational or academic difficulties (Briere et al., 2011; Jackson et al., 2020; Yurasek et al., 2017). Given that rates of simultaneous alcohol and cannabis use in young adults are on the rise (Terry-McElrath & Patrick, 2018), it is critical to identify factors associated with co-use behavior.

While studies examining between-person associations have consistently found that individuals who co-use cannabis and alcohol tend to be heavier drinkers and have elevated risk for substance harms than those who use alcohol only (e.g., Jackson et al., 2020; Linden-Carmichael et al., 2019; Patrick et al., 2018), findings have been more mixed when examining within-person associations between co-use of alcohol and cannabis and various outcomes at the daily-level (i.e., comparing days when an individual uses both substances to days when they use only one substance). These daily-level studies have typically utilized retrospective calendar-based interviews to collect daily substance use data (e.g., Timeline Follow Back; Gunn et al.,

2018; Metrik et al., 2018; Waddell et al., 2021), or prospective approaches, such as ecological momentary assessment (e.g., Patrick et al., 2020; Sokolovsky et al., 2020). Using these methods, within-person analyses comparing days when co-use occurs to single substance use days has not consistently shown differences in substance-related consequences or subjective intoxication (Lee et al., 2020; Lipperman-Kreda et al., 2017; Mallet et al., 2019; Sokolovsky et al., 2020). This highlights the importance of considering within-person associations at the daily level when examining co-use behavior and associated outcomes.

Of particular interest in the area of cannabis and alcohol co-use research is the question of whether cannabis and alcohol act as complements (such that greater use of one substance is associated with greater use of the other substance) or substitutes (such that greater use of one substance is associated with reduced use of the other substance; see O'Hara et al., 2016; Risso et al., 2020; Subbaraman, 2016). Studies utilizing daily-level data to study within-person associations between use of cannabis on a given day and same-day use of alcohol are well suited to examining complementarity versus substitution in co-use behavior. Evidence for complementary use of alcohol and cannabis comes from studies of daily use patterns showing higher likelihood of alcohol consumption (Metrik et al., 2018; Roche et al., 2019), greater number of alcoholic drinks consumed (Gunn et al., 2018; Lee et al., 2020; O'Hara et al., 2016), and higher likelihood of heavy drinking (e.g., 5/4+ drinks for men/women; Metrik et al., 2018) on days when cannabis is also used, relative to days when cannabis is not used. Conversely, one study found that subjective intoxication and drinks consumed by young adults on co-use days did not differ compared to alcohol-only days (Linden-Carmichael et al., 2020); similarly, co-use days did not differ from cannabis-only days in terms of number of "hits" of cannabis or

subjective intoxication. A recent review (Risso et al., 2020) concluded that research on whether alcohol and cannabis complement or substitute one another remains inconclusive.

One potential reason for these inconsistent results is that the daily-level association between cannabis use and alcohol use may be stronger (i.e., complementary) for *certain* individuals, such as veterans with Alcohol Use Disorder (AUD) and college students with more alcohol problems (Gunn et al., 2018; Metrik et al., 2018). In contrast, veterans who used more cannabis each month or had a cannabis use disorder (CUD) were *less likely* to show a pattern of heavy or moderate drinking, consistent with substitution behavior (Metrik et al., 2018). O'Hara et al. (2016) found that college students with coping-oriented patterns of substance use showed evidence of substitution, with a negative relationship between increased evening alcohol use and decreased likelihood of cannabis use. These findings suggest that person-level moderators can influence whether someone is more or less likely to co-use cannabis and alcohol on a given day, in complementary or substitutive ways.

There are conceptual reasons to expect that impulsivity may moderate alcohol and cannabis use associations. Impulsivity is typically considered to be a multidimensional trait, consisting of distinct, but related subfacets. In the context of the UPPS-P model of impulsivity (see Whiteside & Lynam, 2001), negative and positive urgency (i.e., acting rashly in response to negative or positive emotions, respectively), along with sensation seeking (i.e., seeking new and exciting experiences), lack of perseverance (i.e., lack of focus), and lack of premeditation (i.e., lack of planning) are consistent predictors of alcohol use problems and dependence (Berg et al., 2015; Coskunpinar et al., 2013). Recent work has also revealed that most of these impulsivity subfacets are associated with cannabis use and cannabis-related problems (see VanderVeen et al., 2016; Wardell et al., 2016), though there is weaker evidence for lack of perseverance. High

levels of these traits may predict riskier alcohol and cannabis use practices as a way to escape from negative emotional experiences, enhance positive emotional experiences, seek novelty and stimulation, and/or reflect a lack of planning and focus (Smith & Cyders, 2016). Importantly, higher negative urgency, positive urgency (Jackson et al., 2020), and sensation seeking (Jackson et al., 2020; Linden-Carmichael et al., 2019) in young adults predict simultaneous alcohol and cannabis use behavior (versus alcohol-only use) use, but not greater frequency of simultaneous use, reported over the past 3 months or past year. However, these studies examined whether these impulsive traits were related to the presence or frequency of co-use (in an ordinal fashion, i.e., once a month or less versus 2-3 times per month) and not whether impulsivity impacts daily-level associations between cannabis use and alcohol use (i.e., complementarity). Only one prior study to our knowledge (Waddell et al., 2021) examined impulsivity as a moderator of daily-level associations between cannabis and alcohol use. Using data from a 6-month timeline follow back, this study found that veterans with mean and low levels of positive urgency and lack of perseverance demonstrated substitution by drinking less alcohol on days when cannabis was used (versus alcohol-only days). Overall, few empirical studies have examined the role of impulsivity in co-use of cannabis and alcohol, and in daily-level associations between cannabis and alcohol use in particular.

Beyond self-report measures, behavioral measures of impulsivity-related constructs may predict unique variance in alcohol and cannabis use behavior. For example, behavioral disinhibition reflects impairment in the ability to limit or prevent a dominant behavioral response in order to implement a more appropriate one. Using Flanker and Stroop performance tasks, research has demonstrated that behavioral disinhibition is associated with cannabis and alcohol use separately (Abdullaev et al., 2010; Battisti et al., 2010; Stavro et al., 2013). Further, the

tendency to make riskier decisions that favor immediate rewards over long-term consequences, known as delay discounting, is another facet of impulsivity that is associated with substance use (e.g., Heitzeg et al., 2015). Delay discounting can be assessed using behavioral tasks in which individuals must decide between a smaller, more immediate monetary reward compared to a larger, delayed reward (Bickel et al., 2014; MacKillop et al., 2011). Although behavioral disinhibition and delay discounting have been implicated in substance use behavior, research has not yet examined their role in cannabis and alcohol co-use. Disinhibition and delay discounting may strengthen the daily association between cannabis and alcohol use by making it more difficult for some people to inhibit or delay the rewarding effects of using both substances simultaneously. However, no study to our knowledge has examined the role of these behavioral indices of impulsivity in the daily-level association between cannabis and alcohol use.

To date, it remains unclear how impulsive traits might moderate daily cannabis and alcohol use associations among young adults, and especially how the amount of cannabis used is associated with quantity of same-day alcohol consumption. Though Waddell et al. (2021) found some moderation effects for self-reported UPPS impulsivity subfacets, they did not include behavioral measures and used a veteran rather than young adult sample. The current study sought to extend past research by examining the moderating role of several facets of impulsivity (including behavioral measures of impulsivity) in the daily-level associations between cannabis and alcohol use among young adults. Moreover, as few studies examining daily associations between cannabis and alcohol use have assessed the *quantity* of cannabis consumed, we examined the relationship between grams of cannabis used and quantity of alcohol consumed each day using 90 days of Timeline Follow Back interview data. This allowed us to examine the full range of complimentary versus substitutive associations by modelling whether the amount of

alcohol consumed each day varied as a function of the *quantity* of cannabis used, rather than merely the presence of cannabis use. We also included days in which alcohol was not used in our analysis (unlike many prior studies) as this allowed us to model occasions when cannabis fully substitutes alcohol use (and therefore no drinking co-occurs on the same day). We expected that all UPPS subfacets, behavioral disinhibition, and delay discounting would moderate the relationship between cannabis use and alcohol use at the daily level, such that the relationship would be stronger (i.e., more complementary) for individuals higher on these impulsivity measures.

Materials and Methods

Participants and Procedures

Young adults (*N*=160) aged 19-25 who reported a history of regular cannabis use (i.e., at least once per month for 6+ months) were recruited from a larger experimental study on the neurocognitive correlates of cannabis use in young adults. The study took place in a large urban centre in Canada, after cannabis was legalized in 2018. All participants were above the legal age for purchasing cannabis in the jurisdiction. Exclusion criteria for the larger study included: monthly (or higher) use of substances other than cannabis, alcohol, or tobacco; reporting use of cannabis exclusively for medical reasons; current or past treatment for alcohol or other substance use; and history of severe mental illness (e.g., psychosis, mania), severe head injury, neurological or neurodevelopmental disorder. Participants were recruited from the community using online advertisements and posters. Interested individuals completed an online eligibility survey, and eligible participants were scheduled for an in-person assessment session from which the data for the current analyses were drawn. Participants were instructed to abstain from cannabis and alcohol for 48 hours prior to the assessment session. Breathalyzer tests were

administered to confirm that blood alcohol content was zero prior to testing. Following informed consent, participants completed behavioral tasks first, followed by semi-structured interviews and self-report questionnaires which were organized into briefer sections and then interspersed to optimize participant engagement during assessment sessions. Questionnaires analyzed in the current study immediately followed the Timeline Follow Back interview but preceded clinical interviews. Participants were compensated with $115 for participating in the larger study. All procedures were approved by the Centre for Addiction and Mental Health Research Ethics Board (#099/2018).

Seven individuals did not report any alcohol use in the past 90 days and were therefore excluded from the present analyses, leaving 153 participants (60.1% female) with an average age of 22.22 (*SD* = 2.07, Range = 19-26). Participants reported their race and ethnicity by selecting among several descriptors and were able to select all that applied. A large proportion identified as White (52.9%), 15.7% as Black or African descent, 17.0% as Asian, 9.2% as East Indian, 4.9% as Hispanic/Latinx, 2.6% as Pacific Islander, 0.7% as Native North American, and 9.2% as "other". With respect to sexual orientation, 65.3% identified as heterosexual, 7.8% as gay/lesbian, 21.6% as bisexual, 1.3% as asexual, and 3.9% selected "other". On average, participants reported 1.44 (*SD* = 1.61) AUD symptoms in the past year, and 55 (35.9%) met criteria for current AUD. Participants reported 2.31 (*SD* = 2.37) symptoms of CUD and 81 (52.9%) met criteria for current CUD.

Measures

The *Structured Clinical Interview for DSM-5 (SCID), Substance Use Module* (First et al., 2015) was administered to assess current (past-year) symptoms of alcohol and substance use

disorders. The SCID was administered by master's level research assistants who received training and ongoing supervision from the study PI (JDW) who is a licensed psychologist.

The *Timeline Follow Back* (TLFB; Sobell & Sobell, 1992) interview was used to collect data on the quantity of alcohol (in standard drinks) and cannabis (in grams) consumed each day over the last 90 days. A cannabis substitute (oregano) was used to provide a visual example of different quantities of cannabis joints to aid in reporting cannabis quantities in grams (Norberg et al., 2012), while a standard drink chart was also used to convert common alcohol beverages to standard drinks. We also assessed alternate forms of cannabis each day (e.g., edibles, THC oil, and vaping), and use of cannabis in one of these alternate forms was coded as an additional binary variable (used vs. not used on a given day). We also assessed whether any form of tobacco was used each day (including number of cigarettes smoked each day). The TLFB has been shown to be a valid retrospective interview measure of alcohol and other substance use against other self-report and biological measures (Hjorthoj et al., 2012; DeMarce et al., 2007), and has been used in studies looking at the daily associations between cannabis and alcohol co-use (e.g., Gunn et al., 2018; Metrik et al., 2018; Waddell et al., 2021).

The *UPPS-P Impulsive Behavior Scale* (Lynam et al., 2007) was used to assess Negative Urgency (12 items; α=.87); Positive Urgency (14 items; α=.93); Sensation Seeking (12 items; α=.84); Lack of Perseverance (10 items; α=.86) and Lack of Premeditation (12 items; α=.85). Participants rated how strongly they agreed/disagreed with each item on a 4 point scale (1=agree strong; 2=agree some; 3=disagree some; 4=disagree strong) and the average of responses to each subscale were utilized because of the differing number of contributing items. The UPPS-P has been found to be a reliable and valid measure of impulsivity (Cyders et al., 2007; Cyders et al., 2009; Smith et al., 2007).

The *Flanker Inhibitory Control and Attention Test* (Weintraub et al., 2013) is part of the NIH Toolbox neuropsychological battery and provided a behavioral measure of disinhibition. In this task, which was completed on an iPAD (6^{th} generation, iOS 12.0.4; Apple, Cupertino, CA), participants focused on a specific object (middle arrow) while inhibiting their attention to distractor objects (surrounding arrows) to make a correct judgement over 20 trials. Participants indicated whether the target object is pointing left or right. Trials are divided into two sections and randomized within the task where the distractor objects appear congruent or incongruent to the direction of the target stimulus. The reliability and validity of this task has been established in previous research (Zelazo et al., 2014). As part of the scoring procedures, age-corrected standardized scores were obtained to measure inhibitory control performance. We multiplied each score by -1 to use in our multilevel models so that higher values reflected behavioral disinhibition (i.e., greater impulsivity), consistent with the direction of scores on other measures.

The *Monetary Choice Questionnaire* (MCQ; Kirby et al., 1999) was used to assess delay discounting. This questionnaire contains 27 items where participants indicate their preference between hypothetical monetary rewards (i.e., small rewards today vs. larger rewards at a future date). MCQ responses are used to derive a delay discounting function, *k*, with larger values reflecting greater discounting of delayed rewards (i.e., preference for immediate rewards). An overall index of delay discounting was derived for each participant by computing the geometric mean of the participant's *k* value across small, medium, and large reward sizes, and then taking the natural logarithm to normalize the distribution (Kirby et al., 1999). Scoring methods and procedures developed by Gray et al. (2016) were implemented. No participants showed low consistency, and only one missing data point was imputed by using the next closest response.

Statistical Analyses

To examine the moderating role of impulsivity in the daily-level association between cannabis use and alcohol use, we specified a series of zero-inflated, generalized linear mixed models in which number of drinks reported on each day (from the TLFB) was specified as the level 1 outcome variable nested within each participant. Non-drinking days (coded as zero) were included in our analyses so that we could examine the association between cannabis use on a given day and both (a) the likelihood of drinking (vs. not) and (b) the amount of alcohol consumed (in standard drinks). We conducted these analyses using the glmmTMB package (Brooks et al., 2017) in R version 4.0.2 (R Core Team, 2013). A negative binomial distribution was used given the estimated dispersion parameter values for the dependent variable were large (i.e., >4.0 for all models), with maximum likelihood estimation and the Laplace approximation to integrate random effects. The results from glmmTMB are mixture models that include (a) a zero-inflated logistic model, which predicts the *absence* (versus presence) of the dependent variable (in this case, abstinence vs. drinking on a given day); and (b) a count model which predicts the number of standard drinks consumed on a given day. To ease logistic model interpretation, we reversed the direction of interpreting our results so that negative coefficients (which indicate decreased likelihood of *not* drinking) are interpreted as reflecting greater likelihood of drinking, whereas positive coefficients (which indicated increased likelihood of *not* drinking) are interpreted as reflecting decreased likelihood of drinking.

At the daily level, we regressed alcohol consumption (number of standard drinks consumed) onto the amount of cannabis flower consumed each day measured in grams. The cannabis grams variable was person-mean centered and person-mean-SD standardized following suggestions by Wang et al. (2019). We focused on cannabis flower as the predictor in our analyses because it was the most common form of cannabis used (e.g., 5,659 days total versus

886 days for other cannabis preparations overall). However, we also included an indicator denoting whether another cannabis preparation (i.e., edibles, oil-based vape, etc.) was reported on a given day (1=yes, 0=no) as a daily-level covariate. Other daily-level covariates controlled for in our analyses included whether the day was a weekday or weekend day and whether any tobacco was used on the same day (1=yes, 0=no). Random intercepts were estimated in all models for both zero-inflated and count portions of the model.

In addition to prior research showing that AUD and CUD moderates the link between cannabis and alcohol use, several demographic variables have also been shown to influence rates of alcohol and cannabis co-use. For example, males (compared to females), sexual and ethnic/racial minorities (compared to heterosexual and ethnic/racial majority individuals), and older young adults (compared to younger) tend to have higher alcohol and cannabis co-use rates (Drabble et al., 2020; Gunn et al., 2018; Lipperman-Kreda et al., 2018; Subbaraman & Kerr, 2015; Wen et al., 2015). Therefore, we added person-level covariates for sex, age, race (1 = White vs. 0 = non-White), sexual orientation (1 = Heterosexual vs. 0 = non-Heterosexual), average cannabis grams consumed over the past 90 days (to control for between-person variance), and both AUD and CUD symptom count. We then added the impulsivity variables of interest as additional person-level covariates: UPPS impulsivity subfacets, behavioral disinhibition, and delay discounting. All person-level continuous variables were grand-mean centered and standardized. Moderation was examined by first testing each cross-level interaction between daily cannabis amount and each impulsivity index separately (while also controlling the interactions between cannabis grams and both AUD and CUD symptoms in all models). We then obtained our final model by including all interaction terms that were found to be statistically

significant as simultaneous moderators in a single model. Significant interactions were further investigated with simple slopes analyses (Aiken & West, 1991).

Results

Descriptive Statistics

Table 1 displays the descriptive statistics and zero-order correlations between person-level covariates in the present study. Positive and negative urgency were highly correlated as expected. Negative and positive urgency were the subfacets most highly associated with AUD and CUD symptoms in the past year. Further, age, race and sexual orientation were not significantly associated with impulsivity variables (all $|r_s| \leq .15$, ps $> .064$), though female participants had lower negative urgency than men ($r_s = -.17$, $p = .03$).

Across all participants and days (total of 13,770), there were 2,761 days of alcohol use (20.1%), 5,659 days of cannabis use (41.1%), and 2,423 days in which both substances were used (17.6%). In addition, there were 886 days in which other forms of cannabis (e.g., edibles, THC oil, and vape) was used (6.4%), 1,865 days of tobacco use (13.5%). On drinking days, standard drinks consumed ranged from 1 (534 occurrences) to 28 (1 occurrence) with a mean of 3.78 drinks ($SD = 2.92$). For cannabis, the participants reported using an average of .90 grams on days in which cannabis was used ($SD = .91$, Range = 0.02-11.00). Participants also reported an average 15.84 days out of 90 where use of both alcohol and cannabis was reported ($SD = 12.75$; Range = 0-74) and 98% of participants in our analyses had at least one day-level co-use event.

Moderator Analyses

Table 2 displays the interactions terms between each impulsivity variable and grams of cannabis used when examined individually (i.e., without the other impulsivity interactions included in the model). Only negative urgency, sensation seeking, and delay discounting

interacted significantly with cannabis grams when predicting number of drinks consumed each day. Negative urgency and behavioral disinhibition also significantly interacted with cannabis grams when predicting likelihood of any alcohol use each day. We then entered each of the significant interaction terms (i.e., negative urgency, sensation seeking, disinhibition, and delay discounting) simultaneously to obtain our final model.

Results of this final model are shown in Table 3. In the logistic portion of the model predicting likelihood of any drinking, significant covariates included being older, White (vs. non-White), weekdays (vs. weekend days), tobacco use, and use of alternative cannabis preparations. Conversely, greater between-person average amount of cannabis smoked was associated with a higher likelihood of drinking across days. In the count portion of the model predicting standard drinks consumed at the daily-level, the only significant covariates were weekend days and same day tobacco use (within-person), as well as greater average cannabis grams used and greater AUD symptoms (between-person).

In the logistic portion of the model, negative urgency and inhibitory control were significant, unique moderators of the relationship between cannabis grams used and the likelihood of any drinking (versus absence of drinking). Further, there was a significant interaction between CUD symptoms (control variable) and cannabis grams in predicting likelihood of any drinking. Simple slopes analyses revealed that for individuals with high levels of negative urgency (i.e., 1 SD above the mean), greater cannabis grams consumed on a given day was associated with a greater likelihood of same day drinking (b=-.35, SE=.04, Z=-7.82, p<.001, $OR_{drinking}$=1.30). However, contrary to hypotheses, this association was even *stronger* for participants with low levels of negative urgency (i.e., 1 SD below the mean; b=-.47, SE=.04, Z=-11.00, p<.001, $OR_{drinking}$=1.38). Similarly, the association between greater cannabis consumption

and a greater likelihood of drinking on a given day was *stronger* for individuals with low levels of behavioral disinhibition (b=-.48, SE=.04, Z=-11.05, p<.001, $OR_{drinking}$=1.38) relative to high levels of behavioral disinhibition (b=-.34, SE=.04, Z=-7.91, p<.001, $OR_{drinking}$=1.40). Furthermore, the association was stronger for individuals with fewer CUD symptoms (b=-.54, SE=.04, Z=-12.72, p<.001, $OR_{drinking}$=1.42) than for those with greater CUD symptoms (b=-.28, SE=.05, Z=-6.06, p<.001, $OR_{drinking}$=1.24).

In the count portion of the model, negative urgency and delay discounting were statistically significant, unique moderators of the relationship between cannabis grams and number of alcoholic drinks consumed (Table 3). The pattern of the simple slopes was consistent with hypotheses. There was a significant positive association between amount of cannabis used and number of standard drinks consumed each day for those high in negative urgency (b=.09, SE=.02, Z=4.58, p<.001; Figure 1, panel A) and delay discounting (b=.08, SE=.02, Z=4.20, p<.001; Figure 1, panel B), but there was no statistically reliable within-person relationship between cannabis grams and standard drinks consumed each day for those low on negative urgency (b=.02, SE=.02, Z=1.11, p=.27) or delay discounting (b=.03, SE=.02, Z=1.57, p=.12).

Discussion

The present study extends research on the daily-level associations between cannabis use and alcohol use, while also examining the moderating role of several measures of impulsivity. We modelled the *quantity* of cannabis consumed in grams, included non-drinking days, and included behavioral measures of impulsivity, extending previous research that has focused on the presence versus absence of cannabis use on drinking days (Gunn et al., 2018; Metrik et al., 2018; O'Hara et al., 2016; Waddell et al., 2021). The findings provide new insight into the question of whether cannabis and alcohol are use as complements or substitutes by young adults. We found

support for complementarity overall, as there were positive, within-person associations between the amount of cannabis consumed on a given day and both the likelihood and the amount of alcohol consumed on the same day, consistent with past research among young adults (Gunn et al., 2018; Lee et al., 2020; O'Hara et al., 2016). Our analyses also controlled for the interaction between cannabis grams and both AUD and CUD symptoms, suggesting that daily cannabis-alcohol associations may be influenced by multiple components of impulsivity over and above the moderating role of substance use disorder symptoms demonstrated in prior research (Gunn et al., 2018; Metrik et al., 2018).

Results indicated that, when analyzed in separate models, sensation seeking, negative urgency, and delay discounting each moderated the daily relationship between grams of cannabis used and number of drinks consumed. However, only the latter two moderators remained significant when including all other significant interactions simultaneously. Consistent with hypotheses, the daily association between grams of cannabis used and number of drinks consumed was positive and statistically significant for individuals high (i.e., 1 SD above the mean) – but not low (i.e., 1 SD below the mean) – on negative urgency and delay discounting, suggesting that the strength of the complementary association between the two substances is impacted by these facets of impulsivity. This may reflect a tendency to combine large amounts of both substances to facilitate relief and escape from negative emotional experiences for individuals high on negative urgency (Merrill & Read, 2010; Smith & Cyders, 2016) or an overvaluation of the positive synergistic effects of cannabis and alcohol despite potential for greater consequences over the long-term for individuals high on delay discounting (Jackson et al., 2020; Linden-Carmichael et al., 2020). Thus, combined use of cannabis and alcohol may become positively reinforced among these individuals, leading to a positive association between

the amounts of each substance used at the daily level. Although the magnitude of the simple slopes were relatively small at the day level, these effects could accumulate over many co-use days, potentially leading to greater harms over the long run.

These findings partially align with the study by Waddell et al. (2021), which also found that impulsive traits moderated the daily-level associations between cannabis and alcohol use among veterans using data from a 6-month timeline follow back. However, that study found a different pattern of moderation – for veterans low in positive urgency and lack of perseverance, cannabis use (vs. no use) on a given day was associated with significantly *lower* same-day alcohol use (suggesting a substitution effect), with no significant daily-level relationship between cannabis use and alcohol use for those high on positive urgency and lack of perseverance. However, sensitivity analyses constrained to the last 90 days showed a significant and positive association between cannabis use and same-day alcohol consumption for those high in positive urgency and lack of perseverance, in line with complementarity and more consistent with the present findings. Still, the specific impulsivity facets that moderated the cannabis-alcohol associations differed between Waddell et al. and the current study. These differences might be a function of the different populations studied (i.e., predominantly male veterans vs. majority female young adults in the current study) or measurement of cannabis at the day-level (i.e., absence or presence vs. amount in grams in the current study). Further, Waddell et al. also suggest that their veterans were much heavier cannabis users than previous young adult samples (e.g., Gunn et al., 2018; O'Hara, 2014).

In the logistic portion of our model, although negative urgency and disinhibition moderated the association between grams of cannabis used and likelihood of consuming any alcohol on a given day, the moderating effects were in the opposite direction than we predicted.

Specifically, the relationship between greater cannabis amount and greater likelihood of drinking on a given day was stronger (i.e., complementary) for participants who were *lower* on negative urgency and *lower* on behavioral disinhibition compared to those *higher* in negative urgency and *higher* on behavioral disinhibition. One explanation for these unexpected findings may be that individuals high on urgency and disinhibition may have a tendency to impulsively use alcohol and/or cannabis in a variety of contexts (reducing the association between heavier cannabis use and same day initiation of alcohol use), while those lower in these traits may be more purposeful or planful in their co-use (e.g., containing use of both alcohol and cannabis to a weekend social gathering). However, this interpretation remains speculative as we did not assess motivations and context of for co-use behavior in this study. As studies have shown that co-use behavior is affected by context and motives (e.g., Arterberry et al., 2020; Patrick et al., 2020), future research will be necessary to determine how impulsivity interacts with these situational variables. Though the reason for unexpected findings in the moderating effect of negative urgency and disinhibition when predicting abstinence versus any drinking on a given day remain unclear, the results suggest that different processes may be occurring when considering the link between cannabis use and initiation of any drinking versus amount of alcohol consumed when drinking. These novel findings offer a more complex picture of the role of impulsivity in alcohol cannabis co-use than prior daily-level studies that have tended to examine only drinking days and/or dichotomize cannabis use (present vs. absent) at the daily level rather than examining quantity of cannabis used as a continuous variable.

The fact that positive urgency did not moderate the daily-level relationship between cannabis and alcohol use in the current study was unexpected. However, while both positive and negative urgency appear to be related to heavier cannabis use, there is conflicting evidence that

they are both predictive of cannabis problems (VanderVeen et al., 2016; Wardell et al., 2016). Further, although Jackson et al. (2020) found that high positive urgency was related to being someone who uses cannabis and alcohol simultaneously, Waddell et al. (2021) found that the daily association between cannabis use and alcohol use was not significant among participants high in positive urgency when examining 6 months of TLFB data. Further, although we expected that sensation seeking would also moderate the relationship between cannabis and alcohol use, and the moderation effect was significant when considered on its own, it did not remain significant when controlling for the interactions between cannabis use and the other impulsivity measures. Though a previous study found that sensation seeking was positively associated with reporting simultaneous alcohol and cannabis use in the past year (vs. alcohol only use), sensation seeking was not associated with simultaneous use frequency (Linden-Carmichael et al., 2019). Given these mixed findings, the moderating role of positive urgency and sensation seeking in the association between cannabis use and alcohol use should be further investigated in future studies.

Several limitations of the study should be noted. Although the TLFB is often considered the gold standard for retrospective assessment of substance use, recall bias may have impacted results. Our findings would benefit from replication with prospective methods of assessment (e.g., ecological momentary assessment approaches). The present study also relied on daily-level data and so the relative timing of cannabis and alcohol use on co-use days cannot be established. Our main cannabis variable focused on grams of cannabis flower used; although we controlled for alternative forms of cannabis, detailed data on the quantity of alternative forms was not collected and therefore could not be examined in our models. Further, although participants' reports of grams of cannabis used each day was aided by visual cues and physical examples of different cannabis quantities, the reliability of such reports remains to be established. Our sample

of young adult cannabis users (majority female-identifying) is not representative of all cannabis and alcohol users; moreover, in our study we recruited regular cannabis users specifically, resulting in a sample with cannabis use occurring twice as often (40% of days) as alcohol (20%) use, which may limit generalizability to co-users who are less frequent cannabis users or who tend to drink alcohol more often than they use cannabis.

Despite these limitations, the present study allowed us to examine the moderating role of several impulsivity variables in the daily-level relationship between grams of cannabis used and both the presence of drinking and the amount of alcohol consumed each day over the past 90 days. Overall, cannabis acted as a complement, rather than a substitute, to alcohol consumption among young adults. However, the strength of this complementary association varied depending on several person-level facets of impulsivity, two of which were assessed with behavioral tasks. The findings presented here contribute to understanding person-level impulsivity measures that influence cannabis and alcohol co-use patterns in young adults. Findings may help to inform targeted interventions by highlighting which components of impulsivity may play a role in cannabis and alcohol co-use behavior. This might include personality-tailored interventions, which have been shown to reduce alcohol and substance use among youth (Edalati & Conrod, 2019). Given that there is currently little research evaluating the effectiveness of interventions targeting cannabis and alcohol co-use (Yurasek et al., 2017), future research on personality-targeted interventions that specifically address co-use behavior may be informative.

Declarations and Statements

Declaration of Interest Statement: The authors have no conflicts of interest to disclose. The funders had no role in the design of the study, analysis of data, or reporting of results.

Data Availability Statement: Consent to upload data to a repository was not included in our informed consent procedure. Therefore, data will be made available upon request from the corresponding author.

Ethics Statement: All participants provided informed consent to voluntarily participate in this study. An institutional ethics review board approved the study before procedures began.

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Table 1. Descriptive statistics and zero-order correlations between continuous demographic and moderator variables of interest.

	M	*SD*	Range	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Negative Urgency	2.37	.60	1.17-4.00	--	**.64**	.04	**.36**	**.34**	-.10	.15	**.22**	**.32**
2. Positive Urgency	1.82	.61	1.00-4.00		--	.14	**.24**	**.33**	-.03	**.16**	**.26**	**.36**
3. Sensation Seeking	2.92	.60	1.42-4.00			--	**-.17**	.06	**.17**	.09	.05	.08
4. Lack of Perseverance	2.02	.56	1.00-3.40				--	**.46**	.01	-.05	**.18**	**.19**
5. Lack of Premeditation	1.90	.47	1.00-3.27					--	-.05	-.09	.08	**.16**
6. Inhibitory Control[a]	87.58	12.11	60-129						--	.02	-.10	-.01
7. Delay Discounting[b]	-4.74	1.67	-8.75-(-1.39)							--	.03	**.23**
8. AUD Symptoms, past year	1.46	1.64	0-9								--	**.26**
9. CUD Symptoms, past year	2.31	2.36	0-10									--

Note: Bolded values indicate significant Pearson correlations, rs $\geq .16$, ps $\leq .048$. Pearson correlations $\geq .21$ are significant at $p \leq .009$. [a]Age-corrected standardized score on the NIH Toolbox Flanker Task reflecting inhibitory control. We multiplied each score by -1 to use in our multilevel models so that higher values reflected behavioral disinhibition (i.e., greater impulsivity), consistent with the direction of scores on other measures. [b]Natural logarithm of the *k* index (delay discounting) geometric mean for small, medium, and large reward sizes. Values closer to zero (i.e., less negative) indicate higher delay discounting. Values farther from zero (i.e., more negative) indicate less delayed discounting.

Table 2. Cross-level interactions between each impulsivity variable (between-person) and daily grams of cannabis used (within-person) examined one at a time.

	Zero inflated (logistic portion)				*Conditional model (count portion)*		
IV Interaction Term	Estimate	O.R.	SE	Wald Z	Estimate	SE	Wald Z
Negative Urgency × Cannabis Grams	**.07***	**1.07**	**.03**	**2.34**	**.04****	**.01**	**3.19**
Positive Urgency × Cannabis Grams	-.01	.99	.03	-.32	.01	.01	1.22
Sensation Seeking × Cannabis Grams	-.005	1.00	.03	-.18	**-.02***	**.01**	**-2.20**
Lack of Perseverance × Cannabis Grams	.01	1.01	.03	.47	-.005	.01	-.48
Lack of Premeditation × Cannabis Grams	-.01	.99	.03	-.51	-.003	.01	-.28
Behavioral Disinhibition × Cannabis Grams	**.08****	**.92**	**.03**	**3.05**	.02	.01	1.92
Delay Discounting × Cannabis Grams	.001	1.00	.03	.03	**.03***	**.01**	**2.19**

Note: Dependent variable = Standard alcoholic drinks. O.R. = Odds Ratio predicting absence of drinking. Each interaction term was selected from the output of separate models where only that interaction term along with a control interaction term for AUD symptoms (past year) × Cannabis Grams and CUD symptoms (past year) × Cannabis Grams were entered. AUD = Alcohol Use Disorder. Cannabis grams is a level 1 (daily-level) variable that was person-mean centered around 90 days and subsequently person-mean-SD standardized. Bolded values indicate significant predictors, *$p < .05$, **$p < .01$, ***$p < .001$.

Table 3. Final model incorporating all significant all cross-level interactions between each impulsivity variable and daily cannabis grams consumed.

	Zero inflated (logistic portion)				*Conditional model (count portion)*		
	Estimate	O.R.	SE	Wald Z	Estimate	SE	Wald Z
Intercept	**1.76*** **	**5.81**	**.23**	**7.83**	**1.17*** **	**.12**	**9.44**
Sex (1=male, 2=female)	.13	1.14	.18	.71	-.17	.10	-1.69
Age (Z score)	**-.21***	**.81**	**.08**	**-2.47**	-.07	.05	-1.62
Race (1=White, 0=non-White)	**-.59*** **	**.55**	**.17**	**-3.55**	-.04	.09	-.40
Sexual Orientation (1=Heterosexual, 0=non-Heterosexual)	-.13	.88	.19	-.68	.07	.10	.70
Mean cannabis grams/day, grand mean centered (Z score)	**.30****	**1.35**	**.10**	**3.11**	.07	.05	1.36
Day (1=Weekday, 0=Weekend)	**.35*** **	**1.42**	**.06**	**6.26**	**-.22*** **	**.03**	**-7.24**
Tobacco used (1=yes, 0=no)	**-1.08*** **	**.34**	**.13**	**-8.26**	**.24*** **	**.06**	**3.84**
Other cannabis type (1=yes, 0=no)	**-.65*** **	**.52**	**.13**	**-4.96**	-.03	.07	-.41
AUD symptoms, past year (Z score)	-.14	.87	.09	-1.65	**.14****	**.05**	**2.92**
Cannabis grams (daily), person-mean centered (Z score)	**-.41*** **	**.66**	**.03**	**-12.30**	**.06*** **	**.02**	**3.59**
CUD symptoms, past year (Z score)	.10	1.11	.10	1.00	-.01	.05	-.20
Negative Urgency (Z score)	.07	1.07	.09	.77	-.07	.05	-1.50
Sensation Seeking (Z score)	-.03	.97	.09	-.40	-.004	.05	-.09
Inhibitory Control (Z score)	.08	1.08	.09	.90	-.05	.05	-.98
Delay Discounting (Z score)	.10	1.11	.08	1.20	.05	.05	.99
AUD symptoms × Cannabis Grams	-.02	.98	.03	-.94	-.005	.01	-.43
CUD symptoms × Cannabis Grams	**.13*** **	**1.14**	**.03**	**4.59**	.001	.01	.07
Negative Urgency × Cannabis Grams	**.06***	**1.06**	**.03**	**2.11**	**.03****	**.01**	**3.06**
Sensation Seeking × Cannabis Grams	.01	1.01	.03	.04	-.02	.01	-1.81
Behavioral Disinhibition × Cannabis Grams	**.07****	**.93**	**.03**	**2.64**	.005	.01	.42
Delay Discounting × Cannabis Grams	-.01	.99	.03	-.40	**.02***	**.01**	**1.97**

Note: AUD = Alcohol Use Disorder; CUD = Cannabis Use Disorder; O.R. = Odds ratio predicting absence of drinking. Bolded values indicate significant predictors. In the logistic portion, negative coefficients are interpreted as reflecting greater likelihood of drinking, whereas positive coefficients are interpreted as reflecting decreased likelihood of drinking. Cannabis grams is a level 1 (daily-level) variable that was person-mean centered and subsequently person-mean-SD standardized. Z score implies that the variable was standardized before adding to model. Bolded values indicate significant predictors, *$p < .05$, **$p < .01$, ***$p < .001$.

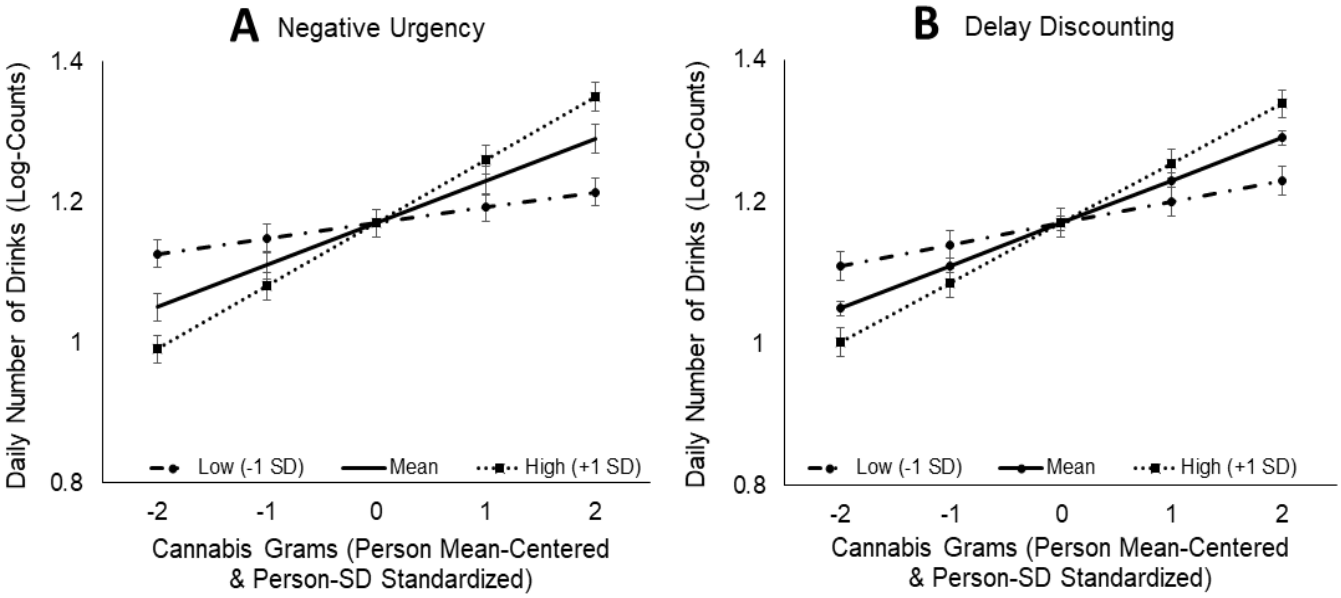

Figure 1. Results of simple slope analyses depicting moderating effects of (A) negative urgency and (B) delay discounting on daily-level associations between cannabis grams used and number of drinks consumed.