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Effects of frequent marijuana use on risky decision-making in young adult college students

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ABSTRACT

Introduction: Marijuana (MJ) is the most widely used illicit substance among adolescents and young adults. Frequent MJ use has been associated with impairments in cognitive flexibility and inhibition, both of which play important roles in decision-making. However, the impact of frequent MJ use on decision-making performance is mixed and not well understood. The current study examined the influence of frequent MJ use on risky decision-making in college students, 18–22 years old. *Methods*: From 2017 to 2019, data was collected from young adult college students ($n = 65$) consisting of 32 healthy controls (HC) and 33 frequent marijuana users (MJ+). Participants completed the Iowa Gambling Task (IGT), a measure of risky decision-making, and net IGT scores (advantageous-disadvantageous decisions) were used as a measure of optimal decision-making. *Results*: The main finding indicated there was a significant effect of group on net IGT scores ($p = 0.018$), which remained significant when sex was included in the model ($p = 0.006$), such that MJ+ had lower net IGT scores than HC. *Conclusions*: These findings highlight potential differences in risky decision-making between MJ+ and HC, but it is uncertain whether these differences are pre-existing and increase vulnerability for frequent MJ use or if they are related to the effects of frequent MJ use on decision-making.

1. Introduction

Recent data from the 2018 Monitoring the Future Study suggests there has been a resurgence of marijuana (MJ) use in young adults over the last three and a half decades (Schulenberg, Johnston, O'Malley, Bachman, Miech, & Patrick, 2019). Specifically, past 12-month and past 30-day MJ use in 19–22 year old college students are at the highest levels reported since 1983. Furthermore, 43% of 19–22 year old college students report past year MJ use, 25% report past month MJ use, while about 5.8% report frequent MJ use (daily or near-daily use) (Schulenberg et al., 2019). In an ongoing study examining the behaviors, attitudes and values of substance users, MJ was considered the least risky among illicit substances in 18–30 year olds (Schulenberg, Johnston, O'Malley, Bachman, Miech, & Patrick, 2017). In addition, the study indicates that over the past 11 years, there has been a continuous decline in perceived risk of regular MJ use. Changing attitudes have likely contributed to the legalization of recreational MJ use in eleven states and Washington D.C. MJ use has also increased in states where recreational use has been legalized (Kerr, Bae, Phibbs, & Kern, 2017) making it a critical time to better understand whether young adult MJ use affects neurocognitive functioning.

1.1. Marijuana use and brain maturation

Adolescence and young adulthood are periods of active biopsychosocial development and brain maturation. Given the protracted development of the prefrontal cortex, young adulthood is a critical period for the maturation of executive functions. Therefore, the establishment and maturation of structural and functional connections between the prefrontal cortex and other brain regions important in higher-order cognitive functions (Arain et al., 2013) during the third decade of life may be especially sensitive to the neurotoxic effects of substance use.

The primary psychoactive constituent of MJ, delta-9-tetrahydocannabinol (THC), directly targets endocannabinoid receptors located in the prefrontal cortex. Acute THC binding to cannabinoid receptor 1 has been shown to increase dopamine release and neural activity (Bloomfield, Ashok, Volkow, & Howes, 2016). THC exposure may disrupt cortical gamma oscillatory activity due to GABAergic reduction and neuronal hyperactivation in the prefrontal cortex (Renard et al., 2017) leading to disruptions in dopamine regulation which may contribute to cognitive impairments in executive functioning associated with MJ use.

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1.2. Marijuana use and executive functioning

Previous studies have reported cognitive functioning impairments in adolescent and young adult MJ users. Frequent MJ use has been shown to impair attention and concentration (Bolla, Brown, Eldreth, Tate, & Cadet, 2002) as well as verbal fluency (Pope et al., 2003). On executive functioning tasks, MJ users were slower on Go trials on the Go/NoGo Task (Maij, van de Wetering, & Franken, 2017), made more commission and omission errors on the Stroop Color Word Test (Dahlgren, Sagar, Racine, Dreman, & Gruber, 2016), and made more perseverative errors (Dahlgren et al., 2016) and had lower executive function standard scores on the Wisconsin Card Sorting Test (Lahanas & Cservenka, 2019), compared to healthy controls. In addition, daily MJ use has been linked to executive functioning impairments in cognitive flexibility and inhibition (Becker, Collins, & Luciana, 2014), both of which play important roles in decision-making (Laureiro-Martínez & Brusoni, 2018; Sakagami, Pan, & Uttl, 2006).

Adaptive decision-making is necessary for selecting healthy choices without significant personal risk, but poor decision-making can lead to risky choice, such as the maintenance of heavy or frequent substance use. Previous research on decision-making in MJ users has been mixed. Many studies have indicated that frequent MJ use is associated with deficits in decision-making performance (Becker et al., 2014; Fridberg et al., 2010; Grant, Chamberlain, Schreiber, & Odlaug, 2012; Moreno et al., 2012; Solowij et al., 2012; Verdejo-Garcia et al., 2007; Whitlow et al., 2004), while some studies have found no clear group differences between chronic MJ users and healthy controls (Dougherty et al., 2013; Gilman, Calderon, Curran, & Evins, 2015; Gonzalez et al., 2012). These mixed findings may be attributed to the heterogeneity of decision-making tasks, variability in MJ use history and the neurodevelopmental stage at first MJ use. In addition, the ages of participants in these studies ranged from adolescents to middle-aged adults and the criteria for frequent MJ use varied from >1 occasion of MJ use/week in the past year (Gilman et al., 2015; Grant et al., 2012; Solowij et al., 2012) to 25 out of 30 days of MJ use for at least five years (Fridberg et al., 2010; Whitlow et al., 2004), highlighting differences in inclusionary criteria for MJ users.

1.3. Marijuana use and the Iowa Gambling Task

One of the most widely used neurocognitive measures of risky decision-making is the Iowa Gambling Task (IGT), which simulates real-life decision-making, the cognitive ability to select the most adaptive course of action among a set of possibilities. Evidence of deliberate risk-taking and impulsivity have been measured using IGT performance (Upton, Bishara, Ahn, & Stout, 2011).

Many studies examining the effects of chronic MJ use on cognitive functioning have utilized the IGT to measure decision-making performance. A study examining group differences on net IGT scores between healthy controls and MJ users who smoked MJ for at least two years and who currently smoked at least four times/week, showed that greater frequency of MJ use was related to poorer IGT performance (Verdejo-Garcia et al., 2007). This study found that cannabis users had significant impairments in decision-making and risk-taking compared to healthy controls (Verdejo-Garcia et al., 2007), suggesting chronic MJ users have difficulty in changing their decision-making strategy towards advantageous card choices. In a subsequent study, frequent MJ users showed a preference for selecting decks having greater wins and infrequent, but greater punishments (Becker et al., 2014), further indicating that MJ users may have a more difficult time in anticipating and strategizing monetary gain and loss.

Frequent MJ use has also been shown to influence brain activity in regions associated with decision-making while participants performed the IGT during functional magnetic resonance imaging (fMRI) and positron emission tomography. A previous study indicated that chronic MJ users exhibited significantly less activity in the anterior cingulate cortex and medial frontal cortex, brain regions that are believed to play roles in impulse control and decision-making, during strategy development for the IGT (Wesley, Hanlon, & Porrino, 2011). This reduction of brain activity during monetary loss suggests MJ users may be less sensitive to negative feedback. Furthermore, chronic MJ users showed increased regional cerebral blood flow in the ventromedial prefrontal cortex compared to healthy controls during monetary decision-making and reward processing which may indicate that MJ users have greater sensitivity to rewards (Vaidya et al., 2011). These studies provide support for the important role of the prefrontal cortex in decision-making skills and highlight the vulnerability of this region to the effects of frequent MJ use during young adulthood.

1.4. Limitations in the current literature

Despite growing research on the effects of frequent MJ use on cognitive deficits in memory, attention and psychomotor function (Crean, Crane, & Mason, 2011), there has been less attention on the influence of frequent MJ use on executive functioning, especially in young adults (Becker et al., 2014; Gonzalez et al., 2012; Grant et al., 2012; Shannon, Mathias, Dougherty, & Liguori, 2010). Specifically, the effects of frequent MJ use on decision-making performance is mixed and not well understood. While some studies indicate cannabis users have significantly impaired decision-making capacities and greater risk-taking tendencies (Becker et al., 2014; Fridberg et al., 2010; Grant et al., 2012; Moreno et al., 2012; Solowij et al., 2012; Verdejo-Garcia et al., 2007; Whitlow et al., 2004), other studies suggest no clear differences between frequent MJ users and healthy controls (Dougherty et al., 2013; Gilman et al., 2015; Gonzalez et al., 2012).

To our knowledge, only one study (Becker et al., 2014) examined the effects of MJ use on risky decision-making within a narrow age range of 18–20 year old young adult college students and found MJ users showed a preference for selecting cards in decks A and B, leading to greater wins with infrequent but greater punishments (Becker et al., 2014). The current study aims to replicate and extend these findings by investigating the effects of frequent MJ use on risky decision-making in young adult college students, 18–22 years old. We chose to specifically examine the effects of frequent MJ use on decision-making in this population as (1) MJ use is most prevalent during emerging adulthood, (2) the prefrontal cortex continues to mature during this time, and (3) MJ use has been associated with poorer academic outcomes in college students (Arria, Caldeira, Bugbee, Vincent, & O'Grady, 2015), suggesting a window of vulnerability to the effects of frequent MJ use on adaptive decision-making in this population.

Furthermore, given that the prefrontal cortex undergoes sex-specific maturation during adolescence (Koolschijn & Crone, 2013), examining the role of sex on decision-making may highlight important differences in risk-taking between MJ users and healthy controls. Specifically, research suggests female participants are more sensitive to losses in advantageous decks on the IGT compared to male participants and, as a consequence, need additional trials before they achieve a similar level of performance (van den Bos, Homberg, & de Visser, 2013). These behavioral differences could be related to underlying neurobiological differences in the activation of the prefrontal cortex. Male participants may be better at suppressing reward-driven behaviors as right dorsolateral prefrontal cortex activity has been reported in males but not females during the IGT (Bolla, Eldreth, Matochik, & Cadet, 2004). Decision-making differences could also be associated with sex differences in the rate of white matter maturation, as male youth show steeper increases in white matter development relative to female youth (Lenroot et al., 2007). A previous study examined sex differences in decision-making on the IGT in young adult MJ users and found that heavier MJ use was associated with poorer decision-making performance in males but not females (Crane, Schuster, & Gonzalez, 2013). However, to our knowledge, no studies have examined group-by-sex interactions on risky decision-making in young adult MJ users and healthy controls.

1.5. Aims of the current study

The aims of the proposed study were to examine the influence of frequent MJ use on risky decision-making in college students using the IGT. A secondary aim was to conduct an exploratory analysis examining group-by-sex interactions on risky decision-making in young adult college students. Since we were interested in examining decision-making within active MJ users who were not yet undergoing cannabis withdrawal, we asked participants to remain abstinent from all substance use for 12 h prior to the study visit to attempt to avoid any withdrawal symptoms that may contribute to impairments in decision-making.

We hypothesized that (1) frequent MJ users would have poorer performance than healthy controls, indicated by lower net IGT scores; (2) frequent MJ users would show faster reaction times in card selection compared with healthy controls, which would reflect greater impulsive tendencies during decision-making; and (3) younger age at first MJ use, greater cumulative MJ use and greater recent MJ use would be related to lower net IGT scores in MJ users.

2. Materials and methods

2.1. Participants

Sixty-five participants, 18–22 years old, completed the study. All participants were native English speakers currently enrolled in college (2 or 4 year) or university. Of these participants, 32 were healthy controls (63% males, 37% females) and 33 were frequent MJ users (61% males, 39% females).

Exclusionary criteria included uncorrected visual impairments, pregnancy, lack of fluency in English, self-reported lifetime history of a diagnosed psychiatric disorder or learning disability, self-reported current use of psychotropic medications, major neurological/medical illness or significant head trauma, prenatal exposure to drugs or alcohol, premature birth and reported history of psychotic disorders in immediate family of biological relatives. Additional exclusion criteria for healthy controls (HC) included: significant substance use history (>51 lifetime drinks (Pfefferbaum et al., 2016), any history of heavy episodic alcohol use: >5 drinks/occasion for males and >4 drinks/occasion for females, >90 lifetime days of cigarette use, MJ use more than once/month in the past year and any other lifetime illicit drug use). Inclusionary criteria for frequent MJ users (MJ+) was ≥5 occasions of MJ use/week in the past year. Given the comorbidity of MJ and alcohol use (Substance Abuse and Mental Health Services, 2018), alcohol use was assessed but not exclusionary for the MJ+ group. MJ+ reporting >15 lifetime occasions of other illicit substance use combined across substances were excluded from study participation. While no participants reported lifetime history of a psychiatric disorder, scores from the Cannabis Use Disorders Identification Test-Revised (CUDIT-R) indicated 23 MJ+ met criteria for a possible cannabis use disorder (scores ≥ 13) (Adamson et al., 2010).

2.2. Procedure

Participants were recruited through flyers posted around the community and at MJ dispensaries as well as through social media advertising. Written consent was obtained from participants who contacted the laboratory to complete an interview to determine eligibility for the study. Following an eligibility interview, eligible participants were invited to take part in a study visit that included measures of substance use and psychosocial functioning as well as neurocognitive tasks of executive functioning. All participants were asked to abstain from substance use for at least 12 h prior to the study visit to limit effects of acute intoxication on neurocognitive measures. No participants appeared intoxicated at the time of the study visit.

After providing consent for participating in the study visit, participants provided a urine sample for a 12-panel urine toxicology test and completed a breathalyzer test to confirm absence of alcohol intoxication. All MJ+ had a positive urine toxicology screen for THC, while all HC had a negative urine toxicology screen for THC. Further, all participants had a blood alcohol concentration of 0.00 at the time of the study visit. A nicotine metabolite test for cotinine was not conducted for this study; thus, recent nicotine use was assessed through self-report. At the end of the study visit, participants were compensated with an Amazon e-gift card. All study procedures were approved by the Oregon State University Institutional Review Board (IRB) and were in accordance with ethical guidelines of research with human participants.

2.3. Measures

Participants completed a brief demographics questionnaire, which included questions on race, and socioeconomic status (SES). As many college students in this age range lack personal income, we asked participants to select their perceived socioeconomic status (poor, lower middle class, middle class, upper middle class, and wealthy). Additionally, participants were asked to estimate lifetime alcohol, MJ and cigarette use, and to report all substance use in the past 30 days using the Timeline Followback procedure (Sobell & Sobell, 1992). Participants also reported age at first use for alcohol, MJ and cigarettes. All participants completed a 2-subtest version of the Wechsler Abbreviated Scale of Intelligence-II (WASI-II) (Wechsler, 2011). Here, we report on the findings from the Iowa Gambling Task (IGT) (Bechara, Damasio, Damasio, & Anderson, 1994), one of the tasks from a larger neurocognitive assessment that was selected as a measure of risky decision-making. Findings from other tasks included in the larger neurocognitive assessment have been previously reported (Cavalli & Cservenka, 2020; Lahanas & Cservenka, 2019).

2.3.1. Iowa Gambling Task

The IGT was administered to participants on a computer (PAR (Version 2.00.040) [PARCopS] (2016)). Four card decks (A–D) were displayed to participants on the computer screen. Participants were read a standardized task script and told that the objective of the game was to win as much money as possible. Participants were also told that some decks were worse than others and were asked to treat the money in the game as real money. Following card selection, participants were given feedback about monetary gain or loss displayed on the computer screen. Participants began the task with $2000 in their bank. After card selection, participants could win $100 in decks A and B or $50 in decks C and D. In some instances, however, participants were credited with money, but were required to pay a penalty. For each card chosen, there was either an immediate gain or an immediate gain followed by a penalty (decks A and B had larger penalties; decks C and D had smaller penalties). Unknown to participants, card selections in decks A and B were classified as disadvantageous decisions because although larger winnings were possible by selecting cards from these decks, selection from these decks was also associated with larger losses, decreasing net earnings during the task. Card selections in decks C and D were classified as advantageous because although smaller winnings were possible by selecting cards from these decks, selection from these decks was also associated with smaller losses, increasing net earnings during the task. Participants completed 100 trials without interruption or caps on deck selections. At the end of administration, the net earnings were displayed on the computer screen. Total net scores were derived by subtracting the total number of cards selected from disadvantageous decks A and B from the total number of cards selected from advantageous decks C and D [Net IGT = (C + D) − (A + B)]. The majority of studies in MJ users have used net IGT scores to examine decision-making between and within groups across the task (Becker et al., 2014; Vaidya et al., 2011; Verdejo-Garcia et al., 2007; Wesley et al., 2011).

This strategy of analysis allows researchers to compare decision-making differences between and within groups across the task by examining differences of advantageous and disadvantageous card selections. Additional analyses for the IGT include comparing the total amount of money lost by each group (Vaidya et al., 2011), or examining net earnings at the end of the task (Vadhan et al., 2007), as well as measuring the amount of time needed to complete each task administration for multiple IGT sessions (Vadhan et al., 2007). However, these strategies do not account for the possibility of detecting between group differences across time. Therefore, we chose to focus the analyses on net IGT scores using a mixed-model analysis of covariance (ANCOVA), as outlined below (Section 2.4).

2.3.2. Timeline followback

Participants were asked to indicate their substance use in the 30 days prior to the study visit including alcohol, MJ, cigarette, or any other illicit substance use (Sobell & Sobell, 1992). To enhance recall, participants were encouraged to label key dates and events on the TLFB calendar.

2.3.3. Wechsler abbreviated scale of intelligence-II

Participants were administered a 2-subtest version (vocabulary and matrix reasoning) of the WASI-II to estimate general intelligence (Wechsler, 2011).

2.4. Data analysis

Data were analyzed using IBM Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL). For parametric, normally distributed data, independent samples *t*-tests were used to examine group differences on demographic variables and reaction times in card selection on the IGT with a significance value set at $p < 0.05$. Mann-Whitney *U*-tests were used to examine group differences on substance use variables that violated normality (skewness and/or kurtosis values greater than ±2), including past 30 day and lifetime substance use variables. Using a repeated measures ANCOVA with age and IQ as covariates, we investigated group differences on net IGT scores across five bins, each consisting of 20 trials. Substance use variables not normally distributed were log-transformed to improve normality (past 30 day and lifetime use) and were examined in relation to IGT performance using Pearson correlations. Finally, an exploratory analysis using a repeated measures ANCOVA examined the main effect of group, sex and their interaction on net IGT scores, controlling for age and IQ.

3. Results

3.1. Demographics

MJ+ and HC were not significantly different on sex ratio ($p = 0.875$), socioeconomic status ($p = 0.687$) or race ($p = 0.783$). However, groups were significantly different on age and IQ, such that MJ+ were older than HC and had lower IQ scores than HC (Table 1). While many of the substance use variables were significantly different between MJ+ and HC (Table 1), substance use variables within the MJ+ group were not significantly different by sex ($p > 0.05$) except a trend toward females being younger than males for age at first MJ use ($p = 0.076$).

Pearson correlations were conducted to determine if age and IQ were significantly associated with net IGT scores. Results showed that age was negatively associated with net IGT scores ($r = -0.30$, $p = 0.015$) and IQ was positively associated with net IGT scores ($r = 0.35$, $p = 0.005$). Thus, both age and IQ were included as covariates for the ANCOVA described below.

3.2. Recent substance use

Previous studies in which participants were asked to maintain a 12 h abstinence period prior to the study visit have not reported verification of this abstinence period at the time of the study visit (Becker et al., 2014; Gruber, Sagar, Dahlgren, Racine, & Lukas, 2012). In the current study, we examined responses on the TLFB to determine whether any participants reported substance use on the day of the study visit. Within MJ+, two participants indicated MJ use, one indicated MJ and alcohol use, and two indicated cigarette use on the day of the visit. However, we are unable to ascertain whether any of this substance use took place within the 12 h directly preceding the study visit. Importantly, none of these participants were outliers on dependent variables from the IGT, and were thus retained in the subsequent analyses.

3.3. Net IGT scores

Group differences on net IGT scores were analyzed using a repeated measures ANCOVA with age and IQ as covariates. We found a significant effect of group on net IGT scores, ($F(1, 61) = 5.93$, $p = 0.018$, $\eta_p^2 = 0.089$), indicating MJ+ had lower net IGT scores than HC (Fig. 1; Table 2). In addition, MJ+ selected more cards from deck A ($t(63) = -2.81$, $p = 0.007$, Cohen's $d = 0.70$) and deck B ($t(63) = -3.58$, $p = 0.001$, Cohen's $d = 0.89$) than HC and fewer cards from deck C ($t(63) = 3.01$, $p = 0.004$, Cohen's $d = 0.74$) than HC, such that MJ+ made more choices from disadvantageous decks A and B and fewer choices from advantageous deck C (Fig. 2). These differences in card selection between MJ+ and HC drove the overall main effect of group on net IGT scores. Age ($F(1,59) = 1.13$, $p = 0.292$, $\eta_p^2 = 0.018$) and IQ ($F(1,59) = 1.92$, $p = 0.171$, $\eta_p^2 = 0.030$) were not significant covariates in this model. Additionally, no significant group-by-bin interaction was found ($F(2.75,167.88) = 0.81$, $p = 0.482$, $\eta_p^2 = 0.013$).

As a secondary aim, a repeated measures ANCOVA was conducted with the main effects of group, sex and their interaction, but no significant group-by-sex interaction was found ($F(1,59) = 1.77$, $p = 0.189$, $\eta_p^2 = 0.029$), so the interaction was removed from the model and the final model only included the main effects of group and sex. In this model, the main effect of group on net IGT scores was significant ($F(1,59) = 7.98$, $p = 0.006$, $\eta_p^2 = 0.119$) and the main effect of sex was a trend ($F(1,59) = 3.40$, $p = 0.070$, $\eta_p^2 = 0.054$), such that MJ+ had overall lower net IGT scores than HC (Fig. 3) and female participants had a trend towards lower net IGT scores than male participants (Fig. 4). We found no significant group differences between male and females participants during card selections in deck A ($t(63) = -1.229$, $p = 0.224$, Cohen's $d = 0.31$) or deck D ($t(63) = -0.327$, $p = 0.744$, Cohen's $d = 0.05$), but female participants had a trend towards selecting more cards from disadvantageous deck B ($t(42.67) = -1.95$, $p = 0.058$, Cohen's $d = 0.51$) and selecting fewer cards from advantageous deck C ($t(63) = 1.90$, $p = 0.062$, Cohen's $d = 0.49$). Age ($F(1,59) = 1.68$, $p = 0.20$, $\eta_p^2 = 0.028$) and IQ ($F(1,59) = 0.81$, $p = 0.372$, $\eta_p^2 = 0.014$) were not significant covariates in this model. Additionally, no significant group-by-bin interaction ($F(2.76,163.05) = 0.63$, $p = 0.584$, $\eta_p^2 = 0.011$) or sex-by-bin interaction ($F(2.76,163.05) = 0.77$, $p = 0.504$, $\eta_p^2 = 0.013$) was found.

3.4. IGT reaction times

Using Spearman correlations, we found that age ($r(63) = 0.12$, $p = 0.331$) and IQ ($r(63) = -0.13$, $p = 0.320$) were not related to mean reaction times across all card selections. Results from a Mann-Whitney *U* test indicated no significant group differences in mean reaction times between HC and MJ+ during card selection on the IGT ($U = 478$, $p = 0.512$).

Furthermore, there were no significant group differences for advantageous mean reaction times ($U = 455$, $p = 0.338$) or

Table 1
Demographics and substance use characteristics of HC and MJ+.

	HC (n = 32)		MJ+ (n = 33)				
Participant characteristics	*M (SD)*	*%*	*M (SD)*	*%*	*Range*	*X, t or U*	*p*
Age (years)	19.25 (1.27)		20.30 (1.13)			−3.53	<0.001
Sex ratio (male:female)	20:12		20:13			0.03	0.875
Race (%)						1.74	0.783
Caucasian		65.63		75.76			
Black		0		3.03			
Hispanic		9.38		9.09			
Asian		9.38		6.06			
More than 1		18.75		12.12			
Unknown		6.25		3.03			
Socioeconomic status (%)						2.27	0.687
Poor		3.13		6.06			
Lower middle class		3.13		3.03			
Middle class		62.50		51.52			
Upper middle class		31.25		36.36			
Wealthy		0		3.03			
Estimated Full Scale IQ	119.84 (14.83)		105.55 (14.06)			3.99	<0.001
Vocabulary *T*-score	58.63 (12.30)		51.61 (8.96)			2.64	0.011
Matrix reasoning *T*-score	59.91 (8.98)		53.97 (9.31)			2.62	0.011
CUDIT-R	5.50 (4.95)[1]		14.97 (4.38)			−2.95	0.006
Alcohol Use							
Age first used (years)	17.59 (1.68)[2]		16.52 (1.84)			2.20	0.032
Past 30 days	2.30 (4.04)		18.27 (17.68)		0–62	124.50	<0.001
Lifetime use (drinks)	13.79 (16.81)		406.61 (612.23)		1–2500	71.50	<0.001
Cigarette Use							
Age first used (years)	13[3]		17.35 (1.81)[4]			−2.34	0.030
Past 30 days	0		6.30 (20.82)		0–92	478.50	0.160
Lifetime use (cigarettes)	7.50		61.75 (158.02)		1–700	225.50	<0.001
Marijuana Use							
Age first used (years)	18.50 (1.76)[5]		16.15 (1.60)			3.26	0.002
Past 30 days	0.17 (0.41)		49.42 (29.74)		18–134	0	<0.001
Lifetime use (days)	23.53 (128.94)		1117.18 (620.38)		134–2920	9.50	<0.001

[1] n = 2; HC completed the CUDIT-R if they reported any MJ use in the past six months.
[2] n = 22.
[3] n = 1.
[4] n = 20.
[5] n = 6.

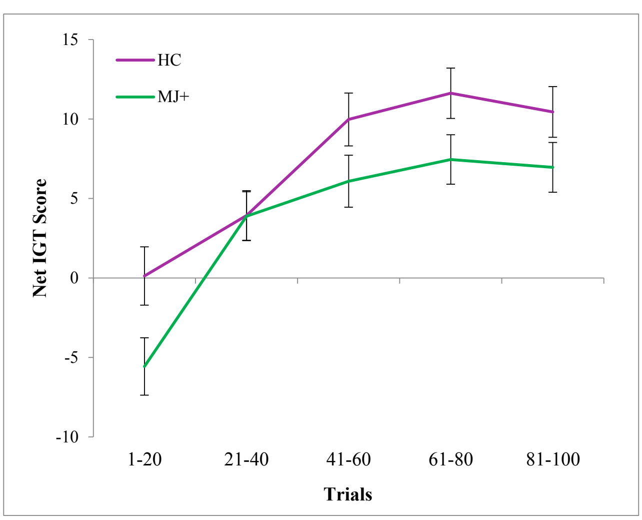

Fig. 1. Net IGT scores across five bins in MJ+ and HC. Main effect of group on net IGT scores showing MJ+ had significantly lower net IGT scores than HC (p = 0.018).

disadvantageous mean reaction times (U = 516, p = 0.875).

Additional Mann-Whitney U-tests found no significant group differences in mean reaction times between male and female participants during card selection for deck A (U = 445, p = 0.458), deck B (U = 487, p = 0.861), deck C (U = 435, p = 0.381) or deck D (U = 416, p = 0.257).

Table 2
Descriptive data of HC and MJ+ on the IGT.

	HC (n = 32)		MJ+ (n = 33)	
Net IGT scores	*M (SD)*	*95% CI*	*M (SD)*	*95% CI*
Trials 1–20	−0.44 (10.63)	−4.27, 3.39	−5.03 (8.00)	−7.87, −2.19
Trials 21–40	4.06 (8.51)	0.99, 7.13	3.76 (7.24)	1.19, 6.33
Trials 41–60	10.25 (8.25)	7.28, 13.22	5.82 (8.62)	2.76, 8.88
Trials 61–80	13.56 (7.99)	10.68, 16.44	5.58 (9.04)	2.37, 8.78
Trials 81–100	12.19 (8.92)	8.97, 15.40	5.27 (8.33)	2.32, 8.23

3.5. *Substance use variables and net IGT scores*

Following log transformation of substance use variables, Pearson correlations were conducted to determine the relationship between age at first use, past 30 day use, and lifetime use, with net IGT scores in the MJ+ group. Results indicated that age at first MJ use (r(31) = 0.14, p = 0.440), past 30 day MJ use (r(31) = −0.06, p = 0.751) and lifetime MJ use (r(31) = −0.13, p = 0.456) were not significantly related to net IGT scores. Additionally, results indicated that age at first alcohol use (r(31) = 0.18, p = 0.320), past 30 day alcohol use (r(31) = −0.001, p = 0.994), lifetime alcohol use (r(31) = −0.08, p = 0.662), age at first cigarette use (r(18) = −0.01, p = 0.966), past 30 day cigarette use (r(31) = 0.04, p = 0.841) and lifetime cigarette use (r(31) = 0.16, p = 0.387) were not significantly related to net IGT scores. Furthermore, as all of the MJ+ participants had used alcohol in

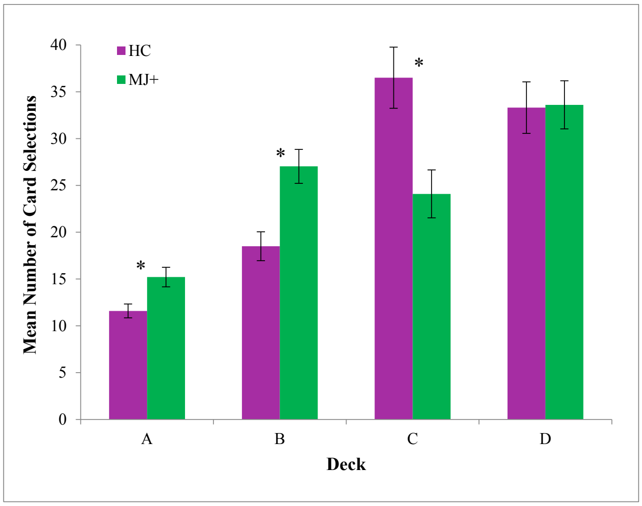

Fig. 2. Mean number of card selections in MJ+ and HC for each deck. Mean card selections between groups from each deck showing MJ+ made more card selections from deck A ($p = 0.007$) and deck B ($p = 0.001$) than HC and fewer card selections from deck C ($p = 0.004$) than HC. $*p < 0.05$.

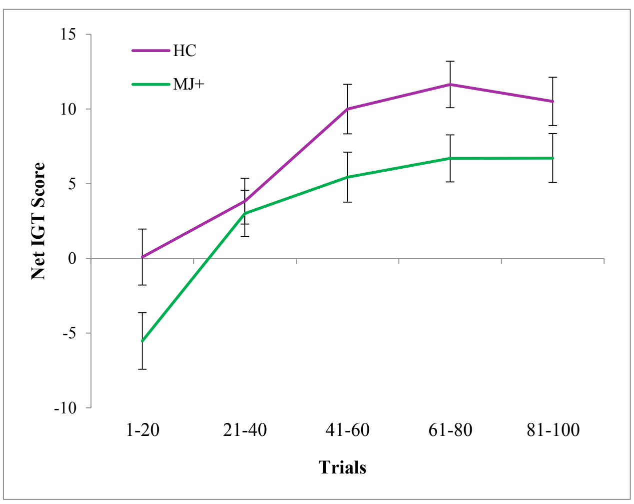

Fig. 3. Net IGT scores across five bins in MJ+ and HC with sex included as a factor in the model. Main effect of group on net IGT scores with sex included as a factor in the model showing MJ+ had significantly lower net IGT scores than HC ($p = 0.006$).

their lifetime, alcohol and MJ use variables were examined together in relation to net IGT scores within three regression models (age at first use, past 30 days use, and lifetime use) in the MJ+ group. There were no significant effects of age at first alcohol and marijuana use ($R^2 = 0.03$, $F(2,30) = 0.50$, $p = 0.614$), past 30 day alcohol and MJ use ($R^2 = 0.003$, $F(2,30) = 0.05$, $p = 0.951$), or lifetime alcohol and marijuana use ($R^2 = 0.02$, $F(2,30) = 0.30$, $p = 0.744$) on net IGT scores.

4. Discussion

This study examined the relationship between frequent MJ use and risky decision-making in young adult college students using the IGT. To our knowledge, only one other study has examined risky decision-making using the IGT in a similar and narrow age range of young adults (Becker et al., 2014). In the current study, MJ+ were older and had significantly lower IQ scores relative to HC. As both age and IQ were related to IGT performance, they were included as covariates in the analyses.

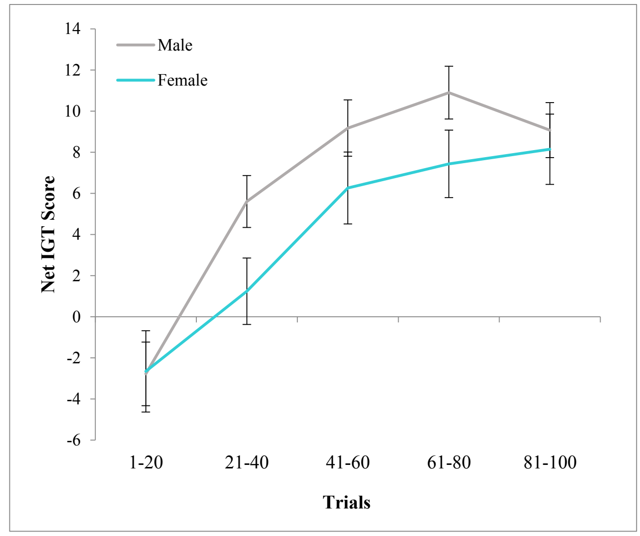

Fig. 4. Net IGT scores in male and female participants with sex included as a factor in the model. Main effect of sex on net IGT scores showing a trend for female participants to have lower net IGT scores than male participants ($p = 0.070$).

There was a significant main effect of group on net IGT scores, suggesting that MJ+ had lower net IGT scores relative to HC (Fig. 1). Although MJ+ made advantageous card selections as indicated by the positive net IGT scores, they made less advantageous choices compared to HC. This effect is consistent with prior research examining group differences between MJ users and healthy controls in young adults (Becker et al., 2014; Grant et al., 2012; Moreno et al., 2012). Research suggests that MJ users are more likely to make risky judgments despite subsequent monetary punishment than healthy controls (Grant et al., 2012) and exhibit increased impulsive decision-making by selecting more disadvantageous cards than healthy controls (Moreno et al., 2012). Additionally, the current findings support prior research that found young adult MJ users made more selections from disadvantageous decks A and B compared to healthy controls (Becker et al., 2014). However, in the current study, MJ+ also made fewer card selections than HC from deck C, an advantageous deck, but one that is associated with frequent punishments relative to deck D (Fig. 2). This could suggest MJ users may prefer decks that are associated with frequent rewards and infrequent losses, which could drive reward-driven behavior. This observed performance difference in reward-driven behavior may be attributed to differences in utilization of the prefrontal cortex during strategy and choice selection. Future studies that utilize the IGT in young adults during fMRI are needed to explore this question.

Furthermore, we found that the effect of group on net IGT scores was significant when including sex as a factor in the model. Overall, MJ+ had lower net IGT scores compared with HC (Fig. 3). Additionally, there was a trend for female participants to have lower net IGT scores than male participants (Fig. 4). In the current study, the trend towards poorer net IGT performance in female relative to male participants appears to be driven by females tending to make more disadvantageous selections from deck B, where rewards are frequent and losses are infrequent, while at the same selecting fewer cards from advantageous deck C in which loss frequency is equal to gain frequency. Females may also be performing worse than males due to differences in the time needed to develop decision-making strategies towards advantageous choices. Male participants may be better at suppressing reward-driven behaviors due to activity in the right dorsolateral prefrontal cortex activity that has been shown in males but not females completing the IGT (Bolla et al., 2004). A previous study that examined sex differences between young adult male MJ and female MJ users found that lifetime

MJ use was associated with poorer decision-making performance in male but not female participants (Crane et al., 2013). However, this study did not perform an interaction between group and sex on net IGT scores due to the absence of healthy controls. Thus, it is unknown whether similar findings would have also been seen if female and male non-MJ users had been included.

The observed trend for sex differences on the IGT may also be attributed to the possible influence of sex hormones on executive functioning. A study examining the interactive effects of dopamine base levels and cycle phase on executive functions found that women were significantly faster on the Stroop during the luteal phase compared to menses and pre-ovulatory phases (Hidalgo-Lopez & Pletzer, 2017). This suggests women have improved verbal skills during the luteal phase when levels of progesterone and estradiol are high. Another study found that women ovulating were more likely to choose risky options than men (Lazzaro, Rutledge, Burghart, & Glimcher, 2016). In the current study, females may have performed worse on the IGT because we may have unknowingly sampled a high percentage of women in a stage of their menstrual cycle where they are more likely to take risks. However, since we did not ask female participants to report menstrual cycle stage at the time of the study visit, we are unable to confirm whether hormone levels may have influenced IGT performance.

No differences were observed between MJ+ and HC mean reaction times during the IGT, which is inconsistent with our initial hypothesis. To our knowledge, no studies in MJ users have examined mean reaction times on the IGT. While risky decision-making may be related to impulsivity, it may be important to utilize other neurocognitive measures that assess motor impulsivity and response inhibition. In a fMRI study investigating the relationship between MJ use and inhibitory control processing, MJ users tended to have faster reaction times than healthy controls (Gruber et al., 2012). Additionally, brain activity differences were observed in the dorsal anterior cingulate cortex, a region of the brain thought to be involved in impulse control. In the present study, as mean reaction time was not significantly related to IGT performance, MJ+ took the same amount of time as HC to make decisions during card selection. This finding suggests that lower net IGT scores in MJ+ relative to HC may be related to maladaptive decisions that are not associated with motor impulsivity during card selection.

Although age at first MJ use, 30 day MJ use and lifetime MJ use were not significantly related to IGT performance among MJ+, between group differences on the IGT suggests there may be potential differences between MJ+ and HC that could be related to pre-morbid vulnerability for risk-taking tendencies and/or the effects of substance use itself. Underlying differences in prefrontal cortex development between MJ+ and HC could explain some of these findings. For example, a previous study showed that early-onset frequent marijuana users had a thicker prefrontal cortex than late-onset frequent MJ users, which could indicate reductions in normative grey matter pruning in the prefrontal cortex in participants who begin using MJ at a younger age (Filbey, McQueeny, DeWitt, & Mishra, 2015). While previous studies have found associations between early adolescent MJ use and impairments in executive functioning (Fontes et al., 2011; Gruber et al., 2012; Pope et al., 2003), we did not find a relationship between age at first MJ use and risky decision-making. In the current study, we asked participants to report their age at first MJ use instead of age at *regular* MJ use, which may be more closely associated with patterns of MJ use that could predict neurotoxic consequences of use. Age at first use can be a difficult variable to assess, especially in young adults aged 18–22 years, since age at first MJ use may have occurred very recently in this population and thus, participants may have only had a year or two of substance use prior to the study visit.

4.1. Limitations and future directions

One limitation of the current study is the modest sample size. Although our sample was relatively well matched in the number of participants in each group, our findings may not be readily generalizable to young adult college students. Another related issue is the overrepresentation of males in the MJ group. Although the prevalence of MJ use is higher in males than females (Substance Abuse and Mental Health Services, 2018), our findings may not be generalizable to female MJ users. Although onset of cannabis withdrawal symptoms typically occur in frequent MJ users after 24 h of abstinence, and peak 2–6 days post cannabis abstinence (Budney, Moore, Vandrey, & Hughes, 2003), we cannot confirm whether or not participants were in active withdrawal during the study visit. Future studies should administer the Marijuana Withdrawal Symptoms checklist (Budney, Novy, & Hughes, 1999) to assess withdrawal symptoms in participants at the time of the study visit. In addition, the potency of MJ is not standard and our study design does not take into account dose-response associations in MJ+. Future studies will need to assess other indicators of MJ use, such as asking participants to report THC content of the MJ they typically use. Another limitation is that we utilized a laboratory task of decision-making and provided participants with hypothetical earnings rather than tangible incentives. In future studies, it will be important to use other real-life decision-making measures to determine if our findings are specific to the IGT, are associated with non-monetary risk-taking behaviors, or are associated with decision-making in general. As we only used one task of decision-making, our findings may not generalize across a wide range of decision-making tasks. Future studies may want to utilize additional tasks to assess risky decision-making, such as the Balloon Analogue Risk Task (Lejuez et al., 2002) or Cambridge Risk Task (Rogers et al., 1999). Additionally, as most MJ users are also alcohol users, alcohol was not used as exclusionary criteria for MJ+. While post-hoc analyses suggested alcohol use was not related to IGT performance, we cannot rule out the possibility that the neurotoxic effects of alcohol may play a role in the observed group differences on decision-making performance. In models examining the effects of both MJ use and alcohol use on net IGT scores, neither significantly predicted decision-making performance in MJ+, which may be due to lack of refined measure to assess frequency of these substances and premorbid characteristics that distinguish MJ+ from HC. Other studies that reported group differences on the IGT between MJ users and healthy controls either did not examine relationships between marijuana use variables and IGT performance (Wesley et al., 2011), only examined other substance use variables in relation to IGT performance (Becker et al., 2014), or did not find associations between substance use variables and IGT performance (Vaidya et al., 2011). One study by Verdejo-Garcia et al. (2007) reported greater joints smoked/week was associated with lower net IGT scores in abstinent marijuana users, but did not examine other substance use characteristics in relation to IGT scores within the same model. We believe future studies should consider the relationship between MJ use and decision-making performance, while accounting for poly-substance use. Finally, while we observed a trend for MJ+ to report greater recent anxiety on the Beck Anxiety Inventory (Beck, Epstein, Brown, & Steer, 1988), compared with HC ($p = 0.08$), the main effect of group remained significant when controlling for BAI scores in the ANCOVA models with ($p = 0.014$) and without sex ($p = 0.035$) included as a factor. As anxiety levels may affect decision-making, future studies should ascertain that anxiety levels in MJ users are not driving any observed decision-making differences between MJ users and healthy controls.

In summary, the current study examined the effects of frequent MJ on risky decision-making in college-aged young adults. We found a main effect of group on net IGT scores, such that MJ+ had overall lower net IGT scores than HC. These findings may highlight differences in decision-making performance between young adult MJ+ and HC. Results from this study underscore the importance of interventions targeted at reducing risky decision-making in young adult MJ users. As our study is cross-sectional, further longitudinal research is needed to understand whether impairments in MJ users are related to the neurotoxic effects of MJ or if riskier decision-making may be present in MJ users prior to initiation of use, and whether these differences persist after abstinence.

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Contributors

Author AC designed the study and wrote the protocol. Authors JC and AC conducted literature searches of previous research studies. Author JC wrote the first draft of the manuscript, conducted the data analyses, and prepared the tables and figures. Both AC and JC revised, edited, and approved the final manuscript.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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Data availability statement

The data that supports the findings of this study are available from the corresponding author, AC, upon reasonable request.

Data deposition statement

The data that supports the findings of this study are not publicly available but are available from the corresponding author, AC, upon reasonable request.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.abrep.2020.100253.

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