Effects of Marijuana on Risky Decision-Making in Young Adult College Students

by
Jorie L. Casey

A THESIS

submitted to

Oregon State University

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in partial fulfillment of
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degree of

Honors Baccalaureate of Science in Biochemistry & Molecular Biology
(Honors Scholar)

Presented May 15, 2019
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Abstract approved:____

Anita Cservenka

Marijuana (MJ) is a 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 on decision-making performance is mixed and not well understood. The current study examined the influence of heavy MJ use on risky decision-making in college students, 18-22 years old. 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. A trend was found for the effect of group on net IGT scores, such that marijuana users (MJ+) had lower net IGT scores than healthy controls (HC). The final model with main effects of group and sex showed a significant effect of group on net IGT scores and a trend for the main effect of sex. MJ+ had lower net IGT scores than HC and female participants had a trend towards lower net IGT scores than male participants. These findings highlight potential differences in risky decision-making between young adult MJ users and healthy controls, but it is uncertain whether these differences are pre-existing and increase vulnerability for heavy MJ use or if they are related to the effects of heavy MJ use.

Key Words: marijuana, young adult, risky, decision-making, Iowa Gambling Task
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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

Jorie L. Casey, Author

Effects of Marijuana on Risky Decision-Making in Young Adult College Students

Introduction

Marijuana (MJ) is one of the most widely used illicit substances, especially among adolescents and young adults. In the United States, 51.8% of 18-25 year olds report MJ use during their lifetime and 22.1% report being current MJ users (Substance Use and Mental Health Services, 2016; Substance Abuse and Mental Health Services, 2018). 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 nine 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.

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.

Marijuana Use and Executive Functioning

Previous studies have reported cognitive functioning impairments in adolescent and young adult MJ users. Heavy 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). In addition, chronic 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 substance use. Previous research on decision-making in MJ users has been mixed. Many studies have indicated that heavy 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 heavy 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.

Chronic 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, heavy 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.

Heavy 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 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 heavy MJ use during young adulthood.

Limitations in the Current Literature

Despite growing research on the effects of chronic MJ use on cognitive deficits in memory, attention and psychomotor function (Crean, Crane, & Mason, 2011), there has been less attention on the influence of heavy 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 chronic 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; Grant et al., 2012; Whitlow et al., 2004; Verdejo-Garcia et al., 2007; Fridberg et al., 2010; Solowij et al., 2012; Moreno et al., 2012) other studies suggest no clear differences between chronic MJ users and healthy controls (Gonzalez et al., 2012; Dougherty et al., 2013; Gilman et al., 2015).

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 heavy MJ use on risky decision-making in young adult college students, 18-22 years old. We chose to specifically examine the effects of heavy 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 heavy 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.

Aims of the Current Study

The aims of the proposed study were to examine the influence of heavy 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.

We hypothesized that (1) heavy MJ users would have poorer performance than healthy controls, indicated by lower net IGT scores; (2) heavy 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.

Methods

Participants

Sixty participants, 18-22 years old, completed the study. All participants were college (2 or 4 year) or university students and native English speakers. Of these participants, 33 were healthy controls (55% males, 45% females) and 27 were frequent MJ users (67% males, 33% 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 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 heavy MJ users (MJ+) was $\geq$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.

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 MJ use for at least 12 hours prior to the study visit to limit effects of acute intoxication on neurocognitive measures.

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. 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.

Measures

In addition to completing a brief demographics questionnaire, 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, 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) (Weschler, 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.

Iowa Gambling Task. The IGT was administered to participants on a computer. 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 $2,000 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 a 50% chance of penalty ($250 penalty for decks A and B; $50 penalty for decks C and D). 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 and 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)].

Timeline Followback (Sobell, 1992). 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. To enhance recall, participants were encouraged to label key dates and events on the TLFB calendar.

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 (Weschler, 2011).

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 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.

Results

Demographics

MJ+ and HC were not significantly different on sex ratio ($p = 0.340$), socioeconomic status ($p = 0.753$) or race ($p = 0.650$). 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 ($p > 0.1$).

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 ($r = -0.268$, $p = 0.039$) and IQ was positively associated with net IGT scores ($r = 0.343$, $p = 0.007$). Thus, both age and IQ were included as covariates for the ANCOVA described below.

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 trend for the effect of group on net IGT scores,

(F(1,56) = 3.209, p = 0.079, η_p^2 = 0.054), suggesting that overall, MJ+ tended to make more disadvantageous decisions on the IGT compared with HC (Figure 1). In addition, MJ+ selected more cards from deck B than HC (t(58) = -3.332, p = 0.002) and fewer cards from deck C than HC (t(58) = 2.291, p = 0.026), such that MJ+ made more choices from disadvantageous deck B and fewer choices from advantageous deck C (Figure 2). These differences in card selection between MJ+ and HC drove the overall main effect of group on net IGT scores. Additionally, no significant group-by-time interaction was found (F(2.7,154) = 1.09, p = 0.35), such that over time, changes in net IGT scores did not significantly differ between MJ+ and HC.

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(1,54) = 1.999, p = 0.168, η_p^2 = 0.035), 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 effects of group on net IGT scores was significant (F(1,54) = 5.399, p = 0.024, η_p^2 = 0.091) and the main effect of sex was a trend (F(1,54) = 3.295, p = 0.075, η_p^2 = 0.058), such that MJ+ had overall lower net IGT scores than HC (Figure 3) and female participants had a trend towards lower net IGT scores than male participants (Figure 4). Additionally, no significant group-by-bin interaction was found (F(2.7, 148) = 0.76, p = 0.51) and no significant sex-by-bin interaction was found (F(2.6, 147) = 0.66, p = 0.56).

IGT Reaction Times

Using Spearman correlations, we found that age (r(58) = 0.071, p = 0.589) and IQ (r(58) = -0.077, p = 0.556) 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 during card selection on the IGT (U = 419, p = 0.694).

Furthermore, there were no significant group differences for advantageous mean reaction times (*U* = 404, *p* = 0.537) or disadvantageous mean reaction times (*U* = 440, *p* = 0.935).

Substance Use Variables and Net IGT Scores

Following 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*(25) = 0.040, *p* = 0.845), past 30 day MJ use (*r*(25) = -0.035, *p* = 0.862) and lifetime MJ use (*r*(25) = -0.306, *p* = 0.121) were not significantly related to net IGT scores. Additionally, results indicated that age at first alcohol use (*r*(25) = 0.174, *p* = 0.387), past 30 day alcohol use (*r*(25) = 0.119, *p* = 0.580), lifetime alcohol use (*r*(25) = -0.075, *p* = 0.710), age at first cigarette use (*r*(25) = -0.089, *p* = 0.733), past 30 day cigarette use (*r*(25) = 0.322, *p* = 0.678) and lifetime cigarette use (*r*(25) = 0.333, *p* = 0.191) were not significantly related to net IGT scores.

Discussion

This study examined the relationship between chronic 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.

There was a trend towards a main effect of group on net IGT scores, suggesting that MJ+ had lower net IGT scores relative to HC (Figure 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, prior research has shown significant group differences between MJ users and healthy controls in the number of cards selected from deck B, such that MJ users showed a preference for selecting cards in deck B, a deck associated with frequent rewards, but occasional large losses (Becker et al., 2014). These findings along with the findings from the current study indicate that during the task, MJ+ failed to acquire an effective strategy, suggesting MJ+ were more sensitive to frequent rewards, but less sensitive to infrequent punishment compared to HC (Figure 2). This observed performance difference in reward-driven behavior may be attributed to differences in utilization of the prefrontal cortex during strategy and choice selection.

Furthermore, we found that the effect of group on net IGT scores was significant after including sex as a factor in the model. Overall, MJ+ had lower net IGT scores compared with HC (Figure 3), suggesting MJ+ failed to reach the same learning curve as HC. Additionally, there was a trend for female participants to have lower net IGT scores than male participants (Figure 4). This finding supports previous research suggesting that females tend to focus on win-loss frequencies and need more trials than males to achieve a similar level of IGT performance (van den Bos et al., 2013). Poorer net IGT performance suggests that females could be more heavily influenced by frequency of losses during learning, resulting in inconsistent decision-making strategies. 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 looking at sex differences between young adult male MJ and female MJ users found that lifetime MJ use was associated with poorer decision-making performance in males but not females (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.

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 looked at mean reaction times on the IGT. While risky decision-making may be related to impulsivity, it may be important to look at other neurocognitive measures that assess motor impulsivity and response inhibition. In a fMRI study looking at the relation between MJ use and inhibitory processing, MJ users tended to have faster reaction times than healthy controls (Gruber, Sagar, Dahlgren, Racine, & Lukas, 2012). Additionally, brain activity differences were observed in the dorsal anterior cingulate activity, 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 heavy users and HC could explain some of these findings. For example, a previous study showed that early-onset heavy marijuana users had a thicker prefrontal cortex than late-onset heavy MJ users, which could indicate reductions in normative grey matter pruning in the prefrontal cortex in early-onset heavy MJ users (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. This may be due to using age at first MJ use as a predictor instead of age at *regular* MJ use, which may be more closely associated with patterns of MJ use and could predict neurotoxic consequences of use. Age at first use can be a difficult variable to assess, especially when looking at 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.

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. In addition, the potency of marijuana is not standard and our study design does not take into account dose-response associations in MJ+. However, our sample of MJ+ was relatively homogenous in terms of use in the past year as inclusionary criteria required MJ+ to use MJ at least 5 times/week. 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. 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 summary, the current study examined the effects of heavy MJ on risky decision-making in college-aged young adults. We found a main effect of group on net IGT scores when sex was included in the model, 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 maintenance of risky decision-making in chronic young adult MJ+. Further research is needed to understand whether impairments in MJ+ are related to the neurotoxic effects of MJ or if riskier decision-making may be present in MJ+ prior to initiation of use, and whether these differences persist after abstinence.

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Appendix

Table 1

Demographics and substance use characteristics of MJ+ and HC

	HC (n = 33)		MJ+ (n = 27)				
Participant characteristics	*M (SD)*	*%*	*M (SD)*	*%*	*Range*	*X, t or U*	*p*
Age (years)	19.18 (1.13)		20.22 (1.19)			-3.47	< 0.001
Sex ratio (male:female)	18:15		18:9			0.91	0.340
Race (%)						1.64	0.650
Caucasian		66.67		77.78			
Hispanic		9.09		11.11			
Asian		12.12		3.70			
More than 1		18.18		14.81			
Unknown		3.03		3.70			
Socioeconomic status (%)						1.90	0.753
Poor		3.03		3.70			
Lower middle class		3.03		3.70			
Middle class		60.61		48.15			
Upper middle class		33.33		40.74			
Wealthy		0		3.70			
Estimated Full Scale IQ	118.42 (13.63)		106.96 (12.80)			3.33	0.002
Vocabulary *T*-score	58.39 (11.08)		52.74 (7.11)			2.29	0.026
Matrix reasoning *T*-score	58.76 (8.58)		54.26 (8.71)			2.01	0.050
Alcohol Use							
Age first used (years)	17.38 (1.47)		16.59 (1.62)			252	0.159
Past 30 days	1.98 (3.66)		18.96 (18.27)		0-62	64.50	< 0.001
Lifetime use (drinks)	14.82 (17.14)		420.59 (638.25)		1-2500	119	< 0.001
Cigarette Use							
Age first used (years)	18*		17.82 (1.42)			8.50	1.000
Past 30 days	0.03 (0.03)		4.67 (18.02)		0-92	391	0.091
Lifetime use (days)	0.03 (0.17)		41.81 (137.77)		0-700	170	< 0.001
Marijuana Use							
Age first used (years)	17.67 (1.51)		16.33 (1.54)			1.92	0.064
Past 30 days	0.33 (0.52)		50.22 (31.10)		18-134	0	< 0.001
Lifetime use (days)	126.83 (295.52)		1066.41 (606.91)		200-2920	94.5	< 0.001

*only 1 HC indicated past cigarette use

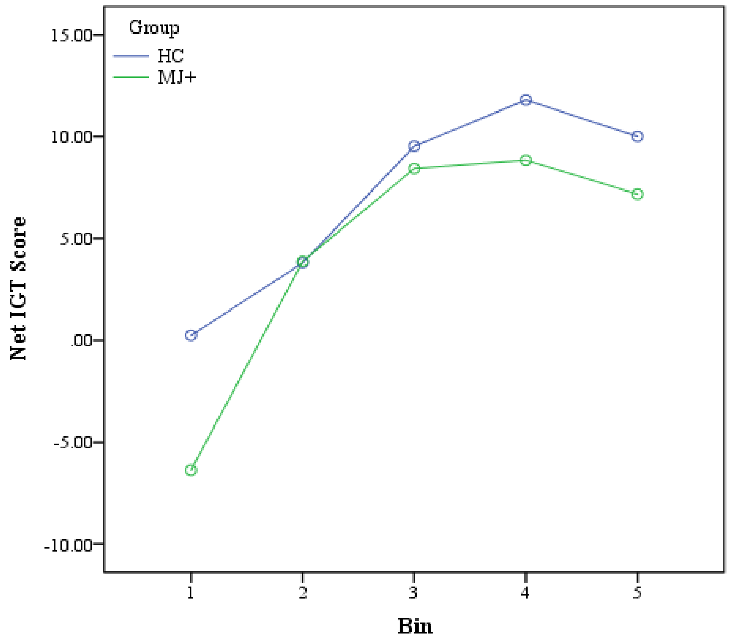

Figure 1. Net IGT scores in MJ+ and HC.

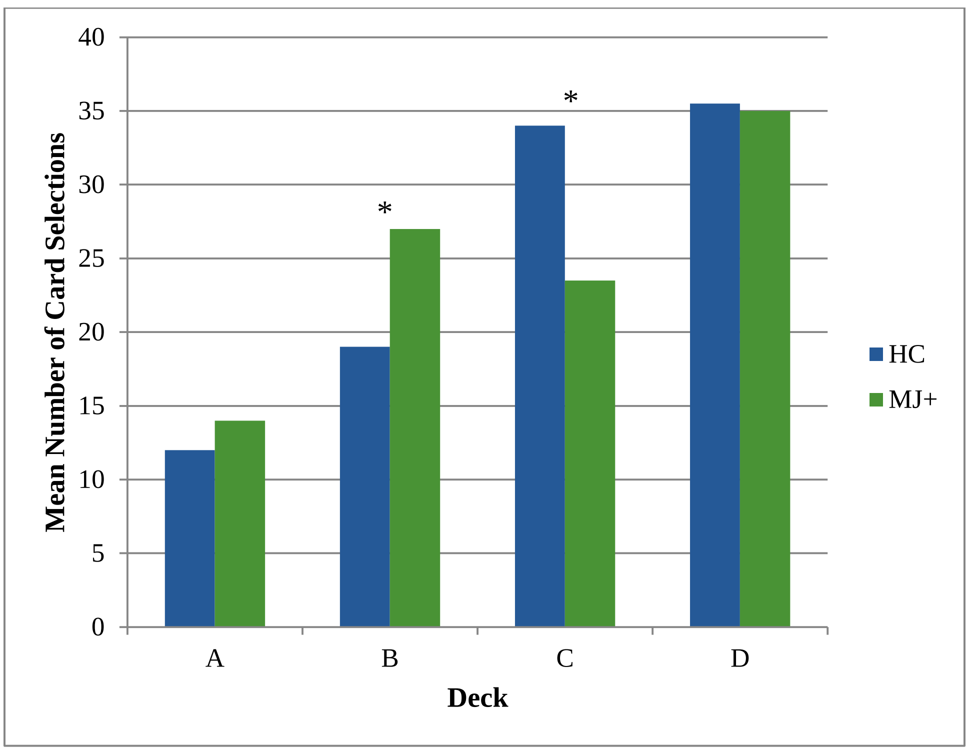

Figure 2. Mean number of card selections in MJ+ and HC for each deck. *$p < 0.05$

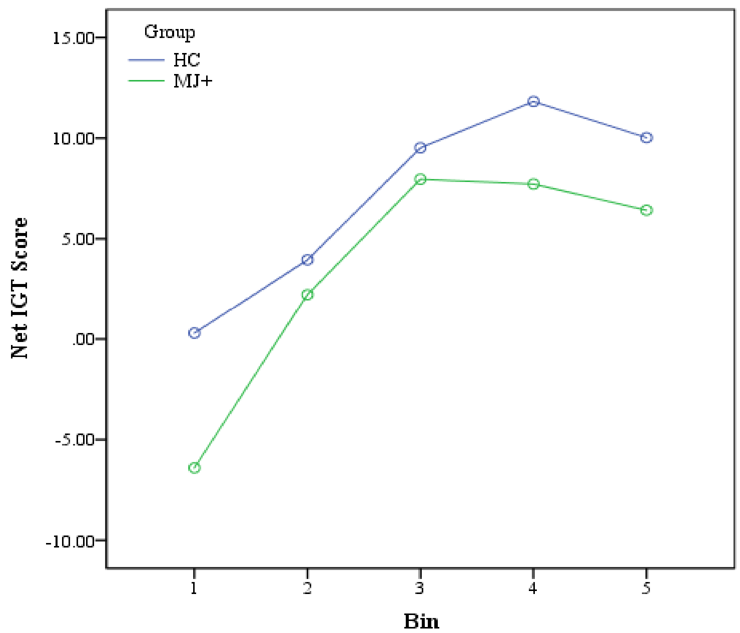

Figure 3. Net IGT scores in MJ+ and HC with sex included as a factor in the model.

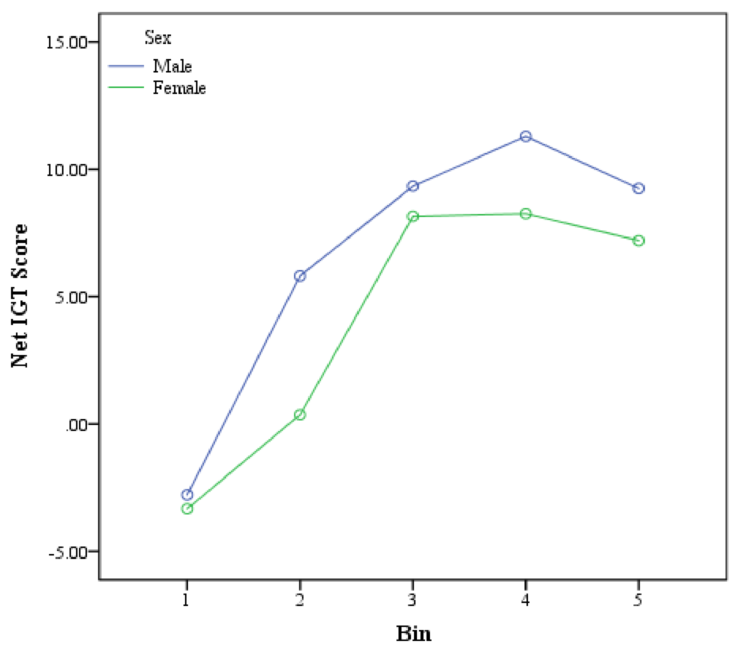

Figure 4. Net IGT scores in male and female participants with sex included as a factor in the model.