Associations Between Cannabis Use and Inhibitory Executive Functioning in Young Adults

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Abstract

Much of the controversy surrounding cannabis legalization concerns the uncertain effect of cannabis use on the developing brains of adolescents and young adults. In order to develop effective harm reduction strategies, research must accurately identify such effects, as well as identify factors that impact this relationship. This study examines relationships between cannabis use on executive functioning in young adults by analyzing the collective and individual impact of variables relating to cannabis use on six correlated measures of IEF ability. We failed to demonstrate any meaningful relationship between cannabis use and IEF ability in young adults. This was true whether cannabis variables were assessed collectively, as in the comparison of nested models, or individually, as predictors within the full linear regression models. Although the study may have been affected by a restriction of range, this null effect of cannabis is validated by considerable internal consistency within measures of inhibitory executive functions and cannabis use. The lack of significant results in the presence of strong construct validity, suggests the relationship between cannabis and IEF is complicated and dependent on a number of factors.

Throughout the United States, attitudes and policies surrounding cannabis are becoming increasingly progressive. A 2017 Gallup poll showed the highest level of public support for cannabis legalization in decades, with 64% of Americans supporting cannabis legalization, compared to 12% in 1969 (McCarthy, 2017). Thirty states have legalized cannabis for medical use; nine states and Washington D.C. additionally legalized recreational use of cannabis for adults over the age of 21 (Robinson, Burke, & Gould, 2018). Such policies have led to increased availability of cannabis (McCarthy, 2017), which has been linked to increased use (Keyes, Wall, Cerdá, Schulenberg, O'Malley, Galea, Feng, & Hasin, 2016) and decreased perceived harmfulness of cannabis (Schuermeyer, Salomonsen-Sautel, Price, Balan, Thurstone, Sung-Joon, & Sakai, 2014). These societal shifts have sparked considerable debate regarding possible unintended consequences of these cultural shifts.

Much of the controversy surrounds the uncertain effect of cannabis use on the developing brains of adolescents and young adults. An inconsistent body of research suggests that early onset cannabis use is associated with long-term deficits in *executive functions* such as attention, motivation, and impulse control. Such findings are particular concern because healthy development of EF is important for the growth and learning that ideally characterizes young adulthood. Such skills are often necessary in order to be successful in school and work environments, as well as for health-promoting habits such as exercise and emotion regulation (Diamond, 2012).

Laws and public policies surrounding cannabis, specifically harm reduction strategies, must be based on facts if they are to be effective. In order to develop effective harm reduction strategies, research must accurately identify the effects of cannabis use on developing brains, as well as identify factors that impact this relationship. Putative deleterious effects on cannabis use on developing brains may be mitigated by identifying characteristics associated with risk and resilience. This study examines relationships between cannabis use on executive functioning in young adults.

Literature Review

Executive Functions

Executive functions (EFs) are a multifarious set of cognitive abilities that regulate and facilitate goal-directed behavior (Friedman, du Pont, Corley, & Hewitt, 2018). Centered in the pre-frontal cortex (Banich & Compton, 2012), EFs act as the brain's control system, enlisting and modulating lower level cognitive abilities for use in complex processes such as attention, organization, decision making, and self-control (Crean, Crane, & Mason, 2011). EFs allow us to select behaviors that align with a desired outcome (e.g. deciding how to act when entering party or job interview) (Diamond, 2012), resist undesired automatic responses (e.g. fighting the urge to eat junk food while on a diet) (Miyake & Friedman, 2012), and estimate the effects and relative worth of decisions (e.g. deciding to attend graduate school) (Banich & Compton, 2011).

Measuring executive functions. EFs are difficult to measure because they are functionally inseparable from other cognitive abilities that are under their control. Because EFs necessarily operate on other cognitive processes, a portion of variance in any single EF measure is inevitably caused by individual differences in these other cognitive abilities (Friedman, Miyake, Young, DeFries, Corley, & Hewitt, 2008). This inability to distinguish EF variance from non-EF variance is known as the *task-impurity problem*, and can be mitigated by using *latent-variables* (underlying cognitive abilities that impact performance on a set of related yet separable assessments (Miyake & Friedman, 2012)) as dependent measures. *Latent variable* *analysis* illuminates latent variables by statistically extracting variance that is common among these related observations (Friedman & Miyake, 2004).

Miyake & Friedman (2000) used latent variable analysis to reveal a set of underlying *core EFs*. They analyzed nine EF measures and found three distinct latent factors: updating (the continuous addition and deletion of working memory contents), shifting (flexibly switching between tasks or mental sets), and inhibition (deliberately overriding dominant thoughts and behaviors). These three core EFs were significantly but imperfectly correlated, suggesting the presence of shared variance and portions of variance that were unique to the core EFs. Shared variance was termed *common EF*, as it captures abilities that are essential for each of the three core EFs. Common EF is conceptualized as the ability to actively maintain task goals and related information, and use this information to bias lower-level processing in favor of said goal. Friedman and Miyake showed that inhibition was statistical indistinguishable from common EF, with no meaningful remaining variance.

Inhibition. *Inhibitory executive functions* (IEFs) are cognitive mechanisms that dampen neuronal, mental, or behavioral activity (Friedman & Miyake, 2004). IEFs enable purposeful control of attention, thoughts, behavior, and emotions, often to override a powerful internal predisposition or external lure, and instead do what's more appropriate or needed (Diamond, 2012). IEFs are often defined by the cognitive process being inhibited: *cognitive inhibition* is the suppression of unwanted thoughts or memories, *inhibitory control of attention* allows us to focus on what we choose while ignoring (i.e. inhibiting attention to) irrelevant stimuli, and *response inhibition* is the ability to inhibit impulses and other dominant reactions to stimuli (Diamond, 2012). These seemingly diverse IEFs are actually the same neural system impacting different cognitive functions.

Measuring inhibition. Significant correlations between outwardly distinct measures of IEF suggest the presence of a universally influential underlying ability (Diamond, 2012; Friedman & Miyake, 2004). Friedman & Miyake (2004) found strong associations between measures of *resistance to distractors* (the ability to selectively attend to relevant stimuli while ignoring irrelevant stimuli) and *prepotent response inhibition* (the ability to suppress a powerful automatic behavior), likely because both measures rely on the ability to actively maintain task goals when confronted with interference from external stimuli. As previously mentioned, this factor is functionally identical to common EF. Thus, when latent variable analysis of a comprehensive EF battery is not an option, these measures constitute the "purest" measures of IEF by maximizing reduction of variance associated with other cognitive processes.

Eriksen flanker task. Developed in 1974 by Barbara and Charles Eriksen, the flanker task assesses attentional control by requiring subjects to respond to relevant stimuli while ignoring distracting stimuli. Dependent measures are typically related to accuracy and reaction time (RT). High IEF ability is characterized by little RT difference between baseline (non-distracting conditions) and inhibitory conditions (Eriksen & Erikson, 1974).

Stroop task. The Stroop task has long served as a standard measure of prepotent response inhibition. Subjects are presented with a series of words printed in a variety of colors, and asked to name the color that the word is printed in, rather than read the word. Our society encourages us to prioritize meaning over unessential details like color or font (Diamond, 2012), thus the prepotent response is to read the word, rather than name the color. The Stroop task measures the degree to which inhibition of this dominant response impairs performance.

Cannabis and Cognition

Cannabis use has long been associated with cognitive impairment. Scientific and anecdotal evidence alike show significant deficits in attention, decision making, working memory, and encoding and retrieval of long-term memories during episodes of acute cannabis intoxication (characteristic cognitive and perceptual changes that accompany a state of intoxication – in other words, the “high”) (Curran, Freeman, Mokrysz, Lewis, Morgan, & Parsons, 2016). However, less certain is whether cannabis use causes long-term cognitive deficits. Several studies show significant effects of cannabis on cognition, while other studies have failed to find differences between cannabis users and non-users. These inconsistent results may be caused by a number of factors (Pope, Gruber, & Yurgelun-Todd, 1995).

Cannabis research is often constrained by legal and ethical restrictions, which forces researchers to settle for flawed study designs. For example, when studying the effects of long-term cannabis use on the brain, researchers cannot ethically choose a random sample and administer large amounts of cannabis over a long period of time. Such a study would be illegal, too expensive, and unfair to participants. Instead, researchers must choose a sample that has already been using cannabis long term, which raises the questions of whether findings are the result of cannabis use, or pre-existing differences between the groups. Individuals who use cannabis may be systematically different from those who do not use in more ways than cannabis use. Researchers are also impaired by legal restrictions regarding the acquisition and administration of cannabis. They must go through a long process to get the government to administer cannabis for research purposes. There is only one available strain of cannabis, which eliminates direct study of effects of other strains.

Such methodological restrictions increase the possibility of the study being impacted by confounding variables. Research on the cognitive effects of cannabis often fails to control for the amount of time between participants’ last use of cannabis and the assessment, which obscures the distinction between acute and drug residue effects of cannabis (Pope et al., 1995). Residual effects can be categorized into two types of lingering damage: drug residue effects (cognitive effects of lingering cannabinoids and metabolites in the system) and central nervous system (CNS) alteration (permanent changes to brain structure and function caused by exposure to cannabis). Drug residue effects can be expected to dissipate after a prolonged period of abstinence from cannabis, while CNS damage would persist in spite of cannabis abstinence.

Adolescents and young adults.

Although the effects of cannabis use on the adult brain are inconsistent, early onset cannabis use has been reliably associated with a number of cognitive deficits. Pope, Gruber, Hudson, Cohane, Huestis, & Yurgelun-Todd (2002) found that early-onset cannabis use (defined as use before age 17) was associated with significantly lower performance on measures of verbal intelligence. Pope et al. (2002) propose three possible explanations for these effects. The first is that cognitive differences may be due to pre-existing cognitive differences between early and late onset users. This is especially true for differences in verbal intelligence, since verbal intelligence tends to be resilient to a wide range of cortical damage **(Luria, 66)**. Additionally, longitudinal research suggests that low executive functioning is a risk factor for substance use during adolescence, which implies that low EF is a cause in addition to an effect of cannabis use. Additionally, the relationship between onset of cannabis use and cognitive ability may be caused by an unknown mediating or moderating variable. Cannabis may exacerbate deficits by preventing individuals from engaging in stimulating activities. However, in this situation, the relationship between cannabis use and low verbal intelligence is caused by the relationship of both variables to lack of academic engagement. The last hypothesis is a true neurotoxic effect of cannabis on the developing brain.

The Present Study

This study aimed to explicate the relationship between cannabis use and IEF ability in young adults. Multiple dimensions of cannabis use were assessed to comprehensively capture participants' cannabis use behavior. The Eriksen flanker task and Stroop task were the chosen measures of IEF. We chose EF measures that theoretically provide the most IEF was used because of the strong relationship between inhibition and common EF. IEFs constitute the purest, most universal measure of EF. Thus, when a comprehensive battery of EF assessments is not feasible (as in this study), measures of IEF may yield a reasonably accurate estimate of overall EF ability. Six regressions with correlated outcome variables theoretically allow true effects of cannabis to be distinguished from random statistical noise. If cannabis truly predicts IEF ability, such a relationship would be present in all regressions (since the outcomes are highly correlated). If not, the relationship can be attributed to statistical noise. Effects of these variables on IEF task performance were analyzed collectively, using an analysis of variance (ANOVA) of nested regression models, and individually as predictors within full linear models. To maximize validity, we accounted for time since participants' most recent use of cannabis (to control for effects of acute intoxication and drug residue) and recent use of non-cannabis recreational substances (to control for cognitive effects of other substances).

Hypothesis.

Cannabis use is expected to predict performance on all measures of IEF ability. Comparison of nested models should show significant differences in R2 between full and reduced regression models. The full regressions would significantly predict IEF ability, with significant effects of variables relating to amount, frequency, age of onset, attitude, and control.

Method

Participants

Participants were 393 undergraduate students enrolled in an introductory psychology course at CU Boulder. Participation in the study was voluntary and self-selective. Students signed up via Sona, a web-based psychological research administration system ("Product Overview," 2018). At the time of enrollment, students received no information about the study other than expected duration. In exchange for their participation, students received two credits toward a 12-credit introductory psychology course requirement.

Three-hundred-sixty-seven participants were included in the final analyses (11 were excluded due to color blindness; 15 due to incomplete or mislabeled data). Two-hundred-eight (57%) were women, and 159 (43%) were men. Ages ranged from 17.83 years to 24.83, with a mean of 19.18 and a standard deviation of 1.05. Of these 367 participants, 74% identified as white, 10% as Hispanic, 9% as Asian, 3% as other (i.e. none of the listed answers), 3% as black, and 1% as Native American. On average, the students had completed 12.38 years of education (SD = 0.74), with a mean GPA of 3.22 (SD = 0.48).

Measures

All measures were fully computerized (Mac Mini, OS X, v.10.6.8). Stimuli and survey questions were presented on a monitor screen (Acer S220HQL) located approximately 36 inches from the participants, who responded using the attached keyboard (Logitech Internet 350).

IEF Measures. The Flanker and Stroop tasks were coded in Python by the present author using PsychoPy software (v.1.85.2) (Peirce, 2007). Task design was based on that of Friedman & Miyake (2004). A series of instruction screens introduced each task and asked participants to respond as quickly as possible without sacrificing accuracy. Instructions and stimuli were printed in white Arial font on a black background (exempting the Stroop task, which necessarily presented stimuli in red, yellow, or blue). Trial conditions appeared in a random order. Each trial began with a 500-millisecond empty black screen, followed by a 500-ms fixation point positioned in the center of the screen. Stimuli appeared after the fixation point, and remained on the screen until the participant entered a response. Trials were evenly divided into blocks; participants received a short break and reiteration of task instructions after completing each bock.

Eriksen flanker task. Participants were asked to respond to a letter located in the center of the screen (the *target*), while ignoring any distractor letters (*noise*) located to the left and right of the target. The 'A' key was pressed if the target was *S* or *C*, and the 'L' key was pressed if the target was *H* or *K*. Trials were randomly assigned one of three noise conditions: 1) noise same as the target (*KKKKKKK*), 2) noise/response compatible (*HHHKHHH*), and 3) noise/response incompatible (*SSSKSSS*). A no-noise condition (*K*) served as a baseline. A series of 32 practice trails was followed by 11 blocks of 32 trials (total of 352 trials; 88 in each condition).

Stroop task. The prototypical Stroop task was adapted for computer administration by assigning each color to a keyboard key. Rather than naming the color of the word aloud, participants pressed the key that corresponded to the color. Stimuli were shown in red, yellow, or blue; the 'A' key was pressed if the word was printed in red, the 'S' key was pressed if the word was printed in yellow, and the 'D' key was pressed if the word was printed in blue. Trials were randomly assigned to one of four word conditions: 1) color/word congruent ('blue' printed in blue), 2) color/word incongruent ('blue' printed in red), 3) neutral word ('ship' printed in blue), and 4) asterisks ('****' printed in blue). Participants completed 36 practice trials, followed by 8 blocks of 48 trials (total of 384 trials; 96 in each condition).

Outcomes. Dependent measures were dimensions of performance on the flanker and

Stroop tasks. For both tasks, performance was described by accuracy (number of correct responses), median RT, and an additional measure that captured the effect of inhibition on RT. For the flanker task, the degree to which distractors slowed RT (*distractor interference*) was calculated by subtracting each subject's median RT in the no-noise (baseline) condition from their median RT in the noise-response incompatible condition (Friedman & Miyake, 2004). A similar measure was created for the Stroop task: *switch cost* was the difference in median RT between the color/word incongruent and neutral word conditions (Friedman & Miyake, 2004).

Survey. A 28-question survey assessed attitudes and behaviors relating to cannabis use, as well as other variables that often covary with cannabis use and/or IEF. The survey was written by the present author and administered using Qualtrics software (2018), and contained multiple choice, short answer, and Likert-type questions.

***Cannabis*.** Cannabis behavior was assessed across multiple dimensions to comprehensively describe each participant's unique pattern of cannabis use. Cannabis use was conceptualized in terms of frequency (average number of days each week, average number of hours each week spent intoxicated), amount of cannabis used each week (consumption of flower, concentrate, and edibles was assessed separately), and age of onset (age of first use, age at which participants began using cannabis regularly). Time since participants' most recent use of cannabis was measured to control for acute intoxication and drug residue effects.

Two questions evaluated participants' views of cannabis as a positive, negative, or neutral force in their lives. Attitude was captured by asking students to report the degree to which they agreed with the statement, "Cannabis makes my life better". Control over cannabis use was assessed by the question, "It is hard for me to control my cannabis use". These items were presented in a seven point Likert-type format (7 = strongly agree; 1 = strongly disagree).

An additional response option for "I don't use cannabis" was included to distinguish low scores (indicating a negative view of cannabis or low sense of control) from lack of use.

Covariates.

Demographic. Demographic information was assessed to control for individual differences that may impact cannabis use or IEF ability, as well as evaluate the representativeness of the sample. The following variables were measured: a) age (reported in month/year format to maximize precision while preserving participants' anonymity), b) gender (male, female, other), c) racial background (white, black, Hispanic, Asian, Native American, other), d) years of education completed, e) college major, and f) parents' educational attainment. Academic performance was measured by college GPA (first-semester freshmen reported their high school GPA).

Health. Mental health (of participants and first-degree relatives) was measured in terms of the following: a) diagnosis of one or more psychiatric disorders, and b) history of treatment for substance abuse. The above survey items included an optional field in which students could "briefly explain" the nature of any affirmative response. ADHD was measured separately to control for unique effects of ADHD on IEF ability (Miyake & Friedman, 2012. Participants were asked if they had a history of traumatic brain injury (TBI), and if they have any form of color blindness. Colorblind participants were excluded from the analysis, as the Stroop task relies on color perception. To account for cognitive effects of substances other than cannabis, participants were asked if they used any of the following within the previous month: a) alcohol, b) amphetamines, c) opiates, d) hallucinogens, and e) other (a blank field allowed entry of a non-listed response).

Situational. Three additional Likert-type questions controlled for factors relating to the experimental situation. Participants' degree of motivation and effort controlled for possible mediating effects of low engagement on task performance. Perceived task difficulty was measured to control for individual differences in IEF ability that are unrelated to cannabis use.

Procedure

The experiment was conducted in a computer laboratory in the Muenzinger Psychology building on the University of Colorado Boulder campus. When participants arrived at the lab, a research assistant (RA) confirmed the students' enrollment in the study, then instructed them to leave cellular phones and other distractions outside of the experiment room. Participants read and signed consent forms detailing their rights as participants, as well as any risks associated with participation. Questions were encouraged l/;throughout this process.

After obtaining informed consent, the RA provided a verbal overview of the study procedures, then escorted the participants to individual lab computers, where they completed the Eriksen flanker task, which was immediately followed by the Stroop task. Upon completion of both IEF tasks, participants signaled to the RA, who then administered the survey (the IEF tasks and survey were administered through different software programs; thus, a researcher was needed to manually exit the IEF tasks and start the survey). The survey was administered after the IEF tasks to eliminate any effect of the survey on task performance.

After finishing the survey, participants were instructed to leave the experiment room and notify the RA. Each participant received a debriefing form containing information about the study and a receipt verifying their participation and credit fulfillment. In total, the study lasted 40 – 45 minutes (30 – 35 minutes for the IEF tasks; 5 – 10 minutes for the survey).

Data Analysis

IEF task data were automatically saved onto lab computers at the point of task completion. Survey data were stored in the Qualtrics website, then downloaded after completion of data collection. Data were analyzed using Microsoft Excel (2017) and RStudio (v. 0.99.903) (R Core Team, 2015); data analysis scripts were written by the present author. All statistical tests were two-tailed with a significance threshold of 0.05.

Certain raw variables were altered in order to be compatible with statistical analysis. Binary variables (gender, history of TBI, colorblindness, and psychiatric disorders/substance use treatment in self and immediate family) were coded as either 1 or 0 (1 = male or affirmative response, respectively). Ordinal variables (e.g. parents' education), and Likert-type variables (attitude, control, effort, motivation, and difficulty) were coded as sequential single digits (e.g. "a great deal" of effort was coded as 5, while "none at all" was coded as 1). Continuous measures were converted to uniform units (e.g. responses given in US customary units were converted to metric). Age in months (reported as birth month/year) was converted to years using the following formula (formula was developed by the present author):

$$years = (2017 - birth\ year) + (((12 - birth\ month) - (12 - \ test\ month))/12)$$

Categorical variables were converted to *dummy variables*, which are proxy variables that account for the presence or absence of potentially significant categorical effects (Hardy, 1993). Dummy variables accounted for unique effects of race, three levels of substance abstinence ("never used cannabis", "do not use cannabis regularly", "no substance use within the previous month"), and the use of alcohol, amphetamines, opiates, or hallucinogens within the previous month (use of amphetamines, opiates, and hallucinogens was consolidated into a single dummy variable, *AOH*). Each response option for the above (exempting the modal response, which functioned as the reference class) was converted to a binary variable (1 = present, 0 = absent).

Correlations. Bivariate correlations were measured to a) establish internal consistency within sets of cannabis use and IEF variables, b) elucidate relationships between pairs of variables, and c) facilitate data interpretation by clarifying questions of common variance. The type of correlation was determined by scale of measurement (continuous/continuous relationships were analyzed using Pearson's correlation; ordinal/ordinal and ordinal/continuous relationships were tested using Spearman's correlation; correlations involving binary variables were assessed using point biserial correlations).

Regressions. Six multivariate linear regressions evaluated the degree to which cannabis use and related covariates collectively predicted three measures of performance (accuracy, median RT, inhibition cost) each on the Stroop and Flanker tasks. Each model was comprised of thirty-seven predictor variables (see Tables 5 – 10). Any missing data was replaced with the mean. Grade level was excluded from the analyses because it was highly correlated with age (r = 0.70), and age (measured in months rather than years) was the more precise measurement.

Nested regressions. Overlapping variance among related measures of cannabis use was likely to obscure the impact of individual predictors on the regression models. Therefore, to assess the combined predictive power of all cannabis use variables, a set of two nested regressions (comprised of a *full model* and a *reduced model*) was created for each of the six IEF outcomes. The reduced model was compared to the original regression model using ANOVA, to determine whether the cannabis variables collectively increased R^2 by a significant amount. Full models contained all 37 predictors; reduced models retained the covariates but eliminated 12 variables related to cannabis use (age of initial use, age of regular use, time since last use, days of use, hours of use, amount of flower, concentrate, edibles, no regular use, never tried cannabis, attitude, control). Time since last use was originally included in both models, but since the results below indicate no combined impact of acute intoxication and drug residue, there was no need to control for such effects.

Results

Descriptive Statistics

Figure 1 shows frequency distributions for the six IEF outcome measures. The flanker and Stroop tasks elicited similar patterns of performance: accuracy was significantly negatively skewed (over three quarters of participants scored 90% or higher), while temporal measures of median RT and distractor interference were normally distributed. Switch cost was positively skewed across subjects. In both tasks, average median RT during inhibitory conditions was slower than during baseline conditions.

Flanker task. Average accuracy was 324.22 correct trials (*SD* = 39.52, median = 334) out of 352 trials, with an average median RT of 0.51 seconds (*SD* = 0.07) and an average distractor interference of 0.04 seconds (*SD* = 0.03).

Stroop task. Average accuracy was 351.45 correct trials (*SD* = 36.17, median = 361) out of 384 trials, with an average median RT of 0.54 seconds (*SD* = 0.10), and average switch cost of 0.06 seconds (*SD* = 0.07).

Frequency distributions for age of onset are shown in Figure 2. Of the 367 participants, 294 (80%) had used cannabis at least once before, with initial use occurring at an average age of 15.66 years (*SD* = 1.64). Two-hundred-thirteen participants (58%) reported using cannabis regularly; onset of regular use occurred at a mean age of 17.03 (*SD* = 1.49). Participants used cannabis an average of 1.99 days each week (*SD* = 2.52), with a modal estimate of 2 – 5 weekly intoxicated hours. Two-hundred-ninety participants (79%) reported alcohol use during the previous month; 47 (13%) used AOH; 63 (17%) did not use any recreational substances.

Figure 4 shows frequency distributions for weekly cannabis consumption (measured in flower, concentrate, and edibles) and time since most recent use of cannabis. Because these distributions are considerably positively skewed, the median is provided as a more representative measure of central tendency. In an average week, participants consumed 1.69 grams of cannabis flower (*SD* = 3.03, median = 0), 0.14 g of cannabis concentrate (*SD* = 0.40, median = 0), and 3.63 milligrams of edibles (*SD* = 20.51, median = 0). The median interval between assessment and most recent use of cannabis was 3.00 days (*M* = 55.22, *SD* = 189.18).

Correlations.

Table 1 shows correlations between cannabis variables and covariates. Age was related to age of first use (r = 0.20), age at which regular use began (r = 0.31), and time since last use (r = 0.21). Task difficulty was associated with time since last cannabis use (r = 0.16), days of cannabis use each week (r = -0.16), hours of use each week (r = -0.20), amount of cannabis flower used each week (r = -.18), and attitude (r = -0.13).

Table 2 shows correlations between the IEF outcome measures and covariates. Accuracy on the Flanker task was associated with mother's education (r = -0.16), motivation (r = 0.15), and effort (r = 0.12). Accuracy on the Stroop task was associated with motivation (r = 0.28) and effort (r = 0.21).

Table 3 shows significant relationships within sets of IEF and cannabis use variables, but few relationships between cannabis use and IEF variables. Median RT on the flanker task was related to days of cannabis use each week (r = 0.11) and control (r = 0.14).

Regressions.

As shown in Table 4, for all six outcome measures, there was no significant difference in R^2 between the full and reduced regressions. In other words, variance explained by the collective cannabis variables was insufficient to significantly increase the predictive power of the models.

Flanker Task.

Accuracy. **(**Table 5.) The full regression model significantly predicted accuracy on the Flanker task, $R^2 = 0.17$, $F(35, 331) = 1.91$, $p < 0.01$. There were significant main effects of attitude (b = 3.94, $p < 0.01$), weekly amount of cannabis concentrate (b = -12.09, $p < .05$), substance abstinence (b = 36.84, $p < 0.01$), alcohol use (b = 38.01, $p < 0.01$), GPA (b = 12.39, $p < 0.05$) motivation (b = 34.44, $p < 0.01$), and mother's education (b = -9.97, $p < 0.01$)

Median RT. **(**Table 6.) The full model did not significantly predict median RT on the Flanker task, $R^2 = 0.12$, $F(35, 331) = 1.27$, $p = 0.15$. There were negative main effects of race-Hispanic (b = -2.97 e-2, $p < 0.05$) and race-other (b = -4.77 e-2, $p < 0.05$) (compared to a reference class of race-white).

Distracter interference. **(**Table 7.) The full model did not predict distractor interference, $R^2 = 0.09$, $F(35, 331) = 0.94$, $p = 0.56$. There were no significant predictor variables.

Stroop Task.

Accuracy. **(**Table 8.) The full regression model was statistically significant, $R^2 = 0.19$, $F(35, 331) = 2.27$, $p < 0.01$. There were main effects of non-ADHD psychiatric disorder (b = -18.28, $p < 0.05$), ADHD in a first-degree relative (b = -13.97, $p < 0.05$), effort (b = 8.54, $p < 0.01$), and motivation (b = 5.03, $p < 0.01$).

Median RT. **(**Table 9.) The full model was not significant, $R^2 = 0.08$, $F(35, 331) = 2.57$, $p < 0.01$. The only significant predictor was weekly hours of intoxication, b = 2.14 e-2, $p < 0.05$.

Switch cost. **(**Table 10.) The full model did not significantly predict switch cost R^2 = 0.07, $F(35, 331) = 0.73$, $p = 0.88$. The only significant predictor was TBI, b = -2.09 e-2, $p < 0.05$.

Discussion

This study failed to demonstrate any meaningful relationship between cannabis use and IEF ability in young adults. This was true whether cannabis variables were assessed collectively, as in the comparison of nested models, or individually, as predictors within the full linear regression models. Although some cannabis variables were significant in single regressions, the fact that such effects are isolated within a single model suggests they represent an effect of random noise in the data, rather than a true effect of cannabis on IEF ability. The null effect of cannabis was supported by correlational results, which show little association between pairs of cannabis/IEF variables. This lack of relationship between cannabis use and IEF ability is supported by a large body of cannabis research that found cannabis use to be unrelated to measures of inhibition as well as other cognitive abilities. For example, Lyketsos, Garrett, Liang, & Anthony (1999) found no significant differences in cognitive ability between light users, heavy users and non-users of cannabis.

Bivariate correlations showed significant internal consistency within sets of related independent variables (see Table 3). Every IEF measure was significantly correlated with all other IEF variables, which is consistent with latent-variable analyses showing strong relationships between measures of attentional control and prepotent response inhibition (Friedman & Miyake, 2012). Cannabis variables also showed strong internal consistency, as measures of related cannabis use were significantly correlated.

Although both models of accuracy were significant, they showed no overlapping predictor variables. In the flanker-accuracy regression, much of the explained variance was attributed to variables relating to substance use, which is consistent with evidence of deleterious cognitive effects of substance use (Pope et al., 1995). Conversely, Stroop-accuracy was largely explained by psychiatric and situational factors. The impact of psychiatric disorders on IEF is consistent with previous literature (Friedman & Miyake, 2012). The significance of effort and motivation may be related to the fact that the flanker and Stroop tasks were not counterbalanced. The Stroop task came after the flanker task and was longer by 32 trials. This possible effect of task order may be attributable to exhaustion of IEF abilities, as studies show significant effects of task order on IEF performance (Diamond, 2012). Thus, situational effects relating to fatigue may have been the dominant factor of performance on the Stroop task.

Implications.

The lack of significant findings suggests that any relationship between cannabis use and EFs is far from simple and straightforward. An large body of mixed results imply that the relationship between cannabis and IEF is likely impacted by a variety of other factors. These factors likely include legal and ethical restrictions that limit researchers' ability to control for confounding variables. The strong correlations among IEF performance measures support the claim that diverse manifestations of IEF all utilize the same underlying ability.

Limitations.

The sample was unbalanced on gender, age, socioeconomic status and other demographic variables, which may have led to a restriction of range. The sample may not have captured the all of the variance that would be present in the overall population. This study used a sample of college students. Generally, college students have higher EF than the general population, so it's possible that individuals with low IEF were not adequately represented in the sample. This is especially true for any relationship between age of onset and cannabis use. Early onset users are much less likely to attend college. Additionally, the sample may not have captured the full range of cannabis use behavior.

The Stroop task was modified in a way that may have decreased construct validity. Keyboard responses for the Stroop task are not prepotent (i.e. typing *A* in response to a word printed in red is not an automatic response). Rather, have reduced the capacity to capture a pure measure of IEF. Rather than verbally name the color of the word, participants pressed a corresponding key on the keyboard, which almost certainly involved working memory (another cognitive ability) in addition to IEF. Working memory involvement would theoretically increase task-impurity on the Stroop task, and thus the variability, which would reduce the likelihood of significant results.

The survey relied entirely on self-report data, which has been shown to be questionable, especially when assessing past cannabis use behavior. Results could also have been impacted by the lack of defined constructs. For example, the survey did not provide a definition for the term, "regularly" (used when assessing age of onset of regular cannabis use), which is a relative term that could refer to a range of use patterns. Additionally, there were not enough questions asking about certain constructs. More would be needed to establish internal consistency.

Future research.

Future studies should seek to increase validity in cannabis research by designing experiments that control for common sources of residual variance. Naturalistic studies can useful for detecting covariance among variables of interest, but the lack of control makes them ill-suited to establish cause. well-executed association studies establish covariance between variables, which in turn informs later experimental research. They fail to establish temporal precedence and are impacted by too many confounding variables. Administration and longitudinal studies are more expensive and time consuming, but they offer much more reliability and validity. Administration studies are experiments in which the researchers administer cannabis to the participants. Such designs allow researchers to control for variables relating to the drug itself, including dose, potency, strain, and method of use. Longitudinal studies are association studies that compare subjects over time.

Concluding Remarks

Although the results did not support the hypothesis, strong intercorrelations showed significant internal validity among measures of inhibition and cannabis use. Ultimately, validity is a respectable achievement, because the purpose of science is to reveal the truth about the around us. Whether that truth supports or contradicts a hypothesis is ultimately irrelevant.

Finding the truth about the relationship between cannabis and cognitive ability will not be an easy task. The relationship between cannabis use and cognitive ability is likely to be indirect and mediated and moderated by a number of known and unknown factors. Nonetheless, the evolving social and political climate necessitates elucidation of these factors.

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Table 1. Cannabis and Covariates

(r_{pb}) = Point biserial correlation (significance not reported), (r_s) = Spearman correlation, * = $p < 0.05$, ** = $p < 0.01$

1. Age (first use), 2. Age (regular use), 3. Days since last use, 4. Frequency (days), 5. Frequency (hours) (r_s),

6. Amount (flower), 7. Amount (con.), 8. Amount (edi.), 9. Attitude (r_s), 10. Control (r_s)

Variable	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*
Demographic										
Age	.20**	.31**	.21**	-.04	-.07	-.09	-.09	.08	-.05	.03
Gender (r_{pb})	.01	.05	-.04	.27	.29	.16	0	.13	.15	.22
GPA	.03	.02	-.06	-.09	-.05	-.03	-.01	-.09	.04	-.02
Mother's ed. (r_s)	.04	-.03	-.03	.04	.04	.03	-.02	.02	-.08	-.03
Father's ed. (r_s)	0	-.06	-.05	.05	.05	.03	.02	.03	-.01	.07
Mental Health										
TBI (r_{pb})	-.07	-.03	-.09	.21	.20	.13	.04	-.05	.08	.08
Psych. disorder (r_{pb})	.03	.02	.26	.06	.01	-.09	-.11	-.01	0	.12
ADHD (r_{pb})	-.19	-.12	.01	.26	.25	.14	-.07	-.08	.07	.10
SU treatment (r_{pb})	-.54	-.53	-.13	.61	.58	.29	.09	-.07	.24	.48
Psych. disorder (relative) (r_{pb})	-.09	-.06	.01	-.01	-.02	-.04	.12	-.08	-.01	.01
ADHD (relative) (r_{pb})	-.12	-.01	-.08	.17	.17	.03	-.10	-.03	.02	.03
SU treatment (relative) (r_{pb})	-.22	-.15	-.13	.14	.15	.06	.03	-.05	.12	.05
Situation										
Motivation (r_s)	-.07	-.06	0	.02	.05	.06	.02	-.01	.07	-.05
Effort (r_s)	-.02	-.03	.01	-.02	-.01	-.01	.07	.09	-.03	-.06
Difficulty (r_s)	.02	-.02	.16**	-.16**	-.20**	-.18**	-.05	-.02	-.13*	-.07

Table 2. Covariates and IEF outcomes

(r_{pb}) = Point biserial correlation (significance not reported), (r_s) = Spearman correlation, * = $p < 0.05$, ** = $p < 0.01$

Flanker: 1. Accuracy, 2. Median RT, 3. Dist. int.

Stroop: 4. Accuracy, 5. Median RT, 6. Switch cost

Variable	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
Demographic						
Age	.04	-.07	-.01	-.02	-.05	-.05
Gender (r_{pb})	.02	-.05	.03	-.10	-.14	-.10
GPA	.09	-.06	-.03	-.04	0	.01
Mother's ed. (r_s)	-.16**	0	.01	-.06	-.05	0
Father's ed. (r_s)	-.09	-.02	-.02	-.06	-.08	-.05
Mental Health						
TBI (r_{pb})	.01	-.09	-.01	-.07	-.14	-.19
Psych. disorder (r_{pb})	-.01	-.09	-.04	-.15	-.07	.03
9. ADHD (r_{pb})	-.14	-.02	.09	.01	0	.01
SU treatment (r_{pb})	-.10	-.17	-.05	-.31	-.25	-.10
Psych. disorder (relative) (r_{pb})	-.01	-.07	-.02	.06	.02	.16
ADHD (relative) (r_{pb})	-.09	.09	-.02	-.19	-.02	.01
SU treatment (relative) (r_{pb})	-.01	-.04	.02	0	-.02	-.03
Situation						
Motivation (r_s)	.15**	-.07	-.05	.28**	-.02	0
Effort (r_s)	.12*	-.02	-.02	.21**	.02	.01
Difficulty (r_s)	-.10	.01	.04	-.06	.05	.08

Table 3. Cannabis and IEF Outcomes

(r_s) = Spearman correlation, * = $p < 0.05$, ** = $p < 0.01$

Variable	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*	*11.*	*12.*	*13.*	*14.*	*15.*
Cannabis															
1. Age (first use)															
2. Age (regular use)	.63**														
3. Days since last use	.04	-.04													
4. Frequency (days)	-.30**	-.11*	-.25**												
5. Frequency (hours) (r_s)	-.21**	-.17**	-.84**	.95**											
6. Amount (flower)	-.21**	-.12*	-.18**	.61**	.85**										
7. Amount (con.)	-.14**	-.11*	-.12*	.39**	.54**	.26**									
8. Amount (edi.)	.10	.10	-.05	.20**	.30**	.07	.10*								
9. Attitude (r_s)	-.20**	-.20**	-.39**	.53**	.50**	.45**	.29**	.11*							
10. Control (r_s)	-.17**	-.16**	-.31**	.42**	.36**	.33**	.19**	.12*	.39*						
Outcome															
Flanker															
11. Accuracy	.02	.04	-.08	.04	.03	.01	-.04	.02	.10	.09					
12. Median RT	-.09	-.10	-.06	.11*	.07	.09	.07	.07	.08	.14**	.22**				
13. Dist. int.	-.09	-.01	-.07	.07	.07	.08	-.07	.03	.09	.10	.11*	.40**			
Stroop															
14. Accuracy	0	-.04	.01	.03	.04	.02	.01	-.01	.07	.03	.38**	.29**	.18**		
15. Median RT	.02	.04	.01	-.04	0	-.01	.05	.06	-.01	.01	.20**	.65**	.16**	.45**	
16. Switch cost	-.02	-.01	-.02	-.08	-.02	-.06	.04	.03	.03	-.02	.15*	.29**	.15**	.24**	.49**

Table 4. Comparison of Nested Regression Models using ANOVA

* = $p < 0.05$, ** = $p < 0.01$

Variable	R^2 (full)	R^2 (reduced)	F(12, 331)	p
Flanker				
Accuracy	.17	.12	1.58	.095
Median RT	.12	.07	1.46	.139
Dist. Int.	.09	.04	1.41	.161
Stroop				
Accuracy	.19	.18	.61	.830
Median RT	.08	.05	.88	.564
Switch Cost	.07	.05	.63	.816

Table 5. Regression Results: Flanker Accuracy

$* = p < 0.05$, $** = p < 0.01$

Variable	b	Std. Error	*t*	*p*
Cannabis				
Age (first use)	-.25	1.94	-.13	.899
Age (regular use)	-.04	2.55	-.02	.988
Days since last use	-.02	.01	-1.43	.153
Frequency (weekly)				
Days	.41	2.16	.19	.849
Hours	-1.66	3.60	-.46	.646
Amount (weekly)				
Flower	-.13	.89	-.15	.882
Concentrates	-12.09	5.63	-2.15	.032*
Edibles	-.05	.11	-.42	.678
Never tried cannabis	-.17	7.56	-.02	.982
No reg. cannabis use	-5.54	6.43	-.86	.390
Attitude	3.95	1.86	2.12	.035*
Control	3.37	2.18	1.54	.123
Covariates				
Race				
Black	5.21	12.75	.41	.682
Native American	-13.99	28.18	-.50	.620
Hispanic	8.51	7.26	1.17	.242
Asian	4.39	7.77	.57	.572
Other	1.72	11.87	.15	.884
Age	.22	.19	1.14	.254
Gender	3.77	4.83	.76	.449
GPA	12.58	5.22	2.41	.016*
Mother’s ed.	-9.97	3.48	-2.87	.004**
Father’s ed.	4.86	3.38	1.44	.152
TBI	-.60	5.40	-.11	.915
Psych. disorder	-4.57	8.32	-.55	.583
ADHD	-4.30	6.77	-1.19	.237
SU treatment	-1.17	15.96	-.07	.941
Psych. disorder (relative)	5.80	8.38	-.70	.489
ADHD (relative)	-4.29	6.33	-.68	.498
SU treatment (relative)	1.39	6.40	.22	.828
Alcohol	38.01	11.00	3.46	0**
AOH	-11.91	6.98	-1.71	.889
No substance use	36.84	12.32	2.99	.003**
Motivation	4.06	2.10	1.94	.054
Effort	5.34	3.09	1.73	.085
Difficulty	-.27	1.52	-.18	.860

Table 6. Regression Results: Flanker Median RT

* = $p < 0.05$, ** = $p < 0.01$

Variable	b	Std. Error	*t*	*p*
Cannabis				
Age (first use)	2.00 e-3	3.75 e-3	.53	.594
Age (regular use)	8.09 e-3	4.93 e-3	-1.64	.102
Days since last use	-1.24 e-5	2.63 e-5	-.47	.638
Frequency (weekly)				
Days	-4.01 e-4	4.17 e-3	-.10	.924
Hours	6.37 e-3	6.95 e-3	.92	.360
Amount (weekly)				
Flower	8.86 e-4	1.71 e-3	.52	.605
Concentrates	5.67 e-3	1.09 e-2	.52	.602
Edibles	2.36 e-4	2.15 e-4	1.10	.273
Never tried cannabis	2.06 e-2	1.46 e-2	1.41	.159
No reg. cannabis use	-7.83 e-3	1.24 e-2	-.63	.529
Attitude	-7.03 e-4	3.60 e-3	-.20	.845
Control	3.93 e-3	4.21 e-3	.93	.351
Covariates				
Race				
Black	3.23 e-2	2.46 e-2	1.35	178
Native American	-6.16 e-2	5.44 e-2	-1.13	.258
Hispanic	-2.97 e-2	1.40 e-2	-2.12	.035*
Asian	-6.43 e-2	1.50 e-2	-.43	.669
Other	-4.77 e-2	2.29 e-2	-2.08	.038*
Age	-2.31 e-4	3.70 e-4	-.63	.532
Gender	-1.66 e-2	9.34 e-3	-1.78	.076
GPA	-1.27 e-2	1.01 e-2	-1.26	.207
Mother’s ed.	3.40 e-3	6.71 e-3	.51	.612
Father’s ed.	-9.29 e-3	6.53 e-3	-1.42	.156
TBI	-1.07 e-2	1.04 e-2	-1.02	.308
Psych. disorder	-4.94 e-3	1.61 e-2	-.31	.759
ADHD	-3.73 e-3	1.31 e-2	-.29	.775
SU treatment	-5.44 e-2	3.08 e-2	-1.76	.079
Psych. disorder (relative)	-1.45 e-2	1.62 e-2	-.90	.370
ADHD (relative)	1.59 e-2	1.22 e-2	1.30	.195
SU treatment (relative)	-1.20 e-2	1.24 e-2	-.97	.331
Alcohol	1.62 e-2	2.13 e-2	.76	.446
AOH	8.48 e-3	1.35 e-2	.63	.530
No substance use	3.49 e-2	2.38 e-2	1.47	.144
Motivation	-5.59 e-3	4.06 e-3	-1.38	.169
Effort	3.65 e-3	5.96 e-3	.61	.541
Difficulty	7.68 e-4	2.94 e-3	.26	.794

Table 7. Regression Results: Flanker Distractor Interference

* = $p < 0.05$, ** = $p < 0.01$

Variable	b	Std. Error	*t*	*p*
Cannabis				
Age (first use)	-2.49 e-3	1.63 e-3	-1.53	.127
Age (regular use)	9.51 e-4	2.14 e-3	.44	.658
Days since last use	-6.42 e-6	1.14 e-5	-.56	.574
Frequency (weekly)				
Days	-1.48 e-3	1.81 e-3	-.81	.416
Hours	3.84 e-3	3.02 e-3	1.27	.204
Amount (weekly)				
Flower	6.94 e-4	7.44 e-4	.93	.352
Concentrates	-8.32 e-3	4.72 e-3	-1.76	.079
Edibles	3.05 e-5	9.34 e-5	.33	.744
Never tried cannabis	2.62 e-3	6.35 e-3	.41	.680
No reg. cannabis use	1.80 e-3	5.40 e-3	.33	.739
Attitude	5.87 e-4	1.56 e-3	.38	.707
Control	2.90 e-3	1.83 e-3	1.58	.114
Covariates				
Race				
Black	1.49 e-2	1.07 e-2	1.39	.166
Native American	-1.82 e-2	2.36 e-2	-.77	.442
Hispanic	-3.24 e-3	6.09 e-3	-.53	.595
Asian	9.51 e-3	6.52 e-3	1.46	.145
Other	-1.74 e-2	9.96 e-3	-1.75	.081
Age	-6.51 e-7	1.61 e-4	0	.100
Gender	-2.05 e-3	4.06 e-3	.51	.613
GPA	-1.33 e-3	4.38 e-3	-.31	.761
Mother’s ed.	1.65 e-3	2.92 e-3	.56	.573
Father’s ed.	-2.37 e-3	2.84 e-3	-.84	.403
TBI	-1.16 e-4	4.53 e-3	-.03	.980
Psych. disorder	6.69 e-4	6.98 e-3	.10	.924
ADHD	6.79 e-3	5.68 e-3	1.20	.232
SU treatment	-1.29 e-2	1.34 e-2	-.96	.337
Psych. disorder (relative)	-1.41 e-3	7.03 e-3	-.20	.842
ADHD (relative)	-4.71 e-3	5.31 e-3	.89	.376
SU treatment (relative)	-1.38 e-4	5.37 e-3	-.03	.980
Alcohol	-1.68 e-3	9.23 e-3	-.18	.855
AOH	-7.31 e-3	5.86 e-3	-1.25	.213
No substance use	-3.81 e-3	1.03 e-2	-.37	.713
Motivation	-2.58 e-3	1.76 e-3	-1.46	.144
Effort	8.29 e-4	2.59 e-3	.32	.749
Difficulty	1.80 e-3	1.28 e-3	1.41	.161

Table 8. Regression Results: Stroop Accuracy

* = $p < 0.05$, ** = $p < 0.01$

Variable	b	Std. Error	*t*	*p*
Cannabis				
Age (first use)	1.53	1.75	.88	.381
Age (regular use)	-2.06	2.30	-.89	.372
Days since last use	0	.01	.31	.758
Frequency (weekly)				
Days	-.82	1.95	-.42	.675
Hours	4.24	3.24	1.31	.192
Amount (weekly)				
Flower	-.64	.80	-.80	.422
Concentrates	-6.22	5.07	-1.23	.220
Edibles	-.08	.10	-.80	.424
Never tried cannabis	4.98	6.81	.73	.465
No reg. cannabis use	-.72	5.79	-.89	.372
Attitude	1.27	1.68	.76	.448
Control	1.29	1.96	.66	.512
Covariates				
Race				
Black	-9.31	11.48	-.81	.418
Native American	-17.30	25.37	-.68	.496
Hispanic	4.53	6.54	.69	.489
Asian	2.72	7.00	.39	.698
Other	-13.20	10.69	-1.24	.218
Age	0	.17	.03	.977
Gender	-3.63	4.35	-.83	.405
GPA	-2.59	4.70	-.55	.581
Mother's ed.	-4.81	3.13	-1.54	.125
Father's ed.	-.85	3.05	-.28	.781
TBI	-2.20	4.86	-.45	.651
Psych. disorder	-18.28	7.49	-2.44	.015*
ADHD	3.93	6.09	.65	.520
SU treatment	-20.98	14.37	-1.46	.145
Psych. disorder (relative)	12.64	7.54	1.68	.095
ADHD (relative)	-13.96	5.70	-2.45	.015*
SU treatment (relative)	-1.38	5.76	-.24	.810
Alcohol	9.84	9.90	.99	.321
AOH	1.42	6.28	.23	.821
No substance use	9.43	11.09	.85	.396
Motivation	5.03	1.89	2.66	.008**
Effort	8.54	2.78	3.07	.002**
Difficulty	-1.21	1.37	-.88	.380

Table 9. Regression Results: Stroop Median RT

* = $p < 0.05$, ** = $p < 0.01$

Variable	b	Std. Error	*t*	*p*
Cannabis				
Age (first use)	$9.88\ e^{-4}$	$5.01\ e^{-3}$	.20	.844
Age (regular use)	$8.80\ e^{-3}$	$6.59\ e^{-3}$	.58	.564
Days since last use	$9.04\ e^{-6}$	$3.51\ e^{-5}$	.26	.797
Frequency (weekly)				
Days	$-8.88\ e^{-3}$	$5.57\ e^{-3}$	-1.59	.112
Hours	$2.14\ e^{-2}$	$9.28\ e^{-3}$	2.31	.022*
Amount (weekly)				
Flower	$-2.77\ e^{-4}$	$2.29\ e^{-3}$	-.12	.904
Concentrates	$1.31\ e^{-2}$	$1.45\ e^{-2}$	.90	.370
Edibles	$2.59\ e^{-4}$	$2.87\ e^{-4}$	.90	.368
Never tried cannabis	$1.90\ e^{-2}$	$1.95\ e^{-2}$	.98	.330
No reg. cannabis use	$9.06\ e^{-3}$	$1.66\ e^{-2}$	.55	.585
Attitude	$-4.97\ e^{-3}$	$4.80\ e^{-3}$	-1.04	.301
Control	$1.70\ e^{-3}$	$5.62\ e^{-3}$	.30	.762
Covariates				
Race				
Black	$4.61\ e^{-2}$	$3.29\ e^{-2}$	1.40	.161
Native American	$-4.03\ e^{-2}$	$7.27\ e^{-2}$	.56	.579
Hispanic	$-1.51\ e^{-2}$	$1.87\ e^{-2}$	-.80	.422
Asian	$-8.11\ e^{-3}$	$2.00\ e^{-2}$	-.41	.686
Other	$-3.76\ e^{-2}$	$3.06\ e^{-2}$	-1.23	.220
Age	$-5.38\ e^{-4}$	$4.93\ e^{-4}$	-1.09	.278
Gender	$-2.30\ e^{-2}$	$1.25\ e^{-2}$	-1.85	.065
GPA	$-6.19\ e^{-3}$	$1.35\ e^{-3}$	-.46	.646
Mother’s ed.	$-5.34\ e^{-3}$	$8.96\ e^{-3}$	-.60	.552
Father’s ed.	$-7.57\ e^{-3}$	$8.72\ e^{-3}$	-.87	.386
TBI	$-1.38\ e^{-3}$	$1.39\ e^{-3}$	-.99	.322
Psych. disorder	$-1.33\ e^{-2}$	$2.15\ e^{-2}$	-.62	.535
ADHD	$1.11\ e^{-2}$	$1.75\ e^{-2}$	.63	.527
SU treatment	$-4.84\ e^{-2}$	$4.12\ e^{-2}$	-1.18	.241
Psych. disorder (relative)	$5.54\ e^{-3}$	$2.16\ e^{-2}$	.26	.798
ADHD (relative)	$-1.89\ e^{-3}$	$1.63\ e^{-2}$	-.12	.908
SU treatment (relative)	$-1.26\ e^{-2}$	$1.65\ e^{-2}$	-.76	.446
Alcohol	$4.18\ e^{-3}$	$2.84\ e^{-2}$	.15	.883
AOH	$1.47\ e^{-2}$	$1.80\ e^{-2}$	.82	.414
No substance use	$1.93\ e^{-2}$	$3.18\ e^{-2}$	.61	.544
Motivation	$-2.47\ e^{-4}$	$5.42\ e^{-3}$	-.05	.964
Effort	$5.74\ e^{-3}$	$7.96\ e^{-3}$	.72	.471
Difficulty	$6.43\ e^{-4}$	$3.93\ e^{-3}$	.16	.870

Table 10. Regression Results: Stroop Switch Cost

* = $p < 0.05$, ** = $p < 0.01$

Variable	b	Std. Error	*t*	*p*
Cannabis				
Age (first use)	-4.24 e-3	3.38 e-3	-1.25	.211
Age (regular use)	2.58 e-3	4.45 e-3	.58	.562
Days since last use	-9.59 e-6	2.37 e-5	.40	.686
Frequency (weekly)				
Days	-4.98 e-3	3.77 e-3	-1.32	.187
Hours	4.06 e-3	6.27 e-3	.65	.518
Amount (weekly)				
Flower	-5.21 e-4	1.55 e-3	-.34	.737
Concentrates	9.98 e-3	9.81 e-3	1.02	.310
Edibles	1.72 e-4	1.94 e-4	.89	.376
Never tried cannabis	-4.85 e-3	1.32 e-2	-.37	.713
No reg. cannabis use	1.28 e-2	1.12 e-2	1.14	.254
Attitude	3.12 e-3	3.25 e-3	.96	.337
Control	-7.82 e-4	3.80 e-3	-.21	.837
Covariates				
Race				
Black	8.16 e-4	2.22 e-2	.04	.971
Native American	-1.41 e-2	4.91 e-2	-.29	.774
Hispanic	7.39 e-3	1.27 e-2	.58	.560
Asian	5.44 e-3	1.36 e-2	.40	.688
Other	-1.48 e-2	2.07 e-2	-.72	.475
Age	-1.67 e-4	3.34 e-4	-.50	.617
Gender	-2.66 e-4	8.43 e-3	-.03	.975
GPA	-2.07 e-3	9.09 e-3	-.23	.820
Mother’s ed.	4.00 e-3	6.06 e-3	.66	.509
Father’s ed.	-1.32 e-3	5.90 e-3	-.22	.824
TBI	-2.09 e-2	9.41 e-3	-2.22	.027*
Psych. disorder	3.08 e-4	1.45 e-2	.02	.983
ADHD	9.76 e-4	1.18 e-2	.08	.934
SU treatment	1.04 e-3	2.78 e-2	.04	.970
Psych. disorder (relative)	1.65 e-2	1.46 e-2	1.13	.260
ADHD (relative)	-1.06 e-3	1.10 e-2	-.10	.923
SU treatment (relative)	-6.48 e-3	1.12 e-2	-.58	.562
Alcohol	1.05 e-2	1.92 e-2	.55	.584
AOH	-3.69 e-3	1.22 e-2	-.30	.762
No substance use	-6.70 e-3	2.15 e-2	-.31	.756
Motivation	2.76 e-3	3.66 e-3	.76	.451
Effort	-3.36 e-3	5.38 e-3	-.62	.533
Difficulty	4.20 e-3	2.66 e-3	1.58	.115

Figure 1.

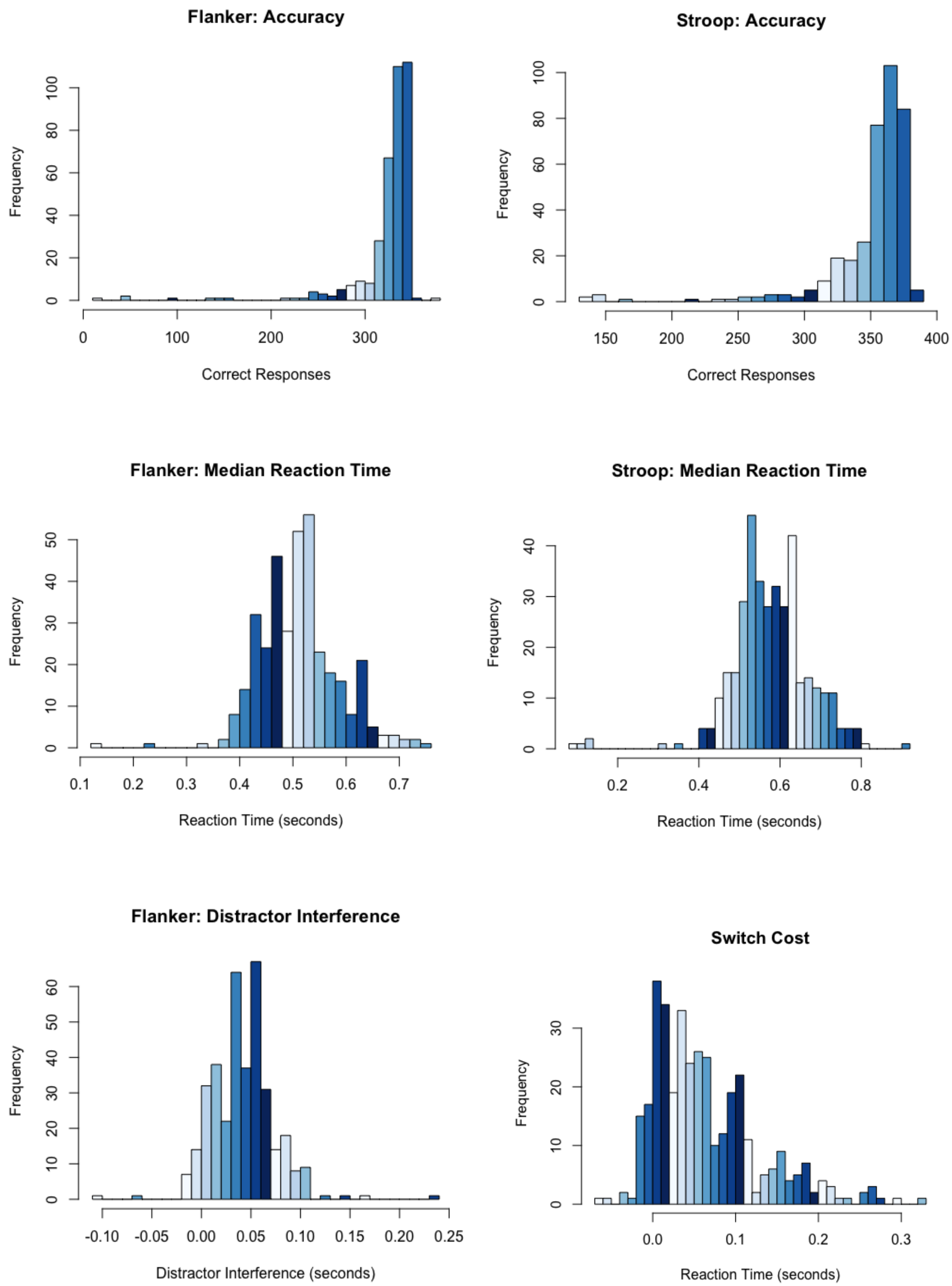

Flanker: Accuracy
Frequency
0
20
40
60
80
100
0
100
200
300
Correct Responses
Stroop: Accuracy
Frequency
0
20
40
60
80
100
150
200
250
300
350
400
Correct Responses
Flanker: Median Reaction Time
Frequency
0
10
20
30
40
50
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Reaction Time (seconds)
Stroop: Median Reaction Time
Frequency
0
10
20
30
40
0.2
0.4
0.6
0.8
Reaction Time (seconds)
Flanker: Distractor Interference
Frequency
0
10
20
30
40
50
60
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
Distractor Interference (seconds)
Switch Cost
Frequency
0
10
20
30
0.0
0.1
0.2
0.3
Reaction Time (seconds)

Figure 2.

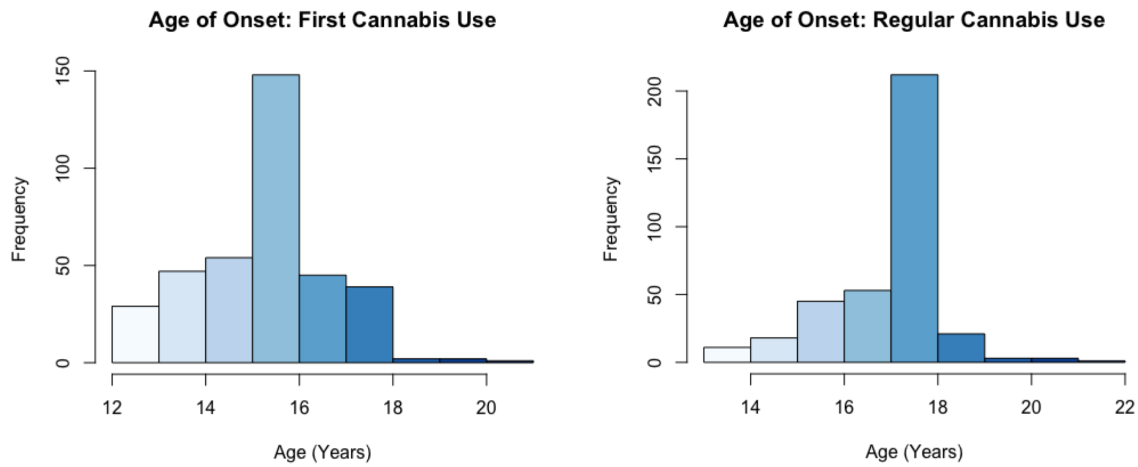


Figure 3.

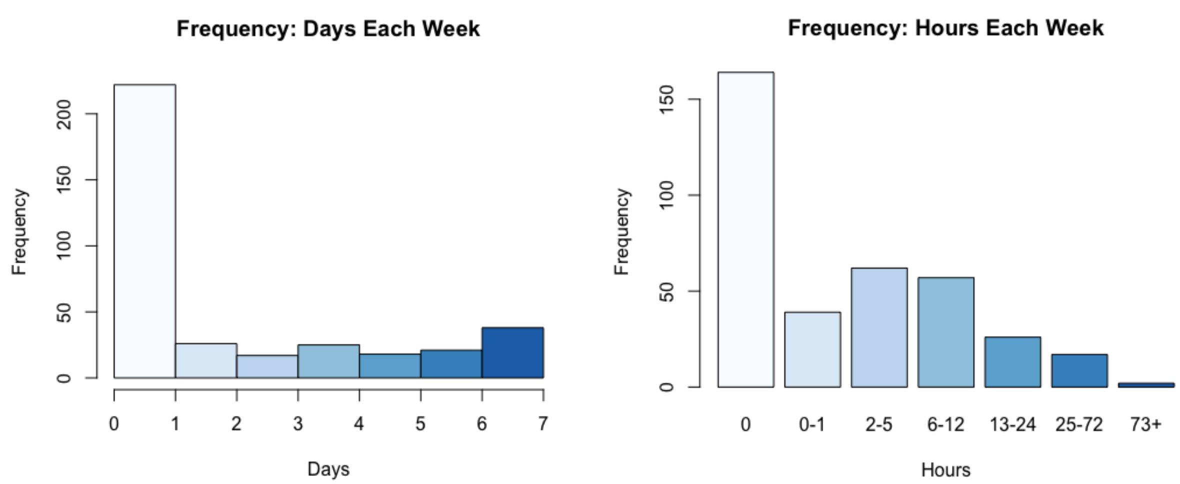
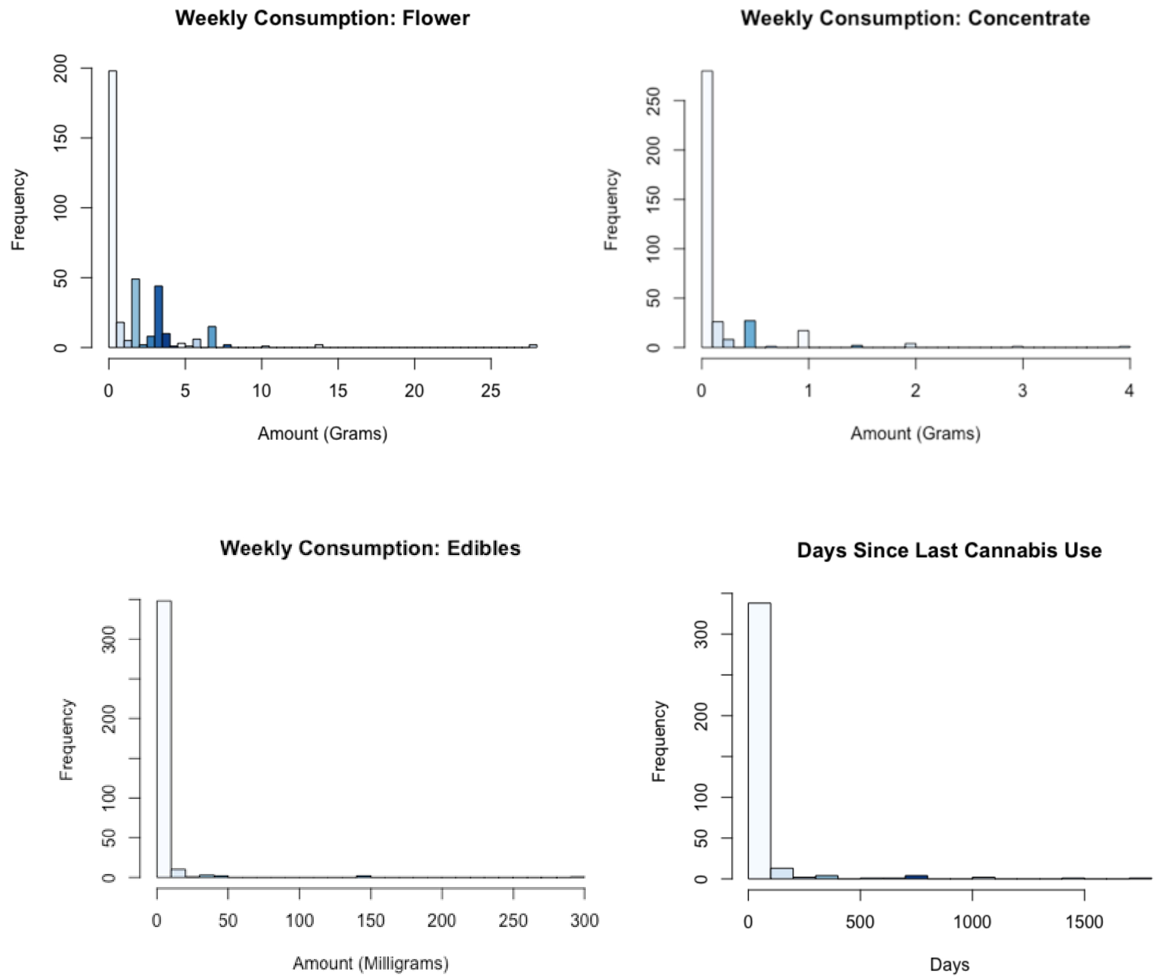


Figure 4.


Weekly Consumption: Flower
Frequency
Amount (Grams)
Weekly Consumption: Concentrate
Frequency
Amount (Grams)
Weekly Consumption: Edibles
Frequency
Amount (Milligrams)
Days Since Last Cannabis Use
Frequency
Days