Executive Functions and Behavioural Economic Demand for Cannabis Among Young Adults: Indirect Associations with Cannabis Consumption and Cannabis Use Disorder

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Abstract

Background: Behavioural economic demand for cannabis is robustly associated with cannabis consumption and cannabis use disorder (CUD). However, few studies have examined processes underlying individual differences in the relative valuation of cannabis (i.e., demand). This study examined associations between executive functions and cannabis demand among young adults who use cannabis. We also examined indirect associations of executive functions with cannabis consumption and CUD severity through cannabis demand.

Method: Young adults (*N*=113; 58.4% female; mean age 22 years) completed a Marijuana Purchase Task. Participants also completed cognitive tasks assessing executive functions (set shifting, inhibitory control, working memory) and semi-structured interviews assessing past 90-day cannabis consumption (number of grams used) and CUD severity (number of symptoms).

Results: Poorer inhibitory control was significantly associated with greater O_{max} (peak expenditure on cannabis) and greater intensity (cannabis consumption at zero cost). Poorer working memory was significantly associated with lower elasticity (sensitivity of consumption to escalating cost). Lower inhibitory control was indirectly associated with greater cannabis consumption and CUD severity through greater O_{max} and intensity, and poorer working memory was indirectly associated with greater cannabis consumption and CUD severity through reduced elasticity.

Conclusions: This study provides novel evidence that executive functions are associated with individual differences in cannabis demand. Moreover, these results suggest that cannabis demand could be a mechanism linking poorer executive functioning with heavier cannabis use and CUD, which should be confirmed in future longitudinal studies.

Keywords: Behavioral economics; marijuana; inhibition; working memory; set shifting.

Public Health Significance Statement

This study found that young adults who performed more poorly on cognitive tasks assessing working memory and inhibitory control had higher behavioral economic demand for cannabis. Further, poorer cognitive performance was indirectly associated with increased cannabis consumption and cannabis use disorder severity *through* greater cannabis demand. Results suggest that cannabis demand may be an important mechanism linking certain cognitive deficits with cannabis use among young adults.

Introduction

Cannabis is widely used among young adults in North America (Government of Canada, 2021; Substance Abuse and Mental Health Services, 2021), with many reporting daily or near-daily use (Health Canada, 2021). Given potential harms associated with frequent cannabis use in this population, including elevated rates of cannabis use disorder (CUD; Han et al., 2019; Leung et al., 2020), there is a need to understand risk factors for heavy cannabis use and CUD among young adults. Several individual-level risk factors for heavy cannabis use and CUD have been identified, including male sex, premorbid and comorbid psychopathology, and motives for cannabis use (for a review, see Courtney et al., 2017). In addition, behavioural economics provides a useful framework for understanding individual differences in cannabis use by combining psychology and economics to understand substance-use-related decision making (Bickel et al., 2014; Mackillop & Murphy, 2007). A core tenet of behavioural economic models of substance use is that the relative valuation of a reinforcer (e.g., cannabis) is an important proximal determinant of its use (Bickel et al., 2014). The reinforcing value of cannabis is indicated by behavioural economic demand for cannabis, or changes in consumption of cannabis as a function of increasing cost (Aston et al., 2015; Collins et al., 2014).

Cannabis demand is typically assessed using the Marijuana Purchase Task (MPT; Aston et al., 2015; Aston & Berey, 2022; Collins et al., 2014), which quantifies the association between cannabis consumption and cannabis cost by asking participants to estimate the amount of cannabis they would consume at increasing price points. Five related indices of behavioural economic cannabis demand may be obtained from the MPT: intensity (i.e., cannabis consumption at zero cost), O_{max} (i.e., peak expenditure on cannabis), P_{max} (i.e., price corresponding to peak expenditure on cannabis), breakpoint (i.e., the cost at which cannabis consumption is suppressed to zero), and elasticity (i.e., the sensitivity of consumption to cost, or the degree to which consumption of cannabis decreases as price increases) (Aston et al., 2015; Collins et al., 2014). These demand indices, and especially O_{max}, intensity, and elasticity, are robustly associated with patterns of cannabis use, including quantity and frequency of use, craving, and symptoms of CUD, in a variety of populations including young adults (Aston et al., 2015; Aston & Berey, 2022; González-Roz et al., 2022; Minhas et al., 2021; Strickland et al., 2017; Zvorsky et al., 2019).

Few studies to date have examined the processes that underlie individual differences in cannabis demand. Executive functions (EFs)—higher-order mental processes that facilitate goal-directed and future-oriented behaviour—play an important role in decision-making (Diamond, 2013; Miyake & Friedman, 2012; Suchy, 2009). Thus, EFs may contribute to the decision-making processes that are central to demand; that is, decisions about whether and how much cannabis to consume amid environmental fluctuations in cost (Strickland & Lacy, 2020). Miyake and Friedman (2012) provide a framework for understanding individual differences in EFs, asserting that these functions show unity and diversity (i.e., are correlated yet separable), have substantial genetic underpinnings, predict clinically and societally relevant outcomes, and are somewhat developmentally stable. Per this framework, three core domains of EFs are set shifting (the ability to move flexibly between tasks, operations, or mental sets; Miyake et al., 2000), inhibitory control (the ability to control one's behaviours to override prepotent behavioural or cognitive responses; Anderson & Weaver, 2009; Diamond, 2013), and working memory (the ability to monitor, update, and manipulate information that is no longer perceptually present; Baddeley & Hitch, 1994; Diamond, 2013).

Less efficient EF systems may be associated with higher cannabis demand due to a diminished ability to fully consider the costs associated with substance use (Bickel et al., 2014). For example, a young adult with poorer inhibitory control may experience greater difficulty orienting attention toward higher prices of cannabis on the MPT (which would normally reduce the likelihood of purchasing cannabis) due to a heightened susceptibility to distraction by strong internal predispositions to use cannabis (e.g., craving). Poor set shifting ability may similarly exacerbate difficulties adjusting cannabis consumption behaviour in response to changes in environmental contingencies (i.e., escalating costs). Working memory may also be crucial to accessing, continuously monitoring, and ultimately evaluating information needed to estimate the relative value of cannabis, and particularly to re-evaluating the relative value of cannabis amid environmental fluctuations in cost. Thus, relative deficits in these EF domains may manifest in the MPT as greater cannabis consumption and expenditure (i.e., greater intensity and O_{max}, respectively) or lower sensitivity to the escalating cost of cannabis (i.e., reduced elasticity). Although one prior study of alcohol demand and found that poorer working memory was associated with lower elasticity (i.e., insensitivity to cost; Abram et al., 2021), no studies to our knowledge have examined the links between EFs and cannabis demand.

The lack of previous studies on the role of executive functions in cannabis demand is an important research gap given evidence of a relationship between EFs and cannabis use (Castellanos-Ryan & Conrod, 2020). Indeed, prospective studies have found that poorer EFs during early adolescence predict earlier cannabis use initiation and greater cannabis use frequency in late adolescence and early adulthood (Castellanos-Ryan et al., 2017; Cavalli et al., 2022; Squeglia et al., 2014). This is consistent with the broader substance use literature suggesting that poorer EFs (and especially inhibitory control) confer increased risk of substance use initiation, escalation to hazardous substance use, and continuation of substance use despite negative consequences (Castellanos-Ryan & Conrod, 2020; Garavan et al., 2015; Khurana et al., 2013; Koob & Volkow, 2010). Further research is needed to elucidate the mechanisms by which EFs may be associated with cannabis use and CUD. Should poorer EFs contribute to higher cannabis demand, the latter may represent a mechanism linking poorer EFs with greater cannabis use and risk for CUD.

The Present Study

The present study examined whether EF domains (i.e., inhibitory control, set shifting, working memory) are associated with indices of behavioural economic demand for cannabis among young adults who use cannabis. As a secondary aim, we examined whether there were indirect associations of EF domains with current levels of cannabis consumption and CUD symptoms through cannabis demand indices. We hypothesized that poorer inhibitory control, set shifting, and working memory would be associated with indices of greater cannabis demand, which in turn would partially explain the associations of poorer EFs with both greater cannabis consumption and severity of CUD symptoms. Given the dearth of prior research, we did not forward hypotheses regarding domain-specific associations between EFs and cannabis demand indices, and instead conducted exploratory analyses of these specific associations.

Method

Participants

Participants were young adults ages 19–25 years who participated in a larger study of the associations between cannabis use and cognitive functioning. Although N=160 completed the study, we focused analyses on the N=149 participants reporting past-90-day cannabis use given our interest in examining cannabis demand among young adults who currently use cannabis. We also excluded participants who did not provide valid cannabis demand data (*n*=36; see 2.4. Data Analysis) from the current analyses, resulting in an analytic sample of *N*=113. Demographic characteristics of the sample are provided in Table 1.

Procedures

All procedures were approved by the Research Ethics Board of the Centre for Addiction and Mental Health (protocol #099-2018). The study took place in Toronto, Canada, after the legalization of nonmedical cannabis use. Legal aged young adults were recruited via advertisements, and interested individuals completed an online eligibility questionnaire. Eligibility criteria for the larger study were: 1) ages 19 to 25; 2) reporting at least one period of regular cannabis use in their lifetime (i.e., two or more times per month for 6 months); 3) no history of severe head injury; 4) absence of current or past treatment for alcohol use; 5) absence of regular (monthly) use of illicit substances other than cannabis; 6) no history of substance use treatment; 7) no history of psychosis, mania, neurological disorder, or neurodevelopmental disorder; 8) not using cannabis exclusively for medical reasons; and 9) ability to complete the assessment in English.

Eligible participants were scheduled for an in-person assessment session and were asked to abstain from cannabis and alcohol use for 48 hours prior to their appointment. Nine participants (7.96%) reported having used cannabis or alcohol within 48 hours of their appointment; however, none had used cannabis or alcohol on the day of their appointment or exhibited signs of acute intoxication, and thus all proceeded with testing. Following informed consent, a breathalyzer test was administered to confirm a blood alcohol concentration of zero prior to testing. A urine screen was used to help verify eligibility regarding absence of recent illicit drug use. One participant reported a history of regular cocaine use prior to providing the urine sample and was withdrawn from further participation. Six participants who were initially enrolled were withdrawn for meeting criteria for current or past mania or psychosis upon further screening, leaving N=160 who were eligible to proceed with the testing session.

Participants completed a series of cognitive and clinical assessments that were included in the larger study. Given the aims of the current secondary analysis, we selected tasks that closely mapped onto the executive function domains of inhibition, set shifting, and working memory. When multiple tasks were available that assessed similar constructs, we selected the task with norms available for interpreting relative performance (e.g., tasks included in the NIH Toolbox Neuropsychological Battery; see 2.3. Measures). Participants first completed cognitive tasks followed by semi-structured interviews assessing cannabis use history and symptoms of CUD, as well as self-report questionnaires (administered via laptop), including the assessment of cannabis demand. The full assessment for the larger study took approximately 6 hours to complete, and participants were compensated $115 in cash.

Measures

Demographic characteristics. Participants reported their age, sex, gender, race/ethnicity, annual household income, and other demographic factors.

Executive Functions. Set shifting was measured using a Category Switch Task (Friedman et al., 2008; Mayr & Kliegl, 2000) programmed for Inquisit software (Borchert, 2017). In each trial, participants were presented with a word (on the screen) that could be categorized as either (1) living versus non-living, or (2) larger versus smaller than a basketball. Above each word was a symbol indicating which categorization method to use, and participants were told to press a key to categorize each stimulus as quickly as possible during each trial. In half of the 32 trials, the method of categorization switched from that of the previous trial. Of these switch trials, half were congruent, in which the key presses required for a correct response were the same for either categorization method. Scores represent the difference between the average reaction times of switch trials and the average reaction times of non-switch trials, with lower scores indicating better set shifting ability.

Inhibitory control was measured using the Flanker Inhibitory Control and Attention Test from the NIH Toolbox neuropsychological battery (Weintraub et al., 2013). In each trial, participants were instructed to judge the direction to which a central arrow pointed while inhibiting attention toward similar distractor stimuli (other arrows) on the left and right sides of the target. Participants completed 10 trials each in which the distractor stimuli were either congruent or incongruent to the direction of the central target stimulus. Scores integrate both accuracy and reaction time and are age-corrected and standardized (mean of 100, standard deviation of 15). Higher scores indicate better inhibitory control.

Working memory was measured using the List Sorting Working Memory Test from the NIH Toolbox neuropsychological battery (Weintraub et al., 2013). In each trial, participants were presented with series of objects (on an iPad), with each simultaneously presented both visually and orally. After each series of stimuli was presented, participants were required to repeat the objects to the examiner in order from smallest to largest, requiring complex manipulation of stimuli in working memory. In the first condition, stimuli all belonged to the same category (e.g., animals). In the second condition, stimuli belonged to two categories (e.g., animals, food), and participants were required to list objects from smallest to largest, first from category 1 and then from category 2. Trials progressively increased in the number of stimuli presented, and the test was discontinued when a participant failed two trials of the same list length. Scores represent the total number of correct items across all trials which are converted to age-corrected standard scores.

Marijuana Purchase Task (MPT; Aston et al., 2021). Behavioural economic demand for cannabis was assessed with the MPT, a self-report questionnaire that describes a hypothetical marijuana purchasing scenario. In the current study, the term marijuana was defined for participants as referring to dried cannabis flower/leaf. We used a modified version of the MPT that quantifies marijuana amounts in grams (Aston et al., 2021). In this version, participants reported how many grams of cannabis flower they would consume over a typical week at 20 different price points, ranging from "free" to "$60 per gram." Prices were presented simultaneously on the same page. We used a version of the instruction set presented in Amlung and MacKillop (2019), which outlined several assumptions, including that the marijuana had to be used within the week and was exclusively for personal use (not shared with others). In the current study, participants were asked to round to the nearest gram, and we capped responses at 28 grams to avoid extreme outliers.

Timeline Follow Back (TLFB; Sobell & Sobell, 1992). Cannabis consumption during the past 90 days was assessed with the calendar-based TLFB interview, which yields reliable and valid retrospective estimates of cannabis use (Hjorthøj et al., 2012; Robinson et al., 2014). Participants first reported whether they had used cannabis each day, and if so, whether it was a flower or non-flower form of cannabis. For days involving cannabis flower use, participants reported total cannabis flower consumed in grams. To aid in reporting, a cannabis substitute (oregano) was rolled into joints of different weights to provide visual examples (Norberg et al., 2012). Participants were also shown a to-scale image depicting different sized cannabis buds and piles of ground cannabis flower, borrowed from the Daily Sessions, Frequency, Age of Onset, and Quantity of Cannabis Use Inventory (Cuttler & Spradlin, 2017). Total cannabis consumption was calculated as the sum of grams of cannabis flower used each day over the 90-day period. We focused on grams of cannabis flower as the main outcome in analyses given that the MPT assessed demand only for cannabis flower (and not for other cannabis products).

Structured Clinical Interview for DSM-5 (SCID) Substance Use Module (First et al., 2015). The SCID was used to assess symptoms of CUD in the past year. Master's-level research assistants administered the SCID with training and supervision from the study PI (JDW), a licensed clinical psychologist. CUD severity was calculated as the total number of past-year CUD symptoms for which criteria were met. A score of two or more meets criteria for CUD.

Data Analysis Plan

Calculation of demand indices. As two points of demand (i.e., consumption beyond zero cost) are required to generate elasticity, 16 participants were excluded due to reporting zero cannabis demand at every price, and 17 participants were excluded due to only reporting demand at zero cost. Two participants were removed for displaying constant demand (i.e., invariant responding across escalating price) and one additional participant was excluded for committing five reversals (i.e., bounce violations; Stein et al., 2015) indicating poor task comprehension, resulting in a final analytic sample of N=113. Subsequently, raw MPT data (i.e., reported consumption at each price point) were examined for outliers using standard scores, with a criterion of z scores greater than 3.29 to retain maximum data. A small number of outliers were detected (1.33%) and were determined to be legitimate high-magnitude values. Thus, prior to the calculation of demand indices, these outliers were winsorized (i.e., recoded as one unit higher than the next non-outlying value; Tabachnick & Fidell, 2007). We did not further winsorize MPT data at the index level. Observed values for intensity, O_{max}, P_{max}, and breakpoint were estimated by directly examining MPT performance. Elasticity was derived by fitting individual curves in GraphPad Prism using the Koffarnus exponentiated demand equation (Koffarnus et al., 2015a), $Q = Q_0 \times 10^{k(e^{-\alpha Q_0 C} - 1)}$, where Q = quantity consumed, Q_0 = derived intensity, k = a constant across individuals that denotes the range of the dependent variable (cannabis grams), C = the cost of the commodity, and α = elasticity or the rate constant determining the rate of decline in consumption based on increases in price (i.e., essential value). The appropriate k value (k=1.875) was determined by subtracting the $\log_{10}$-transformed average consumption at the highest price used in curve fitting ($60) from the $\log_{10}$-transformed average consumption at the lowest price ($1). An R^2 value was generated to reflect percentage of variance accounted for by the demand equation (i.e., the adequacy of the fit of the model to the data) in each dataset.

EF associations with cannabis demand. We ran a series of multiple linear regression models to examine the associations between EFs and cannabis demand indices. Separate models were specified with each cannabis demand index (O_{max}, P_{max}, breakpoint, intensity, elasticity) as the outcome. Each model included the three EF domains of set shifting, inhibitory control, and working memory as independent variables. Sex and income were also included in each model as covariates. EF scores were examined for extreme outliers, defined as values with z scores greater than 3.29 and that were disconnected from the distribution (Tabachnick & Fidell, 2007). One outlier (0.88%) was detected for each EF task; outliers were winsorized prior to analyses.

Path Analyses. Next, we ran a series of path analyses to examine the indirect associations between executive function domains (independent variables) and cannabis use (dependent variable) through cannabis demand (intervening variable). We included only the cannabis demand indices that were significantly predicted by one or more EF variable in the previously described regression analyses. In each model, all three EF variables (set shifting, working memory, inhibitory control) were specified as independent variables. Because several of the demand indices were highly intercorrelated, only one cannabis demand index was included in each model to reduce multicollinearity. Separate models were specified for the outcomes of (1) grams of cannabis flower used (i.e., cannabis consumption), and (2) number of current CUD symptoms (i.e., CUD severity), neither of which included any extreme outliers. As CUD severity was assessed along a spectrum (i.e., number of symptoms), we included both participants who did and did not meet CUD criteria in all models. In each of the six models, the dependent variable was regressed on both the cannabis demand variable and the three EF variables. In each model, sex and income were also included as covariates.

All models were specified using the *lavaan* package in R (version 4.2.0) and RStudio (R Core Team, 2022; Rosseel, 2012; RStudio Team, 2020), and were fit using maximum likelihood estimation. Given the non-normal distributions of the MPT indices, we used the adjusted bootstrap percentile method[1] (with 5000 samples) to derive 95% bias-corrected confidence intervals to assess significance of all direct and indirect associations.

Transparency and Openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study, and we follow JARS (Kazak, 2018). Code for analyses is available at https://osf.io/cj3me/. Anonymized data and research materials are available upon request from the corresponding author, subject to any applicable ethics requirements. The study's design and its analysis were not pre-registered.

Results

[1] The adjusted bootstrap percentile method adjusts for bias but not acceleration.

Descriptive Statistics

Means, standard deviations, and zero-order correlations among all cannabis use, cannabis demand, and EF variables are provided in Table 2. Participants used an average of 28.2 (*SD*=43.3) grams of cannabis flower and reported an average of 39.20 (*SD*=29.16) cannabis use days in the past 90 days. A total of 60 (53.10%) participants reported using any non-flower forms of cannabis (e.g., edibles, concentrates) in the past 90 days. The average number of non-flower cannabis use days was 3.75 (*SD* = 8.24), and only 7.08% (*n* = 8) of participants reported having used a non-flower cannabis product on more days than they used cannabis flower in the past 90 days, suggesting that cannabis flower was the dominant form of cannabis used in our sample. Participants reported an average of 2.26 (*SD*=2.30) CUD symptoms in the past year, and 59 (52.21%) participants met criteria for CUD. The mean age-corrected standard score for the List Sorting Working Memory Test (103.58) suggested average working memory performance in our sample relative to test norms, whereas the average age-corrected standard score for the Flanker Inhibitory Control and Attention Test (87.10) indicated below-average inhibitory control in our sample relative to test norms (see Table 2).

The modified exponentiated demand equation (Koffarnus et al., 2015b) provided an excellent fit to the overall demand data (R^2=0.984) and a good fit to the individual data (median R^2=0.883, interquartile range=0.813–0.941). Figure 1 depicts consumption and expenditure curves generated from MPT performance.

Associations of EFs with Cannabis Demand

Results of regression models examining associations between EFs and each cannabis demand index are reported in Table 3. Controlling for set shifting, working memory, sex, and income, poorer inhibitory control was significantly associated with higher cannabis demand in terms of both greater peak expenditure on cannabis (O_{max}) and greater unrestricted purchase of cannabis at zero cost (intensity). In addition, controlling for set shifting, inhibitory control, sex, and income, poorer working memory was significantly associated with reduced sensitivity to increasing costs of cannabis use (elasticity). No EFs were significantly associated with P_{max} or breakpoint and thus these indices were excluded from subsequent analyses.

Indirect Associations Through Cannabis Demand Indices

Tables 4 and 5 contain all results of the path analyses. In these models, O_{max}, intensity, and elasticity were all significantly associated with both greater cannabis consumption and greater CUD severity (see Table 4). There were significant indirect associations of poorer inhibitory control with both greater cannabis consumption and greater CUD severity through greater O_{max} (see Table 5). There were also significant indirect associations of poorer inhibitory control with both increased cannabis consumption and increased CUD severity through greater intensity (Table 5). Finally, there were significant indirect associations of poorer working memory with greater cannabis consumption and greater CUD severity through lower elasticity (Table 5). No other indirect associations were statistically significant.[2]

Discussion

Although behavioural economic demand for cannabis is a robust predictor of cannabis consumption and CUD severity (Aston et al., 2015; Aston & Berey, 2022; González-Roz et al., 2022), few studies have examined factors that are associated with individual differences in cannabis demand. This is the first study to our knowledge to examine associations between EFs (i.e., inhibitory control, set shifting, working memory) and indices of cannabis demand. Overall,

[2] All significant direct and indirect associations observed in multiple linear regression and path analyses held when controlling for alcohol, nicotine, and other drug use. Analyses controlling for alcohol, nicotine, and other drug use are detailed in the Supplementary Material.

we observed significant associations between specific EF domains and specific cannabis demand indices. Further, we found that cannabis demand indices accounted for associations between some EF domains and both current cannabis consumption and CUD severity. These findings persisted when controlling for alcohol, nicotine, and other drug use (see Supplementary Material), supporting their specificity to cannabis. Findings provide new insight into the role of EFs in cannabis demand among young adults.

Of the EFs we examined, we observed significant associations of inhibitory control and working memory (but not set shifting) with cannabis demand indices. Specifically, individuals with relatively poorer ability to inhibit attention toward irrelevant stimuli on a flanker task exhibited greater maximum expenditure on cannabis (O_{max}) and greater unrestricted purchase of cannabis when cost was set at zero (intensity) on the MPT. Individuals with poorer inhibitory control may experience greater difficulty inhibiting attention toward strong internal (e.g., craving) and external (e.g., social pressure) cues to use cannabis despite monetary and opportunity costs of use. This may lead to elevated unrestricted purchase of and maximum expenditure on cannabis, as was observed in the present study. Although the underlying mechanism remains speculative, findings suggest that relative weaknesses in inhibitory control as an important domain for further study in the context of cannabis demand. It is also noteworthy that the average inhibitory control performance in the current sample fell nearly one standard deviation below that of the normative reference sample, which could reflect a predisposition to lower inhibitory control in this cannabis-using group of young adults or influence of cannabis use on this cognitive ability (Morie & Potenza, 2021; Morin et al., 2019).

Lower working memory performance was also associated with increased cannabis demand, and specifically, with reduced elasticity, or insensitivity to escalating costs of cannabis.

This is consistent with research showing that poorer working memory is associated with lower elasticity in an alcohol purchase task (Abram et al., 2021). Complex working memory functions facilitate the constant monitoring and manipulation of information in working memory (Baddeley & Hitch, 1994; Diamond, 2013; Miyake & Friedman, 2012). This is directly relevant to the MPT, in which participants must mentally simulate cannabis purchase and consumption while accommodating environmental fluctuations in the cost of cannabis, manipulating this information in working memory to determine cannabis' relative reinforcing value and make decisions about purchasing. A lower capacity to execute these complex mental manipulations may result in difficulties adjusting cannabis consumption in response to escalating cost, manifesting as inelastic cannabis demand. Working memory also facilitates the active mental representation of self-regulatory goals using information recruited from long-term memory (Hofmann et al., 2012). A diminished ability to hold relevant self-regulatory goals in mind, such as to limit expenditure, might result in cannabis maintaining its reinforcing value even at costs that undermine these goals, further exacerbating inelasticity. As the present study is the first to demonstrate that poorer working memory is associated with reduced elasticity, future research will be needed to clarify the exact mechanisms driving this association.

Given that cannabis demand is a robust predictor of cannabis consumption and CUD severity (Aston et al., 2015; Aston & Berey, 2022; González-Roz et al., 2022), we were interested in examining whether cannabis demand may partially explain the associations of EFs with cannabis consumption and CUD severity. We found that poorer inhibitory control was indirectly associated with greater cannabis consumption and CUD severity through both increased O_{max} and intensity, and poorer working memory was indirectly associated with greater cannabis consumption and CUD severity through lower elasticity. Our findings are consistent with previous studies demonstrating that poorer EFs are a risk factor for heavy cannabis use and CUD (Castellanos-Ryan et al., 2017; Castellanos-Ryan & Conrod, 2020; Cavalli et al., 2022; Squeglia et al., 2014) and substance use more broadly (Castellanos-Ryan & Conrod, 2020; Garavan et al., 2015; Koob & Volkow, 2010), extending this research by providing initial evidence for the role of cannabis demand as a potential mechanism in this link.

Some limitations of this study should be noted. First, the MPT only assesses demand for cannabis flower, excluding other cannabis products such as concentrates and edibles. Future work is needed to assess cannabis demand more comprehensively. Second and relatedly, our index of past-90-day cannabis consumption included only cannabis flower consumption, as we only assessed grams of cannabis flower used on the TLFB and not quantities of other forms of cannabis. However, cannabis flower was the dominant form of cannabis used in our sample and was used on the majority of cannabis use days. Still, findings should be replicated with more comprehensive indices of cannabis consumption that include a wider range of cannabis products. Third, our study exclusively assessed cannabis demand. Given frequent concurrent alcohol use among young adults who use cannabis, including in our sample, there remains a need to examine the combined effects of cannabis demand *and* alcohol demand on cannabis use and cannabis-alcohol co-use. Fourth, state and contextual factors that were not formally assessed may have influenced performance on EF tasks, such as experiencing cannabis withdrawal at the time of testing. Thus, we are not able to infer that observed EF task performance reflects stable individual differences in EF capacity. Fifth, our sample was limited to non-treatment-seeking young adults with an absence of brain injuries and other neurocognitive disorders, and thus findings may not generalize to clinical populations. An additional limitation is that our data were cross-sectional, and thus the directionality of the associations observed cannot be inferred. This is an important consideration, as the associations of EFs with cannabis consumption and CUD may be bidirectional (Castellanos-Ryan & Conrod, 2020). A bidirectional association could result in a positive feedback loop wherein poorer EFs contribute to increased cannabis demand, driving heavier cannabis use, and in turn, further impairments in EFs (Koudys & Ruocco, 2020). Future studies employing longitudinal methods are needed to examine these temporal relationships. Finally, future research should replicate these findings with additional EF tasks as findings may be task-specific.

Conclusions

In sum, this study demonstrated that EFs, including inhibitory control and working memory, may subserve individual differences in cannabis demand among young adults who use cannabis. In addition, cannabis demand may be an important mechanism by which EFs are associated with cannabis use and CUD severity in this population. Findings suggest that for young adults exhibiting poorer inhibitory control and working memory, cannabis demand may be an important target of intervention for cannabis-related risk—a possibility that should be explored in future research.

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Table 1. Sample demographic characteristics

Characteristic	M (*SD*) or *n* (%)
Age	22.11 (2.04)
Sex	
Male	47 (41.59)
Female	66 (58.41)
Gender	
Man	46 (40.71)
Woman	67 (59.29)
Non-binary	0 (0)
Sexual Orientation	
Heterosexual/Straight	72 (63.72)
Gay	5 (4.42)
Lesbian	5 (4.42)
Bisexual	27 (23.89)
Asexual	2 (1.77)
Other	2 (1.77)
Race/Ethnicity[a]	
White	56 (49.56)
Black	21 (18.58)
Asian	20 (17.70)
Pacific Islander	3 (2.65)
Indigenous/Native North American	0 (0)
East Indian	10 (8.85)
Hispanic/Latinx	3 (2.65)
Other	9 (7.96)
Annual Household Income	
$19,999 or less	34 (30.09)
$20,000–$49,999	28 (24.78)
$50,000–$99,999	26 (23.01)
$100,000–$199,999	15 (13.27)
$200,000 or more	4 (3.54)
Prefer not to answer	6 (5.31)
Highest Level of Education	
Less than high school	1 (0.88)
High school diploma or GED	44 (38.94)
Some college	26 (23.01)
Associates degree or technical certificate	7 (6.19)
Bachelor's degree	34 (30.09)
Master's degree or higher	1 (0.88)

[a] Participants could select more than one race/ethnicity option and may thus be represented in more than one category.

Table 2. Means, standard deviations, and zero-order correlations among executive functions, cannabis demand, and cannabis use variables

	M (*SD*)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Set shifting	227.68 (166.23)	–									
2. Inhibitory control	87.10 (13.16)	-0.18	–								
3. Working memory	103.58 (12.08)	-0.05	0.12	–							
4. Cannabis consumption (grams)	28.19 (43.34)	0.16	-0.25**	-0.13	–						
5. CUD severity (symptom count)	2.26 (2.30)	0.02	-0.12	-0.07	0.58***	–					
6. O_{max}	42.97 (36.66)	0.05	-0.33***	-0.21*	0.64***	0.47***	–				
7. P_{max}	14.71 (12.47)	-0.12	0.02	0.05	-0.06	-0.13	0.11	–			
8. Breakpoint	24.98 (15.18)	<0.01	-0.01	-0.03	0.21*	0.12	0.54***	0.60***	–		
9. Intensity	8.27 (8.74)	0.09	-0.31***	-0.18	0.58***	0.56***	0.75***	-0.19*	0.25**	–	
10. Elasticity	0.01 (0.02)	-0.05	0.28**	0.22*	-0.65***	-0.49***	-0.97***	-0.09	-0.56***	-0.77***	–

Note: SD = standard deviation; CUD = Cannabis Use Disorder. Zero-order correlation estimates presented are Spearman's rank correlation coefficients.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3. Multiple linear regression models examining associations between executive functions and cannabis demand indices

	β	*B*	*SE*	95% CI
DV: O_{max}				
Set shifting	0.018	0.004	0.026	-0.048, 0.054
Inhibitory control	**-0.295**	**-0.820**	**0.247**	**-1.300, -0.352**
Working memory	-0.175	-0.530	0.328	-1.218, 0.083
Sex	-0.032	-2.345	6.549	-15.87, 9.487
Income	0.061	0.560	0.798	-1.029, 2.117
DV: P_{max}				
Set shifting	-0.105	-0.008	0.007	-0.022, 0.004
Inhibitory control	-0.048	-0.046	0.093	-0.239, 0.125
Working memory	0.006	0.006	0.107	-0.221, 0.205
Sex	**0.160**	**4.035**	**2.089**	**0.230, 8.369**
Income	-0.082	-0.253	0.219	-0.714, 0.149
DV: Breakpoint				
Set shifting	0.090	0.008	0.010	-0.011, 0.026
Inhibitory control	-0.041	-0.047	0.105	-0.264, 0.151
Working memory	0.016	0.020	0.122	-0.221, 0.258
Sex	0.085	2.602	2.825	-3.169, 7.922
Income	-0.050	-0.190	0.297	-0.760, 0.416
DV: Intensity				
Set shifting	-0.012	-0.001	0.006	-0.013, 0.011
Inhibitory control	**-0.258**	**-0.171**	**0.060**	**-0.292, -0.052**
Working memory	-0.112	-0.081	0.066	-0.212, 0.045
Sex	-0.091	-1.614	1.640	-4.925, 1.498
Income	0.101	0.221	0.210	-0.198, 0.632
DV: Elasticity				
Set shifting	0.011	0.000001	0.00001	-0.00001, 0.00002
Inhibitory control	0.142	0.0002	0.0002	-0.0001, 0.001
Working memory	**0.153**	**0.0002**	**0.0002**	**0.00004, 0.001**
Sex	-0.014	0.004	0.004	-0.010, 0.008
Income	-0.130	0.0005	0.0005	-0.002, 0.0001

Note: CI = confidence interval; DV = dependent variable. 95% CIs were obtained using bias-corrected bootstrapping with 5000 samples. Bolding indicates confidence intervals that do not contain zero.

Table 4. Direct associations with (A) cannabis consumption, and (B) cannabis use disorder severity from path models

	(A) Models Predicting Cannabis Consumption				(B) Models Predicting CUD Severity			
	β	*B*	*SE*	95% CI	*β*	*B*	*SE*	95% CI
Models with O_{max} as the Mediator								
DV: O_{max}								
Set shifting	0.018	0.004	0.026	-0.048, 0.054	0.018	0.004	0.026	-0.046, 0.055
Inhibitory control	**-0.295**	**-0.820**	**0.247**	**-1.300, -0.352**	**-0.295**	**-0.820**	**0.249**	**-1.333, -0.350**
Working memory	-0.175	-0.530	0.328	-1.218, 0.083	-0.175	-0.530	0.324	-1.216, 0.059
Sex	-0.032	-2.345	6.549	-15.870, 9.487	-0.032	-2.345	6.674	-16.199, 10.021
Income	0.061	0.560	0.798	-1.029, 2.117	0.061	0.560	0.804	-1.092, 2.120
DV: (A) Cannabis use quantity, or (B) CUD severity								
O_{max}	**0.442**	**0.523**	**0.133**	**0.291, 0.816**	**0.347**	**0.022**	**0.007**	**0.010, 0.036**
Set shifting	0.142	0.037	0.026	-0.005, 0.096	0.064	0.001	0.001	-0.002, 0.004
Inhibitory control	-0.025	-0.083	0.292	-0.708, 0.450	0.126	0.022	0.019	-0.015, 0.061
Working memory	-0.124	-0.446	0.302	-1.158, 0.067	-0.062	-0.012	0.019	-0.049, 0.024
Sex	**-0.268**	**-23.447**	**6.487**	**-38.085, -12.242**	**-0.203**	**-0.943**	**0.411**	**-1.763, -0.150**
Income	0.100	1.079	0.758	-0.394, 2.623	0.142	0.081	0.054	-0.017, 0.194
Models with Intensity as the Mediator								
DV: Intensity								
Set shifting	-0.012	-0.001	0.006	-0.013, 0.011	-0.012	-0.001	0.006	-0.013, 0.011
Inhibitory control	**-0.258**	**-0.171**	**0.060**	**-0.292, -0.052**	**-0.258**	**-0.171**	**0.061**	**-0.294, -0.050**
Working memory	-0.112	-0.081	0.066	-0.212, 0.045	-0.112	-0.081	0.064	-0.212, 0.044
Sex	-0.091	-1.614	1.640	-4.925, 1.498	-0.091	-1.614	1.657	-5.073, 1.528
Income	0.101	0.221	0.210	-0.198, 0.632	0.101	0.221	0.212	-0.198, 0.632
DV: (A) Cannabis use quantity, or (B) CUD severity								
Intensity	**0.437**	**2.169**	**0.500**	**1.306, 3.304**	**0.442**	**0.116**	**0.027**	**0.063, 0.172**
Set shifting	0.155	0.041	0.025	-0.004, 0.096	0.075	0.001	0.001	-0.001, 0.004
Inhibitory control	-0.043	-0.141	0.319	-0.820, 0.450	0.137	0.024	0.019	-0.012, 0.063
Working memory	-0.153	-0.548	0.308	-1.230, 0.001	-0.073	-0.014	0.018	-0.050, 0.021
Sex	**-0.242**	**-21.171**	**6.259**	**-35.205, -10.202**	**-0.174**	**-0.807**	**0.383**	**-1.586, -0.073**
Income	0.083	0.893	0.769	-0.553, 2.506	0.119	0.068	0.056	-0.037, 0.184

Models with Elasticity as the Mediator[a]								
DV: Elasticity								
Set shifting	0.011	0.000001	0.00001	-0.00001, 0.00002	0.011	0.00001	0.0001	-0.0001, 0.0002
Inhibitory control	0.142	0.0002	0.0002	-0.0001, 0.001	0.142	0.002	0.002	-0.001, 0.007
Working memory	**0.153**	**0.0003**	**0.0002**	**0.00004, 0.001**	**0.153**	**0.003**	**0.002**	**0.0004, 0.006**
Sex	-0.014	-0.001	0.004	-0.010, 0.008	-0.014	-0.006	0.045	-0.097, 0.081
Income	-0.130	-0.001	0.0005	-0.002, 0.0001	-0.130	-0.007	0.005	-0.019, 0.001
DV: (A) Cannabis use quantity, or (B) CUD severity								
Elasticity	**-0.155**	**-309.327**	**243.139**	**-917.773, -96.955**	**-0.179**	**-1.900**	**1.902**	**-6.395, -0.173**
Set shifting	0.152	0.040	0.030	-0.015, 0.102	0.072	0.001	0.001	-0.002, 0.004
Inhibitory control	-0.134	-0.441	0.342	-1.129, 0.214	0.049	0.008	0.020	-0.029, 0.051
Working memory	-0.178	-0.639	0.354	-1.448, 0.030	-0.095	-0.018	0.019	-0.056, 0.019
Sex	**-0.284**	**-24.856**	**7.663**	**-41.732, -11.276**	**-0.217**	**-1.006**	**0.431**	**-1.841, -0.150**
Income	0.107	1.155	0.917	-0.567, 3.027	0.140	0.080	0.058	-0.025, 0.203

Note: CI = confidence interval; DV = dependent variable; CUD = Cannabis Use Disorder. 95% CIs were obtained using bias-corrected bootstrapping with 5000 samples.

[a]In the model with elasticity as the mediator and CUD severity as the dependent variable, elasticity was rescaled by a factor of 10 to resolve model non-convergence.

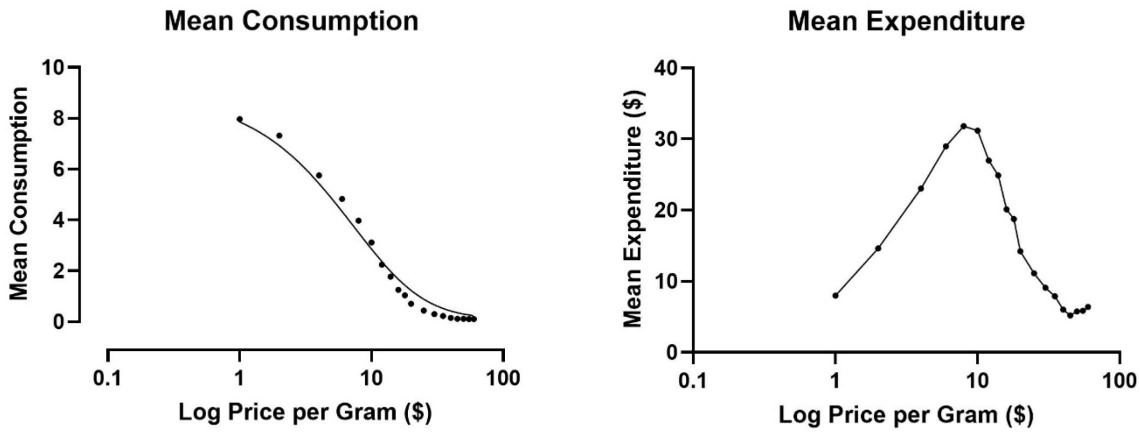
Table 5. Indirect associations between executive functions and (A) cannabis consumption, or (B) cannabis use disorder severity through cannabis demand indices derived from path models

	(A) Indirect Associations with Cannabis Consumption				(B) Indirect Associations with CUD Severity			
	β	*B*	*SE*	95% CI	*β*	*B*	*SE*	95% CI
Models with O_{max} as the Mediator								
Set shifting→ O_{max}	0.008	0.002	0.014	-0.026, 0.029	0.006	0.0001	0.001	-0.001, 0.002
Inhibitory Control → O_{max}	**-0.130**	**-0.429**	**0.189**	**-0.911, -0.154**	**-0.102**	**-0.018**	**0.007**	**-0.038, -0.007**
Working memory → O_{max}	-0.077	-0.277	0.203	-0.807, 0.022	-0.061	-0.012	0.008	-0.033, 0.001
Models with Intensity as the Mediator								
Set shifting→ Intensity	-0.005	-0.001	0.013	-0.028, 0.025	-0.005	-0.0001	0.001	-0.002, 0.001
Inhibitory Control → Intensity	**-0.113**	**-0.372**	**0.164**	**-0.766, -0.110**	**-0.114**	**-0.020**	**0.009**	**-0.041, -0.006**
Working memory → Intensity	-0.049	-0.176	0.150	-0.521, 0.075	-0.049	-0.009	0.008	-0.030, 0.004
Models with Elasticity as the Mediator[a]								
Set shifting→ Elasticity	-0.002	-0.0004	0.003	-0.006, 0.005	-0.002	-0.00003	0.0002	-0.0003, 0.0004
Inhibitory Control → Elasticity	-0.022	-0.072	0.054	-0.179, 0.039	-0.025	-0.004	0.003	-0.013, 0.001
Working memory → Elasticity	**-0.024**	**-0.085**	**0.059**	**-0.220, -0.002**	**-0.027**	**-0.005**	**0.005**	**-0.016, -0.00003**

Note: CI = confidence interval; DV = dependent variable; CUD = Cannabis Use Disorder. 95% CIs were obtained using bias-corrected bootstrapping with 5000 samples. Bolding indicates confidence intervals that do not contain zero.

[a]In the model with elasticity as the mediator and CUD severity as the dependent variable, elasticity was rescaled by a factor of 10 to resolve model non-convergence.

Figure 1. Cannabis demand and expenditure curves



Note. Curve for consumption of cannabis grams (left) and curve for expenditures on cannabis grams (right). The x-axis provides log-transformed price in dollars and the y-axis provides mean cannabis grams purchased (left) and mean expenditure on cannabis grams in dollars (right).

Supplemental Analyses Involving Other Substance Use

During the Timeline Follow Back interview, in addition to reporting their past-90-day cannabis, participants also reported on their alcohol use (i.e., whether they had used alcohol, number of standard drinks consumed), nicotine use (i.e., whether they had used nicotine-containing combustible cigarettes or e-cigarettes), and other drug use (i.e., whether they had used any substance other than cannabis, alcohol, or nicotine) during each of the past 90 days. Participants reported an average of 16.07 (*SD* = 11.83) drinking days and an average of 58.05 (*SD* = 52.25) standard drinks consumed in total across the 90-day period. A total of *n* = 57 participants (50.44%) reported using nicotine in the past 90 days. Across the full sample, the average number of cigarette use days in the past 90 days was 12.90 (*SD* = 27.83), and the average number of e-cigarette use days in the past 90 days was 4.35 (*SD* = 16.76). A total of *n* = 22 participants (19.47%) reported using other drugs in the past 90 days. An average of 1.43 (*SD* = 8.47) other drug use days was reported across the full sample.

As a supplemental analysis, we re-ran all multiple linear regression and path analyses with total number of standard drinks consumed in the past 90 days (with three outliers winsorized), past-90-day nicotine use (1 = yes, 0 = no), and past-90-day other drug use (1 = yes, 0 = no) added as covariates, on which all dependent variables (i.e., cannabis demand, cannabis consumption, and CUD severity) were regressed. Nicotine use was dichotomized due to the bimodal distribution of frequency of use (i.e., many participants reporting non-use and many participants reporting daily or near-daily use with few participants reporting infrequent or moderate use), and other drug use was dichotomized due to the large proportion of participants who had not used other drugs and relatively low frequency of drug use in our sample due to our exclusion criteria. Although there were significant associations between alcohol quantity and

O_{max}, and between nicotine use and intensity, the inclusion of these covariates did not account for any of the findings reported in the manuscript, as all direct and indirect associations observed among EF, cannabis demand, and cannabis consumption and CUD severity remained statistically significant. Results of regression models are presented in Table S1, and results of path models are presented in Tables S2 and S3.

Table S1. Multiple linear regression models examining associations between executive functions and cannabis demand indices

	β	*B*	*SE*	95% CI
DV: O_{max}				
Set shifting	0.021	0.005	0.025	-0.045, 0.055
Inhibitory control	**-0.254**	**-0.708**	**0.242**	**-1.17, -0.228**
Working memory	-0.142	-0.431	0.329	-1.111, 0.189
Sex	-0.051	-3.787	6.765	-17.435, 8.67
Income	0.039	0.356	0.843	-1.268, 2.024
Total standard drinks (past 90 days)	**-0.145**	**-0.102**	**0.046**	**-0.200, -0.020**
Used nicotine (past 90 days)	0.156	11.354	6.569	-0.73, 25.077
Used other drug (past 90 days)	-0.017	-1.571	8.644	-16.773, 17.549
DV: P_{max}				
Set shifting	-0.096	-0.007	0.007	-0.021, 0.004
Inhibitory control	-0.057	-0.054	0.1	-0.273, 0.127
Working memory	0.04	0.041	0.107	-0.179, 0.245
Sex	0.121	3.052	1.984	-0.722, 7.097
Income	-0.104	-0.324	0.225	-0.783, 0.091
Total standard drinks (past 90 days)	-0.081	-0.019	0.019	-0.060, 0.015
Used nicotine (past 90 days)	-0.017	-0.43	2.699	-5.595, 5.051
Used other drug (past 90 days)	**-0.159**	**-4.974**	**2.075**	**-9.193, -1.041**
DV: Breakpoint				
Set shifting	0.089	0.008	0.009	-0.011, 0.024
Inhibitory control	0.003	0.004	0.113	-0.234, 0.22
Working memory	0.051	0.065	0.125	-0.181, 0.311
Sex	0.056	1.706	2.829	-4.078, 7.119
Income	-0.083	-0.315	0.303	-0.908, 0.301
Total standard drinks (past 90 days)	-0.108	-0.031	0.025	-0.086, 0.014
Used nicotine (past 90 days)	0.169	5.099	3.245	-1.222, 11.608
Used other drug (past 90 days)	-0.142	-5.427	3.252	-12.062, 0.865
DV: Intensity				
Set shifting	-0.011	-0.001	0.006	-0.013, 0.011
Inhibitory control	**-0.209**	**-0.139**	**0.058**	**-0.255, -0.021**
Working memory	-0.088	-0.064	0.068	-0.203, 0.066
Sex	-0.098	-1.721	1.693	-5.266, 1.365
Income	0.086	0.187	0.215	-0.232, 0.599
Total standard drinks (past 90 days)	-0.136	-0.023	0.013	-0.050, 0.001
Used nicotine (past 90 days)	**0.184**	**3.195**	**1.545**	**0.140, 6.230**
Used other drug (past 90 days)	0.053	1.157	2.105	-2.817, 5.567
DV: Elasticity				
Set shifting	0.018	0.000002	0.00001	-0.00001, 0.00003
Inhibitory control	0.123	0.0002	0.0002	-0.0001, 0.001
Working memory	**0.16**	**0.0003**	**0.0002**	**0.0001, 0.001**
Sex	-0.022	-0.001	0.004	-0.010, 0.006
Income	-0.127	-0.001	0.001	-0.002, 0.0001
Total standard drinks (past 90 days)	-0.041	-0.00002	0.00003	-0.0001, 0.00003
Used nicotine (past 90 days)	-0.063	-0.003	0.003	-0.009, 0.004
Used other drug (past 90 days)	0.029	0.002	0.006	-0.007, 0.015

Note: CI = confidence interval; DV = dependent variable. 95% CIs were obtained using bias-corrected bootstrapping with 5000 samples. Bolding indicates confidence intervals that do not contain zero.

Table S2. Direct associations with (A) cannabis consumption, and (B) cannabis use disorder severity from path models

	(A) Models Predicting Cannabis Consumption				(B) Models Predicting CUD Severity			
	β	*B*	*SE*	95% CI	*β*	*B*	*SE*	95% CI
Models with O_{max} as the Mediator								
DV: O_{max}								
Set shifting	0.027	0.006	0.026	-0.046, 0.058	0.018	0.004	0.025	-0.045, 0.055
Inhibitory control	**-0.308**	**-0.869**	**0.256**	**-1.411, -0.405**	**-0.295**	**-0.824**	**0.249**	**-1.324, -0.342**
Working memory	-0.164	-0.504	0.335	-1.19, 0.108	-0.176	-0.533	0.318	-1.204, 0.041
Sex	-0.036	-2.702	6.793	-16.75, 9.623	-0.030	-2.233	6.542	-16.093, 9.783
Income	0.067	0.616	0.82	-0.912, 2.324	0.063	0.574	0.786	-1.046, 2.040
Total standard drinks (past 90 days)	-0.067	-0.048	0.041	-0.137, 0.026	0.000	0.0002	0.004	-0.007, 0.008
Used nicotine (past 90 days)	-0.056	-4.166	3.465	-10.988, 2.51	-0.004	-0.321	0.320	-0.944, 0.302
Used other drug (past 90 days)	0.085	7.941	6.165	-3.494, 20.908	0.012	1.144	0.637	-0.022, 2.472
DV: (A) Cannabis use quantity, or (B) CUD severity								
O_{max}	**0.468**	**0.545**	**0.156**	**0.279, 0.898**	**0.375**	0.024	0.008	**0.010, 0.040**
Set shifting	0.157	0.041	0.028	-0.006, 0.105	0.075	0.001	0.001	-0.002, 0.004
Inhibitory control	-0.041	-0.133	0.31	-0.774, 0.444	0.112	0.020	0.018	-0.017, 0.056
Working memory	-0.075	-0.268	0.324	-0.980, 0.313	-0.038	-0.007	0.019	-0.047, 0.029
Sex	-0.048	-4.166	3.465	-10.988, 2.51	-0.069	-0.321	0.320	-0.944, 0.302
Income	-0.004	-0.048	0.041	-0.137, 0.026	0.000	0.0002	0.004	-0.007, 0.008
Total standard drinks (past 90 days)	-0.058	-0.048	0.041	-0.137, 0.026	0.005	0.0002	0.004	-0.007, 0.008
Used nicotine (past 90 days)	-0.048	-4.166	3.465	-10.988, 2.510	-0.070	-0.321	0.320	-0.944, 0.302
Used other drug (past 90 days)	0.073	7.941	6.165	-3.494, 20.908	0.197	1.144	0.637	-0.022, 2.472
Models with Intensity as the Mediator								
DV: Intensity								
Set shifting	-0.008	-0.0004	0.006	-0.013, 0.011	-0.011	-0.001	0.006	-0.013, 0.011
Inhibitory control	**-0.232**	**-0.153**	**0.06**	**-0.274, -0.037**	-0.262	**-0.174**	**0.061**	**-0.293, -0.049**
Working memory	-0.093	-0.067	0.068	-0.204, 0.064	-0.115	-0.083	0.064	-0.211, 0.039
Sex	-0.097	-1.697	1.701	-5.048, 1.612	-0.087	-1.528	1.645	-4.810, 1.634
Income	0.095	0.205	0.217	-0.218, 0.622	0.107	0.232	0.211	-0.184, 0.639
Total standard drinks (past 90 days)	-0.125	-0.021	0.013	-0.048, 0.003	-0.003	-0.0005	0.003	-0.007, 0.006
Used nicotine (past 90 days)	0.106	1.839	1.488	-1.054, 4.847	-0.014	-0.239	0.297	-0.808, 0.358
Used other drug (past 90 days)	0.085	1.859	2.03	-2.07, 5.855	0.045	0.985	0.587	-0.074, 2.238
DV: (A) Cannabis use quantity, or (B) CUD severity								
Intensity	**0.467**	**2.338**	**0.578**	**1.334, 3.639**	0.466	**0.123**	**0.029**	**0.068, 0.182**
Set shifting	0.163	0.043	0.029	-0.006, 0.105	0.086	0.001	0.001	-0.001, 0.004

Inhibitory control	-0.035	-0.115	0.341	-0.795, 0.538	0.127	0.022	0.018	-0.012, 0.058
Working memory	-0.106	-0.383	0.329	-1.089, 0.217	-0.051	-0.010	0.019	-0.049, 0.027
Sex	0.021	1.839	1.488	-1.054, 4.847	-0.051	-0.239	0.297	-0.808, 0.358
Income	-0.002	-0.021	0.013	-0.048, 0.003	-0.001	-0.0005	0.003	-0.007, 0.006
Total standard drinks (past 90 days)	-0.025	-0.021	0.013	-0.048, 0.003	-0.010	-0.0005	0.003	-0.007, 0.006
Used nicotine (past 90 days)	0.021	1.839	1.488	-1.054, 4.847	-0.052	-0.239	0.297	-0.808, 0.358
Used other drug (past 90 days)	0.017	1.859	2.03	-2.07, 5.855	0.170	0.985	0.587	-0.074, 2.238
Models with Elasticity as the Mediator[a]								
DV: Elasticity								
Set shifting	0.018	0.000002	0.00001	-0.00001, 0.00003	0.019	0.00002	0.0001	-0.0001, 0.0003
Inhibitory control	0.123	0.0002	0.0002	-0.0001, 0.001	0.119	0.002	0.002	-0.001, 0.006
Working memory	**0.160**	**0.0003**	**0.0002**	**0.0001, 0.001**	**0.159**	**0.003**	**0.002**	**0.001, 0.007**
Sex	-0.022	-0.001	0.004	-0.010, 0.006	-0.020	-0.009	0.041	-0.096, 0.067
Income	-0.127	-0.001	0.001	-0.002, 0.0001	-0.124	-0.007	0.005	-0.017, 0.001
Total standard drinks (past 90 days)	-0.041	-0.00002	0.00003	-0.0001, 0.00003	-0.042	-0.0002	0.0003	-0.001, 0.0003
Used nicotine (past 90 days)	-0.063	-0.003	0.003	-0.009, 0.004	-0.075	-0.032	0.032	-0.095, 0.031
Used other drug (past 90 days)	0.029	0.002	0.005	-0.007, 0.014	0.050	0.027	0.056	-0.058, 0.164
DV: (A) Cannabis use quantity, or (B) CUD severity								
Elasticity	**-0.172**	**-343.108**	**256.89**	**-1001.923, -149.095**	**-0.201**	**-2.125**	**1.841**	**-6.859, -0.432**
Set shifting	0.16	0.042	0.034	-0.019, 0.112	0.082	0.001	0.002	-0.002, 0.005
Inhibitory control	-0.138	-0.456	0.369	-1.202, 0.237	0.044	0.008	0.021	-0.030, 0.052
Working memory	-0.131	-0.469	0.372	-1.262, 0.200	-0.049	-0.009	0.019	-0.049, 0.026
Sex	<0.001	-0.003	0.003	-0.009, 0.004	-0.007	-0.032	0.032	-0.095, 0.031
Income	<0.001	-0.00002	0.00003	-0.0001, 0.00003	<0.001	-0.0002	0.0003	-0.001, 0.0003
Total standard drinks (past 90 days)	<0.001	-0.00002	0.00003	-0.0001, 0.00003	-0.004	-0.0002	0.0003	-0.001, 0.0003
Used nicotine (past 90 days)	<0.001	-0.003	0.003	-0.009, 0.004	-0.007	-0.032	0.032	-0.095, 0.031
Used other drug (past 90 days)	<0.001	0.002	0.005	-0.007, 0.014	0.005	0.027	0.056	-0.058, 0.164

Note: CI = confidence interval; DV = dependent variable; CUD = Cannabis Use Disorder. 95% CIs were obtained using bias-corrected bootstrapping with 5000 samples.

[a]In the model with elasticity as the mediator and CUD severity as the dependent variable, elasticity was rescaled by a factor of 10 to resolve model non-convergence.

Table S3. Indirect associations between executive functions and (A) cannabis consumption, or (B) cannabis use disorder severity through cannabis demand indices derived from path models

	(A) Indirect Associations with Cannabis Consumption				(B) Indirect Associations with CUD Severity			
	β	*B*	*SE*	95% CI	*β*	*B*	*SE*	95% CI
Models with O_{max} as the Mediator								
Set shifting→ O_{max}	0.013	0.003	0.014	-0.024, 0.034	0.007	0.0001	0.001	-0.001, 0.002
Inhibitory Control → O_{max}	**-0.144**	**-0.473**	**0.212**	**-1.015, -0.168**	**-0.111**	**-0.019**	**0.009**	**-0.042, -0.007**
Working memory → O_{max}	-0.077	-0.275	0.221	-0.902, 0.027	-0.066	-0.013	0.009	-0.039, 0.0003
Models with Intensity as the Mediator								
Set shifting→ Intensity	-0.004	-0.001	0.014	-0.030, 0.027	-0.005	-0.0001	0.001	-0.001, 0.001
Inhibitory Control → Intensity	**-0.108**	**-0.358**	**0.167**	**-0.767, -0.096**	**-0.122**	**-0.021**	**0.009**	**-0.044, -0.007**
Working memory → Intensity	-0.044	-0.157	0.165	-0.548, 0.117	-0.054	-0.010	0.009	-0.032, 0.004
Models with Elasticity as the Mediator[a]								
Set shifting→ Elasticity	-0.003	-0.001	0.003	-0.008, 0.005	-0.004	-0.0001	0.0002	-0.001, 0.0004
Inhibitory Control → Elasticity	-0.021	-0.069	0.06	-0.189, 0.057	-0.024	-0.004	0.004	-0.012, 0.003
Working memory → Elasticity	**-0.028**	**-0.099**	**0.055**	**-0.220, -0.013**	**-0.032**	**-0.006**	**0.004**	**-0.016, -0.0003**

Note: CI = confidence interval; DV = dependent variable; CUD = Cannabis Use Disorder. 95% CIs were obtained using bias-corrected bootstrapping. All models controlled for sex, income, total number of standard drinks consumed in the past 90 days, past-90-day nicotine use, and past-90-day other drug use.

[a]In the model with elasticity as the mediator and CUD severity as the dependent variable, elasticity was rescaled by a factor of 10 to resolve model non-convergence.