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Contribution of cannabis-related cues to concurrent reinforcer choice in humans

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ABSTRACT

Background: Drug-related cues play a critical role in the development and persistence of substance use disorder. Few human laboratory studies have evaluated how these cues contribute to decisions between concurrently presented reinforcers, and none have examined the specific role of cannabis cues. This study evaluated the contribution of cannabis-related cues to concurrent monetary reinforcer choice in humans.
Methods: Participants with a cannabis use history (i.e., use in the past two weeks and 50 or more lifetime uses; n = 71) and controls without this history (i.e., 5 or less lifetime uses; n = 79) were recruited using Amazon Mechanical Turk. A cued concurrent choice task was used in which cannabis trials presented two cues (one cannabis and one neutral) side-by-side followed by concurrent monetary offers below each image. The primary dependent measure was choice for cannabis-cued monetary reinforcers on equal value trials. Secondary analyses evaluated individual difference variables related to choice bias.
Results: Participants in the cannabis group showed a significant bias for cannabis-cued choices (mean 76.0%) whereas participants in the control group showed a significant bias against cannabis-cued choices (mean 30.3%). Reaction times on cannabis trials were faster than neutral filler trials and did not differ by group. Cannabis-cued choice was significantly associated with more frequent cannabis use (r = .44), higher cannabis demand intensity (r = .28), and lower cannabis elasticity (r = -.30).
Conclusions: These findings suggest that cannabis-related cues can influence reinforcer choice and potentially promote disadvantageous decision-making related to non-drug reinforcers.

1. Introduction

Theoretical perspectives in addiction science highlight the relevance of drug-related cues in the development and persistence of substance use disorder. Incentive salience theory, for example, posits that repeated substance use results in the sensitization of brain circuits associated with salience and motivation (Robinson and Berridge, 1993, 2008). Over time the associative pairing of drug-taking behavior with accompanying stimuli results in a transfer of incentive salience and subsequent cue-elicited motivational behaviors. Such cue reactivity is then thought to contribute to clinically relevant outcomes such as relapse to substance use following periods of abstinence (Cooney et al., 1997; Papachristou et al., 2014).

A rich body of work has evaluated cue reactivity in alcohol, tobacco, opioid, and cocaine use (see meta-analysis in Carter and Tiffany, 1999). Only more recently has cue reactivity research examined cannabis-related cues using experimental laboratory methods (Filbey and DeWitt, 2012; Norberg et al., 2016). Some of these studies have highlighted the salience of cannabis stimuli by documenting a cannabis-cue attentional bias that is related to an individual's cannabis use history (Alcorn et al., 2019; Vujanovic et al., 2016). Other studies have demonstrated increases in subjective craving, cannabis valuation, and physiological arousal following exposure to cannabis stimuli of a varied nature (e.g., visual stimuli, cannabis-related paraphernalia, unlit and lit cannabis cigarettes) (Gray et al., 2011; Henry et al., 2014; McRae-Clark et al., 2011; Metrik et al., 2016; Schacht et al., 2009). Meta-analytic summaries of this work present a similar conclusion that cannabis-related cues elicit moderate effect size increases in subjective craving and

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arousal in populations reporting regular cannabis use (Norberg et al., 2016).

The specific impact that cannabis-related cues may have on subsequent decision-making processes and choice behavior remains unclear from existing work. Broadly speaking, research in alcohol, cigarette, and cocaine use suggests that explicit choice for substance-related cues in a concurrent setting is associated with substance use frequency and severity (Hardy and Hogarth, 2017; Hardy et al., 2018; Hogarth and Chase, 2011, 2012; Miele et al., 2018; Moeller et al., 2013, 2009). Moeller et al. (Moeller et al., 2013, 2009), for example, have demonstrated that when participants are presented with a concurrent choice between a cocaine and non-drug image, individuals with cocaine use disorder choose to view more cocaine images than controls and that the percentage of image choice is associated with cocaine use frequency and severity (see review in Moeller and Stoops, 2015).

The impact of drug-related cues on decision-making may extend beyond the drug-taking event and influence choices for other reinforcers presented in the context of those cues. A recent study determined how cocaine cues may influence decisions between concurrently presented non-drug reinforcers (Strickland et al., 2018). Participants in that study completed a novel cued concurrent choice task in which choice for monetary reinforcers was evaluated in the presence of spatially contiguous cocaine and matched neutral stimuli. A significant and robust bias was observed for reinforcers contiguous with cocaine cues. This bias was selective to individuals with a cocaine use history, specific to trials involving cocaine cues, and positively associated with substance use severity. A major conceptual and procedural difference of this procedure from previous work is that prior studies focused on direct selections for drug stimuli. In contrast, this cued concurrent choice task evaluated the impact a drug stimulus may have on contextually associated choices for non-drug reinforcers (e.g., money). Observation of a preference then indicates that a drug cue can bias decision-making towards spatially contiguous choices beyond the reinforcing effects of drugs.

The current study sought to extend this finding to determine the contribution of cannabis-related cues to concurrent reinforcer choice. Participants with and without cannabis use histories completed a cued concurrent choice task to evaluate the influence of cannabis-related cues on decision-making involving concurrent monetary reinforcers. Demographic and substance use variables, including behavioral economic measures of cannabis use, were also collected to evaluate putative individual differences. It was predicted that a significant cannabis-cue choice bias would be observed. It was also predicted that bias would be related to cannabis use history and would positively associate with cannabis use frequency and severity measures.

2. Material and methods

2.1. Participants and screening

Participants were sampled using the crowdsourcing website Amazon Mechanical Turk (mTurk). Crowdsourcing provides an effective and efficient means of recruiting research participants in behavioral and addiction science, with prior research demonstrating the validity of data collected using these sources (see reviews in Chandler and Shapiro, 2016; Strickland and Stoops, 2019). Participants were required to have a 95% or higher approval rating on all previously submitted mTurk tasks, over 100 approved tasks, and current residence in the United States to view the screener. This screener was included to determine eligibility. Inclusion criteria for the *cannabis history group* were cannabis use in the past two weeks and 50 or more lifetime uses (n = 78). Inclusion criteria for the *control group* were no cannabis use in the past two weeks and 5 or fewer lifetime uses (n = 86). All participants were required to be 18 or older. Participants provided informed consent and the University of Kentucky Institutional Review Board approved the protocol.

2.2. Measures

2.2.1. Cued concurrent choice task

The effects of cannabis-related cues on concurrent choice was evaluated using a cued concurrent choice task (Strickland et al., 2018). This task consisted of a series of trials in which concurrent choice was evaluated between two monetary values (e.g., $0.10 versus $0.05). Each concurrent choice was immediately preceded by two visual stimuli presented side-by-side. On *cannabis trials*, one image was cannabis-related and the other a paired neutral image. Cannabis-related images contained cannabis plant, product (e.g., joints), and/or paraphernalia and were selected from a prior study on cannabis attentional bias (Alcorn et al., 2019). Paired neutral images were chosen to match the number of objects, color, and size of cannabis images. On *neutral filler trials*, both images were unrelated to cannabis or cannabis paraphernalia (e.g., furniture pieces). All trials began with a fixation point presented for 1000 ms in the center of the screen. The two visual stimuli then replaced the fixation point and were displayed for 2000 ms. Finally, a monetary value appeared below each image and participants were instructed to select the monetary reinforcer they would want to receive.

Participants completed 10 practice trials followed by 72 experimental trials (48 *cannabis trials* and 24 *neutral filler trials*). Monetary values were $0.05, $0.10, and $0.25 selected for correspondence to common US denominations. Equal value trials were the trials of interest and presented the same monetary values on the cannabis- and neutral-cued side (e.g., $0.05 on cannabis and $0.05 on neutral) and were oversampled (i.e., half of all trials). The location of cannabis and neutral images was randomized across trials and trial type was also randomized. Participants were told to respond carefully because study payments would be selected from random trials. In actuality, all participants received $2.55 to provide standardized payments estimated on recommendations of per hour compensation for crowdsourcing platforms (median study completion time 24 min = $6.38/hour) (see Chandler and Shapiro, 2016).

The primary outcome was percent choices for cannabis-cued values (cannabis-cued/[cannabis-cued + paired neutral-cued choices] * 100). Side bias was evaluated on the neutral filler trials as percent choices for left-cued values.

2.2.2. Behavioral economic measures

Participants completed behavioral economic demand and delay discounting tasks relevant to cannabis and other substance use as a part of the study survey. Portions of these data were previously presented in a secondary analysis evaluating the unique contribution of demand and discounting to cannabis use behaviors (Strickland et al., 2017).

Behavioral economic demand was evaluated for cannabis, alcohol, and chocolate using commodity purchase tasks (Aston et al., 2015; Murphy and MacKillop, 2006; Strickland and Stoops, 2017). A standard instructional vignette was provided in which participants were instructed to consume all purchases in a single day, told that they could not stockpile or get the commodity from another source, and had no commodity available from previous days. The commodities available for each task were one hit of cannabis (0.09 g or 1/10th of a 0.9 g size joint), one standard US drink, or one Hershey's Kisses® chocolate piece (or equivalent size chocolate candy). Consumption was evaluated across 13 monetary increments consisting of $0.00 [free], $0.01, $0.05, $0.13, $0.25, $0.50, $1, $2, $3, $4, $5, $6, $11/unit. Participants only completed tasks relevant to self-reported use behaviors (e.g., individuals not reporting weekly chocolate consumption did not complete the chocolate purchase task). Curves were also evaluated for systematic data using standardized criteria (Stein et al., 2015).

Data from commodity purchase tasks were analyzed using the exponentiated demand equation (Koffarnus et al., 2015):

$$Q = Q_0 * 10^{k*}(e^{(-\alpha * Q_0 * C)} - 1)$$

where Q = consumption; Q_0 = derived demand intensity; k = a constant related to consumption range (*a priori* set to 2); C = commodity price; and α = derived demand elasticity. Demand intensity refers to a theoretical consumption of a commodity at a unit price of zero. Demand elasticity refers to the sensitivity of consumption to changes in price. Analyses focused on demand intensity and elasticity given that research has demonstrated these measures reflect a two-factor structure underlying purchase task data (Aston et al., 2017; Bidwell et al., 2012; Epstein et al., 2018; Mackillop et al., 2009). Intensity and elasticity were log-transformed to achieve normality.

Delay discounting rates (k values) for money and cannabis were determined using a 5-trial adjusting delay task (Koffarnus and Bickel, 2014). Participants made five choices between an immediate, smaller reinforcer ($500/half ounce of cannabis) and a delayed, larger reinforcer ($1000/ounce of cannabis delayed) at delays that titrated up or down based on prior selections. Only participants in the cannabis group completed the cannabis discounting task. This task was selected for its validation against longer test forms (Cox and Dallery, 2016; Koffarnus and Bickel, 2014) and its utility for a brief online setting (Stein et al., 2017; Strickland et al., 2017). Delay discounting rates were log-transformed to achieve normality.

2.2.3. Substance use history

Use frequency and severity measures were collected for alcohol, cigarette, and cannabis use. A written version of the Mini-International Neuropsychiatric Interview (MINI) was used to evaluate *DSM-IV* criteria for cannabis abuse and dependence (Sheehan et al., 1998). No other items from the MINI were included. *DSM-IV* criteria were used because at the time of data collection a validated and brief written questionnaire for *DSM-5* criteria was not available.

2.3. Data analysis

Data for participants failing one or more consistency checks were removed from analysis. These checks included 1) recall of a single digit number that participants were instructed to remember, 2) comparison of age and sex across the survey, 3) an item that instructed participants to select a particular response, and 4) an item that asked if participants had been attentive. This resulted in a final analyzed sample size of 71 (91.0% of those recruited) in the cannabis group and 79 (91.9% of those recruited) in the control group. Sensitivity analyses indicated that inclusion of participants who failed these checks (i.e., a more liberal approach) and exclusion of participants who did not pass checks on other tasks not included in the current analysis (i.e., a more conservative approach) did not change the primary findings (see Supplemental Materials).

Demographic and substance use variables were compared between groups using independent samples t-tests or Fisher's exact test. Percent cannabis-cued choice on critical trials was compared between groups using an independent-samples t-test. This test was planned *a priori* and further justified by a significant interaction between Group and Reinforcer Difference in a mixed factor ANOVA. Follow-up one-sample t-tests compared choice on critical values to indifference (50%) within each group. Side bias was evaluated on neutral filler trials as percent left-side choice. Median reaction times on critical trials were compared by Group and Trial Type using mixed factor ANOVA. Predictors of cannabis-cued choice in the cannabis group were evaluated using bivariate correlations. SPSS Statistics (IBM; Armonk, NY) was used for analyses and inferential tests were two tailed with an alpha rate of .05.

3. Results

3.1. Demographics and substance use history

Demographic and substance use variables for the cannabis history and control groups are presented in Table 1. Comparisons between groups revealed significantly higher rates of daily tobacco cigarette use in the cannabis history compared to control group. Other demographic variables did not differ by group. Delay discounting rates for delayed monetary reinforcers were similar between groups. Behavioral economic demand for alcohol and chocolate reinforcers also did not differ between groups.

Table 1
Demographic and cannabis use history.

	Cannabis (n = 71)		Control (n = 79)		
	Mean	SD	Mean	SD	p
Demographics					
Age	30.5	7.8	33.0	9.6	.08
Female	50.7%		58.2%		.41
White	74.7%		74.7%		.99
College Education	50.7%		64.6%		.10
Income (USD)	41,000	29,000	43,000	29,000	.57
Daily Cigarette Use	60.6%		15.2%		.001
Cigarettes/Day	12.0	7.4	15.4	10.8	.15
Cannabis Use					
Lifetime Uses	5261.1	20149.6	0.8	1.6	< .001
Past Month Use Days	18.2	1.5	–	–	–
Grams/Week	6.1	6.9	–	–	–
Cannabis Use Disorder	45.1%		–		–
Behavioral Economic					
k Money	−2.26	0.73	−2.31	0.65	.71
k Cannabis	−1.41	1.00	–	–	–
Q_0 Cannabis[a]	1.36	0.41	–	–	–
α Cannabis[a]	−1.85	0.56	–	–	–
Q_0 Chocolate[a]	1.01	0.40	1.03	0.45	.84
α Chocolate[a]	−1.12	0.55	−1.18	0.59	.42
Q_0 Alcohol[a]	0.65	0.38	0.64	0.35	.81
α Alcohol[a]	−1.80	0.60	−1.89	0.45	.60

Note. k = delay discounting rate; Q_0 = demand intensity; α = demand elasticity. All behavioral economic variables presented in the log transformed value. Cannabis use disorder refers to meeting DSM-IV abuse or dependence criteria according to a written version of the Mini-International Neuropsychiatric Interview (MINI).

[a] Demand measures only completed by participants with self-reported use behavior of commodity and only analyzed for individuals providing systematic data (Cannabis Group = 64 cannabis, 55 chocolate, and 56 alcohol; Control Group = 64 chocolate, 43 alcohol).

3.2. Cannabis-cued choice bias

Fig. 1 displays percent choice for cannabis-cued monetary values in the cannabis history and control groups (top panel). Comparisons at equal value trials showed a significant and large effect size difference, $t_{148} = 11.02$, $p < .001$, $d = 1.80$. Within-group comparisons to indifference (50% cannabis-cued choice) revealed a bias towards cannabis-cued monetary values in the cannabis group (mean cannabis-cued choice = 76.0%), $t_{70} = 8.73$, $p < .001$, $d = 1.04$, and a bias towards neutral-cued monetary values in the control group (mean cannabis-cued choice = 30.3%), $t_{78} = 6.85$, $p < .001$, $d = 0.77$. Analysis of other difference values indicated that the cannabis group chose the cannabis-cued value more often when disadvantageous compared to the control group (p values < .001; see Fig. 1 for effect size estimates). Cannabis-cued values were also more often selected on advantageous trials, although this effect was of a smaller effect size (p values .02 to .03; Fig. 1).

Fig. 1 also displays percent choice for the left-side monetary values on neutral-neutral filler trials by group (bottom panel). Comparisons at equal value showed no difference between groups, $t_{148} = 0.32$, $p = .75$, $d = 0.05$. Within-group comparisons indicated no difference from 50% in the cannabis group (51.4%), $t_{70} = 0.52$, $p = .60$, $d = 0.06$, or in the control group (50.3%), $t_{78} = 0.12$, $p = .91$, $d = 0.01$.

Fig. 2 presents reaction times by group and trial type. Significantly faster reaction times were observed on cannabis compared to neutral

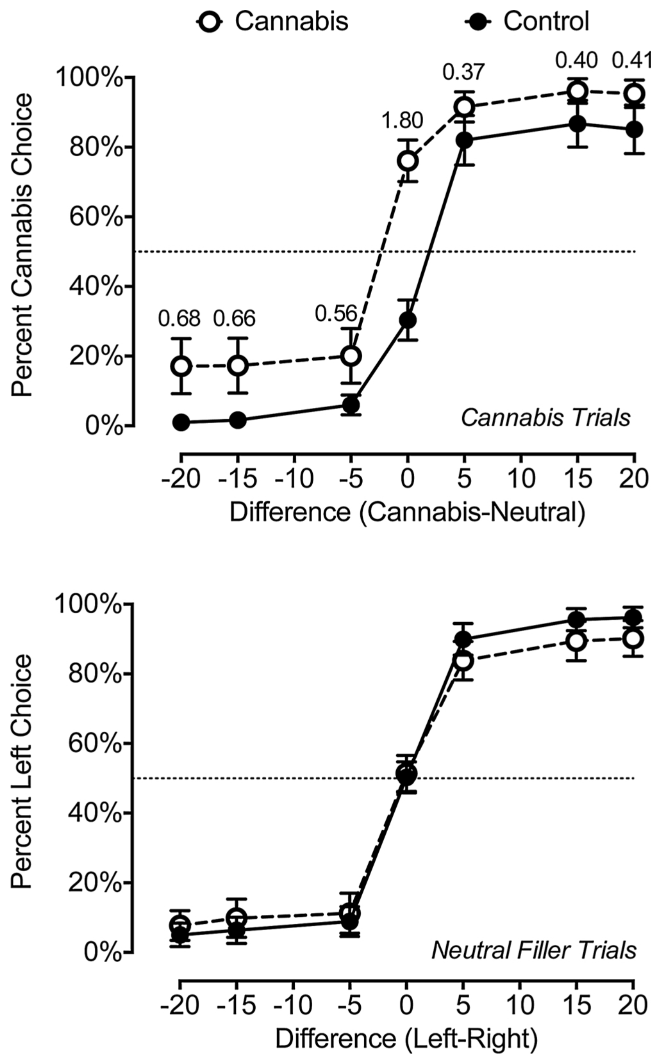

Fig. 1. Cued concurrent choice task performance. Individuals with (open circle; dotted line) and without (solid circle; solid line) a cannabis use history completed a cued concurrent choice task for monetary reinforcers. Presented are mean percent choices for cannabis-cued monetary value across each quantitative difference in cannabis and neutral-cued values (top panel). Also presented are mean percent left-side choice on neutral filler trials (bottom panel). Values in the top panel are effect size estimates for differences between groups (Cohen's *d*). The y-axis dotted line represents indifference (50%). Equal value trials occurred at 0 (x-axis), in which cannabis-cued and neutral-cued values were equal. Error bars represent 95% confidence intervals.

filler trials, main effect of Trial Type, $F_{1,148} = 25.685$, $p < .001$, $\eta_p^2 = 0.15$. This effect did not differ by group nor were overall reaction times different by group as indicated by a non-significant Group x Trial Type interaction, $p = .40$, and non-significant main effect of Group, $p = .63$.

3.3. Correlates of cannabis-cued choice bias

Correlations and significance values for the association between choice bias and individual difference variables are presented in Table 2. Cannabis-cued choice bias was significantly associated with more past month cannabis use days. Greater choice bias was also significantly associated with higher cannabis demand intensity and lower cannabis demand elasticity. Choice bias was not related to chocolate or alcohol demand or delay discounting rates.

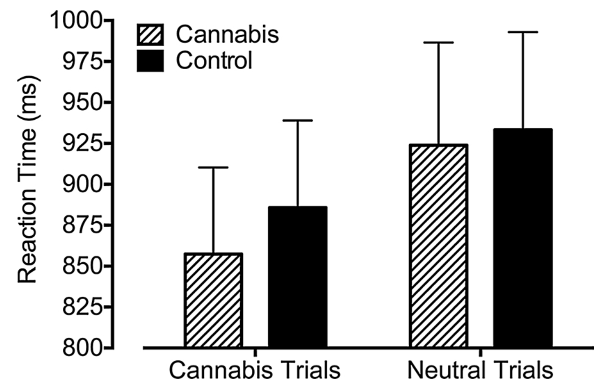

Fig. 2. Cued concurrent choice task reaction times. Presented are group mean values for the median reaction times on equal value trials for individuals with (crossed bar) and without (solid bar) a cannabis use history. Error bars represent 95% confidence intervals.

Table 2
Individual predictors of cannabis-cued choice bias.

	Cannabis-Cued Choice Bias
Demographics	
Age	−.02
Female	−.04
White	−.05
College Education	.02
Income	.04
Daily Cigarette Use	.01
Cigarettes/Day	.08
Cannabis Use	
Lifetime Uses	.07
Past Month Use Days	.44***
Grams/Week	.17
Cannabis Use Disorder	.15
Behavioral Economic	
k Money	.09
k Cannabis	−.10
Q_0 Cannabis[a]	.28*
α Cannabis[a]	−.30*
Q_0 Chocolate[a]	.00
α Chocolate[a]	−.01
Q_0 Alcohol[a]	−.02
α Alcohol[a]	−.14

Note. k = delay discounting rate; Q_0 = demand intensity; α = demand elasticity.
[a] Demand measures only completed by participants with self-reported use behavior of commodity and only analyzed for individuals providing systematic data (64 cannabis, 55 chocolate, and 56 alcohol).
* $p < .05$.
*** $p < .001$.

4. Discussion

The purpose of this study was to determine the contribution of cannabis-related cues to concurrent reinforcer choice. A robust and large effect size preference for cannabis-cued selections was observed that was specific to an individual's cannabis use history. These between-group differences in cannabis-cued selections were unlikely due to differential attention to the task given that reaction times did not vary as a function of cannabis use history. This primary finding of a cannabis-cued bias that was specific to pharmacological history is consistent with significant cocaine-cued choice bias previously reported (Strickland et al., 2018).

Prior cue reactivity research in cannabis use has focused on evaluating attentional bias, subjective craving, and autonomic arousal during and following cue presentation (Filbey and DeWitt, 2012; Norberg et al., 2016). The current study indicates that cue exposure may also have an impact on decision-making in the co-occurring environment. In this regard, reinforcers presented with a contiguous cannabis cue showed a greater likelihood of selection by the cannabis using group, both when the value of the primary reinforcer was equal (i.e., equal value trials) as well as on trials when that response option was of lower value (i.e., disadvantageous). Relatively optimal performance on neutral filler trials that was similar between groups further establishes a specificity for this bias indicating that it is unlikely attributable to a more global impairment in rational decision-making. Cue reactivity research in the animal laboratory has also described similar effects wherein cues alter sensitivity to primary reinforcer value in a way that translates into disadvantageous decision-making (Chow et al., 2017; Smith et al., 2018; Zentall, 2014). For example, animal subjects presented with concurrent reinforcer choice tend to prefer choices that result in stronger conditioned reinforcers even when these choices are suboptimal (i.e., produce lower overall rates of primary reinforcement) (Zentall, 2014). A possible implication of these outcomes that future clinical research should test is whether biased decision-making relates to choices to engage in high-risk activities that were otherwise undesirable without the addition of a salient and motivationally relevant drug cue.

It is relevant to note that individuals without a history of cannabis use did not exhibit indifference on cannabis trials, but instead showed a bias against the cannabis-cued choices that was similar in magnitude, but opposite in direction, to the cannabis using group's bias. This finding is consistent with the results of the previous cocaine study in which a control group without a history of cocaine use showed a similar sized magnitude bias against cocaine-cued selections on cocaine trials (mean cocaine-cued choice = 33.5%) (Strickland et al., 2018). It is possible that this response pattern represents a conditioned cue effect even if it is not attributable to direct pharmacological experience with cannabis. Specifically, cannabis images and cannabis paraphernalia could have previously been presented in the context of undesirable outcomes, such as illicit behavior and negative health consequences, within mass media or educational settings. Such associative pairings in the control group could explain the lower responses for cannabis-cued images observed here through mechanisms such as discriminative signaling of punishment or conditioned aversion. This explanation is exploratory in nature, however, and future studies would benefit from additional within-laboratory conditioning or experimental conditions to test such hypotheses.

Individual differences in cannabis use frequency and valuation were also associated with cannabis-cued bias. Participants reporting more frequent cannabis use and more intense and inelastic cannabis demand showed a greater bias towards cannabis-cued selections. These associations between choice bias and clinical measures of substance use are consistent with the observation that performance on concurrent cue tasks relates to substance use frequency and severity in alcohol, cigarette, and cocaine use (Hardy and Hogarth, 2017; Hardy et al., 2018; Hogarth and Chase, 2011, 2012; Miele et al., 2018; Moeller et al., 2013, 2009). More specifically, these findings are similar to a prior study documenting a relationship between tobacco cigarette demand and concurrent choice for tobacco-related reinforcers (Chase et al., 2013). These studies collectively provide evidence that cued concurrent choice tasks can provide a clinically relevant and efficient behavioral measure indexing the influence of drug-related stimuli on decision-making processes.

Several research lines have provided evidence for a relationship between attention and reinforcer choice (i.e., attention-choice links). For example, food reinforcers presented for longer (900 ms) compared to shorter (300 ms) cue durations are selected 7–11% more (Armel et al., 2008). Similar relevance for attentional bias to drug reinforcers has been observed with one study demonstrating that approximately 30% of reductions in alcohol selection in an alcohol-soda choice task following alcohol devaluation were mediated by reductions in attentional bias (Rose et al., 2013; also see Rose et al., 2018 for a replication, albeit with a smaller effect size of 18%). We previously documented a modest role for cocaine cue attentional bias using this concurrent choice task wherein final fixation location, but not overall fixation time, was correlated with cocaine choice bias (Strickland et al., 2018). Functionally, attention-choice links appear to be, in part, related to value integration processing and an interactive effect with the value of the attended-to-stimulus (e.g., Krajbich et al., 2010; Smith and Krajbich, 2019). Future work would benefit from additional measures of attentional bias to further establish these links.

Other limitations and implications for future directions should be considered. First, crowdsourcing methods were used that precluded biological verification of cannabis use. Offsetting this concern is prior research demonstrating a correspondence between findings obtained via crowdsourcing samples and laboratory samples in behavioral and addiction science (see reviews in Chandler and Shapiro, 2016; Strickland and Stoops, 2019). This body of work has also found that participants report greater comfort sharing sensitive information, such as substance use, through online platforms (Kim and Hodgins, 2017; Strickland and Stoops, 2018a,b). Similarly, the use of crowdsourcing resulted in some demographic features that differed from nationally representative sources. For example, the 2016 National Survey on Drug Use and Health indicated that the demographics of individuals reporting past month cannabis use were 38.2% female, 64.8% White, 22.3% with a bachelor's degree or greater, and 56.9% with an income 200% or greater than the poverty level (200% in 2016 = $23,760-$48,600 for a family of 1–4) (Center for Behavioral Health Statistics and Quality, 2017). The differences in demographics between our sample and nationally representative data are consistent with the general mTurk population, which tends to include more White participants with higher levels of education (Chandler and Shapiro, 2016). It is noteworthy that these deviations were not large, particularly in the case of income, and that some kind of deviation is inherent to convenience sampling whether conducted online or in the research laboratory or clinic.

Second, cannabis use disorder was not significantly associated with choice, which is not consistent with prior work. It is possible that this discrepancy is due to the reliance on a single severity measure (i.e., *DSM-IV* criteria) and use of other measures indexing alternative aspects of use severity could have revealed different outcomes (e.g., CUDIT). Supporting this hypothesis is the observation that studies that have demonstrated an association between severity and similar choice biases used a variety of severity measures besides DSM criteria (e.g., Hogarth and Chase, 2011; Hardy and Hogarth, 2017; Strickland et al., 2018). Third, approximately 9% of participants were excluded for failing embedded consistency checks. Although no systematic synthesis of such rates for online research exists, they are within a reasonable range of other studies in addiction science with varying rates from as low as 0% to upwards of 20% (e.g., 19.8% Johnson et al., 2015; 10.1% Mellis et al., 2017; 3.9% Strickland and Stoops, 2018a,b; 2.5% Huhn et al., 2018; 0% Morris et al., 2018). Sensitivity analyses further demonstrated that these participants removal did not change significance or interpretation of the primary results.

Fourth, groups were not matched for demographics resulting in differences in tobacco cigarette use between groups. Correlational analyses indicated that cigarette use did not associate with choice bias suggesting that it did not contribute to the bias observed. Finally, measures of arousal or craving related to the images were not collected, although faster reaction times on cannabis-cued trials were suggestive of the salience of these images. A previous study using these same images also demonstrated a cannabis-cue attentional bias and ratings of positive valence among individuals with biologically verified cannabis use (Alcorn et al., 2019). Future research would nevertheless benefit from measures of stimulus valence to test mediational pathways relating differences in subjective ratings and choice bias.

5. Conclusion

The current study provides evidence of the influence of cannabis-related cues on concurrent choice for non-drug reinforcers. This extension of concurrent choice and cue reactivity research to cannabis use is important given the potential for an increasing prevalence and salience of cannabis-related cues in everyday life with the continued introduction of medicinal and recreational cannabis laws across the United States and internationally. More specifically, passive environmental exposure to cannabis-related stimuli is likely to increase in the wake of these laws through means such as cannabis advertising, acceptance of cannabis use in popular culture and social media, and visual and olfactory cues from public use (D'Amico et al., 2018; Krauss et al., 2017a, b). Continued research evaluating the influence of drug-related cues on choice and decision-making will prove critical in light of these and other changes in the cannabis use landscape.

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Contributors

J.C. Strickland and W.W. Stoops developed the study concept. Data were collected by J.C. Strickland. J.C. Strickland conducted data analysis with guidance on interpretation provided by W.W. Stoops and J.A. Lile. J.C. Strickland drafted the initial manuscript with critical feedback from W.W. Stoops and J.A. Lile. All authors approved the final version of the manuscript for submission.

Conflict of interest

No conflicts declared.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.drugalcdep.2019.02.022.

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