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Differential Sensitivity to Learning from Positive and Negative Outcomes in Cocaine Users

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Abstract

Background—Altered sensitivity to positive and negative outcomes may be linked to the maladaptive choices characteristic of substance use disorders. Few studies have determined the distinct roles that positive and negative outcomes play in stimulus-response learning in cocaine users. The purpose of the present study was to investigate sensitivity to learning from positive and negative outcomes on a probabilistic learning task in cocaine users employing human laboratory and crowdsourcing techniques.

Methods—Individuals who reported cocaine use were recruited for a laboratory study (Experiment 1) or an online study on [Amazon.com](https://www.amazon.com)'s Mechanical Turk (mTurk) (Experiment 2). All participants completed a feedback-based probabilistic learning task in which images were classified into categories (A versus B). Positive and negative outcomes were provided in a probabilistic manner on separate trials. Proportion of optimal responses and response times were recorded.

Results—Active cocaine users were less sensitive to learning from positive relative to negative outcomes. These effects were consistent across image type and session in the laboratory sample.

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Author Disclosure Statements

Conflict of interest

The authors have no financial conflicts of interest in regard to this research.

Contributors

J.C. Strickland and W.W. Stoops developed the study concept and data collection measures. Data were collected by J.C. Strickland. J.C. Strickland and B.L. Bolin performed the data analysis and interpretation under the guidance of W.W. Stoops. J.C. Strickland drafted the initial manuscript and all authors provided critical reviews. All authors approved the final version of the manuscript for submission.

Similarly, reduced sensitivity to learning from positive outcomes was observed in cocaine users on mTurk. Control participants did not show suboptimal performance following positive or negative outcomes.

Conclusions—This study extends the limited research on feedback-based learning in drug users by demonstrating reduced sensitivity to positive outcomes in cocaine users recruited in the human laboratory and online. Future studies on the clinical significance and mechanisms underlying this bias are needed to understand its relevance as a target for intervention development.

Keywords

bias; decision-making; drug; Internet; mTurk; probabilistic learning

1. INTRODUCTION

Associative, stimulus-response learning contributes to drug-taking behavior (Di Chiara, 1999; Everitt and Robbins, 2005). A critical component of stimulus-response learning is the type of event (i.e., positive or negative) used to maintain behavior. Distorted sensitivity to positive and negative outcomes can contribute to maladaptive choice and is an underlying theme of past and present diagnostic criteria for substance use disorders (American Psychiatric Association, 2000; 2013). For example, decreased sensitivity to positive outcomes may lead to the devaluation of non-drug reinforcers in the environment, resulting in the allocation of behavior away from prosocial alternatives (e.g., interpersonal relationships). Conversely, decreased sensitivity to negative outcomes may render the negative consequences of drug use (e.g., losing friends) ineffective for decreasing drug-seeking behavior.

Many neuropsychological measures used in addiction research are limited in their capacity to dissociate the relative influence of positive and negative outcomes on learning. For example, in the Iowa Gambling Task, participants learn to select cards from four decks based on simultaneous gains and losses associated with each deck (Bechara et al., 1994). Repeated testing using these measures is problematic given that practice effects are observed once the correct strategy to optimize performance has been learned. An alternative to these measures is the feedback-based probabilistic learning task (Bodi et al., 2009). In this task, positive and negative outcome trials, also referred to as “reward/reinforcement” and “punishment” trials, are intermixed to determine the relative sensitivity to these consequences. During positive outcome trials, correct responses are reinforced by point gain, whereas in negative outcome trials incorrect responses are punished by point loss. The alternative response in each trial (i.e., an incorrect response on a positive outcome trial or correct response on a negative outcome trial) has no programmed consequence.

The feedback-based probabilistic learning task has previously been used to evaluate changes in learning that may underlie degenerative and psychiatric conditions, including Parkinson’s disease, post-traumatic stress disorder, schizophrenia, opioid use disorder and major depressive disorder (Bodi et al., 2009; Herzallah et al., 2013; Myers et al., 2013, 2016; Somlai et al., 2011). Non-medicated Parkinson’s patients show a decreased sensitivity to positive, but not negative, outcomes relative to controls (Bodi et al., 2009; Piray et al., 2014).

This impairment is reversed following treatment with dopaminergic drugs, which suggests that decrements in learning from positive outcomes may be associated with alterations in dopaminergic signaling. In individuals with schizophrenia, another condition characterized by alterations in dopaminergic tone, more severe negative symptoms are associated with decreased performance on positive outcome trials (Somlai et al., 2011). These findings suggest that altered performance may reflect the underlying pathology, specifically changes in dopaminergic functioning, in these respective conditions.

Investigating differences in learning from positive and negative outcomes in cocaine users is grounded in the hypothesized neurobiological and behavioral consequences of chronic cocaine use. Chronic use results in the downregulation of dopamine D₂ receptors and a hypodopaminergic state that together result in decreased sensitivity to reinforcement (Goldstein et al. 2010; Volkow et al., 1996). Dopaminergic signaling plays a critical role in basic learning processes, with preclinical evidence suggesting a preferential function for dopamine activation in learning from positive feedback (e.g., Beninger, 1983; Stolyarova et al., 2014). Cocaine users display impairments in probabilistic categorical learning compared to controls and alcohol/marijuana users (Vadhan et al., 2014). However, such impairments have not been consistently observed (Lane et al., 2014; Vadhan et al., 2008) and these prior studies have not dissociated the influence of positive and negative outcomes.

The overall purpose of the present study was to evaluate learning from positive and negative outcomes in cocaine users. In Experiment 1, a sample of cocaine users was recruited for a laboratory study in which probabilistic learning from positive and negative outcomes was measured. Participants completed two variations of the probabilistic learning task in which categorized stimuli were either abstract or cocaine-related. Each task variation was completed during two separate laboratory visits to determine whether performance was stable over time and to detect potential practice effects. In Experiment 2, a sample of individuals with and without a history of self-reported cocaine use was recruited using online crowdsourcing techniques. The goals of Experiment 2 included investigating the specificity of outcomes from Experiment 1 and comparing findings from laboratory and online samples.

2. METHODS AND MATERIALS: EXPERIMENT 1

2.1 Participants

Participants (n = 21) were recruited during screening for studies conducted at the University of Kentucky. All participants reported recent cocaine use verified with a benzoylecgonine positive urine specimen. Participants with a current prescription for a centrally acting medication or dependence on any drug that could produce significant withdrawal symptoms (e.g., alcohol, opioids, benzodiazepines) were excluded. Screening procedures have been described in detail elsewhere (e.g., Stoops et al., 2010). Briefly, participants completed a battery of questionnaires, including a self-reported drug use history and the sensation-seeking and impulsivity subscales of the Zuckerman-Kuhlman Personality Questionnaire (ZKPQ; Zuckerman et al., 1993). All participants met diagnostic criteria for cocaine abuse or dependence according to a computerized version of the Structured Clinical Interview for

the DSM-IV-TR (American Psychiatric Association, 2000). Participants gave sober, written informed consent prior to their enrollment.

2.2 Procedures

Participants completed two test sessions separated by 2 to 13 days. One participant did not return for Session 2 and was not included in data analysis. Participants had to pass a field sobriety test and provide an expired air specimen that was negative for alcohol. The University of Kentucky Institutional Review Board (IRB) approved the protocol and the informed consent document.

2.3 Probabilistic Learning Task

Participants completed a feedback-based probabilistic learning task administered using Eprime software (Psychology Software Tools, Pittsburgh, PA) on a PC computer (Bodi et al. 2009; Figure 1). During each trial, participants viewed one of four images and were asked to indicate whether an image belonged to Category A or B. Two images (one image for positive outcome trials, one image for negative outcome trials) belonged to Category A with 80% probability and the other two images belonged to Category B with 80% probability. During a positive outcome trial, if a participant selected correctly, 25 points were awarded and positive visual feedback provided (i.e., a smiling face); if the participant selected the image category incorrectly, there was no scheduled consequence. During a negative outcome trial, if a participant selected incorrectly, 25 points were deducted and negative visual feedback provided (i.e., a frowning face); if the participant selected the image category correctly, there was no scheduled consequence.

Participants first completed four practice trials during which they were instructed to press specific keys to observe all possible outcomes. After completing the practice trials, participants received 500 points and were told that the goal of the task was to win as many points as possible. The task consisted of 160 trials. The primary dependent measures were the proportion of optimal response (i.e., the choice most often associated with a correct response) and response time.

Two variations of the probabilistic learning task were used. In the first version, abstract images were presented similar to previous studies (Bodi et al., 2009). In the second version, cocaine-related images were used. Cocaine-related stimuli were images of the drug (e.g., crack rocks) and/or drug paraphernalia (e.g., crack pipes) and were selected from a set of images used in other cognitive-behavioral tasks in our laboratory (Strickland et al., in press). Half of the images depicted smoked cocaine and half of the images depicted intranasal cocaine. The order of completion for the two tasks was randomized across participants. All images were randomly assigned to feedback conditions for each participant and unique images were used in each session. Each participant completed both task variations during each of the two separate laboratory visits.

2.4 Data Analysis

Statistical analyses were performed in SPSS Statistics version 22 (IBM Corporation, Armonk, NY) with a type I error rate of .05. Proportion optimal choice and response time

were analyzed using separate $2 \times 2 \times 2 \times 2$ repeated-measures analyses of variance (ANOVAs) with Outcome (Positive versus Negative), Session (Session 1 versus Session 2), Stimulus Type (Abstract versus Cocaine-Related), and Task Order (Cocaine versus Abstract First) as within-subjects factors. Models not including Task Order were also examined given the possibility for model over-parameterization. The correlation between proportion optimal choice and response time on positive and negative trials was analyzed using Pearson bivariate correlations. The relationships between impulsivity and sensation-seeking scores from the ZKPQ and task performance were also assessed using bivariate correlations. Effect sizes were calculated as Cohen's d for repeated measures (d_z) or partial eta-squared (η_p^2) for ANOVA outcomes.

3. RESULTS: EXPERIMENT 1

3.1 Sample Characteristics

Demographic information and self-reported cocaine use are presented in Table 1. All participants reported past month cocaine use and provided a benzoylecgonine positive urine specimen during one (10%) or both (90%) sessions.

3.2 Probabilistic Learning Task

Figure 2 displays proportion optimal choice by Outcome and Stimulus Type for Session 1 (left) and Session 2 (right). A four-way repeated-measures ANOVA revealed a significant main effect of Outcome for proportion optimal choices, $F_{1, 18} = 12.11$, $p = .003$, $\eta_p^2 = .40$, indicating that participants made an overall greater proportion of optimal choices on negative than positive trials. No additional significant effects were observed and similar outcomes were observed in a simpler 3-factor model that did not include Task Order as a factor. Proportion of optimal choices for positive and negative outcomes was not correlated in either session or for either stimulus type, $r = -.15$ to $.03$. Self-reported sensation seeking and impulsivity on the ZKPQ were also not correlated with task performance for either Session or Stimulus Type. Effect-size estimates for Outcome across each Session and Stimulus Type indicated consistent, medium-sized effects ($d_z = 0.44$ to 0.61).

Figure 3 displays response time by Outcome and Stimulus Type for Session 1 (left) and Session 2 (right). The four-factor repeated measures ANOVA revealed significant main effects of Outcome, $F_{1, 18} = 11.16$, $p = .004$, $\eta_p^2 = .38$, and Session, $F_{1, 18} = 10.77$, $p = .004$, $\eta_p^2 = .37$. In general, response times were faster on positive than on negative trials and faster in Session 2 than in Session 1, reflecting the main effects of Outcome and Session, respectively. Additional significant interactions including Task Order were observed (Stimulus $\times$ Task Order; Session $\times$ Stimulus $\times$ Task Order). These interactions reflected a greater change in response time across sessions for the image class seen first by participants in their first session. Response times were also generally faster in the group presented with cocaine images first than the group presented with abstract images first. Similar significant effects were observed in the model that did not include Task Order as a factor. Response times for positive and negative trials were correlated in all tests, $r = .79$ to $.92$. Response times were not correlated with proportion optimal choice or sensation-seeking and impulsivity scores from the ZKPQ for either Session or Stimulus Type. Medium-sized

effects were obtained for Outcome across each Session and Stimulus Type ($d_z = 0.34$ to 0.56).

4. DISCUSSION: EXPERIMENT 1

Cocaine users showed decreased sensitivity to learning from positive outcomes relative to negative outcomes. Optimal choice on positive outcome trials did not deviate from chance (i.e., 50%), whereas optimal choice on negative outcome trials was well above chance performance. Faster response times were also observed on positive relative to negative outcome trials suggestive of an underlying conditioning process (see Section 8). These findings were consistent across test sessions and did not differ when the categorized stimuli were abstract or cocaine-related. Stability in performance was comparable to previous uses of the probabilistic learning task that have demonstrated modest test-retest reliability in healthy populations (Bodi et al., 2009).

To extend the findings of Experiment 1, we compared performance between individuals with and without a history of self-reported cocaine use in Experiment 2. [Amazon.com](https://www.amazon.com)'s Mechanical Turk (mTurk) was used to sample these groups. mTurk is an online crowdsourcing platform that has emerged as a popular alternative to in-person laboratory experiments and includes benefits such as cost-effectiveness and access to hard-to-reach populations. Initial research, including work in substance use, has supported the validity of online research by demonstrating close correspondence between findings obtained using online and traditional laboratory procedures (Johnson et al., 2015; Simons and Chabris, 2012). Considering the novelty of online research, further validation is needed to support its continued use. A second goal of Experiment 2 was to provide further validation of crowdsourcing techniques by demonstrating correspondence in performance between individuals with biologically verified cocaine use in the laboratory and self-reported cocaine use online.

5. METHODS AND MATERIALS: EXPERIMENT 2

5.1 Participants and Procedures

Experimental tasks, hosted on mTurk, were programmed using the QRTengine for Qualtrics (Qualtrics, Provo, UT), a previously validated method for collecting online response time data (Barnhoorn et al., 2015). Participants were required to (1) have an approval rating of 95% or higher on all previously submitted mTurk tasks, (2) have over 100 approved tasks, and (3) currently reside in the United States. Before completing the study task, participants reviewed an informed consent document describing the study procedures, compensation, and the fact that anonymity would be retained throughout the study. All participants indicated that they understood this document and agreed to participate via electronic confirmation. The University of Kentucky IRB approved all procedures.

Participants had to complete the study in one sitting and were informed that it would take approximately 1 to 30 minutes. A screening questionnaire that included questions about each participant's age, sex, and drug-use history was used to determine eligibility. All participants were required to be 18 years of age or older. In order to be included in the cocaine use

group, participants were required to report cocaine use within the past three months and more than five lifetime cocaine uses ($n = 21$). One participant in the cocaine group provided inconsistent responses about the frequency of his cocaine use and was not included in data analysis. Participants who did not endorse cocaine use in the past three months and had five or fewer lifetime uses were included in the control group ($n = 24$). Three control participants reported lifetime cocaine use, but fewer than five instances total (two participants had used once and one participant used three times). The study content was identical for these two groups except that the cocaine use group provided a cocaine-use history and completed a computerized version of the Mini-International Neuropsychiatric Interview (MINI) to determine the presence of cocaine abuse or dependence by endorsement of statements indicative of DSM-IV criteria (Sheehan et al., 1998). Participants who did not qualify were thanked for their time and compensated \$0.05 USD for completing the screening portion of the study. Participants who qualified for and completed any remaining portion of the survey were compensated \$1.55 USD. To ensure that participants remained engaged in the study tasks, attention checks were performed periodically throughout the study. All participants passed these attention checks.

5.2 Probabilistic Learning Task

Given the need to reduce burden for participants when using mTurk (e.g., longer tasks can result in higher dropout rates) and the non-significant effects of stimulus type and session on proportion of optimal choice in Experiment 1, we chose to have participants in Experiment 2 complete the task once and with abstract stimuli only. Otherwise, the procedures for the probabilistic learning task were identical to those used in Experiment 1.

5.3 Data Analysis

Proportion optimal choice and response time were analyzed using 2×2 mixed-factors analysis of covariance (ANCOVAs) with Outcome (Positive versus Negative) as the within-subjects factor and Group (Cocaine versus Control) as the between-subjects factor. Age, sex, education, smoking status, and race were included as covariates based on *a priori* predictions about factors potentially related to task performance and possible between-population differences. All covariates were incorporated into a single model to avoid repeated testing. A model not including covariates was also examined given the possibility for model over-parameterization. Post-hoc pairwise comparisons were conducted using Sidak's correction to control for multiple comparisons. Remaining analyses were identical to Experiment 1, except that bivariate correlations with sensation-seeking and impulsivity scores on the ZKPQ were not conducted.

6. RESULTS: EXPERIMENT 2

6.1 Sample Characteristics

Demographic and drug-use variables for the online samples are presented in Table 2. A majority of participants in the cocaine group reported past-month (85%) and past-week (65%) cocaine use and 70% met criteria for a cocaine abuse or dependence (20% and 50%, respectively). Cocaine-using and control participants did not differ on demographic variables including age, sex, and education. Although cocaine-using participants were more likely to

report cigarette smoking (Fisher's Exact Test, $p = .006$), the groups did not significantly differ in cigarettes per day or scores on the Fagerström Test for Nicotine Dependence (Heatherton et al., 1991).

6.2 Probabilistic Learning Task

Figure 4 (top) displays proportion optimal choice and effect sizes for cocaine (left) and control (right) groups. The mixed-factors ANCOVA revealed a significant Outcome $\times$ Group interaction, $F_{1, 37} = 4.58$, $p = .04$, $\eta_p^2 = .11$. Optimal choice for negative outcome trials was greater than for positive outcome trials in the cocaine-using group, $p < .05$, $d_z = 0.55$, but did not differ in the control group, $p > .05$, $d_z = 0.16$. This interaction was driven by a smaller proportion of optimal choices on positive outcome trials in the cocaine-using group relative to the control group, $p < .05$, $d = 0.62$. Performance on negative outcome trials did not differ between groups, $p > .05$, $d = 0.21$. Similar significant effects were observed in the model without these covariates. Optimal choice on positive and negative trials was not correlated in the cocaine-using group, $r = .05$, $p = .84$, but was robustly correlated in the control group, $r = .81$, $p < .001$. Optimal choice on positive and negative trials in the cocaine group was not associated with cocaine abuse or dependence symptoms.

Figure 4 (Bottom Panel) displays response time and effect sizes for each group. The mixed-factors ANCOVA revealed significant main effects of Outcome, $F_{1, 37} = 7.751$, $p = .008$, $\eta_p^2 = .17$, and Group, $F_{1, 42} = 5.85$, $p = .02$, $\eta_p^2 = .14$. In general, response time was faster on positive than on negative trials and faster in the control than cocaine-using group. Similar significant effects were observed in the model that did not include covariates. Response times on positive and negative trials were significantly correlated in the cocaine-using group, $r = .93$, $p < .001$, and in the control group, $r = .93$, $p < .001$. Response times in the cocaine group were not associated with cocaine abuse or dependence status. Response times were also not correlated with proportion optimal choice in the full data set or within groups.

7. DISCUSSION: EXPERIMENT 2

The results of Experiment 2 suggest that decreased learning from positive outcomes is specific to those with a history of cocaine use. Individuals with a history of self-reported cocaine use also responded in a way that was qualitatively similar to cocaine users in the laboratory sample from Experiment 1. Control participants did not show suboptimal performance, consistent with previous studies in healthy, non-clinical populations (e.g., Bodi et al., 2009; Herzallah et al., 2013; Piray et al., 2014; Somlai et al., 2011). These differences were observed after controlling for demographic factors indicating that this effect was likely not the result of other differences between these groups.

Crowdsourcing technology has recently gained popularity in the field of substance-use research (e.g., Koffarnus et al., 2015; Rass et al., 2015; Strickland and Stoops, 2015; Strickland et al., in press) and carries several benefits relative to laboratory research. For example, crowdsourcing allows for improved demographic and geographic variability in study samples, provides access to hard-to-reach populations, and is generally less expensive than laboratory-based studies. The current findings provide additional support for the use of

crowdsourcing technology in this clinical population by showing close correspondence between outcomes in laboratory and online samples. Performance on the probabilistic learning task was virtually indistinguishable between the laboratory and online samples despite the inability to biologically verify cocaine use in the participants recruited from mTurk. Although future studies are needed to further validate online research, the current findings suggest that crowdsourcing is a viable method for conducting basic cognitive-behavioral research with humans.

8. GENERAL DISCUSSION

The primary finding of the present study was that individuals with a history of cocaine use showed decreased sensitivity to learning from positive relative to negative outcomes. This effect was consistent across stimulus types (i.e., abstract versus cocaine-related) and repeated observations in a laboratory sample. Similar decrements in learning from positive outcomes were observed in an online sample of individuals with self-reported cocaine use, whereas control participants did not show suboptimal performance. Response times were also faster for positive than negative outcome trials in all groups suggestive of an underlying conditioning process. These findings provide insight into biased decision making that may contribute to the patterns of maladaptive choice that are characteristic of cocaine-use disorders, as discussed below.

That cocaine users were less sensitive to positive outcomes relative to controls is consistent with previous research demonstrating reduced probabilistic category learning in cocaine users (Vadhan et al., 2014). Participants in that study completed the Weather Prediction task, which combines learning from positive and negative outcomes, and therefore prevents the determination of the specific mechanism by which decreases in learning occurred. In contrast, the present study used a task in which learning from positive and negative outcomes is independently measured (Bodi et al., 2009). These findings indicate that performance decrements in cocaine users are related to learning from positive and not negative outcomes. In addition, the results of Experiment 1 revealed that decreases in learning from positive outcomes did not differ between abstract and cocaine-related images or across two test sessions, demonstrating the generalizability and consistency of this effect.

Faster response times on positive relative to negative trials were reliably observed across test sessions (Experiment 1) and samples (Experiment 1 and 2), which is concordant with previous findings with the probabilistic learning task in healthy populations (Mattfeld et al., 2011; Sheynin et al., 2013). That response times were faster on positive than negative trials is consistent with Pavlovian conditioning processes. Stimuli associated with positive outcomes could have acquired positive motivational salience, resulting in a conditioned approach towards those stimuli (i.e., faster response times). Conversely, stimuli that predicted negative outcomes might have produced conditioned avoidance in the form of slower responses. The magnitude of differences in response times was similar in the control and cocaine groups. These findings suggest that some forms of associative learning (e.g., Pavlovian conditioning processes) may remain unaffected in cocaine users despite a resistance to altering choice based on changing consequences in the environment.

Previous studies have also shown decreased learning from positive outcomes in non-medicated Parkinson's patients (Bodi et al., 2009; Piray et al., 2014). Parkinson's disease is characterized by neuronal death and disruptions in dopaminergic signaling in areas of the brain involved in reinforcement learning, including the mesocorticolimbic region in addition to characteristic damage along the nigrostriatal pathway (Jellinger, 1991). Treatment with L-DOPA reverses decreased learning from positive outcomes in patients with Parkinson's disease suggesting that alterations in dopaminergic signaling may underlie differences in performance (Bodi et al., 2009). A critical role for dopamine is further supported by imaging studies demonstrating differential activation in both the nucleus accumbens and ventral putamen for positive relative to negative trials in healthy populations (Mattfeld et al., 2011).

We observed decrements in learning from positive outcomes that are strikingly similar to those of non-medicated Parkinson's patients in cocaine users. Chronic cocaine use produces changes in dopaminergic signaling that may decrease sensitivity to reinforcement, including a hypodopaminergic state and downregulation of dopamine D₂ receptors (Volkow et al. 1996, 2000). Neuroimaging has shown a reduced and less complex pattern of activation to reinforcement in active cocaine users compared to control participants (Goldstein et al., 2007; Morie et al., 2016). Preclinical studies support the specific role of dopamine in learning from positive feedback by demonstrating changes in positive, but not negative, feedback sensitivity associated with fluctuations in dopamine concentrations and dopamine transporter binding (Stolyarova et al., 2014). We did not conduct pharmacological manipulations to test these predictions, but parallel outcomes across non-medicated individuals with Parkinson's disease and cocaine users may suggest that a common neurobiological mechanism underlies these alterations in learning from positive outcomes. However, follow-up studies are needed to test this hypothesis because similar behavioral phenotypes may arise from distinct neurobiological mechanisms. The current findings also suggest that this feedback-based probabilistic learning task may provide a rapid, efficient, and non-invasive means to assess dysfunction in dopaminergic function that mediates reward and reinforcement in the human laboratory. These findings could help identify specific remediation of cognitive impairment following putative interventions, such as the use of dopaminergic drugs in treating cocaine use disorder (Stoops and Rush, 2013).

Several limitations should be considered when interpreting the current findings. First, cocaine use could not be biologically verified in the online experiment (but see Elman et al., 2000; Kokkevi et al., 1997). This is an intrinsic limitation of Internet-based research; however, the concordance between findings from the laboratory and online experiments suggests that the subjects who participated in the online experiment were truly cocaine users. Second, response times differed for positive and negative outcome trials. This difference was observed for both groups and is concordant with previous studies (e.g., Mattfeld et al., 2011; Sheynin et al., 2013). The relative magnitude of this difference was consistent across conditions and did not correlate with task performance. Response times were also slower in the cocaine-using group, which argues against the possibility of trading speed for accuracy as an explanation for decreased performance. Third, the current study was cross-sectional. Longitudinal studies would be necessary to examine if the observed decreases in positive outcome learning were pre-existing or a consequence of cocaine use.

This research indicates a decrement in learning from positive relative to negative outcomes in cocaine users that is stable across time and stimuli types, and is specific to cocaine users relative to controls. Close correspondence in performance between an online and laboratory sample was also observed, further supporting the validity of crowdsourcing techniques for cognitive-behavioral research in humans. Future studies could further investigate individual differences related to cocaine use (e.g., behavioral dimensions of impulsivity) to determine their contribution to performance on the probabilistic learning task. These studies should also investigate the underlying neurobiological mechanisms responsible for changes in sensitivity to positive outcomes in cocaine users as well as the relationship between probabilistic learning and response to interventions (e.g., contingency management). The results of such studies could help identify the clinical significance of this learning bias and its relevance as a target for future intervention development.

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Highlights

- Learning from positive and negative outcomes was tested in cocaine users
- Cocaine users showed decreased sensitivity to learning from positive outcomes
- This performance decrement was observed in both laboratory and online samples
- Unlike cocaine users, control participants performed similarly across outcomes

Figure 1.

Procedural diagram of the feedback-based probabilistic-learning task. Participants were asked to classify one of four stimuli into an A or B category. Images belonged to either a Positive Outcome (Panel A) or Negative Outcome (Panel B) condition. Incorrect categorization for positive outcome trials and correct categorization for negative outcome trials produced no programmed consequences. Correct responses for positive outcome trials produced positive visual feedback (i.e., a smiling face) and 25-point gain. Incorrect responses for negative outcome trials produced negative visual feedback (i.e., a frowning face) and 25-point loss. Participants completed two versions of the task in which stimuli were either abstract (top image) or cocaine-related (bottom image). Only a single stimulus type was used in each version of the task.

Figure 2.

Mean (SEM) proportion optimal choices on a probabilistic learning task in a laboratory sample of cocaine users ($n = 20$) during two sessions (Session 1 = Left Panel; Session 2 = Right Panel). Stimuli were either abstract (left bars in each panel) or cocaine-related images (right bars in each panel). Feedback for performance was positive (+25 points; Black Bars) or negative (−25 points; White Bars) for individual stimuli. Effect sizes were calculated as Cohen's d for repeated measures (d_z).

Figure 3.

Mean (SEM) response time in milliseconds on a probabilistic learning task in a laboratory sample of cocaine users ($n = 20$). Remaining details are identical to Figure 2.

Figure 4. Mean (SEM) proportion optimal choice (top) and response time in milliseconds (bottom) on a probabilistic learning task in an online sample of cocaine users ($n = 20$; left) and controls ($n = 24$; right). Remaining details are identical to Figure 2.

Table 1

Demographics and Cocaine Use Variables of Laboratory Sample (Experiment 1)

	Mean (SD)	IQR
Age	42.4 (8.0)	39.3 – 48.3
Female	30%	
Race		
African American	70 %	
White	30%	
Education (Years)	12.4 (1.1)	12 – 13
Sensation-Seeking ^a	2.4 (2.4)	0 – 4
Impulsivity ^a	2.0 (2.3)	0 – 3
Cigarette Use		
CPD ^b	9.4	5 – 10
FTND ^b	3.6	1 – 6
Cocaine Use		
Smoked Use	100%	
Intranasal Use	90%	
Days/Month	14.1 (6.0)	10 – 17.3
Years Used	17.4 (7.3)	12 – 27.8

Note.

^aValues from the Zuckerman-Kuhlman Personality Questionnaire.

^bValues only include participants who reported regular cigarette use.

CPD = cigarettes per day; FTND = Fagerström Test for Nicotine Dependence; SD = standard deviation; IQR = interquartile range. N = 20 participants.

Table 2

Demographic and Drug-Use Variables of Online Samples (Experiment 2)

	Cocaine (n = 20)		Controls (n = 24)	
	Mean (SD)	IQR	Mean (SD)	IQR
Age	33.7 (10.6)	24 – 43	32.5 (10.7)	26 – 36
Female	20%		33.3%	
Race				
White	80 %		87.5%	
African American	15%		0%	
Other	5%		12.5%	
Education (Years)	14.7 (3.2)	14 – 16	14.5 (3.1)	13 – 16
Cigarette Use	70%		25% [*]	
CPD ^a	12.4 (9.4)	5 – 20	4.2 (5.4)	1 – 6
FTND ^a	3.9 (3.4)	1 – 7	2.0 (1.9)	0 – 4
Cocaine Use				
Intranasal Use	95%		-	-
Smoked Use	35%		-	-
Days/Month	5.3 (6.0)	2 – 7.5	-	-
Years Used	5.4 (4.7)	2 – 9.5	-	-

Note.^aValues only include participants who reported regular cigarette use.

CPD = cigarettes per day; FTND = Fagerström Test for Nicotine Dependence; SD = standard deviation; IQR = interquartile range. A full cocaine-use history was not collected in the control group (denoted by dashes).

^{*}
 $p < .05$ between cocaine-using and control groups