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Making risky decisions to take drug: Effects of cocaine abstinence in cocaine users

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ABSTRACT

Risky decision-making is characteristic of drug users, but little is known about the effects of circumstances, such as abstinence, on risky choice behavior in human drug users. We hypothesized that cocaine users would make more risky choices for cocaine (defined as taking a chance to receive a large number of cocaine doses as opposed to choosing to receive a fixed amount of cocaine) after 3 or 7 days of cocaine abstinence, compared to 1 day of cocaine abstinence. Six male nontreatment-seeking current cocaine smokers were enrolled in a 21-day inpatient within-subject study. Participants repeatedly smoked six 25 mg doses of cocaine during a training session and were instructed that they would be making decisions about smoking this dose throughout the study. After 1, 3 and 7 days of cocaine abstinence, participants completed a computerized task in which they repeatedly decided between receiving a guaranteed number of cocaine doses (between 1 and 5; fixed option) or receiving a chance (0.13 to 0.75) to smoke a larger number of cocaine doses (probabilistic option). After completing the computerized task, one of the participants' choices was randomly implemented and they smoked either the fixed number of cocaine doses or had the specified chance to smoke the greater number of doses. Contrary to our hypothesis, 5 of the 6 participants made fewer risky choices after 3 and 7 days of cocaine abstinence compared to one day of abstinence suggesting greater risk-aversion. Thus, even during cocaine abstinence cocaine users make rational decisions related to their drug use.

1. Introduction

Increased risk-taking behavior or risky-decision making, defined as the inability to balance the immediate consequences of choices with their future consequences (Bechara, 2003), is often viewed as a hallmark of individuals with substance use disorders. Excessive risk-taking has been linked to impulsivity (e.g., Lejuez et al., 2005). Evenden (1999) defined impulsive behaviors as "…*actions that are poorly conceived, prematurely expressed, unduly risky, or inappropriate to the situation and that often result in undesirable outcomes* (p. 348)." Excessive impulsivity in turn has been linked to excessive drug use (e.g., Davis et al., 2008). Indeed, impulsivity appears to be a risk factor for drug use (de Wit, 2009), a consequence of long-term drug use (e.g., Grant and Chamberlain, 2014; Jentsch et al., 2014; Rodriguez-Cintas et al., 2016) and an impediment to treatment outcome (e.g., Verdejo-Garcia et al., 2014).

Drug taking, even in heavy users, varies across days and is sensitive to variations in the drug user's situation. A clear example of this is the changes in drug taking and seeking that occur when drug users are abstinent and perhaps experiencing withdrawal. Changes in drug-taking as a function of abstinence could reflect changes in risk-taking behavior (Walmsley, 2016). Impulsivity is often viewed as a trait and as such changes in impulsivity should be slow to occur, yet risk-taking behavior can be state-dependent and often does change in response to acute drug-administration (e.g., Jentsch et al., 2014).

One way to view variations in risk-taking or impulsivity, when these domains are assessed commonly as trait measures, is to assume that the trait domains remain intact and situational conditions affect the perceived reinforcing value of the stimulus maintaining behavior. The changes in relative value are then interpreted within the context of an individual's overall propensity to take risks or behave impulsively. For example, in laboratory rodents the value of a stimulus, defined as the amount of response effort emitted to receive a stimulus, can be decreased by pairing a preferred reinforcer such as palatable food with aversive consequences such as foot shock (e.g., Delamater et al., 2006; Dwyer, 2005). In rats pairing gastric malaise with a preferred sucrose

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solution decreased sucrose consumption on test days but pairing gastric malaise with a solution containing alcohol (Dickinson et al., 2002) or cocaine (Miles et al., 2003) had no effect on consumption of the drug solutions on test days. Reinforcement by one commodity can also be devalued by providing valuable alternative reinforcers. The difficulty in devaluing drug reinforcement, either by directly changing the reinforcing value of the drug itself or by providing more attractive alternatives, is one reason for the persistence of drug-maintained responding (Vanderschuren and Everitt, 2004).

Decision making is clearly influenced by the available reinforcer(s) and also by the motivational state of the decision maker (Hunter, 2013). The term state-dependent valuation has been used to describe the influence of current internal state on decision making such that a current decision is based on the current value of a reinforcer as influenced by both internal state, e.g., time since last meal, and the behavioral history of the decision maker with respect to the available reinforcers (e.g., McNamara et al., 2012). Thus, the state-dependent value of food is greater when an individual is hungry compared to when they are sated (Symmonds et al., 2010). We hypothesize that the value of cocaine and thus the decision to acquire cocaine, is determined by the state dependent value of the cocaine and an individual's proclivity toward risk taking in general.

Levy et al. (2013) examined the effects of 4-hour food deprivation versus eating a meal before the experimental session on decisions for food, money and water. The estimated value of each reinforcer was obtained during choice sessions after 4-hour food deprivation and after eating a meal. Choice sessions included making repeated choices between receiving a small fixed amount of food, money or water, or a chance to earn varying amounts of food, money and water. These outcomes were used to estimate the value of the reinforcer at that point in time. The proportion of trials in which an individual selected the probabilistic option was used as a measure of risk taking: the greater the proportion of probabilistic options the greater the risk taking. Upon completion of the 450 trials, one of the choices for each commodity was randomly selected and realized. Individual differences in response to deprivation were observed such that individuals who were risk-prone when not food deprived tended to decrease risky behavior when food deprived, whereas individuals who were risk-averse when not food deprived tended to increase risky behavior when food deprived.

The purpose of the present study was to adapt the methods of Levy et al. (2013) to study the state-dependent valuation of cocaine in cocaine users in the context of varying drug-deprivation states. Specifically, we examined how abstinence affects choices about cocaine in cocaine users. During choice test sessions we determined the proportion of probabilistic risky choices for cocaine after 1 day, 3 days or 7 days of cocaine abstinence. We hypothesized that the state-dependent value of cocaine would increase with cocaine abstinence, i.e., cocaine users would make riskier decisions about cocaine as abstinence length increased. We also examined choice as a function of the ratio of the expected value (EV) of the probabilistic option divided by the EV of the fixed option [EV(Probabilistic) / EV(Fixed)]. The EV was calculated by multiplying the number of doses by the probability of earning the dose (s). The EV of the fixed option was always 1 × the number of doses (1–5) with a range of 1 to 5 doses, while the EV of the probabilistic option was the 0.13–0.75 probability of receiving that option × the number of doses (1–5) with a range of 0.13 to 3.75 doses. Selecting the option with the greater EV would maximize cocaine intake. We hypothesized that cocaine abstinence would increase the selection of the probabilistic option when the EV(Probabilistic) was less than the EV (Fixed), i.e., choice would be skewed toward the larger number of probabilistic doses even when its EV was less than the EV of the fixed option.

2. Methods

2.1. Participants

Six Black male research volunteers, 35 to 53 years of age (mean = 46.8 years) and with an average of 11 ± 2.7 years of education, participated in this study. Participants were solicited via word-of-mouth referral and newspaper advertisements in New York City, and signed a consent form approved by the Institutional Review Board of The New York State Psychiatric Institute, which described the study, outlined the possible risks, and indicated that cocaine would be administered. Repeated queries were made to ensure that no potential participant was seeking, or had recently been in, drug treatment. Before study enrollment, participants passed comprehensive medical and psychiatric evaluations, including a Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders (DSM-IV SCID; First et al., 1995). Participants met a minimal cocaine use criterion set in advance based on our prior experience with this non-treatment seeking population: each had smoked crack cocaine at least 2 times a week for the past 6 months (current cocaine use was verified by urine toxicology during screening) and reported spending at least $70 per week on cocaine. From our experience, this quantitative use threshold is more pertinent than the diagnostic notion of cocaine dependence in a non-treatment seeking population, as many of non-treatment seekers do not endorse the DSM criterion of experiencing “significant impairment or distress” as a result of their use. No participant met criteria for any Axis I disorder other than cocaine use disorders. On average, participants reported using cocaine by the smoked route for the past 23.3 ± 7.9 years, using cocaine 4.5 ± 1.5 days per week, and spending $70 to $500 per week on cocaine ($247 ± 180; the cost of cocaine was about $30/g in the New York City area when these data were collected). Individuals were financially compensated for their participation.

2.2. Design

Eligible participants were trained on the study procedures prior to the inpatient admission. To ensure that all participants understood the concept of probabilistic reward they completed training on a simple task that demonstrated how probabilities work and that greater probabilities meant a greater chance of winning the probabilistic option. In addition, they practiced completing the task used during the choice sessions.

As shown in Table 1, participants were admitted to the Irving Institute for Clinical and Translational Research in the Columbia University Medical Center for the 19- or 20-day study. Participants were not permitted to leave the unit unless accompanied by a staff member and visitors were prohibited. Urine samples were collected daily for drug monitoring, with no indication of drug consumption aside from study-related dosing. Participants' private rooms were equipped with a television, stereo, and DVD player to help alleviate boredom. Nicotine replacement was provided to tobacco smokers during their inpatient stays as nicotine polacrilex (Nicorette gum, 2 mg or 4 mg doses, one per hour on request; up to 5 times per day) in order to avert nicotine craving or withdrawal symptoms. No nicotine gum use was permitted during laboratory sessions.

Participants experienced one of three testing orders to vary the order of testing the effects of 1 day, 3 days and 7 days of cocaine abstinence on the choice of cocaine, money and food (Table 1). Participants were admitted in the morning and after having lunch on the research floor they completed a Food Choice session (described below) to provide additional practice in the study procedures. After several drug-free days, all participants had 1 cocaine training session where they smoked 6 doses of 25 mg cocaine base at 14 min intervals. Participants were instructed to remember how they felt as this dose (called Dose A) would be the cocaine dose they would be making decisions about for

Table 1
Sequence of experimental conditions.

Study day	Day of week	Order A (n = 2) S1374, S1376	Order B (n = 3) S1367, S1369, S1383	Order C (n = 1) S1365
1	Fri		Admission Food choice	Admission Food choice
2	Sat			
3	Sun			
4	Mon	Admission Food choice	–	Cocaine training
5	Tues	–	Cocaine training	–
6	Wed	Cocaine training	–	–
7	Thurs	Cocaine choice-1 D[a]	–	Cocaine choice-3 D[b]
8	Fri	Cocaine reminder	Food choice	Cocaine reminder
9	Sat			
10	Sun			
11	Mon	Cocaine choice-3 D	–	Food choice
12	Tues	Cocaine reminder	Cocaine choice-7 D[c]	–
13	Wed	–	Cocaine reminder	–
14	Thurs	–	Cocaine choice-1 D	–
15	Fri	Food choice	Cocaine reminder	Cocaine choice-7 D
16	Sat			
17	Sun			
18	Mon	–	Cocaine choice-3 D	Cocaine reminder
19	Tues	Cocaine choice-7 D	Discharge	Cocaine choice-1 D
20	Wed	Discharge		Discharge

[a] Cocaine Choice session after 1 day of abstinence.
[b] Cocaine Choice session after 3 days of abstinence.
[c] Cocaine Choice session after 7 days of abstinence.

the rest of the study.

Participants then had 1 day, 3 days or 7 days of cocaine abstinence before completing a Cocaine Choice session (described below). On the day following each Cocaine Choice session participants had a cocaine reminder session where they smoked 2–4 doses of 25 mg cocaine (Dose A). These sessions insured that all participants started each abstinence phase after smoking similar amounts of cocaine. In order to blind the reminder session procedures, participants were told that they would be smoking 1 to 6 doses of Dose A that session. The actual number of doses was based on the luck of the draw as they had to draw a number from a hat containing six numbers. To keep cocaine exposure prior to abstinence approximately equivalent across participants and conditions, only two each of the numbers 2, 3 and 4 were in the hat. This complicated dosing plan was used so that individuals did not learn that there was a standard amount of cocaine available the day after a Cocaine Choice session, which could affect their decision making during these sessions. After another 1 day, 3 days or 7 days of cocaine abstinence participants experienced another Cocaine Choice session followed by another cocaine reminder session. Then the last abstinence condition was examined similarly.

2.3. Experimental sessions

2.3.1. Cocaine Choice session

Cocaine Choice sessions occurred after 1, 3 and 7 days of cocaine abstinence. At 9:00 AM, participants spent about 60 min completing the decision-making task. They repeatedly made 2 types of decisions about cocaine (Dose A), a preferred candy and money (data from the money and candy option trials were not analyzed). They completed 225 "same-type trials," in which both choice options related to the same commodity, (75 choices for each commodity) to assess risk aversion within each commodity and 150 "mixed-type trials" (75 choices of money vs. cocaine lotteries and 75 choices of money vs. candy lotteries) to assess the relative values of the commodities. In order to have participants finish the task in < 60 min, it was necessary to limit the number of "same-type" and "mixed-type" trials to a total of 375 trials (Levy et al., 2013 used 750 trials).

In "same-type" trials, participants were asked to choose between a fixed amount of a commodity and the chance of winning a different amount of the same commodity. Five different winning probabilities (0.13 chance of receiving 1 reinforcer, 0.22 chance of receiving 2 reinforcers, 0.38 chance of receiving 3 reinforcers, 0.50 chance of receiving 4 reinforcers and 0.75 chance of receiving 5 reinforcers) were tested against each of 5 magnitudes of the non-probabilistic fixed option. Thus, there were 5 probabilistic options for each fixed option yielding a total of 25 trials in a block of questions. Each block was tested 3 times for each commodity yielding 75 trials for each commodity for each abstinence condition. Example trials include: 1) 1 dose of cocaine vs. a 0.38 chance of receiving 3 doses of cocaine; 2) 1 dose of cocaine vs. a 0.50 chance of receiving 4 doses of cocaine; 3) 3 doses of cocaine vs. a 0.38 chance of receiving 3 doses of cocaine; 3) 3 doses of cocaine vs. a 0.50 chance of receiving 4 doses of cocaine. These trials measured the risk preferences for cocaine, money and food. The fixed option reward values were a) 1 to 5 doses of 25 mg cocaine, b) $5, $10, $15, $20 or $25, and c) 1 to 5 bags of M&Ms. Each of the 5 choice levels was examined multiple times at each level of the guaranteed outcome. Based on Levy et al. (2013) the proportion of risky choices, defined as the number of times the probabilistic option (0.13–0.75 chance) was chosen across the trials for each of the 5 the magnitudes of the fixed outcome were calculated.

Data were also summarized based on the EV of the fixed and probabilistic options. Each of the 25 trials resulted in a different [EV (Probabilistic) / EV(Fixed)] ratio: range from 0.026 to 3.75. Because each block of trials was tested 3 times each of the 25 EV ratios were examined 3 times, i.e., 3 choices were tested at each EV ratio.

In "mixed-type" trials participants were asked to choose between a small amount of money ($1) and the chance of either winning Dose A or food. The same 5 reward amounts were tested at the same 5 probabilities in order to assess the relative values of the rewards. These data will not be presented.

After completing the choice questions, participants received at random one of their decisions, based on the 375 trials, and this was implemented. If the option selected was cocaine, then the appropriate number of cocaine doses was administered in the laboratory using the procedures described below. If the option was food, participants were given the candy to take back to their room. If the option was money,

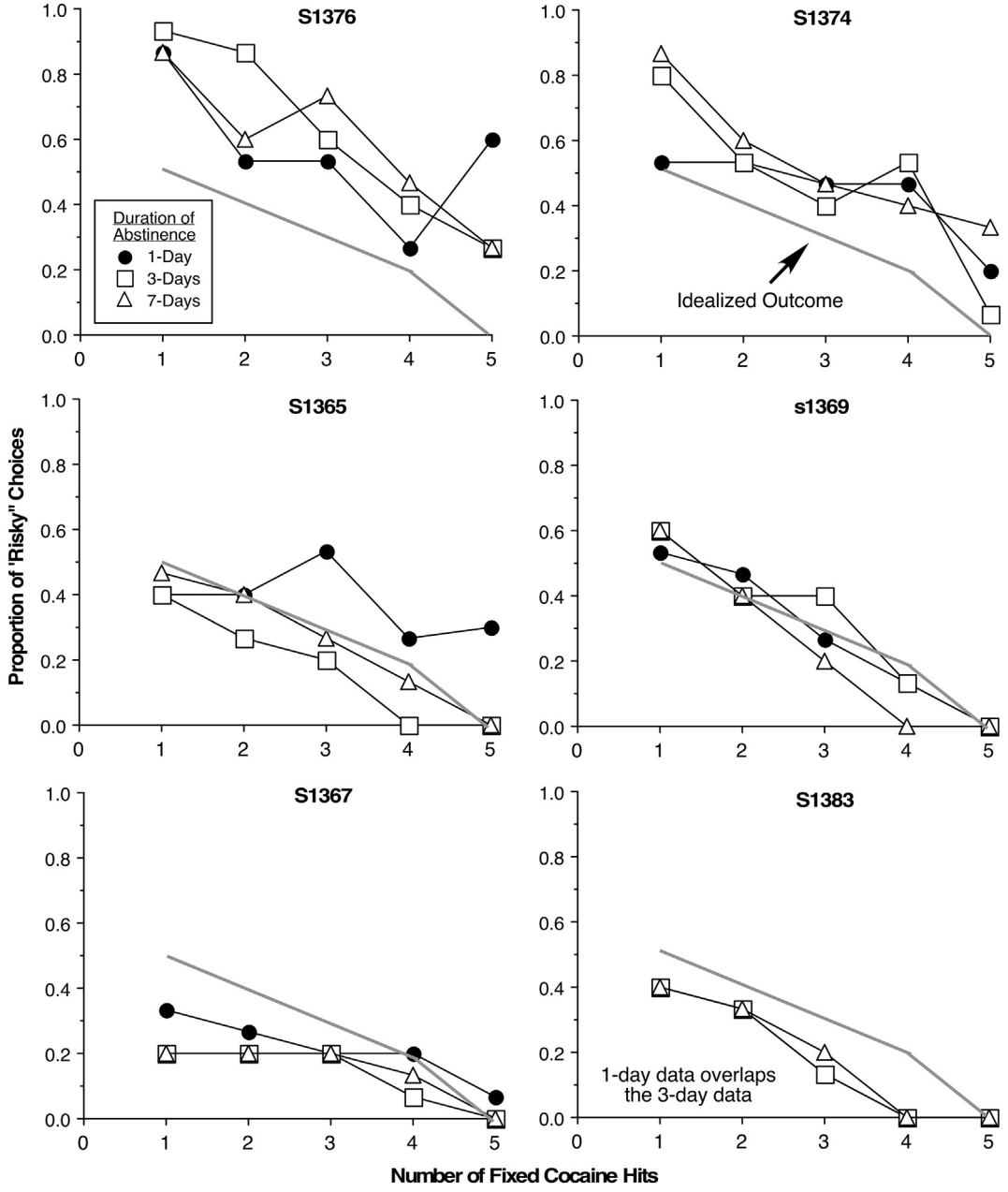

Fig. 1. Proportion of risky (probabilistic) option choices as a function of magnitude of the fixed option and days of cocaine abstinence for each participant. The gray line without symbols represents the idealized proportion of probabilistic option choices that maximizes the opportunity to take cocaine as a function of magnitude of the fixed reinforcer, i.e., choice of the probabilistic option had a greater EV than the fixed option.

this was given as a voucher redeemable for cash upon discharge.

2.3.2. Food Choice session

Food Choice sessions occurred twice: once after lunch on the day of admission and again 3 days into the 7-day period of cocaine abstinence. Sessions were similar to those of the Cocaine Choice sessions except the 3 available commodities were tap water (2, 4, 6, 8, and 10 fluid ounces), candy and money. The number of candy and money options was the same as those used in the Cocaine Choice session. The initial session provided extra training and the session mid-way through the 7 days of cocaine abstinence was done to keep participants engaged in the study during the longer abstinence phase. Data from these sessions were not included in the results.

2.3.3. Cocaine smoking sessions

There were 3 types of cocaine smoking sessions: Training session, Reminder sessions and Reinforcer sessions at the end of the Cocaine Choice sessions if cocaine was the decision randomly selected. The purpose of the Training session, which only occurred on the first inpatient day, was to teach participants to associate 25 mg cocaine with the label of "Dose A." On this training session participants smoked 6 doses of 25 mg cocaine ("Dose A") at 14-min intervals, provided that vital signs were within criteria for drug administration. There were two Reminder sessions scheduled across the inpatient stay during which participants smoked 2 to 4 doses of cocaine (25 mg) at 14 min intervals. A Reinforcer session occurred after completing each of the Cocaine Choice sessions only if the option randomly selected was cocaine. The duration of the cocaine sessions was determined by the number of cocaine doses administered. All cocaine sessions began with a 20 min resting baseline that included subjective-effects battery. The first cocaine dose was delivered at 0 min. A subjective-effects battery was completed 4 min after each cocaine dose was delivered, and the session

ended 30-min after the last cocaine administration (see Foltin et al., 2016, for additional details).

2.4. Data analyses

Only the data from the same-type trials related to cocaine choice were analyzed. Individual data were summarized using the Levy et al. (2013) measure of proportion of risky choices (the number of cocaine doses available under varying probabilities chosen/the total number of choice trials) for each fixed cocaine amount (1–5). Individual data were also summarized using the expected value measure of the total number of fixed choices (maximum = 3) as a function of the EV ratio [EV (Probabilistic) / EV(Fixed)]. A single measure of risk using the EV measure as a function of abstinence condition was obtained by summing the total number of fixed choices across the when the EV ratio < 0 for each abstinence condition, i.e., the fixed option had greater EV than the probabilistic option.

3. Results

3.1. Cocaine training session

The six 25 mg cocaine doses smoked during the training session produced robust physiological and subjective effects relative to baseline. Peak increases in heart rate were about 22 bpm, peak increases in diastolic pressure (DP) were about 17 mmHg, peak increases in systolic pressure (SP) were about 27 mmHg and peak ratings on the Good Drug Effect cluster were about 40 mm (100 mm maximal score based on average rating of 3 items: "I feel… stimulated, high, a good drug effect"). On average, participants indicated that they would pay $2.88 to buy each 25 mg dose.

3.2. Choice outcome

Fig. 1 presents the proportion of risky choices, defined as the number of times the probabilistic option available at 0.13–0.75 chance levels was chosen as a function of the magnitude of the fixed outcome for cocaine during the same-type trials for each of the six participants. The solid gray line on each participant's panel represents the idealized outcome that maximizes the number of cocaine doses available, i.e., choice of the probabilistic option has a greater EV than the fixed option, such that data points above the line indicate more risky choices and data points below the line indicate less risky choices. Participants are presented in order of decreasing risk taking from the upper left to the lower right panel of the figure. The proportion of risky choices decreased as the magnitude of the guaranteed reinforcer increased for all participants. Participants shown in the top 2 panels consistently selected the probabilistic option above the idealized outcome line, participants shown in the bottom 2 panels consistently selected the probabilistic option below the idealized outcome line, while the participants in the middle panel chose the probabilistic option similar to the idealized outcome line. Cocaine abstinence did not consistently affect risky choice using this measure of risk taking: proportion of risky choices increased in S1376, decreased in S1365 and were minimally affected in the remaining 4 participants.

3.3. Expected value outcome

Fig. 2 presents the number of fixed choices as a function of the EV ratio during the same-type trials for each of the six participants. Participant order is based on their proportion of risky choices as presented in Fig. 1. When the EV ratio ≤ 0 selecting the fixed option maximized cocaine opportunities and when the EV ratio was > 0 selecting the probabilistic option maximized cocaine opportunities. Participants choices were related to the EV ratios with participants selecting more of the fixed option when the EV ratio was ≤0 and more of the probabilistic option when the EV ratio was > 0. Participants shown in the top 2 panels, who chose the probabilistic option more often using the choice outcome clearly selected the probabilistic option more often even when selecting the fixed option provided greater value after 1 day of cocaine abstinence, e.g., left portion of each panel shows fewer choices of the fixed option. As shown in the left portions of the panels for the remaining 4 participants these participants mostly selected the fixed option when it had a greater EV than the probabilistic option after 1 day of cocaine abstinence. Although the effects of abstinence duration are difficult to see with all the data points graphed in Fig. 2, graphing the sum of the fixed choices when the EV ratio was < 0 as shown in the top panel of Fig. 3 or as a change from the sum of fixed choices after 1 day of abstinence in the bottom panel of Fig. 3 makes it easier to see the subtle changes in choice as a function of days of abstinence. S1376 was the only participant that deceased the number of fixed choices when the fixed option had a greater EV than the probabilistic option after three or 7 days of cocaine abstinence indicating greater risk-taking. The remaining 5 participants increased the number of fixed choices when the fixed option had a greater EV than the probabilistic option after three or 7 days of cocaine abstinence indicating greater risk-aversion.

4. Discussion

Regular cocaine users repeatedly made decisions to receive cocaine after 1, 3 and 7 days of abstinence from cocaine while living in a research unit with no other sources of drugs. Prior to abstinence, smoked cocaine increased cardiovascular activity and ratings of positive mood and drug effects and the 25 mg dose was valued at slightly less than $3. We initially summarized the data using the approach of Levy et al. (2013) with risky decision-making being defined as the proportion of probabilistic options chosen versus a fixed reinforcer amount. While increasing the magnitude of the fixed reinforcer decreased the choice of the probabilistic option, i.e., decreased risky behavior, this outcome measure was not sensitive to the effects of cocaine abstinence. By contrast using an expected value approach to the data, i.e., risky decision making was defined as choosing the probabilistic option when the EV of the fixed option was greater, choice was related to the relative EV of the fixed and probabilistic options such that participants generally chose the option with the greater EV. Furthermore, the EV analysis yielded consistent effects of cocaine abstinence.

The participant who showed the greatest risk taking after 1 day of cocaine abstinence using both outcome measures was the only participant who increased risk taking after 3 and 7 days of cocaine abstinence. While the amount of risk taking after 1 day of cocaine abstinence varied amongst the other 5 participants using both outcome measures, all 5 remaining participants decreased risk taking after 3 and 7 days of cocaine abstinence using the EV value outcome measure. All 5 participants increased the number of fixed dose choices when the EV of the fixed dose was less than the EV of the probabilistic dose. These data argue that cocaine users are more risk averse during abstinence and more likely to choose a guaranteed cocaine dose than a chance to receive a larger cocaine dose. Cocaine abstinence did not produce the hypothesized increases in risk-taking behavior.

In humans, the effects of food restriction and intake on decision making have previously been examined, yielding complex results (Hunter, 2013). Orquin and Kurzban (2016) conducted a meta-analysis of 42 papers that examined the relationship between blood glucose levels and varying aspects of decision making. Lower glucose levels, indicative of greater time since last meal or snack, increased the willingness to work for or pay for food-related commodities, and also increased delay discounting for food, i.e., food more distant in time had less value than food closer in time. Thus, the relative value of food, but not other stimuli, increased with lower glucose levels, and the ability to delay gratification of eating for a larger amount of food later was decreased. The study by Levy et al. (2013), which we based the current

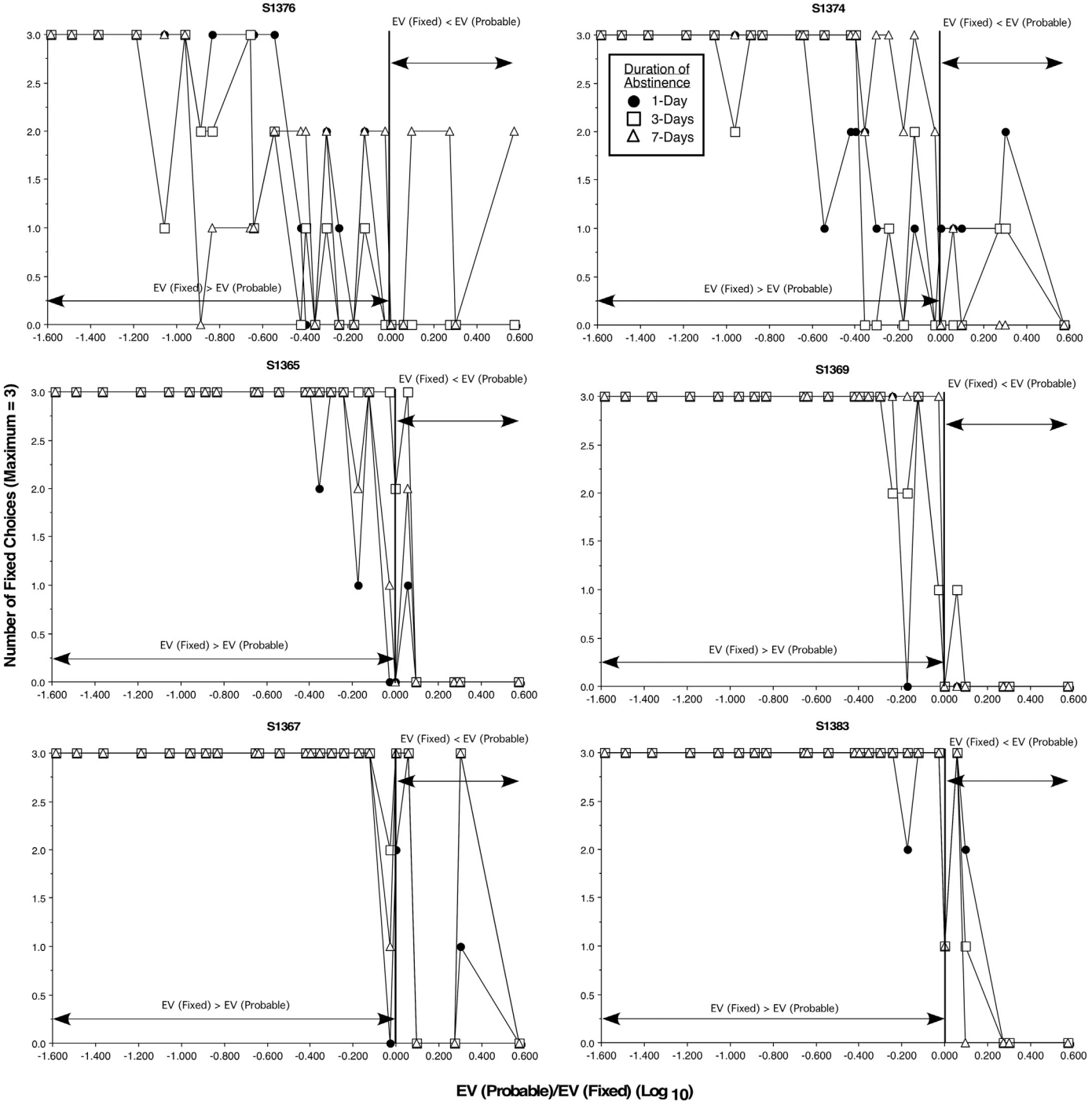

Fig. 2. The number of fixed option choices as a function of the EV ratio [EV(probabilistic) / EV(fixed)] for each participant. When the EV ratio < 0 selecting the fixed option maximized cocaine opportunities and when the EV ratio was > 0 selecting the probabilistic option maximized cocaine opportunities.

procedures on, reported that food deprivation was largely associated with greater tolerance for risk but individuals who made fewer risky choices when satiated tended to make more risky choices when hungry. Symmonds et al. (2010) reported a transient decrease in risky-decision making after participants ate a meal. Thus, food deprivation can increase risky-decision making in some individuals, but often is associated with risk-aversion (e.g., state-dependent valuation; McNamara et al., 2012).

In the current study cocaine abstinence increased risky behavior in one participant while risky behavior was decreased in 5 participants. More variable results were reported with brief food deprivation by Levy et al. (2013). In that study, less risk when satiated was associated with greater risk when hungry and vice versa. Participants were asked under 1 condition to not eat for 4 h prior to coming to the laboratory and asked under another condition to eat a full lunch prior to coming to the laboratory. Because food deprivation was loosely controlled, and food was available shortly after the session ended it is possible that rather than measuring purely an effect of deprivation on risk taking, the study measured the effect of food deprivation plus other unspecified variables, e.g., ability to follow instructions, on risk taking. In the present study, in addition to using cocaine as the reinforcer the abstinence conditions were tightly controlled by having participants reside on an inpatient research unit.

Although the data are orderly there are several obvious limitations

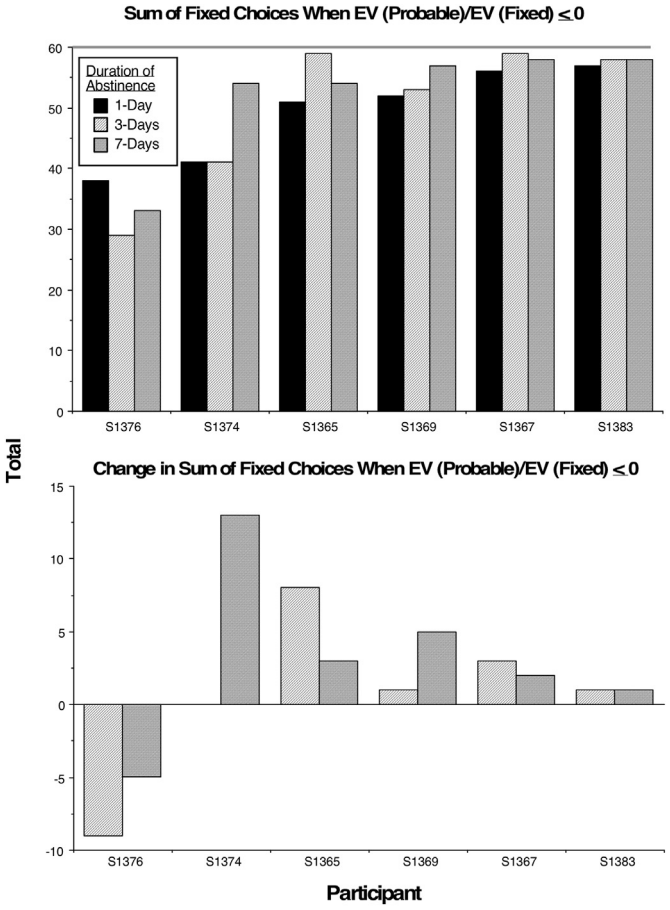

Fig. 3. Top panel. Sum of the number of fixed option choices when the EV ratio < 0 as a function of days of cocaine abstinence for each participant. When the EV ratio < 0 selecting the fixed option maximized cocaine opportunities. Bottom panel. Sum of the number of fixed option choices when the EV ratio < 0 after 3 and 7 days of cocaine abstinence expressed as change from the sum of the number of fixed option choices when the EV ratio < 0 after 1 day of cocaine abstinence.

to the current study including the small sample size and testing only male participants. Several procedural details also limit the interpretation of study outcomes in relationship to the procedures used by Levy et al. (2013). The cocaine users required a large amount of time to complete the utility assessments, so to limit fatigue half the number of data points were obtained at each assessment compared to the earlier study by Levy et al. (2013). Because we did not plan to analyze the data in terms of EV in advance there were a great number of choices for which the EV of the fixed option was greater than the EV of the probabilistic option (data points in the left sections of the graphs in Fig. 2). This high prevalence of greater EV for the fixed option may have skewed the data toward less risk taking, i.e., there were fewer conditions where the EV of the probabilistic option was greater than the EV of fixed option. The fact that participants occasionally made some risky choices (best outcome of a 0.75 chance of getting 5 units) even when 5 units of reinforcers were the fixed option, or they selected the fixed outcome even when the EV of the probabilistic outcome was greater suggests that participants may have not been paying attention during the entire sequence of questions. Finally, although we tested 3 possible testing orders of the abstinence conditions it is possible that test order affected study outcome.

In summary, in contrast to the expected outcome cocaine abstinence did not produce an overall increase in risky decision making for cocaine by heavy cocaine users. Rather 5 of the 6 participants made fewer risky choices after cocaine abstinence, i.e., cocaine abstinence increased the state-dependent value of cocaine. Choices of the risky probabilistic outcomes were orderly and related to the EV of the fixed and probabilistic options across all 3 abstinence conditions. Future work with similar procedures may be of value in understanding decisions to take drug by drug users.

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References

Bechara, A., 2003. Risky business: emotion, decision-making, and addiction. J. Gambl. Stud. 19 (1), 23–51.
Davis, B.A., Clinton, S.M., Akil, H., Becker, J.B., 2008. The effects of novelty-seeking phenotypes and sex differences on acquisition of cocaine self-administration in selectively bred high-responder and low-responder rats. Pharmacol. Biochem. Behav. 90 (3), 331–338.
de Wit, H., 2009. Impulsivity as a determinant and consequence of drug use: a review of underlying processes. Addict. Biol. 14 (1), 22–31.
Delamater, A.R., Campese, V., LoLordo, V.M., Sclafani, A., 2006. Unconditioned stimulus devaluation effects in nutrient-conditioned flavor preferences. J. Exp. Psychol. Anim. Behav. Process. 32 (3), 295.
Dickinson, A., Wood, N., Smith, J.W., 2002. Alcohol seeking by rats: action or habit? Q. J. Exp. Psychol. B 55 (4), 331–348.
Dwyer, D.M., 2005. Reinforcer devaluation in palatability-based learned flavor preferences. J. Exp. Psychol. Anim. Behav. Process. 31 (4), 487.
Evenden, J.L., 1999. Varieties of impulsivity. Psychopharmacology 146 (4), 348–361.
First, M.B., Spitzer, R.L., Gibbon, M., Williams, J.B., 1995. Structured Clinical Interview for DSM-IV Axis I Disorders. New York State Psychiatric Institute, New York.
Foltin, R.W., Haney, M., Bedi, G., Evans, S.M., 2016. Modafinil decreases cocaine choice in human cocaine smokers only when the response requirement and the alternative reinforcer magnitude are large. Pharmacol. Biochem. Behav. 150, 8–13.
Grant, J.E., Chamberlain, S.R., 2014. Impulsive action and impulsive choice across substance and behavioral addictions: cause or consequence? Addict. Behav. 39 (11), 1632–1639.
Hunter, P., 2013. Your decisions are what you eat. Metabolic state can have a serious impact on risk-taking and decision-making in humans and animals. EMBO Rep. 14 (6), 505–508.
Jentsch, J.D., Ashenhurst, J.R., Cervantes, M.C., Groman, S.M., James, A.S., Pennington, Z.T., 2014. Dissecting impulsivity and its relationships to drug addictions. Ann. N. Y. Acad. Sci. 1327, 1–26.
Lejuez, C., Bornovalova, M.A., Daughters, S.B., Curtin, J.J., 2005. Differences in impulsivity and sexual risk behavior among inner-city crack/cocaine users and heroin users. Drug Alcohol Depend. 77 (2), 169–175.
Levy, D.J., Thavikulwat, A.C., Glimcher, P.W., 2013. State dependent valuation: the effect of deprivation on risk preferences. PLoS One 8 (1), e53978.
McNamara, J.M., Trimmer, P.C., Houston, A.I., 2012. The ecological rationality of state-dependent valuation. Psychol. Rev. 119 (1), 114–119.
Miles, F.J., Everitt, B.J., Dickinson, A., 2003. Oral cocaine seeking by rats: action or habit? Behav. Neurosci. 117 (5), 927.
Orquin, J.L., Kurzban, R., 2016. A meta-analysis of blood glucose effects on human decision making. Psychol. Bull. 142 (5), 546–567.
Rodriguez-Cintas, L., Daigre, C., Grau-Lopez, L., Barral, C., Perez-Pazos, J., Voltes, N., Braquehais, M.D., Casas, M., Roncero, C., 2016. Impulsivity and addiction severity in cocaine and opioid dependent patients. Addict. Behav. 58, 104–109.
Symmonds, M., Emmanuel, J.J., Drew, M.E., Batterham, R.L., Dolan, R.J., 2010. Metabolic state alters economic decision making under risk in humans. PLoS One 5 (6), e11090.
Vanderschuren, L.J., Everitt, B.J., 2004. Drug seeking becomes compulsive after prolonged cocaine self-administration. Science 305 (5686), 1017–1019.
Verdejo-Garcia, A., Albein-Urios, N., Martinez-Gonzalez, J.M., Civit, E., de la Torre, R., Lozano, O., 2014. Decision-making impairment predicts 3-month hair-indexed cocaine relapse. Psychopharmacology 231 (21), 4179–4187.
Walmsley, I., 2016. Coming off drugs. Contemp. Drug Probl. 43 (4), 381–396.