

Increased risk-taking decision-making but not altered response to punishment in stimulant-using young adults

David S. Leland^a, Martin P. Paulus^{a,b,*}

^a *Laboratory of Biological Dynamics and Theoretical Medicine, Department of Psychiatry, University of California, San Diego, CA 92093-9116, USA*

^b *Department of Psychiatry, VA San Diego Healthcare System, 3350 La Jolla Village Drive, San Diego, CA 92161, USA*

Received 21 June 2004; received in revised form 27 September 2004; accepted 5 October 2004

Abstract

Stimulant-using and stimulant-naive young adults performed the “risky gains” decision-making task [Paulus, M.P., Rogalsky, C., Simmons, A., Feinstein, J.S., Stein, M.B., 2003. Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. *Neuroimage* 19(4), 1439–1448]. On each trial, the numbers 20, 40, and 80 are presented individually in ascending order. Subjects press a button to receive the displayed number in points. The 20 is always associated with a gain of 20 points (safe response). There is a chance that waiting to select a 40 or 80 will result in punishment of 40 or 80 points, respectively (risky response). All subjects made fewer risky responses immediately following punished trials ($p < .001$). Stimulant-users made more risky responses than never-users overall ($p < .02$) but showed the same inhibition effect of punishment on next-trial risky responding. Risk-taking in the task correlated with measures of sensation-seeking and impulsivity, but not other personality measures, anxiety, or tendency toward alcohol use disorders. Results are consistent with the hypothesis that stimulant-users show increased risk-taking but are not less sensitive to punishments than controls. By requiring selection from a sequence of individual options presented according to a fixed schedule, rather than allowing deliberation between simultaneously available options, the risky gains task may model a different sort of risk-taking than other tasks.

© 2004 Elsevier Ireland Ltd. All rights reserved.

Keywords: Decision-making; Risk-taking; Stimulants

1. Introduction

When subjects make a decision in the laboratory, they typically choose responses that are associated with the highest expected value, i.e. they make choices that are most likely associated with “correct” outcomes or the highest rewards (Calfée and Atkinson, 1966; Goulet and Barclay, 1967; Ludvigson, 1966). This behavior is consistent with the notion that anticipated “success” or “failure” critically influences decision-making (Egelman et al., 1998). On the other hand, performance in these experiments frequently deviates from how one “should decide” according to normative models (for review, see Luce, 1959; Mellers et al., 1998). Factors that contribute to this deviation include how the situation is

presented (framing effects; Tversky and Kahneman, 1981), what stimuli are used to present the situation (stimulus contexts; Slovic and Lichtenstein, 1968), the experimental setup in which subjects are asked to decide (environmental effects; Schwartz and Norman, 1989), and how the subject is asked to respond (response effects; Mellers et al., 1992).

Risk-taking is an important component of decision-making that has garnered much attention in the study of substance abuse and dependence. Risk situations commonly require choosing between, on the one hand, an option with the potential for a high magnitude positive outcome but also the possibility of large adverse outcomes and, on the other, a choice with a smaller but more certain beneficial outcome (Mellers et al., 1997; Slovic, 1987). As with decision-making in general, risk-taking is influenced by a variety of factors such as situation-specific information (Slovic, 1972), whether positive or negative aspects of the decision alternatives are

* Corresponding author. Tel.: +1 858 642 3390; fax: +1 858 642 1429.
E-mail address: mpaulus@ucsd.edu (M.P. Paulus).

emphasized (Huber and Kuhberger, 1996), the global range of options (Mellers and Cooke, 1996), the presence of irrelevant alternatives (Huber et al., 1987), the degree to which response alternatives are comparable (Tversky et al., 1988), and time pressure (Payne et al., 1996). In substance abuse, the prospect of large positive outcomes (e.g. hedonic effects) appears to outweigh that of negative ones (e.g. drug dependence) in decision-making.

The risk of dependence is particularly high in the case of stimulants. Recent studies have demonstrated that cocaine dependence among users develops more rapidly than dependence to marijuana or alcohol (Grant and Dawson, 1998; Wagner and Anthony, 2002), as well as nicotine (Balfour, 2002). The risk for cocaine dependence is especially high in young adults, peaking at about age 22 and declining thereafter (Wagner and Anthony, 2002). According to Chambers et al. (2003), a combination of greater motivational drive for novel experiences and an immature inhibitory control system may predispose young adults to impulsive actions and risky behaviors, including experimentation with and abuse of addictive drugs. Since young adult stimulant-users are at particularly high risk for dependence they may demonstrate correspondingly large biases in risk-taking decision-making in the laboratory. Relative to stimulant-naive individuals, this population may be hypersensitive to rewarding events, hyposensitive to punishing events, or both. Knowing which would provide insight into why individuals continue to use stimulants despite knowledge of the adverse consequences.

A variety of behavioral tasks have been used to assess risk-taking decision-making in substance users. The Bechara Gambling Task (Bechara et al., 1994), in which subjects choose between cards with large immediate rewards but a long-term net loss and smaller immediate rewards with a long-term net gain, has been used to demonstrate high risk-taking in abusers of a variety of substances (e.g. Bechara et al., 2001; Grant et al., 2000; Monterosso et al., 2001; Petry et al., 1998; Petry, 2001; Rotheram-Fuller et al., 2004). Lane and Cherek (2000, 2001) found higher risk-taking with a two-choice risky/non-risky response task performed by subjects with histories of drug dependence and/or conduct disorder. The Balloon Analogue Risk Task (BART; Lejuez et al., 2002), in which subjects choose to either 'cash out' on a current pool of virtual earnings or to increase that pool with the increasing risk of losing it all, has shown increased risk-taking in smokers compared to non-smokers (Lejuez et al., 2003a).

Here we assessed stimulant-users using the "risky gains" decision-making task (RGT), which had been developed to probe the neural circuitry underlying risk-taking decision-making (Paulus et al., 2003). One key feature of this task is that the individuals have a limited amount of time to select between the non-risky option and the two risky options. Thus, subjects cannot deliberate at their leisure in making response decisions but rather choose whether or not to accept an option during a temporal window of opportunity before the next (riskier) option replaces it. The aim of this investigation was two-fold. First, it was hypothesized that stimulant-

users would be more sensitive to rewards and/or less sensitive to punishments in the RGT than individuals who had never used stimulants. Second, we sought to determine whether risk-taking decision-making during the RGT was related to personality factors, particularly impulsivity and sensation-seeking.

2. Methods

2.1. Subjects

Undergraduate psychology students were recruited for the study via general announcements and asked to participate in a decision-making experiment. All subjects completed a standardized drug and alcohol questionnaire (Brown et al., 1998). According to this questionnaire, 19 individuals indicated that they had used stimulants (cocaine, amphetamine, methamphetamine, or methylphenidate when not prescribed) at least once in their lifetime. These individuals comprised the stimulant-user (SU) group, and were compared to 108 stimulant-naive (SN) controls. All subjects were between 17 and 21 years of age. The study was approved by the University of California San Diego (UCSD) Institutional Review Board. All subjects provided written informed consent.

2.2. Materials

2.2.1. Demographics and personality/symptom assessment

Subjects reported their age, gender, race/ethnicity, years of education, number of uses of coffee/tea and of cigarettes per day, and total lifetime number of uses of the following drugs: stimulants, THC, tranquilizers, PCP, opiates, hallucinogens, MDMA.

A battery of personality and symptom assessment questionnaires was administered including the Sensation Seeking Scale (SS; Zuckerman et al., 1978), the Barratt Impulsiveness Scale (BIS-11, Patton et al., 1995), the NEO Five Factor Inventory (NEO-FFI; Costa and McCrae, 1992; Costa and McCrae, 1997), the State-Trait Anxiety Inventory (STAI; Spielberger, 1983), the Alcohol Use Disorders Identification Test (AUDIT; Bohn et al., 1995), and the Social Interaction Anxiety Scale (SIAS; Mattick and Clarke, 1998).

2.2.2. Risky gains task

Subjects are presented with a sequence of three numbers in ascending order (20, 40, and 80). Each number is displayed on screen for 1 s and, if the subject presses a button while that number is displayed, he/she receives that number of points along with immediate positive visual and auditory feedback. When a 40 or 80 appears, however, there is a chance that it will appear in an alternate color, along with immediate negative feedback signaling a loss of 40 or 80 points, respectively. When this occurs, the trial ends immediately (i.e. the subject

may not make a response). Each trial lasts 3.5 s regardless of the subject's selection or punishment.

Subjects are informed that waiting to select a 40 or 80 allows for larger point gains but risks losing points, while selecting a 20 offers fewer points but carries no risk of a penalty. They are not made aware, however, that there is no inherent advantage or disadvantage in selecting the risky response (40 or 80) over the safe response (20). While the optimal response for an individual trial depends on whether and when there is a scheduled punishment, a strategy of selecting all 20s would result in the same final score as one of attempting to select all 40s or all 80s.

The 96 trials of the RGT consist of three trial types, which are presented in randomized order: unpunished ($n = 54$), punished-negative 40 ($n = 24$), punished-negative 80 ($n = 18$). Actual punishment occurs only if the subject holds out long enough for one to occur, so if a response is made during the 20 window of a negative 40 trial or the 20 or 40 window of a negative 80 trial, the result is the same as if it were an unpunished trial. If, on the other hand, a subject plans to hold out for an 80 on a negative 40 trial, punishment arrives immediately after the 1-s window for a 20 response elapses, just as if he or she planned to choose a 40 or had not yet decided when to respond.

The dependent measure in the RGT is response frequency. The main indices of risk-taking are the relative frequency of "safe" responses (20) versus "risky" responses (40 or 80) overall and as a function of previous trial outcome (i.e. punished versus unpunished). The former provides a baseline assessment of risk-taking while the latter probes sensitivity to punishment. To investigate whether outcomes influenced later responses beyond just the subsequent trial, a mutual information analysis (described in the following section) was performed to assess the degree to which action-outcomes (i.e. selecting 20, selecting 40, selecting 80, being punished) for one trial were related to those for earlier trials at each lag between 1 and 10 trials ago.

2.3. Statistical analysis

Analyses were carried out using SPSS 10.0 (Norusis, 1990). A $2 \times 2 \times 2$ ANOVA was used to analyze the task measure with group (SU versus SN) as a between-subjects factor and response type (risky versus safe) and previous trial outcome (punished versus unpunished) as within-subject factors. Partial η^2 is reported along with F and p statistics and indicates, out of the variance associated with an effect and its corresponding error, the proportion accounted for by that effect. Planned comparisons were evaluated using the least significant difference (LSD) while Bonferroni adjustments were used for exploratory ones. Differences between SU and SN students on sociodemographic data were analyzed using χ^2 analyses and relative frequency of other drug use was subjected to a logistic regression analysis to obtain odds ratios, which measure the different rates of drug use among the different groups. Of the 19 SU participants,

all completed the personality/symptom assessment inventory, while the number of SN subjects completing each questionnaire varied between 104 and 108 (the exact number is listed for each questionnaire in Table 2). Eighteen of the 19 stimulant-users and 105 of the 108 never-users completed the RGT. Degrees of freedom were adjusted as appropriate to the number of subjects completing the task and each questionnaire.

Using a mutual information analysis, the degree of non-randomness in sequences of action-outcomes was assessed to determine whether participants delivered responses that were influenced by the outcome of the immediately preceding trial and those of up to 10 trials ago. Mutual information functions (Herzel and Grosse, 1995) are based on the logarithmic likelihood ratio between the observed frequency of an event and the expected frequency of an event. These functions quantify, in units of bits, how much more or less likely than chance it is that two events will co-occur, in this case with 0 bits representing complete independence and 1 bit representing perfect prediction of each event by the other. In the RGT, if the subject selects a risky response less often when the previous trial was punished, the mutual information will measure the degree to which these two occurrences happen more frequently than by chance alone. Mutual information was calculated for action-outcomes at separations of between 1 and 10 lags and compared between SN and SU subjects.

Finally, a step-wise regression analysis was performed to determine the degree to which ever-use versus never-use of various illicit drugs (stimulants, THC, tranquilizers, PCP, opiates, hallucinogens, and MDMA) predicted the number of risky responses.

2.4. Procedure

Subjects participated in one session conducted between 9:00 a.m. and 5:00 p.m. After consenting to the study, subjects were given task instructions and completed the RGT on a laptop computer with headphones. All responses were made via button press on the keyboard. Following the task, subjects completed the inventory of personality questionnaires. Before leaving, subjects were debriefed and given course credit for their participation.

3. Results

3.1. Demographics and personality/symptom assessment

Table 1 summarizes the demographic and drug use comparison of stimulant-users and SN controls. The SU group did not differ from the SN group in age, gender ratio, rate/ethnicity or education. SU subjects had used stimulants an average of just under 9 times in their lives. These individuals also had significantly more experience with other illicit drugs. They were, for instance, 4.0 times more likely to have used THC, 10.7 times more likely to have used MDMA, and

Table 1
Sociodemographics and drug use compared between stimulant-using and stimulant-naive subjects

Sociodemographics	Stimulant-using subjects (<i>n</i> = 19)			Stimulant-naive subjects (<i>n</i> = 108)			χ-squared, <i>t</i> -test, or odds ratio
	<i>n</i>	Mean	S.D.	<i>n</i>	Mean	S.D.	
Age (years)		18.37	0.76		18.38	0.72	0.06 ^a
Gender (<i>n</i>)							
Male	5			30			0.02 ^b
Female	14			78			
Race/Ethnicity (<i>n</i>)							
Caucasian	11			68			3.46 ^b
African American	0			3			
Asian	4			10			
Hispanic	1			15			
Other	3			12			
Education (years)		13.37	0.60		13.25	0.60	0.77 ^a
Currently using (<i>n</i>); uses/day (mean, S.D.)							
Coffee/Tea	17	0.72	0.68	97	0.51	0.87	0.91 ^a
Cigarettes	4	1.22	1.86	12	4.17	5.92	2.29 ^a
Ever used (<i>n</i>); total lifetime use (mean, S.D.)							
Stimulants	19	8.81	17.95	0			
THC	16	392.15	1063.18	61	92.86	181.31	4.0* (1.1–14.6) ^c
Tranquilizers	4	8.00	10.39	4	9.25	13.87	6.8* (1.5–30) ^c
PCP	3	2.00	1.73	1	1.00		20* (1.94–200) ^c
Opiates	5	7.75	8.18	11	8.78	19.24	3.1 (.95–10.4) ^c
Hallucinogens	7	2.33	1.97	12	2.67	2.71	4.6** (1.5–14.5) ^c
MDMA	10	9.10	10.73	10	9.05	14.67	10.7*** (3.5–32) ^c

p* < .05, ** *p* < .01, * *p* < .001.

^a *t*-test.

^b χ-squared.

^c Odds ratio (CI).

Table 2
Personality, anxiety, and alcohol disorder assessment compared between stimulant-using and stimulant-naive subjects and correlated with risky responses on the risky gains task (RGT)

Measures	Stimulant-using subjects (<i>n</i> = 19)		Stimulant-naive subjects			<i>t</i> -Test	RGT Corr. <i>r</i>
	Mean	S.D.	<i>n</i>	Mean	S.D.		
SS							
Total score	23.95	4.82	104	19.73	5.86	2.96**	.24**
Thrill and adventure seeking	7.58	2.34	106	6.25	2.37	2.26*	.12
Experience seeking	6.89	1.79	106	5.08	1.95	3.80***	.20*
Disinhibition	6.26	2.56	105	5.30	2.71	1.44	.19*
Boredom susceptibility	3.21	1.90	106	3.09	1.80	0.26	.17
BIS							
Total score	68.16	7.72	108	64.63	8.91	1.62	.21*
Attentional impulsiveness	17.58	3.70	108	18.00	3.63	0.47	.14
Motor impulsiveness	23.16	3.45	108	21.24	3.86	2.03*	.25**
Non-planning impulsiveness	27.42	3.11	108	25.40	4.08	2.06*	.09
NEO-FFI							
Neuroticism	48.43	10.17	108	48.42	9.16	0.00	-.06
Extraversion	47.70	11.23	108	46.33	11.55	0.48	.02
Openness	50.59	8.02	108	48.59	9.88	0.84	.19
Agreeableness	47.27	11.59	108	52.10	9.46	1.98	-.06
Conscientiousness	48.07	6.81	108	48.74	9.19	0.31	-.11
STAI							
Trait	43.34	7.22	107	46.82	9.22	1.56	-.07
State	41.53	12.61	108	38.90	9.97	1.02	-.04
AUDIT							
Total score	8.00	3.90	108	6.52	5.27	1.16	.15
SIAS							
Total score	22.89	11.91	106	26.58	14.95	1.02	-.04

SS: Sensation Seeking Scale, BIS: Barratt Impulsiveness Scale, NEO: NEO Five Factor Inventory, STAI: State-Trait Anxiety Inventory, AUDIT: Alcohol Use Disorders Identification Test, SIAS: Social Interaction Anxiety Scale; **p* < .05, ** *p* < .01, *** *p* < .001.

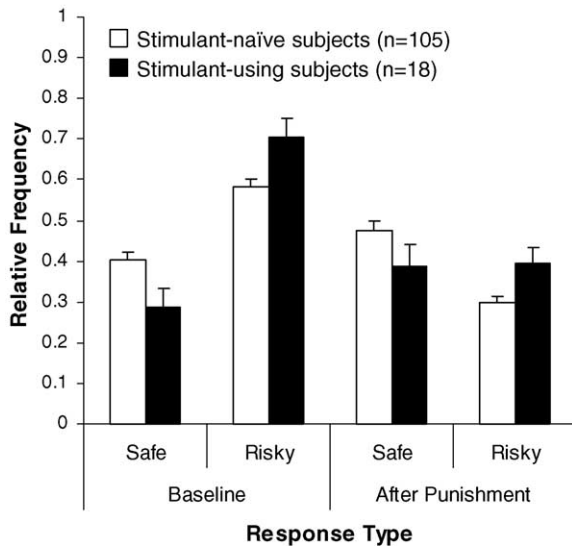


Fig. 1. Relative frequency of risky and safe responses made by stimulant-using and stimulant-naïve participants. “Baseline” trials are those in which no punishment was scheduled to occur, while “After Punishment” trials are those following punishment from the previous trial. Some trials in the latter category also resulted in punishment before a response could be made, so that the frequencies of safe and risky responses do not sum to one; these ‘punished–punished’ trials account for the difference. Stimulant-users had a higher overall rate of risky responding than stimulant-naïve subjects, but punished trials similarly biased both groups toward safer responses on the subsequent trial.

20 times more likely to have used PCP than SN controls. There was a marginally significant difference in opiate use and no significant group difference in the use of coffee/tea or tobacco.

A summary of group scores on personality, depression, and anxiety measures is included in Table 2. Stimulant-users scored significantly higher than SN subjects on measures of sensation-seeking and impulsivity. They did not differ significantly on other personality measures, anxiety, or alcohol use disorders.

3.2. Risky gains task

As reflected in Fig. 1, stimulant-users made more risky responses (i.e. choosing 40 or 80 versus 20) than SN controls ($F(1, 121) = 5.67, p = .019$, partial $\eta^2 = .045$). Subjects overall made fewer risky responses following a punished trial than an unpunished one ($F(1, 121) = 93.67, p < .001$, partial $\eta^2 = .436$). Stimulant-users were not significantly different from controls in the degree to which punished trials decreased risky responding on the subsequent trial ($F(1, 121) < 1$), nor in the degree to which action-outcomes were related to those of previous trials at various lags ($F(1, 121) = 1.78, p = 0.184$). When use versus non-use of stimulants, THC, tranquilizers, PCP, opiates, hallucinogens, and MDMA were entered into a step-wise regression model with the number of risky responses as the dependent variable, a significant model emerged with only stimulant use as a significant pre-

dicator ($F(7, 111) = 6.07, p = .015$, β (unstandardized) = .123, $r^2 = 0.05$).

3.3. Correlations

Table 2 includes correlations between responses on each of the questionnaires and risk-taking on the RGT. Risky responding correlated with measures of sensation-seeking and impulsivity. There was no correlation with neuroticism, extraversion, openness, agreeableness, conscientiousness, trait or state anxiety, social anxiety, or tendency toward alcohol use disorders.

4. Discussion

The main finding of the study is that while stimulant-users had a higher baseline rate of risky responses than stimulant-naïve controls, punishment affected both groups’ subsequent responses equally. This is consistent with the interpretation that SU individuals were more heavily influenced by rewards, i.e. the prospect of gaining 40 or 80 points during the RGT task, but not that they were less influenced by punishments, since both SU and SN subjects showed the same reduced frequency of risky responding immediately following punishment. The SU group was more prone to be sensation-seeking and impulsive, and measures of these traits correlated with risk-taking in the task in the overall sample.

The observation that SU and SN individuals were equally sensitive to preceding-trial punishments and to the outcomes of previous trials at various lags stands in contrast to Lane and Cherek’s findings with high risk-taking adults (2000) and adolescents (2001), who were more likely than controls to continue making risky responses during a streak of negative outcomes in their risk task. There are several possible reasons for the discrepancy. One is age difference, as subjects in their adult study ranged in age from 18–40, with a mean of 27.9 years, and subjects in their adolescent study were between 15 and 17 years old (mean 16.1 years), while subjects in this one were between 17 and 21 (mean 18.4 years). Moreover, 60% of Lane and Cherek’s high-risk adolescents and 62% of their high-risk adults had a history of drug or alcohol dependence, but they were not necessarily stimulant-users. Substance users in this experiment, meanwhile, were selected specifically on the basis of their stimulant use but were not necessarily stimulant-dependent.

The correlation between risk-taking on the RGT and Zuckerman Sensation Seeking and Barratt Impulsiveness Scale total is consistent with the findings of Lejuez et al. (2002) using the Balloon Analogue Risk Task. Both tasks involve increasing risk over the course of each trial, although while this is subject-paced in the BART (subjects increase risk by adding pumps to a virtual balloon), choices become riskier in the RGT according to a fixed time course, creating time pressure. Surprisingly, the BIS subscale score that correlated most strongly with risk-taking in the RGT is motor impulsive-

ness and not attention or planning impulsiveness. Because the RGT options change during a trial from safer to riskier, to the extent that motor impulsivity is associated with earlier responses, it might be expected to lead to safer choices in the task. The motor-related questions on the BIS do not, however, relate to simple motor responses as much as impulsivity that is manifest in observable behavior (as opposed to the mental operations on which the attention and planning subscales focus). Notably, the experiments using the BART with an adolescent population (Lejuez et al., 2003b) and to differentiate smokers and non-smokers (Lejuez et al., 2003a) did not replicate correlations between task performance and personality measures (impulsivity and sensation-seeking). The absence of such correlations was also reported in Lane and Cherek's (2000) adult study, although no correlational analyses were reported for the adolescent study (2001). Those four studies involved far fewer subjects than this study and the original BART study ($n = 86$) and may not have had the statistical power necessary to reveal such relationships.

Differences in the risk tasks themselves may be critical both to understanding divergent findings and appreciating the generalizability of convergent results. The RGT is unusual in that it includes an element of time pressure. Subjects cannot deliberate at length on simultaneously available choices but must act within certain "windows of opportunity" when deciding whether to accept a safe bet or to pass it up for a bigger risk (i.e. larger reward but possibility of a correspondingly large penalty). Normative strategies in risk tasks and how subjects perform relative to them are likewise important to consider. The Bechara Gambling Task as well as Lane and Cherek's task have highest expected values for the "conservative" mode of response, i.e. choosing options that result in small or no immediate gains rather than the potential for large gains but a net loss, and substance abusers typically take longer than controls to realize the better strategy if they do at all. The BART, with its simultaneously incrementing gains and risks, has an expected value that depends on the number of contiguous "risky" responses, increasing to a peak and then dropping back down with continued risk-taking. Interestingly, subjects performing the task tend to be suboptimally risk-averse, even the smokers who take greater risks than non-smokers. In the RGT, meanwhile, contingencies are designed such that the risky and safe responding modes have the same expected value. These differences introduce more sources of variation and can make direct comparison of results more difficult. On the other hand, the use of different tasks and task parameters with varying levels of normative risk-taking is necessary to fully model risk-taking decision-making, given that the optimal level of risk-taking in daily life may be highly context dependent. Likewise, tasks with and without time pressure elements are needed to model both deliberative and fast-paced decision situations.

The lack of subject compensation may have contributed to the divergent findings with the RGT as compared to other tasks. While the Bechara Gambling Task has not always been used with performance-based rewards, the studies described

above using other tasks provided monetary or similar compensation that participants believed were related to task performance (whether or not that was the case). In this study, subjects received a consistent amount of experimental participation credit for enrolled courses. Participants' decision-making may have differed given the prospect of monetary or other material incentives, or if rewards were based (ostensibly or genuinely) on task performance. Gains and losses might have been more salient if they represented actual monetary consequences and such an increase in salience could have differed between groups.

Drug use data were obtained by self-report. Although some investigators have questioned the reliability of self-report measures, particularly in individuals with drug abuse problems, others have found them to be reliable. In a large cohort study, for instance, responses for opiate-dependent individuals were found to be reliable (Amsel et al., 1976). Moreover, a high level of agreement between self-report and random drug testing has been observed in individuals with drug related problems (Brown et al., 1992). Hser (1997) concluded in a review that although the degree of reliability varied across different substance-using populations, in general reliability and validity of self-report measures obtained from these individuals were high.

No face-to-face structured clinical interviews were administered to determine the chronology of drug use or the presence of substance dependence, which could be associated with decision-making deficits or biases not present in non-dependent users. Given the mean of roughly nine lifetime uses of stimulants among the users, however, it is unlikely that stimulant dependence was a characteristic of more than a few, if any, of those individuals. Stimulant-users may have varied in the recency of their last use, so it is important that group difference findings be interpreted with the understanding that the stimulant-users were all stimulant-exposed but not necessarily current users.

Most stimulant-users in the study also had experience with other drugs. Conversely, control subjects were not only stimulant-naïve but also had far fewer experiences with other drugs of abuse. Given the significant differences between SU and SN groups across most assessed categories of illicit drug use, the findings in this study may not be specific to stimulant use per se and may be more reflective of the risk-taking decision-making associated with substance use more generally. It should be noted, however, that only stimulant use was a significant predictor of risky responses in a step-wise regression including the various illicit substances assessed. Regression using extent of use rather than simply use or non-use may be more revealing and should be considered when there are enough drug-using subjects to give such an analysis sufficient power.

As mentioned above, stimulant-users in this study were not necessarily (and in most cases not likely) stimulant-dependent. According to a recent summary of six international epidemiological studies (Merikangas et al., 1998), drug use is reported by approximately 51.5% of the subjects in the

United States (Warner et al., 1995). In comparison, problems associated with drug use are reported in 15.5%, and substance dependence is found in 7.5% of the subjects (Merikangas et al., 1998). Thus, the rate of use versus dependence is approximately 1:7. While this study's stimulant-using group was not hyposensitive to punishments, it is possible that stimulant dependence and/or increased risk for future dependence are associated with higher sensitivity to rewards and lower sensitivity to punishments, and that this could be revealed by the RGT. Testing one stimulant-using group at one time cannot, however, reveal the direction of causality, i.e. whether stimulant use/dependence produces differences in decision-making or is a consequence of them. We will address these important questions in future research using the RGT with stimulant-dependent individuals and in a longitudinal study tracking stimulant-users as they do or do not develop dependence.

Acknowledgements

This research was supported by grants from NIMH (R21DA13186, R01DA016663) and by a VA Merit Grant. We would like to acknowledge the invaluable help of Kelly Winternheimer and Thuy Le in conducting the experiments.

References

- Amsel, Z., Mandell, W., Matthias, L., Mason, C., Hocherman, I., 1976. Reliability and validity of self-reported illegal activities and drug-use collected from narcotic addicts. *Int. J. Addict.* 11 (2), 325–336.
- Balfour, D.J., 2002. The neurobiology of tobacco dependence: a commentary. *Respiration* 69 (1), 7–11.
- Bechara, A., Damasio, A.R., Damasio, H., Anderson, S.W., 1994. Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition* 50, 7–15.
- Bechara, A., Dolan, S., Denburg, N., Hinds, A., Anderson, S.W., Nathan, P.E., 2001. Decision-making deficits, linked to a dysfunctional ventromedial prefrontal cortex, revealed in alcohol and stimulant abusers. *Neuropsychologia* 39 (4), 376–389.
- Bohn, M.J., Babor, T.F., Kranzler, H.R., 1995. The Alcohol-Use Disorders Identification Test (AUDIT)—validation of a screening instrument for use in medical settings. *J. Stud. Alcohol* 56 (4), 423–432.
- Brown, J., Kranzler, H.R., Delboca, F.K., 1992. Self-reports by alcohol and drug-abuse inpatients—factors affecting reliability and validity. *Br. J. Addict.* 87 (7), 1013–1024.
- Brown, S.A., Myers, M.G., Lippke, L., Tapert, S.F., Stewart, D.G., Vik, P.W., 1998. Psychometric evaluation of the customary drinking and drug use record (CDDR): a measure of adolescent alcohol and drug involvement. *J. Stud. Alcohol* 59 (4), 427–438.
- Calfee, R.C., Atkinson, R.C., 1966. Two-choice behavior under limiting cases of contingent reinforcement schedules. *J. Comp. Physiol. Psychol.* 62 (2), 193–200.
- Chambers, R.A., Taylor, J.R., Potenza, M.N., 2003. Developmental neurocircuitry of motivation in adolescence: a critical period of addiction vulnerability. *Am. J. Psychiatry*. 160 (6), 1041–1052.
- Costa, P.T., McCrae, R.R., 1992. The 5-Factor Model of personality and its relevance to personality-disorders. *J. Personal. Disord.* 6 (4), 343–359.
- Costa, P.T., McCrae, R.R., 2000. Stability and change in personality assessment: the revised NEO Personality Inventory in the year. *J. Pers. Assess.* 68 (1), 86–94.
- Egelman, D.M., Person, C., Montague, P.R., 1998. A computational role for dopamine delivery in human decision-making. *J. Cogn. Neurosci.* 10 (5), 623–630.
- Goulet, L.R., Barclay, A., 1967. Guessing behavior of normal and retarded children under two random reinforcement conditions. *Child Dev.* 38 (2), 545–552.
- Grant, B.F., Dawson, D.A., 1998. Age of onset of drug use and its association with DSM-IV drug abuse and dependence: results from the National Longitudinal Alcohol Epidemiologic Survey. *J. Subst. Abuse.* 10 (2), 163–173.
- Grant, S., Contoreggi, C., London, E.D., 2000. Drug abusers show impaired performance in a laboratory test of decision making. *Neuropsychologia* 38 (8), 1180–1187.
- Herzel, H., Grosse, I., 1995. Measuring correlations in symbol sequences. *Physica A* 216 (4), 518–542.
- Hser, Y.I., 1997. Self-reported drug use: results of selected empirical investigations of validity. *NIDA Res. Monogr.* 167, 320–343.
- Huber, O., Kuhberger, A., 1996. Decision processes and decision trees in gambles and more natural decision tasks. *J. Psychol.* 130 (3), 329–339.
- Huber, V.L., Neale, M.A., Northcraft, G.B., 1987. Decision bias and personnel selection strategies. *Organ. Behav. Hum. Perform.* 40 (1), 136–147.
- Lane, S.D., Cherek, D.R., 2000. Analysis of risk taking in adults with a history of high risk behavior. *Drug Alcohol Depend.* 60 (2), 179–187.
- Lane, S.D., Cherek, D.R., 2001. Risk taking by adolescents with maladaptive behavior histories. *Exp. Clin. Psychopharmacol.* 9 (1), 74–82.
- Lejuez, C.W., Aklin, W.M., Jones, H.A., Richards, J.B., Strong, D.R., Kahler, C.W., et al., 2003a. The Balloon Analogue Risk Task (BART) differentiates smokers and nonsmokers. *Exp. Clin. Psychopharmacol.* 11 (1), 26–33.
- Lejuez, C.W., Aklin, W.M., Zvolensky, M.J., Pedulla, C.M., 2003b. Evaluation of the Balloon Analogue Risk Task (BART) as a predictor of adolescent real-world risk-taking behaviours. *J. Adolesc.* 26 (4), 475–479.
- Lejuez, C.W., Read, J.P., Kahler, C.W., Richards, J.B., Ramsey, S.E., Stuart, G.L., et al., 2002. Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *J. Exp. Psychol. Appl.* 8 (2), 75–84.
- Luce, R.D., 1959. *Individual Choice Behavior: A Theoretical Analysis*. Wiley, New York.
- Ludvigson, H.W., 1966. Response units in the prediction of simple event patterns. *J. Exp. Psychol.* 72 (3), 335–360.
- Mattick, R.P., Clarke, J.C., 1998. Development and validation of measures of social phobia scrutiny fear and social interaction anxiety. *Behav. Res. Ther.* 36 (4), 455–470.
- Mellers, B.A., Cooke, A.D.J., 1996. The role of task and context in preference measurement. *Psychol. Sci.* 7 (2), 76–82.
- Mellers, B.A., Ordonez, L.D., Birnbaum, M.H., 1992. A change-of-process theory for contextual effects and preference reversals in risky decision making. *Organ. Behav. Hum. Perform.* 52 (3), 331–369.
- Mellers, B.A., Schwartz, A., Cooke, A.D.J., 1998. Judgment and decision making. *Ann. Rev. Psychol.* 49, 447–477.
- Mellers, B.A., Schwartz, A., Weber, E.U., 1997. Do risk attitudes reflect in the eye of the beholder? In: Marley, A.A.J. (Ed.), *Choice, Decision, and Measurement: Essays in Honor of R. Duncan Luce*. L. Erlbaum, Mahwah, NJ, pp. 57–71.
- Merikangas, K.R., Mehta, R.L., Molnar, B.E., Walters, E.E., Swendsen, J.D., Aguilar-Gaziola, S., et al., 1998. Comorbidity of substance use disorders with mood and anxiety disorders: results of the International Consortium in Psychiatric Epidemiology. *Addict. Behav.* 23 (6), 893–907.
- Monterosso, J., Ehrman, R., Napier, K.L., O'Brien, C.P., Childress, A.R., 2001. Three decision-making tasks in cocaine-dependent patients: do they measure the same construct? *Addiction* 96 (12), 1825–1837.

- Norusis, M.J., 1990. *SPSS Base System User's Guide*. SPSS Inc., Chicago.
- Patton, J.H., Stanford, M.S., Barratt, E.S., 1995. Factor structure of the Barratt Impulsiveness Scale. *J. Clin. Psychol.* 51 (6), 768–774.
- Paulus, M.P., Rogalsky, C., Simmons, A., Feinstein, J.S., Stein, M.B., 2003. Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. *Neuroimage* 19 (4), 1439–1448.
- Payne, J.W., Bettman, J.R., Luce, M.F., 1996. When time is money: decision behavior under opportunity-cost time pressure. *Organ. Behav. Hum. Perform.* 66 (2), 131–152.
- Petry, N.M., 2001. Substance abuse, pathological gambling, and impulsiveness. *Drug Alcohol Depend.* 63 (1), 29–38.
- Petry, N.M., Bickel, W.K., Arnett, M., 1998. Shortened time horizons and insensitivity to future consequences in heroin addicts. *Addiction* 93 (5), 729–738.
- Rotheram-Fuller, E., Shoptaw, S., Berman, S.M., London, E.D., 2004. Impaired performance in a test of decision-making by opiate-dependent tobacco smokers. *Drug Alcohol Depend.* 73 (1), 79–86.
- Schwartz, J.P., Norman, K.L., 1989. Separating cue relevance from cue importance within models of judgment and decision making. *Organ. Behav. Hum. Perform.* 43 (3), 355–384.
- Slovic, P., 1972. Information processing, situation specificity, and the generality of risk-taking behavior. *J. Pers. Soc. Psychol.* 22 (1), 128–134.
- Slovic, P., 1987. Perception of risk. *Science* 236 (4799), 280–285.
- Slovic, P., Lichtenstein, S., 1968. Relative importance of probabilities and payoffs in risk taking. *J. Exp. Psychol.* 78 (3 Pt. 2), 18.
- Spielberger, C.D., 1983. *Manual for the State-Trait Anxiety Inventory (Form Y)*. Consulting Psychologists Press, Palo Alto, CA.
- Tversky, A., Kahneman, D., 1981. The framing of decisions and the psychology of choice. *Science* 211 (4481), 453–458.
- Tversky, A., Sattath, S., Slovic, P., 1988. Contingent weighting in judgment and choice. *Psychol. Rev.* 95 (3), 371–384.
- Wagner, F.A., Anthony, J.C., 2002. From first drug use to drug dependence. Developmental periods of risk for dependence upon marijuana, cocaine, and alcohol. *Neuropsychopharmacology* 26 (4), 479–488.
- Warner, L.A., Kessler, R.C., Hughes, M., Anthony, J.C., Nelson, C.B., 1995. Prevalence and correlates of drug use and dependence in the United States. Results from the National Comorbidity Survey. *Arch. Gen. Psychiatry* 52 (3), 219–229.
- Zuckerman, M., Eysenck, S., Eysenck, H.J., 1978. Sensation seeking in England and America—cross-cultural, age, and sex comparisons. *J. Consult Clin. Psychol.* 46 (1), 139–149.