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Research report

The dark side of emotion in decision-making: When individuals with decreased emotional reactions make more advantageous decisions

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Abstract

Can dysfunction in neural systems subserving emotion lead, under certain circumstances, to more advantageous decisions? To answer this question, we investigated how individuals with substance dependence (ISD), patients with stable focal lesions in brain regions related to emotion (lesion patients), and normal participants (normal controls) made 20 rounds of investment decisions. Like lesion patients, ISD made more advantageous decisions and ultimately earned more money from their investments than the normal controls. When normal controls either won or lost money on an investment round, they adopted a conservative strategy and became more reluctant to invest on the subsequent round, suggesting that they were more affected than lesion patients and ISD by the outcomes of decisions made in the previous rounds.

Theme: Substance dependence and risk-taking behavoir
Topic: Emotion

Keywords: Decision-making; Individuals with substance dependence; Investment task

1. Introduction

Although orbitofrontal cortex abnormalities have been observed in individuals with substance dependence (ISD) for several years [10,30,42,44,45], very little attention was paid to the role of the prefrontal cortex in addiction. However, patients with damage to the ventromedial region of the prefrontal cortex (VMPFC) and individuals with substance dependence show similar behaviors: (1) they often deny, or they are not aware, that they have a problem; and (2) when faced with a choice to pursue a course of action that brings an immediate reward, at the risk of incurring future negative consequences, including the loss of reputation, job, home, and family, they choose the immediate reward and ignore the future consequences. Because of this "myopia" for future consequences seen in VMPFC patients and ISD, the first attempt to establish a link between the two using strategies applied to the study decision-making in neurological patients was conducted by Grant and colleagues, who investigated the mechanisms of decision-making in cocaine addicts using the Iowa Gambling Task (IGT) [2,22–24]. Since then, several groups have used similar strategies and found a relationship between substance abuse and poor decision-making [31,35,37]. We have also used strategies applied to the study of decision-making and its influence by emotions in neurological patients, and we investigated these mechanisms in ISD. Studies have shown that the abnormal mechanisms of processing drug reward in ISD generalize to other rewards, including monetary reward [8,9]. This explains the abnormalities found in ISD when processing reward and punishment information that are not related to drugs, but rather information related to reward and punishment in general, such as the monetary reward used in the IGT paradigm.

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All results from these previous studies are in line with an increasing body of research in neuroscience and psychology that has highlighted the positive roles played by emotions in decision-making [3,11,15,16,27,28,34,36]. Despite growing evidence that ISD and patients who are dysfunctional in their capacity to process emotional information normally, which is critical for helping individuals make decisions that are advantageous in the long term, there are reasons to believe that, under certain circumstances, such individuals might actually make better decisions than normal individuals [11]. An example described by Damasio [11] concerns a patient with damage to the orbitofrontal region of the prefrontal cortex who was driving under hazardous road conditions. While other drivers were hitting their brakes in panic on an icy patch, causing their vehicles to skid out of control, the patient crossed the icy patch unperturbed, gently pulling away from a tailspin, and driving ahead safely. The patient remembered the fact that not hitting the brakes was the appropriate behavior, and his lack of fear allowed him to perform optimally. A broad thrust of this research is to delve into this latter possibility, that ISD, who have abnormal emotional reactions that perhaps translate into "fear" (conscious or unconscious) of the negative consequences of their drug use in real-life, might, in certain situations, demonstrate advantage in making rational decisions. Indeed, most of us learn from early on in life, that logical, rational calculation forms the basis of sound decisions. Many people say that emotion can only cloud the mind and interfere with good rational decisions. Thus, can we reconcile these opposing views regarding the role of emotions in decisions? Can we demonstrate instances in which individuals who lost their capacity to process emotional information normally make more advantageous decisions than normal individuals? The primary goal of this study was to reveal this negative side of emotions in decision-making in (1) a group of individuals with substance dependence (ISD), (2) a group of patients with focal brain lesions known to be critical for processing emotional information, and (3) a comparison group of normal healthy individuals. In relation to the group of patients with brain lesions, we included patients with either bilateral damage to the ventromedial region of the prefrontal cortex (which includes the orbitofrontal region), or right side damage to the insular/somatosensory cortex. The rationale for including both types of lesions was that (1) damage to either area leads to severe deficits in emotions and decision-making [4,11], and (2) most importantly, previous evidence has suggested that ISD may have abnormalities in any one, or both, of these two regions, i.e., the ventromedial prefrontal and insular/somatosensory cortex [5].

Recent evidence suggests that even relatively mild negative emotions can play a counterproductive role among normal individuals in some situations [7]. Most people display extreme levels of risk aversion toward gambles that involve some possible loss, when the gambles are presented one-at-a-time, a condition known as "myopic loss aversion" [7]. For example, most people will not voluntarily accept a 50–50 chance to gain $200 or lose $150, despite the gamble's high expected return. Myopic loss aversion has been advanced as an explanation for the large number of individuals who prefer to invest in bonds, even though stocks have historically provided a much higher rate of return, a pattern that economists refer to as the "equity premium puzzle" [33,40].

In line with research showing (1) that neurological patients with focal brain damage in areas (e.g., VMPFC and insular/somatosensory cortex) that hinder their capacity to process emotional information normally take risks in pursuing actions even when they result in catastrophic losses [4], and (2) based on anecdotal evidence mentioned earlier, which suggest that such patients may, under certain circumstances, behave more efficiently than normal subjects [11], Shiv et al. [39] found that these same patients make more advantageous decisions than normal subjects when faced with the types of positive expected value gambles highlighted above. Specifically, Shiv et al. [39] used a decision-making instrument known as the 'investment task,' which simulates real-life investment decisions in terms of uncertainties, rewards, and punishments. The task, closely modeled after a paradigm developed in previous research to demonstrate myopic loss aversion [21], was designed in such a way that the rational choice of participants would be to invest in every single round because the expected value on each round was higher if one invested than if one did not. The results revealed that lesion patients with abnormal emotional circuitry experienced less myopic loss aversion, and made more advantageous decisions. In other words, they earned more money by investing in more rounds than individuals with an intact emotional circuitry. These results suggest that dysfunction in neural systems subserving emotion leads to reduced levels of risk aversion, and, thus, leads to more advantageous decisions in cases where risk-taking is rewarded.

In this study, we tested the hypothesis that ISD, who have also been shown in previous research to suffer from abnormalities in neural systems critical for processing emotional information, would make more advantageous decisions in the investment task, similar to the lesion patients. Such a finding would provide additional support for the idea that emotions play an important role in decisions to take or avoid risks.

We note that our use of the term "emotion" is in a broad sense. It includes "affect", and is central to "somatic markers", a concept that was developed to address the problems of decision-making encountered in patients with certain kinds of prefrontal damage and with compromised emotions. As explained by Damasio in 1994 [11] "*somatic markers are a special instance of feelings generated from secondary emotions. Those emotions and feelings have been connected by learning to predicted future outcomes of certain scenarios. When a negative somatic marker is juxtaposed to a particular future outcome the combination*

functions as an alarm bell. When a positive somatic marker is juxtaposed instead, it becomes a beacon of incentive". Thus, somatic markers are emotion-related signals, which can be either conscious or unconscious, and were always conceived as bioregulatory signals of the sort that expresses themselves as emotions. On that basis, we apply the term "emotion" to the type of task manipulations carried out in the present study.

Table 1
Demographics of subjects who participated in the study

	Lesion patients	ISD	Normal controls
Total *N*	12	32	19
Age (years): mean ± SD	56.7 ± 12.4	32.9 ± 7.2	47.5 ± 14.2
Gender (M/F)	6M/6F	16M/16F	7M/12F
Education (years): mean ± SD	13.4 ± 2.7	12.8 ± 2.1	14.9 ± 2.7

2. Methods

2.1. Subjects

We recruited normal controls (n = 19) through a local advertisement. The selection criteria of normal subjects include the absence of a history of mental retardation, learning disability, psychiatric disorder, substance abuse, neurological disorder, or systemic disease that may affect the central nervous system, based on clinical interviews conducted with these subjects before their induction. All normal control subjects were paid for their participation.

Individuals with substance dependence (ISD) (n = 32) were brought for testing shortly before their completion of a drug rehabilitation treatment at the Mid-Eastern Center for Chemical Abuse (MECCA). All ISD were paid for their participation in gift certificates at an hourly rate that was identical to that of normal controls. The selection criteria for ISD were (1) meeting the DSM-IV criteria for substance dependence; (2) absence of psychosis; (3) absence of any current major depressive episodes; (4) absence of other psychiatric conditions determined by the co-morbid psychopathology score; and (5) no documented head injury or seizure disorder.

Lesions patients (n = 12) were selected from the Patient Registry of the University of Iowa's Division of Behavioral Neurology and Cognitive Neuroscience. All patients had undergone basic neuropsychological assessment [43] and neuroanatomical characterization [12–14].

All participants were adults (>18 years old) and provided informed consent that was approved by the appropriate human subject committees at the University of Iowa. The demographic data on the two groups are presented in Table 1.

2.2. Characteristics of the ISD, control, and lesion patient groups

After screening, qualified participants were interviewed to assess the presence of psychiatric disease.

In this study, all ISD were inpatients that had been admitted to MECCA for detoxification and treatment. All ISD had experienced serious substance abuse problems in the past that had required professional intervention, which was the reason for their treatment. The duration of abstinence from substance use was known in these participants based on their length of stay at MECCA. Each ISD was tested at the end-stage of their treatment, i.e., shortly before their discharge. The time varied among individuals, but the minimum period of abstinence from any substance use was 15 days. Thus, at the time of their testing, the ISD were no longer in acute withdrawal or taking any medications to control withdrawal (e.g., benzodiazepines).

Urine toxicology screening for opiates, stimulants, marijuana, and breathalyzers tests were conducted on these ISD immediately before testing. However, these ISD were also routinely checked at MECCA, including the day before they were brought for testing. Therefore, not only very recent substance use can be ruled out, but also it is reasonable to rule out the use of substances during the entire period of abstinence. The primary drug of choice, the duration of abstinence, and the total number of years of abuse were obtained from verbal reports and available information from MECCA, as shown in Table 2.

The Structured Clinical Interview for DSM-IV (SCID-IV) was used to assign Axis I diagnoses (including alcohol and other drug abuse and/or dependence). We used a comprehensive self-report version of the SCID [20], which covers fewer areas of psychopathology, and thus requires a shorter time for administration. The areas of co-morbid psychopathologies that we probed with the SCID were:

a. *Psychoses*: Any ISD who met the criteria for psychoses was excluded.
b. *Current Major Depressive Episode* (*MDE*): Any ISD who met the criteria for current MDE was excluded from the study.
c. *A history of MDE or Major Depressive Disorder*: ISD with a history of MDE were not excluded. However, we assigned either a score of 1 (i.e., present) or 0 (i.e., absent).
d. *Current Anxiety Disorder including Panic*, *Agoraphobia*, *Obsessive–Compulsive Disorder* (*OCD*), *Post-Traumatic Stress Disorder* (*PTSD*), *Generalized Anxiety Disorder* (*GAD*), *Social Phobia*, *or any specific phobia*: ISD meeting these diagnoses were not excluded. However, we assigned scores of 0 (i.e., absent), 1 (i.e., 1 anxiety disorder is present), or 2 (i.e., 2 anxiety disorders or more are present).
e. *A history of anxiety disorder*: We assigned scores of 0 (i.e., absent), 1 (i.e., 1 anxiety disorder was present), or 2 (i.e., 2 anxiety disorders or more were present).

Table 2
Drug histories of SDI who participated in the study

Primary drug of choice (Used > 80% of the time)		Secondary or occasional drug use
Alcohol (*N*)	9	
Cocaine/Crack (*N*)	9	Alcohol, Cannabis, Amphetamine
Metamphetamine (*N*)	14	Alcohol, Cannabis, Cocaine
Abstinence in days: mean ± SD	32.7 ± 16.0	
Times in treatment: mean ± SD	11.0 ± 20.1	
Years of abuse: mean ± SD	10.2 ± 7.2	

f. *Other diagnoses*: This included current or a history of Attention Deficit and Hyperactivity Disorder (ADHD), Anorexia Nervosa, or Bulimia Nervosa. We assigned a score of 0 (i.e., absent), 1 (i.e., one disorder is present), or 2 (i.e., more than 1 disorder is present).

2.2.1. Co-morbid psychopathology score

In order to obtain an index of the co-morbid psychopathologies present in an individual subject, we obtained the sum of scores from the psychopathologies listed above for each participant. ISD with co-morbid psychopathology score >3 were excluded from the study.

Normal participants were subjected to the same screening protocol. Any individual who demonstrated a history of mental retardation, learning disability, psychiatric disorder, substance abuse, or any systemic disease capable of affecting the central nervous system was a candidate for exclusion.

The selection of lesion patients conformed to the above criteria for normal controls. In addition, the patients had to have chronic and stable focal lesion (at least 3 months post onset) in the ventromedial sector of the prefrontal cortex including the orbitofrontal region (bilaterally; 8 patients), or the right insular/somatosensory cortex (4 patients). The reason we selected both regions is because previous evidence has suggested that ISD may be affected in any one of these two regions [5], both of which are known to be critical for the processing of emotions [11,15,16,27,36,38]. All these lesion patients have been shown in other studies to perform poorly on the Iowa Gambling Task [6] and to have low emotional intelligence as measured by the Emotional Quotient Inventory (EQi) [1].

2.3. Investment task

At the beginning of the experiment, each participant was endowed with $20 of play money, which they were told to treat as real because they would receive a gift certificate for the amount they were left with at the end of the study. Participants were told that they would be making several rounds of investment decisions, and that, in each round, they had to make a decision between two options: invest $1 or not invest. If the decision were not to invest, they would keep the dollar, and the task would advance to the next round. If the decision were to invest, they would hand over a dollar bill to the experimenter. The experimenter would then toss a coin in plain view of the subject. If the outcome of the toss were heads (50% chance), then they would lose the $1 that was invested; if the outcome of the toss were tails (50% chance), then $2.50 would be added to the participant's account. The task would then advance to the next round.

The task consisted of 20 rounds of investment decisions and the three groups of participants took roughly the same time on the task. Note that, as indicated earlier, the design of the investment task is such that it would behoove participants to invest in all the 20 rounds because the expected value on each round is higher if one invests ($1.25) than if one does not ($1). In fact, if one invests on each and every round, there is only around a 13% chance of obtaining lower total earnings than if one does not invest in every round and simply keeps the $20. However, our conceptualized differences between normal participants and lesion patients/ISD would suggest that normal participants would behave sub-optimally, investing in fewer rounds and, thus, end up making less money compared to lesion patients and ISD.

2.4. Statistical method

To provide support for the core predictions highlighted earlier, and for several other analyses that we carried out to provide support to our conceptualization, we used a more conservative non-parametric (Wilcoxon) test.

3. Results

As indicated earlier, three groups of participants engaged in the experimental task: 19 normal controls, 12 lesion patients, and 32 individuals with substance dependence (ISD). No significant differences in demographics had emerged among these groups. We note that the mean age for ISD was smaller than the rest. However, the lesion patients included young and older individuals, and the control group was selected to match, as much as possible, the demographics of all target subjects, so that there were great overlap in age, and the difference was not statistically significant.

Table 3
Mean (median) percentage of decisions to invest-overall and following what occurred on previous rounds

	Lesion patients	ISD	Normal controls
Decision to invest—overall	83.3% (90%)	80.9% (95%)	57.6% (50%)
No invest on previous round	70.2% (66.7%)	63.4% (75%)	64.4% (77.8%)
Invest and lost on previous round	85.4% (95.5%)	81.8% (100%)	40.5% (33.3%)
Invest and won on previous round	84.2% (100%)	84.6% (100%)	61.7% (66.7%)

3.1. Overall proportion of rounds invested and amounts earned

Examination of the proportion of the 20 rounds in which participants decided to invest reveals that, like the lesion patients, ISD made decisions that were closer to a profit-maximizing viewpoint (see Table 3 for mean percentages; corresponding medians are presented in parentheses; we also note that the results reported in this section were no different across the various subgroups of ISD). Specifically, as compared to normal controls who invested in 57.6% (median = 50%) of the rounds, lesion patients invested in 83.3% (median = 90%) of the rounds on average (Wilcoxon two-sample test statistic = 257, $P < 0.004$). Like lesion patients, ISD invested in 80.9% (median = 95%) of the rounds on average, which was higher than the number of rounds normal controls invested in (Wilcoxon two-sample test statistic = 345, $P < 0.002$). Further, as hypothesized, ISD earned more money over the 20 rounds of the experiment ($27.20, on average; median = $27.25) than did normal participants ($22.8, on average; median = $22.5; Wilcoxon statistic = 341, $P < 0.002$). Lesion patients also earned more money ($24.60, on average; median = $24) than normal participants (Wilcoxon statistic = 223.5, $P < 0.10$).

3.2. Alternative account for the basic findings

While we propose an emotion-based explanation to account for our core predictions, the results presented in the previous section can also be accounted for by a more cognitive-based explanation. Specifically, it is quite possible that normal participants made more disadvantageous decisions by adopting an erroneous, cognitively-based heuristic while making their decisions. For example, unlike lesion patients and ISD, normal participants might have calculated the expected value on each round by subtracted the cost of the investing on each round from the final outcome as follows: Expected Value = 0.5 ($2.50 − $1.00) = 0.5 ($1.50) = $0.75, and, thereby, underestimated the expected value of each trial, making investing on each round seem disadvantageous relative to not investing. We attempt to rule out this alternative, cognitive-based account in the sections below.

3.3. Proportion of rounds invested in four blocks of five rounds each

Fig. 1 shows the mean proportion of rounds in which participants decided to invest in four blocks of five rounds each (corresponding medians are presented below Fig. 1). The pattern of results suggests that normal participants made fewer investment decisions in the final block than in the initial block (difference on the mean percentages = 22.1) compared to lesion patients (corresponding difference = 6.6%; Wilcoxon statistic = 232.5, $P < 0.05$) and ISD (corresponding difference = 5.6%; Wilcoxon statistic = 381, $P < 0.01$). Stated differently, the results suggest that all three groups of participants seemed to start off with the investment task closer to the normative benchmark. However, unlike lesion patients and ISD who remained close to the normative benchmark, normal participants seemed to become more conservative, investing in fewer rounds, as the investment task progressed.

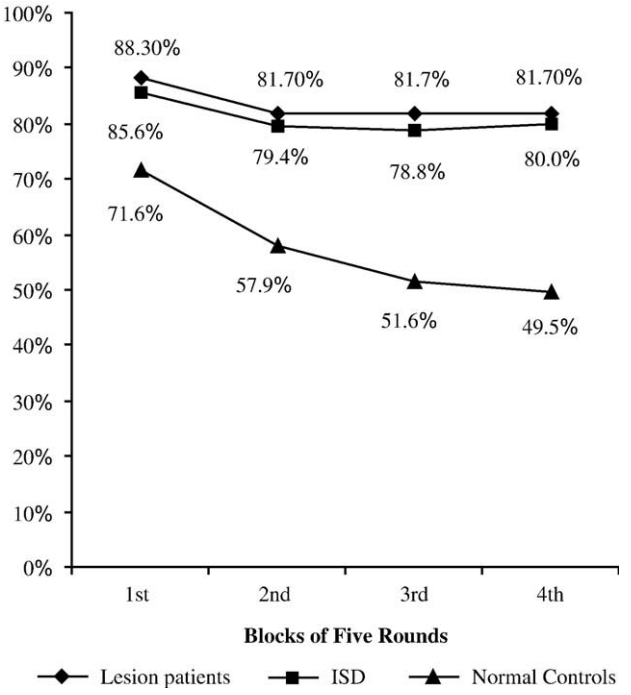

Fig. 1. Mean percentage of rounds in which participants decided to invest $1. Corresponding median percentages across the 1st, 2nd, 3rd, and 4th blocks, respectively, were as follows. Lesion patients: 100%, 90%, 80%, and 100%; ISD: 100%, 100%, 100%, and 100%; Normal Controls: 80%, 60%, 40%, and 40%.

Note that the pattern of results across the four blocks of rounds reduces the viability of the alternative, cognitively-based account. If normal participants had been using an erroneous heuristic (i.e., underestimating the expected value of each trial, thereby, making investing on each round seem disadvantageous), they should have been investing less often uniformly across all blocks of rounds compared to patients and ISD. This does not seem to be the case.

3.4. Impact of outcomes on previous rounds on decisions in subsequent rounds

A lagged logistic regression analysis was carried out to delve into potential differences between ISD and lesion patients, on one hand, and normal "control" participants, on the other, in the way they made decisions in the investment task. The goal of the analysis was to examine whether the decision/outcome combination in preceding rounds (did not invest, invested and won, invested and lost) affected decisions made on successive rounds more so for control

participants than for ISD and lesion patients. The dependent variable, *decision*, in the logistic regression analysis was whether the decision on a particular round was to invest (coded as 1) or not invest (coded as 0). The independent variables were several dummies that were created for the analysis. These variables included *control* (coded as 1 for control participants, 0 otherwise), *invest-won* (coded as 1 if the participant invested on the previous round and won, 0 otherwise), *invest-lost* (coded as 1 if the participant invested on the previous round and lost, 0 otherwise), and participant-specific dummies (e.g., *dummy1*, coded as 1 for participant 1, 0 otherwise). The overall logit model that was tested was: *decision = control invest-won invest-lost control * invest-won control * invest-lost dummy1 dummy2 etc*. Note that any significant interactions would indicate that the effects of the decisions and outcomes in preceding rounds on decisions made in successive rounds were different for normal participants compared to ISD and lesion patients.

Both interactions in the logit model were significant: *control * invest-won* (chi-square = 4.91, $P < 0.03$); *control * invest-lost* (chi-square = 18.74, $P < 0.0001$). These results suggest that normal participants behaved differently than ISD and lesion patients both when they had won on the previous round, and when they had lost. As detailed in Table 3, which examines the proportions of normal participants, lesion patients, and ISD who invested as a function of the decision/outcome on the previous round, only normal participants were more likely to withdraw from risk-taking *both* when they lost on the previous round *and* when they won. Compared to normal participants who invested in only 40.5% of the rounds following losses (median = 33.3%), lesion patients invested in 85.4% of rounds (median = 95.5%; Wilcoxon statistic = 262.5, $P < 0.002$), and ISD participants invested in 81.8% of the rounds following such losses (median = 100%; Wilcoxon statistic = 317, $P < 0.0002$). Similarly, compared to normal participants who invested in only 61.7% of rounds following wins (median = 66.7%), lesion patients invested in 84.2% of rounds (median = 100%; Wilcoxon statistic = 240.5, $P < 0.02$), and ISD invested in 84.6% of rounds following such wins (median = 100%; Wilcoxon statistic = 360, $P = 0.003$).

These results suggest that normal participants were likely to avoid risk (be more conservative) regardless of winning or losing in the previous round. Further, the results suggest that normal participants were considerably less risk aversive following wins than following losses (normals: 61.7% vs. 40.5%, a difference of 21.2% on mean percentages; 66.7% vs. 33.3%, a difference of 33.4% on median percentages) compared to lesion patients (84.2% vs. 85.4%, a difference of −1.2% on mean percentages; 100% vs. 95.5%, a difference of 4.5% on median percentages), and ISD (84.6% vs. 81.8%, a difference of 2.8% on mean percentages; 100% vs. 100%, a difference of 0% on median percentages).

These results also further reduce the viability of the cognitively-based alternative account highlighted earlier. If normal participants had been consistently using the erroneous cognitive heuristic across all rounds, they ought to have been no different in their investment behavior following "No Invest", "Invest and Lost", and "Invest and Won", which does not seem to be the case. It must, however, be noted that our evidence in support of our emotion-based account and against the alternative, cognitive-based account, is based on the pattern of results obtained and not on direct measures of emotion (e.g., skin conductance).

4. Discussion

The results of this study support our hypothesis that individuals with substance dependence (ISD), who have also been shown in previous research to suffer from abnormalities in a neural circuitry critical for processing emotion, can under certain conditions make more advantageous decisions than normal individuals, when faced with the types of positive expected value gambles that most people routinely shun. One compelling interpretation of these findings is that emotional reactions to the outcomes on preceding rounds influence decisions of normal participants on subsequent rounds, so that they become conservative and aversive to taking risks. In contrast, ISD and lesion patients, who are thought to be abnormal in experiencing these emotional reactions, were not influenced by the emotional reactions associated with the outcomes of preceding rounds, so that they were more predisposed to taking risks.

Such findings lend support to theoretical accounts of risk-taking behavior that posit a central role for emotions [29]. Most theoretical models of risk-taking assume that risky decision-making is largely a cognitive process of integrating the desirability of different possible outcomes with their probabilities. However, recent treatments have argued that emotions play a central role in decision-making under risk [32,41]. The current finding lends further support to such accounts.

The demonstration that ISD were minimally influenced by losses encountered on previous investment rounds, and more willing to re-invest after encountering gains on previous rounds, are consistent with previous studies showing that ISD were hyposensitive to punishment, and hypersensitive to reward [5]. Indeed, the hyposensitivity of ISD to punishment should minimize their emotional reactions to losses, while hypersensitivity to reward should energize their reactions to gains. Therefore, hypersensitivity to reward in ISD, compounded by hyposensitivity to punishment, should promote decisions that are in the same direction, i.e., investing on the next round, thus leading to a superior performance on the investment task. However, it is important to note here that the apparently more rational decisions made by ISD (and also lesion patients) should not be viewed as signs of possessing superior capacity for making decisions, so that ISD may perhaps make better

investment decisions in the real world. On the contrary, these individuals suffer from poor decision-making, and the better performance expressed in ISD is likely the indirect consequence of their emotional indifference about losses, and their willingness to risk punishment in order to obtain reward. If we were to modify the investment task and turn the expected value of each round in a negative direction, we anticipate that ISD would still invest in all rounds, and would risk substantial losses. Indeed, the results from ISD on the current investment task are reminiscent of previous results from a subgroup of ISD who made poor decisions on the original version of the IGT, but optimal decisions (better than normal) on a variant version of the IGT, in which, relative to normal healthy participants, these ISD were more willing to take higher number, and higher magnitude, of punishment before obtaining a larger sum of reward [5]. Together, these findings are consistent with several models of addiction suggesting that substance-taking relates to two processes [19,25,26]. One process relates to abnormal activity in the extended amygdala system, which tends to exaggerate the processing of the incentive values of substance-related stimuli. The other process relates to abnormal activity of the prefrontal cortex system, which tends to undermine the negative values of the future consequences associated with escalating substance use, a mechanism that is necessary for inhibiting the substance-seeking action associated with immediate reward.

Our results raise several issues related to the role of emotions in decision-making involving risk. It is apparent that neural systems that subserve human emotions have evolved for survival purposes. The automatic emotions triggered by a given situation help the normal decision-making process by narrowing down the options for action, either by discarding those that are dangerous or endorsing those that are advantageous. Emotions serve an adaptive role speeding up the decision-making process. However, there are circumstances in which a naturally occurring emotional response must be inhibited, so that a deliberate and potentially wiser decision can be made. The current study demonstrates this "dark side" of emotions in decision-making. Depending on the circumstances, moods and emotions can play useful as well as disruptive roles in the process of making advantageous decisions. It is important to note that previous experiments that demonstrated a positive role of emotion in decision-making involved tasks of decisions under ambiguity (i.e., the outcome is unknown) [3]. In the present experiment, the patients were tested using tasks of decisions under risk (i.e., the outcome is risky but it is defined by some probability distribution).

It is important to note that studies of neurological patients with decision-making impairments show that these patients can still make many sorts of decisions, especially decisions under certainty (where the outcome is a sure thing). Their most pronounced impairment is in decisions that involve uncertainty, i.e., risk and ambiguity. Indeed, behavioral economists describe three classes of choice: (1) choice under certainty; (2) choice under risk; and (3) choice under ambiguity [17,18]. The emerging neuroscientific evidence suggests that these three mechanisms are subserved by separate neural mechanisms. However, what remains unclear is the impact of emotion on each of these mechanisms of decision-making. Could it be that emotion is disruptive to one mechanism, but not the other? Regardless, despite the strong evidence illustrating the important role of emotions in decision-making, it is not a simple issue of trusting emotions as the necessary arbiter of good and bad decisions. It is a matter of discovering the circumstances in which emotions can be useful or disruptive, and using the reasoned coupling of circumstances and emotions as a guide to human behavior.

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