Effects of Virtual and Real Monetary Reward Magnitudes on Risky Decision-Making in Heroin Abstainers

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Abstract

Previous studies have demonstrated that risk decision-making ability is impaired in individuals with heroin addiction; however, few studies have examined how different magnitudes of monetary reward influence risk decision-making in heroin abstainers, and whether this influence is moderated by reward type. Therefore, the present study employed the Balloon Analogue Risk Task (BART) to investigate, across two experiments, the effects of different magnitudes of virtual and real monetary rewards on risk decision-making in heroin abstainers. The results revealed that in the virtual reward scenario, heroin abstainers exhibited significantly greater numbers of pumps on unburst balloons and burst balloons compared to healthy control participants; furthermore, both groups showed significantly greater numbers of pumps on unburst balloons and burst balloons under the 25-point reward condition than under the 1-point reward condition. Conversely, in the real reward scenario, heroin abstainers displayed significantly fewer pumps on unburst balloons and burst balloons relative to healthy control participants, and both groups exhibited significantly fewer pumps on unburst balloons and burst balloons under the 25-point reward condition compared to the 1-point reward condition. These findings further suggest that risk decision-making behavior differs between heroin abstainers and healthy individuals; monetary reward magnitude exerts comparable effects on risk decision-making change characteristics in both groups, with these effects being moderated by monetary reward type.

Full Text

The Influence of Hypothetical and Real Monetary Reward Magnitude on Risky Decision-Making in Abstinent Heroin Users

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Abstract

Previous research has demonstrated that heroin addicts exhibit impaired risky decision-making abilities, yet few studies have examined how different magnitudes of monetary reward affect risk decision-making in abstinent heroin users or whether such effects are moderated by reward type. The present study employed the Balloon Analogue Risk Task (BART) to investigate the impact of varying magnitudes of hypothetical and real monetary rewards on risky decision-making in abstinent heroin users through two experiments. Results showed that in the hypothetical reward scenario, both the number of pumps on unburst balloons and the number of burst balloons were significantly greater for abstinent heroin users compared to normal controls, and both groups exhibited significantly higher scores on these measures under the 25-cent reward condition than under the 1-cent condition. Conversely, in the real reward scenario, abstinent heroin users showed significantly fewer pumps on unburst balloons and fewer burst balloons than normal controls, with both groups displaying significantly lower scores on these measures under the 25-cent condition compared to the 1-cent condition. These findings further indicate that abstinent heroin users exhibit different risk decision-making patterns compared to normal individuals; monetary reward magnitude influences risk decision-making characteristics similarly in both groups, and this influence is moderated by reward type.

Keywords: abstinent heroin users; risky decision-making; monetary reward magnitude; Balloon Analogue Risk Task

Risky decision-making refers to the process by which individuals weigh and choose among two or more uncertain outcome options (Kahneman & Tversky, 1979). Deficits in risk decision-making are considered a primary characteristic of drug addicts, who tend to prefer immediate rewards (e.g., drug intake) despite facing increasingly negative consequences in their personal, emotional, occupational, and social lives (e.g., physical harm, loss of employment, family, friends, or social status) (Fein & Chang, 2008; Li et al., 2013). They struggle to make adaptive decisions based on outcome feedback (Redish, Jensen, & Johnson, 2008). Experimental studies across different drug types support this

view, including research on marijuana (Gonzalez, Schuster, Mermelstein, & Diviak, 2015), methamphetamine (Kohno, Morales, Ghahremani, Hellemann, & London, 2014), and cocaine (Verdejo-Garcia et al., 2007). Neuroimaging studies reveal abnormal activation in brain regions associated with risk decision-making among drug addicts, including the ventromedial prefrontal cortex (VMPFC), orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), and insula, indicating impaired risk decision-making capacity (Bolla et al., 2004; Ersche et al., 2005, 2006; Hanlon, Wesley, Stapleton, Laurienti, & Porrino, 2011; Vaidya et al., 2012; Yan, Li, & Sui, 2011). Meanwhile, accumulating research emphasizes that risk decision-making deficits also play a crucial role in maintaining addictive behaviors and relapse (Verdejo-Garcia et al., 2014), with impaired decision-making functions potentially exacerbating substance use and jeopardizing users' ability to cease drug use and resist relapse (Gonzalez et al., 2015; Fein & Chang, 2008). Studies have further specified that decision-making deficits in drug addicts significantly predict treatment retention duration and post-treatment relapse rates (Black & Rosen, 2011; Passetti, Clark, Mehta, Joyce, & King, 2008). Building on this foundation, researchers have employed various methods to intervene in addicts' risk decision-making, such as non-invasive brain stimulation (Gorini, Lucchiari, Russell-Edu, & Pravettoni, 2014), goal management training, and mindfulness meditation (Alfonso, Caracuel, Delgado-Pastor, & Verdejo-García, 2011). A comprehensive and in-depth investigation of risk decision-making in drug addicts not only helps us understand the causes of addictive behaviors but also provides insights for future intervention and treatment of drug abuse.

Common experimental paradigms in addiction decision-making research include the Delay Discounting Task (DDT) (Petry & Casarella, 1999), Iowa Gambling Task (IGT) (Bechara, Damasio, Damasio, & Anderson, 1994), and Cambridge Gambling Task (CGT) (Rogers et al., 1999). While DDT primarily assesses impulsive decision-making, IGT and CGT mainly examine risky decision-making (Yao et al., 2017; Zhao, Li, Hu, Wu, & Liu, 2017). Numerous studies have used these tasks to investigate decision-making functions in various substance abusers, including not only illicit drug addicts but also users of legal addictive substances such as cigarette smokers (Bickel, Odum, & Madden, 1999; Reynolds, Karraker, Horn, & Richards, 2003) and alcohol-dependent individuals (Petry, 2001; Noel, Bechara, Dan, Hanak, & Verbanck, 2007; Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009). As research has progressed, investigators have moved beyond simply confirming decision-making impairments in addicts to examining internal and external factors influencing these functions, aiming to provide scientific evidence for effective interventions. Studies have found that different drug types may cause varying degrees of cognitive impairment, including decision-making functions. For instance, early research showed that compared to normal individuals, cocaine addicts exhibited higher activation in the right orbitofrontal cortex and lower activation in the right dorsolateral prefrontal cortex (DLPFC) and left medial prefrontal cortex (MPFC) (Bolla et al., 2003), whereas marijuana users showed lower activation in the right orbitofrontal cortex and right DLPFC but higher activation in the cerebellum (Bolla, Eldreth,

Matochik, & Cadet, 2005). These studies used the same experimental paradigm for indirect comparison at the cognitive neuroscience level. Other research directly comparing behavioral data across different substance abusers found that abstinent cocaine addicts exhibited higher impulsivity and risk-seeking behavior compared to heroin addicts (Bornovalova, Daughters, Hernandez, Richards, & Lejuez, 2005), and cocaine addicts showed higher delay discounting rates than nicotine addicts and healthy controls (García-Rodríguez, Secades-Villa, Weidberg, & Yoon, 2013). Research also emphasizes that poly-substance use may exacerbate decision-making impairments (Hopko et al., 2006), and that decision-making deficits may recover with prolonged abstinence (Zhou et al., 2014a). Heroin and other opioids remain primary substances of abuse in China, making further investigation of risk decision-making characteristics in abstinent heroin users crucial for rehabilitation treatment.

Most decision-making research incorporates monetary rewards because money possesses social attributes that can maximally approximate real-world decision-making scenarios. Experimental studies manipulating monetary reward magnitude (high, medium, low) to examine cognitive processing characteristics are relatively common (Ji, Chen, Ding, & Wei, 2015). Research has shown that monetary reward magnitude affects individual risk decision-making. For example, in probability discounting tasks, participants' discounting rates for low-magnitude rewards are smaller than for high-magnitude rewards, whereas the opposite pattern occurs in delay discounting tasks (Estle, Green, Myerson, & Holt, 2006). Another study manipulating the magnitude differences between immediate rewards and losses in the IGT found that when reward magnitude differences decreased, participants chose disadvantageous decks less frequently to obtain larger monetary rewards. Conversely, when reward magnitude differences increased, participants chose disadvantageous decks more frequently, resulting in greater monetary losses (Van den Bos, Houx, & Spruijt, 2006). This suggests that individuals are more likely to exhibit risk-averse behavior under low monetary reward conditions and risk-seeking behavior under high monetary reward conditions during risk decision-making. However, some studies report opposite findings, showing that individuals' risk preference levels decrease as reward magnitude increases (Bornovalova et al., 2009). Further research has found that the effect of monetary reward magnitude on risk decision-making is moderated by reward type, with hypothetical monetary reward magnitude having no impact on participants' risk decision-making behavior, whereas real monetary reward magnitude can significantly alter risk decision-making behavior, specifically by reducing risk preference levels under high real monetary reward conditions (Xu et al., 2018; Xu, Fang, & Rao, 2013). Given inconsistent findings regarding the relationship between reward magnitude and risk decision-making and the absence of studies examining differences in risk decision-making between drug addicts and normal individuals under hypothetical and real reward scenarios, the present study aims to address this gap. Decision-making processing involves evaluating the reward value or emotional valence of environmental stimuli, assessing potential rewards or punishments, integrating potential positive or nega-

tive outcome information, and ultimately making a choice (Zhao, Huang, & He, 2016). Drug addicts exhibit impaired reward processing and are less sensitive to changes in reward magnitude compared to normal individuals (Goldstein et al., 2008; Goldstein et al., 2007). Investigating the impact of monetary reward magnitude on risk decision-making using drug addicts as participants not only expands previous research but also enhances our understanding of risk decision-making characteristics in this population.

The Balloon Analogue Risk Task (BART) (Lejuez et al., 2002) is a recently developed cognitive task that more closely approximates real-life risk decision-making. Participants increase balloon size through repeated pumping, with each pump accumulating higher gains but also greater risk of loss. Compared to DDT, IGT, and CGT, BART has gained favor among researchers due to its high ecological validity and multiple behavioral indices (Xu et al., 2013). More importantly, the task can relatively easily manipulate reward magnitude to explore participants' risk decision-making behavior under different reward levels (Bornovalova et al., 2009). Numerous studies have used BART to investigate risk decision-making across different populations. Lejuez et al. (2003) first validated BART using smokers and non-smokers; Fein and Chang (2008) examined electrophysiological differences in risk decision-making between alcohol users and normal individuals using event-related potentials; Crowley et al. (2010) explored differential brain activation between adolescents with antisocial and addictive behaviors and typical adolescents; Hevey et al. (2017) compared risk decision-making between depressed patients and normal controls; and Tian et al. (2018) investigated the effects of peer presence and self-esteem on adolescent risk-taking behavior. Few studies have used BART to examine risk decision-making in drug addicts (Bornovalova et al., 2005; Hopko et al., 2006), and existing studies have not thoroughly investigated the effects of monetary reward magnitude and reward type on risk decision-making in this population.

In summary, the present study used abstinent heroin users as participants and employed BART to comprehensively investigate the influence of monetary rewards on risk decision-making. Experiment 1 used hypothetical monetary rewards to examine differences in risk decision-making between abstinent heroin users and normal controls under 1-cent and 25-cent hypothetical reward conditions. Experiment 2 used real monetary rewards to investigate differences in risk decision-making between abstinent heroin users and normal controls under 1-cent and 25-cent real reward conditions.

Experiment 1: Hypothetical Reward Condition

2.1.1 Participants

A total of 64 participants were recruited, including 33 male abstinent heroin addicts from a compulsory isolation drug rehabilitation center in Lanzhou, Gansu Province. Their ages ranged from 19 to 54 years (mean age = 40.94 $\pm$ 9.74 years). Educational backgrounds included: illiterate/semi-illiterate (n = 2), el-

ementary school (n = 8), junior high school (n = 20), high school/vocational school/technical school (n = 2), and college (n = 1). All met DSM-IV diagnostic criteria for opioid dependence. Mean age at first heroin use was 25.94 ± 7.76 years, and mean duration of current abstinence was 14.09 ± 6.43 months.

The normal control group consisted of 31 male participants recruited through verbal announcements and advertisements, with no history of drug use. Their ages ranged from 18 to 52 years (mean age = 40.45 ± 9.10 years). Educational backgrounds included: elementary school (n = 9), junior high school (n = 17), and high school/vocational school/technical school (n = 5). All participants were right-handed, had normal or corrected-to-normal vision, no color vision deficits, and no history of psychiatric illness or cardiovascular disease. Statistical tests revealed no significant differences between groups in age ($t(62) = 0.21$, $p > 0.05$) or education level ($^2 = 4.05$, $p > 0.05$).

2.1.2 Experimental Design

The experiment employed a 2 (reward magnitude: 1 cent vs. 25 cents) × 2 (participant type: abstinent heroin group vs. normal control group) mixed factorial design. Reward magnitude was a within-subjects variable, while participant type was a between-subjects variable. Dependent variables were the average number of pumps on unburst balloons and the total number of burst balloons.

2.1.3 Procedure

A balloon initially appeared at the center of the computer screen, with three labels displayed below: "Current Balloon Earnings," "Previous Balloon Earnings," and "Total Earnings." Participants pressed the "1" key to inflate the balloon. Each press increased balloon size by 0.3 cm and earned the monetary amount corresponding to the reward condition, with "Current Balloon Earnings" displaying the accumulated total after each pump. As the number of "1" key presses increased, the balloon gradually expanded and current earnings increased accordingly. Each balloon could be inflated between 1 and 128 times, with explosion points also ranging from 1 to 128 and an average explosion point of 64. Participants could stop pumping at any time and press the "5" key to save current balloon earnings to the total earnings. If the number of pumps reached the balloon' s explosion point, the balloon would burst, "Current Balloon Earnings" would display the corresponding loss amount, and this loss would be subtracted from total earnings. The trial ended either when the balloon burst or when the participant saved the current earnings. A new balloon would then appear until the experiment concluded (see Figure 1 [Figure 1: see original paper]). Before the formal experiment, participants completed practice trials to ensure complete understanding of the task.

The experiment included 60 balloons, with 30 balloons each under the 1-cent and 25-cent reward conditions. The presentation order of the two reward conditions was counterbalanced across participants to reduce practice and order

effects. Participants received brief rest periods between reward conditions to minimize fatigue effects. Although hypothetical rewards were used, participants were instructed to imagine the rewards as real monetary rewards and to maximize earnings. Participants provided informed consent before beginning the experiment.

2.2 Results

First, a 2 (reward magnitude: 1 cent vs. 25 cents) × 2 (participant type: abstinent heroin group vs. normal control group) repeated measures ANOVA was conducted on the average number of pumps on unburst balloons. Results revealed a significant main effect of reward magnitude ($F(1, 62) = 25.59$, $p < 0.001$, $p^2 = 0.29$). Post-hoc tests (LSD) indicated that the average number of pumps was lower under the 1-cent reward condition than under the 25-cent condition ($p < 0.001$). The main effect of participant type was also significant ($F(1, 62) = 6.99$, $p < 0.05$, $p^2 = 0.10$), with post-hoc tests showing that abstinent heroin users made more pumps than normal controls ($p = 0.01$). The interaction between reward magnitude and participant type was not significant ($F(1, 62) = 0.65$, $p > 0.05$) (see Figure 2 [Figure 2: see original paper]).

Second, a 2 (reward magnitude: 1 cent vs. 25 cents) × 2 (participant type: abstinent heroin group vs. normal control group) repeated measures ANOVA was conducted on the number of burst balloons. Results showed a significant main effect of reward magnitude ($F(1, 62) = 15.10$, $p < 0.001$, $p^2 = 0.20$). Post-hoc tests (LSD) revealed fewer burst balloons under the 1-cent reward condition than under the 25-cent condition ($p < 0.001$). The main effect of participant type was significant ($F(1, 62) = 7.45$, $p < 0.01$, $p^2 = 0.11$), with abstinent heroin users bursting more balloons than normal controls ($p = 0.008$). The interaction between reward magnitude and participant type was not significant ($F(1, 62) = 0.002$, $p > 0.05$) (see Figure 3 [Figure 3: see original paper]).

2.3 Discussion

Experiment 1 results showed that abstinent heroin users exhibited significantly greater average pumps on unburst balloons and more burst balloons than normal controls, indicating higher risk preference levels among heroin users who tend to ignore potential risks and pursue immediate rewards. These findings align with research on other substance abusers (Lejuez et al., 2003; Fein & Chang, 2008; Hanson, Thayer, & Tapert, 2014) and suggest that decision-making functions remain impaired even after long-term abstinence (Li et al., 2013; Zhou et al., 2014a). Additionally, Experiment 1 found that both groups showed significantly greater average pumps on unburst balloons and more burst balloons under the 25-cent reward condition compared to the 1-cent condition, demonstrating that individual risk decision-making is influenced by reward magnitude, with risk-seeking behavior more likely under high hypothetical reward conditions. Given controversies regarding whether hypothetical and real monetary rewards elicit similar decision-making behaviors, Experiment 2 used real monetary rewards

to further examine differences in risk decision-making between abstinent heroin users and normal controls and to explore the relationship between reward magnitude and participant type.

Experiment 2: Real Reward Condition

3.1.1 Participants

A total of 82 participants were recruited, including 42 male abstinent heroin addicts from a compulsory isolation drug rehabilitation center in Lanzhou, Gansu Province. Their ages ranged from 28 to 60 years (mean age = 47.52 ± 6.88 years). Educational backgrounds included: illiterate/semi-illiterate (n = 3), elementary school (n = 13), junior high school (n = 17), high school/vocational school/technical school (n = 8), and college (n = 1). All met DSM-IV diagnostic criteria for opioid dependence. Mean age at first drug use was 33.40 ± 9.82 years, and mean duration of current abstinence was 13.71 ± 7.15 months.

The normal control group consisted of 40 male participants recruited through verbal announcements and advertisements, with no history of drug use. Their ages ranged from 27 to 60 years (mean age = 48 ± 8.06 years). Educational backgrounds included: illiterate/semi-illiterate (n = 1), elementary school (n = 5), junior high school (n = 17), high school/vocational school/technical school (n = 14), college (n = 1), and university (n = 2). All participants were right-handed, had normal or corrected-to-normal vision, no color vision deficits, and no history of psychiatric illness or cardiovascular disease. Statistical tests revealed no significant differences between groups in age ($t(80) = -0.29$, $p > 0.05$) or education level ($^2 = 7.87$, $p > 0.05$). No participants overlapped between Experiment 2 and Experiment 1.

3.1.2 Experimental Design

The experimental design was identical to Experiment 1.

3.1.3 Procedure

The procedure was essentially the same as Experiment 1, with the following differences: Before the experiment began, the experimenter informed participants that real monetary rewards would be used. After completing the task, participants' earnings would be converted into actual payment, with greater earnings resulting in higher compensation. Experiment 2 established four reward tiers based on performance: less than 60 points earned a 5 RMB cash reward, 60-80 points earned 10 RMB, 80-100 points earned 15 RMB, and over 110 points earned 20 RMB. Participants were not informed of the specific conversion method beforehand and were simply instructed to maximize their earnings. Participants provided informed consent before beginning the experiment.

3.2 Results

First, a 2 (reward magnitude: 1 cent vs. 25 cents) × 2 (participant type: abstinent heroin group vs. normal control group) repeated measures ANOVA was conducted on the average number of pumps on unburst balloons. Results revealed a marginally significant main effect of reward magnitude ($F(1, 80) = 3.22$, $p = 0.077$, $p^2 = 0.04$). Post-hoc tests (LSD) indicated more pumps under the 1-cent reward condition than under the 25-cent condition ($p = 0.077$). The main effect of participant type was significant ($F(1, 80) = 6.33$, $p < 0.05$, $p^2 = 0.07$), with abstinent heroin users making fewer pumps than normal controls ($p = 0.014$). The interaction between reward magnitude and participant type was not significant ($F(1, 80) = 1.52$, $p > 0.05$) (see Figure 4 [Figure 4: see original paper]).

Second, a 2 (reward magnitude: 1 cent vs. 25 cents) × 2 (participant type: abstinent heroin group vs. normal control group) repeated measures ANOVA was conducted on the number of burst balloons. Results showed a significant main effect of reward magnitude ($F(1, 80) = 4.16$, $p < 0.05$, $p^2 = 0.05$). Post-hoc tests (LSD) revealed more burst balloons under the 1-cent reward condition than under the 25-cent condition ($p = 0.045$). The main effect of participant type was significant ($F(1, 80) = 4.14$, $p < 0.05$, $p^2 = 0.05$), with abstinent heroin users bursting fewer balloons than normal controls ($p = 0.045$). The interaction between reward magnitude and participant type was not significant ($F(1, 80) = 1.24$, $p > 0.05$) (see Figure 5 [Figure 5: see original paper]).

3.3 Discussion

Experiment 2 results showed that abstinent heroin users exhibited significantly fewer average pumps on unburst balloons and fewer burst balloons than normal controls, indicating reduced risk preference levels among heroin users who became more cautious when facing risky options. Additionally, Experiment 2 found that both average pumps on unburst balloons and number of burst balloons were significantly greater under the 1-cent reward condition than under the 25-cent condition, suggesting that in the real reward scenario, both abstinent heroin users and normal controls showed reduced risk preference as reward magnitude increased. These results are consistent with previous research (Bornovalova et al., 2009; Johnson & Bickel, 2002).

General Discussion

The present study used the BART paradigm to investigate the effects of different magnitudes of monetary rewards on risk decision-making in abstinent heroin users and normal controls through hypothetical and real reward experiments. Results showed that in the hypothetical reward scenario, individuals' risk preference levels increased with reward magnitude, whereas the opposite pattern emerged in the real reward scenario. Furthermore, comparing risk decision-making characteristics between abstinent heroin users and normal con-

trols revealed that heroin users exhibited higher overall risk preference levels than normal controls in the hypothetical reward scenario but lower risk preference levels in the real reward scenario. Further analysis and discussion are as follows:

First, whether hypothetical and real rewards elicit the same decision-making behavior has long been controversial, with numerous studies providing in-depth examination of this issue. Early behavioral experiments found no significant differences in delay discounting rates between hypothetical and real reward conditions, suggesting equivalent ecological validity for assessing impulsive decision-making (Johnson & Bickel, 2002). Subsequent research confirmed these conclusions (Madden, Begotka, Raiff, & Kastern, 2003). Further neuroimaging results showed no significant differences in activation of the anterior cingulate cortex, striatum, posterior cingulate cortex, and prefrontal cortex between hypothetical and real reward conditions (Bickel, Pitcock, Yi, & Angtuaco, 2009). These studies primarily examined the impact of reward type on impulsive decision-making, but recent research on the relationship between reward type and risky decision-making has yielded inconsistent results. Studies have found that in BART, participants made significantly fewer pumps on unburst balloons under real versus hypothetical reward conditions (Xu et al., 2013), and showed larger feedback-related negativity (FRN) following negative feedback under real reward conditions (Xu et al., 2016), suggesting that monetary losses in real reward conditions increase negative emotions and correspondingly reduce risk-taking behavior. The present findings partially support recent experimental research on risk decision-making.

However, some results differ from previous studies. Bornovalova et al. (2009) used BART to examine risk decision-making under three real monetary reward magnitudes (1 cent, 5 cents, 25 cents), finding that risk preference levels decreased significantly as reward magnitude increased. Xu et al. (2013) further noted that risk preference levels decreased with increasing reward magnitude under real reward conditions but did not change with reward magnitude under hypothetical reward conditions. Subsequent ERP research similarly found that participants showed larger FRN components when facing negative feedback under large versus small real reward conditions, a difference that did not emerge under hypothetical reward conditions (Xu et al., 2018). The present study confirms this view, showing that both abstinent heroin users and normal controls exhibited reduced risk preference levels as reward magnitude increased in the real reward risk decision-making task. Nevertheless, some studies have found that risk preference increases with reward magnitude (Estle et al., 2006; Van den Bos et al., 2006). The primary reason for this discrepancy may be differences in experimental tasks and reward amounts. Studies consistent with our findings used BART with small monetary rewards approximating real-world contexts, whereas other studies used probability discounting tasks and IGT paradigms typically associated with high monetary rewards. Research suggests that high rewards in delay discounting tasks deviate from real-world contexts, causing individuals to underestimate the true value of monetary rewards (Hinvest &

Anderson, 2010). Therefore, motivational differences induced by different monetary reward conditions may be the main factor influencing risk decision-making patterns. Another result from our study provides evidence for this hypothesis: participants showed increased risk preference with reward magnitude under hypothetical reward conditions. Additionally, as previously mentioned, research has indicated that reward magnitude moderates risk decision-making behavior under real but not hypothetical reward conditions (Xu et al., 2013; Xu et al., 2018). The inconsistency between our results and these findings may be due to differences in participant samples. Previous studies used university students who, compared to the adult participants in our study, may make more rational decisions, rendering reward magnitude differences less significant.

Second, our study found that abstinent heroin users showed higher risk preference levels than normal individuals in the hypothetical reward scenario but lower risk preference levels in the real reward scenario. This partially contradicts previous research. Numerous studies using various experimental paradigms have generally shown that substance abusers exhibit higher risk preference levels than normal individuals, preferring high-risk large rewards over low-risk small rewards. For example, Li et al. (2013) used IGT and found that abstinent heroin users preferred disadvantageous decks more than normal controls; Lejuez et al. (2003) used BART and found that smokers made significantly more pumps than non-smokers; and Hanson, Thayer, and Tapert (2014) found that marijuana addicts burst more balloons than normal controls. Our study did not find higher risk preference levels among abstinent heroin users than normal controls in the real reward scenario, possibly because our participants were compulsory isolation rehabilitation residents whose perception of monetary value was higher than that of normal individuals. In other words, equivalent monetary amounts had greater exchange value for compulsory isolation heroin addicts, making them more cautious and exhibiting lower risk-taking behavior. Hypothetical rewards held equivalent meaning for both groups and may more accurately reflect risk decision-making differences between abstinent heroin users and normal controls. A similar study using IGT found that cocaine addicts made significantly more disadvantageous choices than controls under hypothetical reward/punishment conditions, but no significant group differences emerged under real reward/punishment conditions (Vadhan, Hart, Haney, van Gorp, & Foltin, 2009). Thus, using hypothetical rewards to assess risk decision-making in substance abusers, particularly those in special environments, remains important.

Finally, in both hypothetical and real reward scenarios, reward magnitude influenced risk decision-making change patterns similarly in abstinent heroin users and normal controls: risk preference levels increased with reward magnitude under hypothetical rewards but decreased with reward magnitude under real rewards. This pattern may be explained by two factors. First, heroin addicts' monetary reward sensitivity shows some recovery with increasing abstinence duration (Zhou et al., 2014b), resulting in risk decision-making patterns similar to normal individuals. Second, our study only examined the behavioral-level

impact of reward magnitude on risk decision-making change patterns in both groups, and behavioral measures may lack sufficient sensitivity to detect group differences in risk decision-making change patterns.

Given the limitations of our study and inconsistencies with previous findings, future research should address several questions: (1) Whether the mechanisms underlying the effects of hypothetical versus real rewards on risk decision-making are identical, and whether reward magnitude effects on risk decision-making are moderated by reward type. Xu et al. (2016) attributed inconsistent findings regarding hypothetical and real monetary rewards to factors such as delay reward length, reward amount, and reward probability, though specific causes and conclusions require further verification. (2) Most drug abstainers in China are in compulsory isolation environments; whether addicts' risk decision-making characteristics are influenced by their environment, and whether hypothetical monetary rewards offer advantages over real monetary rewards for assessing addicts' risk decision-making. (3) Future studies should use more sensitive cognitive neuroscience methods to investigate differences in how monetary reward magnitude affects risk decision-making in other substance abusers (e.g., cigarette smokers, alcohol users) versus normal controls.

In conclusion, in the hypothetical reward scenario, risk preference levels in both abstinent heroin users and normal controls increased with reward magnitude; however, in the real reward scenario, risk preference levels in both groups decreased with reward magnitude. Abstinent heroin users exhibited higher risk preference levels than normal controls in the hypothetical reward scenario but lower risk preference levels in the real reward scenario.

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