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Differences in Decision-Making as a Function of Drug of Choice

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Abstract

Poor decision-making is a central feature of all substance use disorders (SUD), but substances vary in the legal and health consequences associated with their use. For example, while the negative health consequences associated with cigarette smoking are often years away, the consequences of heroin abuse can be fatal in mere hours. It remains unclear if users of these substances show decision-making patterns that differ with the relative riskiness of their drug of choice. To address this question, we reviewed studies that compared decision-making of individuals using different substances. We focused on studies assessing two of the most commonly investigated decision-making processes—delay discounting and risk taking—and specifically focused on decision-making that involved selection between options for hypothetical monetary rewards. For delay discounting, we reviewed studies that assessed decisions regarding delayed or immediate monetary rewards, and for risk-taking we reviewed studies using the Iowa Gambling Task. Studies directly comparing different SUD groups were limited in number and tended to compare alcohol or cocaine users to other substance users. Overall, these studies do not support the hypothesis that decision-making differed by drug of choice. Major limitations in the literature include failing to account for comorbid substance use and a lack of prospective longitudinal studies. Due to these limitations, conclusions should be considered provisional. Nonetheless, current findings suggest that these two facets of decision-making are similar across drugs of abuse.

Introduction

We all make decisions every day and, while some have trivial consequences, others can profoundly alter the course of our lives. Poor decision-making is a central feature of substance use disorder (SUD). Risky choices may lead to trying an addictive substance for

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the first time or continuing to use a drug despite devastating consequences. Decision-making involves many factors and can be affected by a range of internal and external influences, such as stress, mood, and social pressures (Giordano *et al*, 2002). A fundamental question is whether an individual's drug of choice can inform us about their decision-making. Does an individual who uses a substance with a risk of fatal overdose such as heroin rather than a more benign substance such as cannabis have especially poor judgment? Neurobiological evidence on the etiology of SUD offers mixed evidence. On the one hand, individuals may have pre-existing neurobiological characteristics which may affect their choices and lead to abuse of a particular drug (Ersche *et al*, 2012). Furthermore, different drugs alter specific neurotransmitter systems and may therefore differentially affect decision-making. On the other hand, there may be vulnerability factors (Tsuang *et al*, 1998), neuroanatomical pathways (Nestler, 2005) and, potentially, decision-making patterns common to all addictive substances.

To determine whether decision-making differences exist between individuals primarily dependent upon one substance relative to another, we conducted a review of the literature. We defined decision-making as the selection of an action from among available alternatives, resulting in an outcome that engenders a specified neural, cognitive, or emotional state (Paulus, 2007). We limited the scope of our review to two primary decision-making processes: delay discounting and risk-taking. To assess delay discounting, we reviewed studies which employed variants of the monetary delay discounting tasks developed by Rachlin and colleagues (1991), Kirby and colleagues (1999), Bickel and colleagues (1999) and Green and colleagues (1994). To assess risk-taking, we reviewed studies which employed the Iowa Gambling Task (IGT) developed by Bechara and colleagues (1994). These tasks present participants with repeated opportunities to make decisions that only vary on a few parameters, and thereby reduce variation in task design, which can significantly impact decision-making and study results. For example, framing of decisions (Kahneman and Tversky, 1984), type of reward (Chapman and Elstein, 1995), and even the presence of irrelevant information (Tversky and Kahneman, 1974) can alter decision-making. Thus, by using these tasks, we sought to examine the measures of decision-making that are most frequently employed in SUD populations while limiting task variability.

While a large literature exists comparing IGT and delay discounting in individuals with a specific SUD to controls (Bechara, 2005; MacKillop *et al*, 2011), only one meta-analysis has assessed whether delay discounting differs between substance users of one type relative to another (Amlung *et al*, 2017). Importantly, this meta-analysis assessed the relationship between continuous measures of addiction severity and delay discounting measures, but did not review studies which directly compared substance using groups. While comparing across studies in this fashion provides important information, different samples may harbor idiosyncrasies related to recruitment strategies, task modifications, inclusion and exclusion criteria, and regional differences in populations. Thus, there is reason to believe that head-to-head comparisons of different substance using groups in a single study may fill a void in the understanding of the literature. No prior attempts have been made to synthesize the literature investigating such comparisons for either delay discounting or risk-taking. Our goal is to review the findings from head-to-head comparisons of groups who used different substances

and discuss what remains to be done to resolve whether differences truly exist across users of different substances in their patterns of decision-making.

Methods

We conducted a literature search on April 14, 2017 on PubMed using the following terms “Delay Discounting” OR “Iowa Gambling Task” AND “Substance-related Disorders”. We examined each of these studies to determine if they met the following inclusion criteria: 1) an original data paper, 2) use of either a monetary delay discounting task or the Iowa Gambling Task, 3) examination of participants who were diagnosed with a substance use disorder for either alcohol, nicotine, cocaine, opioids, amphetamines, or marijuana (or who reported heavy use of these substances as defined by the study authors), 4) direct comparison of at least two distinct substance using groups (e.g. marijuana users versus cocaine users). The search yielded 113 results. Of these, 20 met the inclusion criteria (10 delay discounting, 10 IGT) and are described in the sections below.

Delay Discounting

Delay discounting refers to a trait observed across many species (Mazur, 1987) to weigh immediate outcomes more heavily than future ones. For example, most children would rather have a cookie now than wait until after dinner. In human research, the majority of studies assess monetary rewards as the outcome of interest (Fishburn and Rubinstein, 1982), although discounting rates correlate across reinforcers, such that an individual who rapidly discounts delayed money is also likely to rapidly discount delayed food or drugs (Odum, 2011). The two primary factors that affect such decisions are the length of the delay and the amounts of money. If $1000 and $2000 are both offered immediately, $2000 is clearly preferable. If someone must wait to receive $2000, however, at some point the delay becomes too long. Would you prefer $1000 today or $2000 in ten years? The future time when the subjective value of the large reward diminishes to the equivalent of the small immediate reward is called the indifference point. Studies of delay discounting typically establish a person’s indifference point for a variety of monetary values and delay periods. From this, it is possible to fit an individual’s indifference points to a hyperbolic function defined by the following equation (Mazur, 1987): $V = A/(1 + kD)$, where V is the subjective value, A is the actual monetary value, and D is the time delay. Higher levels of delay discounting are represented by higher values of k, which can be referred to as the delay discounting constant. Since k is not normally distributed, there are a variety of ways to compare groups, such as logarithmic transformation of k or nonparametric analyses. Alternatively, as the hyperbolic function does not always fit a person’s decisions, some studies use the area under the curve of the indifference point plot to index delay discounting.

Meta-analyses of studies comparing substance using groups to controls have found small to medium effect sizes for delay discounting differences (MacKillop *et al*, 2011), but no evidence of differences in effect sizes between users of different substances (Amlung *et al*, 2017). Importantly, these meta-analyses found little evidence of publication bias, indicating that these effects are reliable. These studies provide strong evidence that individuals with an SUD prefer immediate relative to delayed rewards compared to controls. In the following

section, we will examine the studies that met our search criteria to determine if delay discounting tendencies differ as a function of substance of abuse.

Discounting of Delayed Monetary Rewards Across SUD Groups

The most common comparisons in monetary delay discounting studies have been between cocaine, alcohol, and nicotine users. As seen in Table 1, existing studies have not found any differences in delay discounting between cocaine and alcohol users (Kirby and Petry, 2004; Moody *et al*, 2016b), alcohol and nicotine users (Moallem and Ray, 2012; Moody *et al*, 2016b), and alcohol and polysubstance users (Taylor *et al*, 2016). In contrast, two studies have found that cocaine users discount at higher rates than nicotine users (García-Rodríguez *et al*, 2013; Moody *et al*, 2016b). Another study compared smoking and nonsmoking polysubstance users to a smoking only group and found no difference across groups (Businelle *et al*, 2010). Thus, cocaine users may have steeper rates of delay discounting than nicotine users, but smokers discount money similarly to other substance using groups.

There is mixed evidence as to whether opioid users have higher rates of delay discounting compared to other substance users (see Table 1 sections “Opioids” and “Alcohol” and “Cocaine”). Heroin users have been found to have greater delay discounting than alcohol users but not cocaine users (Kirby and Petry, 2004). However, this study employed unconventional substance use thresholds to define each group (daily use of heroin, drinking alcohol to the point of intoxication 3x/week) rather than using clinical interviews to determine formal diagnoses. A small study set in a residential treatment program found that crack cocaine users had higher discounting rates relative to heroin users (Bornovalova *et al*, 2005). The study had a potential confound, however, as the cocaine users were also more likely to use alcohol, marijuana and PCP, implying that polysubstance abuse, and SUD severity, is associated with steeper delay discounting (MacKillop *et al*, 2011). A third study compared two groups of opioid users that used either heroin or prescription opioids and found that heroin users showed greater rates of discounting than prescription opioid users (Karakula *et al*, 2016). As heroin users tends to have more severe use disorders than prescription opioid users, despite similar pharmacology of their drug of choice, this finding supports the idea that decision-making differences may be a product of severity of substance use disorder rather than reflecting differences across substances of abuse. However, another study compared two groups of patients who had been receiving methadone maintenance therapy for two years. One group continued using heroin, cocaine, and alcohol during treatment, while the other adhered strictly to methadone, but the groups showed no differences in delay discounting (Robles *et al*, 2011).

There are a limited number of studies comparing individuals with other substance use disorders. We did not find any specific studies comparing amphetamine users to other substance users. Only one study recruited marijuana users and found that they did not differ from a cocaine using group (Mejía-Cruz *et al*, 2016). More effort should be made to study individuals with these disorders.

In summary, most studies showed no delay discounting differences between users of different substances, although two studies showed that cocaine users discounted delayed

monetary rewards more rapidly than smokers. There was mixed evidence that more severe drug use behaviors, such as injecting heroin rather than ingesting prescription opioids, were associated with higher rates of discounting. The meta-analysis by Amlung and colleagues (2017) suggests no difference in effect size between users of different drugs and controls, implying that substance using groups have similar rates of discounting, and the studies reviewed here concur with this conclusion. In the studies reviewed here, all but one of the comparisons between substance users and controls showed a statistically significant difference (Supplemental Table 1). Although a formal meta-analysis was not conducted, the median effect size for comparisons between two SUD groups was Cohen's $d = 0.31$ (interquartile range = 0.70; see Table 1). In contrast, the median effect size for case-control comparisons was Cohen's $d = 0.61$ (interquartile range = 0.57, see Supplemental Table 1), indicating that there is a larger difference in delay discounting between cases and controls than between substance using groups. However, decisions regarding delayed monetary rewards represent only one aspect of the broader domain of decision-making.

Measuring Risk Taking Using the Iowa Gambling Task

The Iowa Gambling Task (IGT) was developed to probe for neuropsychological abnormalities following lesions to the ventromedial prefrontal cortex (Bechara *et al*, 1994). Patients with these lesions performed normally on standardized neurocognitive tests, but they made troubling decisions in their real lives. For example, following bilateral ablation of the ventral medial prefrontal cortex, one patient divorced his wife, was fired from his job, and lost his savings by investing in a risky business plan, yet he maintained a high IQ (Eslinger and Damasio, 1985). The IGT probes decision-making by asking participants to choose a card from one of four decks to receive money. Two of the decks are associated with large short-term gains, but even larger eventual losses, leading to a net loss. The other two decks are associated with smaller payouts but an overall net gain. Participants are not informed of these contingencies, so decision-making on this task involves an element of risk-taking (Gowin *et al*, 2013) and an element of learning from the outcomes of each choice. IGT behavior is typically summarized with a numeric score equal to the number of selections from the net-gain decks minus selections from the net-loss decks, where a higher score indicates more advantageous decision-making. While healthy individuals tend to learn which decks are associated with a net gain and shift toward selecting from those decks across trials, patients with ventromedial prefrontal cortex lesions continue to choose from the disadvantageous decks across the task, showing a slower rate of learning contingencies (Bechara *et al*, 1994).

Since its development, many studies have examined the behavior of substance users on the IGT. Interestingly, individuals with SUD show deficits on the IGT that parallel those of the frontal lesion patients, in that they show a slower rate of learning to choose the advantageous decks and they continue to select more often from the disadvantageous decks throughout the task (Bechara *et al*, 2001). Studies have shown that alcohol, nicotine, methamphetamine, cocaine, marijuana, heroin, and polysubstance users all choose from the disadvantageous decks at higher rates than controls (Barry and Petry, 2008; Bolla *et al*, 2003; Gonzalez *et al*, 2007; Kjome *et al*, 2010; Petry *et al*, 1998; Stephan *et al*, 2016; Stout *et al*, 2004; Whitlow *et al*, 2004; Xiao *et al*, 2008). In the following section, we will examine the studies that met our

search criteria to determine if performance on the IGT differ as a function of substance of abuse.

Iowa Gambling Task Performance Across SUD Groups

Several studies directly compared individuals who abused different substances (see Table 2 for a list of studies and estimated effect sizes). Most studies that have compared SUD groups found no evidence of differences in decision-making, including cocaine-dependent and heroin-dependent individuals (Verdejo-García *et al*, 2007) cocaine, alcohol and methamphetamine users (van der Plas *et al*, 2009), and cocaine- and marijuana-dependent individuals (Verdejo-Garcia *et al*, 2007). Further, cocaine-only dependent males did not differ from cocaine- and heroin-dependent males (Vassileva *et al*, 2007). One study assessed substance use disorders in combination with comorbid bipolar disorder (type I or II) and similarly found no difference in total score between cocaine and methamphetamine dependent individuals (Nejtek *et al*, 2013). However, bipolar disorder has been associated with impulsivity and risky decision-making (Sloan *et al,* 2014; Adida *et al,* 2011) and this may have obscured the effects of drug use in this sample. Collectively, these studies argue against substance-specific effects.

Several other studies have compared polysubstance abusers to individuals dependent on specific substances or attempted to parse out the effects of specific drugs in individuals with polysubstance abuse (see Table 2 subsections “Polysubstance” and “Alcohol”). One study comparing non-smokers with an SUD, smokers with an SUD, and smokers without an SUD found no difference in net score on the IGT by smoking status, but individuals with an SUD had lower net scores than individuals with no SUD (Businelle *et al*, 2008). Interestingly, this study contained many overlapping participants with a delay discounting study with the same lead author, and the lack of differences in IGT performance parallel the lack of delay discounting differences across groups. Studies have found no difference between individuals dependent on alcohol, cocaine or heroin and polysubstance users (Barry and Petry, 2008; Kornreich *et al*, 2013). In a large study comparing alcohol dependent individuals to controls, dependent individuals had lower scores than the controls, but covarying for marijuana, nicotine, and other substance use did not explain any additional variance in IGT score (Cantrell *et al*, 2008), indicating common covariance among substance use variables. Lastly, a study comparing MDMA polysubstance users to a polysubstance group that never used MDMA showed no difference in IGT score between the groups, although both groups showed lower scores relative to controls, and less evidence of shifting toward the advantageous decks across blocks (Hanson *et al*, 2008). Overall, these studies provide little evidence of an effect of polysubstance abuse on IGT scores relative to other substance abusing groups.

Only one study has shown differences between substance using groups, finding that methamphetamine users had lower net scores than alcohol users with a medium effect size (Gonzalez *et al*, 2007). However, the alcohol group did not differ significantly from controls despite having lower scores on average. Notably, the sample size of this study was relatively small, and the difference between alcohol and methamphetamine users contradicts a larger study showing no differences between users of these substances (van der Plas *et al*, 2009).

Further, the lack of a difference between the alcohol group and controls contrasts the meta-analytic findings suggesting that alcohol dependence is associated with poorer performance than controls (Stephan *et al*, 2016). Thus, conclusions regarding differences between methamphetamine and alcohol users will require additional studies with larger sample sizes. Collectively, the IGT literature provides a much clearer picture than the delay discounting literature regarding differences between substance using groups. Only one study reviewed here showed evidence of a difference between SUD groups, but the small sample size of the study raises the possibility that this is a false positive effect. The head-to-head comparisons using the IGT indicate that performance is similar across substance using groups. While formal meta-analyses were not conducted, the median effect size across the included studies was Cohen's $d = 0.33$ (interquartile range 0.35; see Table 2). In contrast, the median effect size for case-control comparisons was Cohen's $d = 0.55$ (interquartile range = 0.25, see Supplemental Table 2), suggesting that the substance using groups are more similar to each other than they are to non-substance abusing groups. However, with regards to differences between substance users and healthy controls, the IGT studies reviewed here were less consistent than their delay discounting counterparts, with multiple studies showing no statistically significant differences between cases and controls. Future studies should systematically review the broader IGT literature comparing cases to controls to address these heterogeneous findings.

These results expand on the delay discounting findings and suggests that similarities in decision-making across substance of abuse extends beyond choices regarding immediate versus delayed rewards into choices involving risk-taking preferences and the ability to learn contingencies. They may also suggest that the type of decision-making probed by the IGT, relative to delay discounting, has less variance with regard to substance use effects. For example, whereas six of the ten delay discounting studies showed at least some evidence of a difference between substance using groups, only one of the ten IGT studies found a difference. The mixed findings in the delay discounting literature may be a product of variable task design, as there is substantial heterogeneity across and within studies as to the duration of delay and the magnitude of rewards. The IGT, in contrast, employs the same contingencies and levels of riskiness across most studies. Alternatively, the discrepancy between the IGT and delay discounting literature may suggest that decision-making involving delayed rewards shows some sensitivity to drug of choice or SUD status, whereas decision-making on the IGT does not.

Discussion

In summary, and consistent with other recent reviews, we conclude that there is insufficient evidence to support the hypothesis that there are differences in decision-making patterns across substances of abuse. The reviewed literature shows that substance users have consistent differences relative to controls (see Supplemental Tables 1 and 2), but the differences between users of different substances were either substantially smaller or undetectable. Confidence in this conclusion should be tempered by the small number of comparisons and the paucity of studies designed to assess the contribution of psychiatric and substance use comorbidities. While many individuals with a SUD are polysubstance users (Yoon *et al*, 2015), most studies reviewed assumed that decision-making behavior resulted

from the influence of a primary drug. In reality the confluence of a primary SUD, concurrent drug use, and other psychopathologies (Moody *et al*, 2016a; Petry, 2002) may jointly contribute to these effects. These factors should be more carefully addressed in future studies.

It remains unclear whether decision-making deficits precede or are caused by substance use. To address these possibilities, prospective studies are needed, such as the recently initiated Adolescent Brain Cognitive Development (ABCD) study. Such studies should follow a cohort of adolescents to identify pre-existing decision-making deficits and track how these decision-making deficits progress across the lifespan in both healthy individuals and substance users. Longitudinal studies are essential to determine whether decision-making differs across drug of abuse, and could help address three possible relationships between substance use and decision-making that are depicted in Figure 1. Individuals with any SUD may possess common inherent differences in decision-making that are entirely present prior to substance use (Panel A). Here, decision-making patterns should not vary by drug of choice. Second, repeated substance use may be solely responsible for decision-making deficits (Panel B). In this case, individuals with SUD would only display deficits following the neuroadaptive sequelae of chronic substance use (Koob and Volkow, 2016) that would likely vary by drug of choice. Third, there could be an interaction between pre-existing decision-making deficits and substance use consequences (Panel C). Small differences in decision-making patterns that exist prior to substance use may be exacerbated by either the drug's chronic pharmacological action or by psychopathology associated with SUD, and exacerbation may vary by drug of choice.

There is evidence that decision-making differences are present prior to the development of substance use disorders and may reflect familial influences. A study of young adults stratified by family history of substance use problems showed that family history positive individuals had worse scores on the IGT, although some participants had developed a SUD so it was not possible to isolate the effect on IGT performance due to family history(O'Brien *et al*, 2014). However, not all studies using the IGT have found an effect of family history, as two studies of adults (Acheson *et al*, 2009; Lovallo *et al*, 2006) were both negative. As for delay discounting, there is consistent evidence that adolescents and young adults with a family history of substance abuse show greater discounting of delayed rewards, although the effect sizes of these differences have been small (Acheson *et al*, 2011; Dougherty *et al*, 2014, 2015; VanderBroek *et al*, 2016). Greater discounting has also been linked to earlier onset of alcohol, cigarette and marijuana use in college students (Kollins, 2003) and adolescents (Richardson and Edalati, 2016). Thus, altered patterns of decision-making appear to precede substance use. Since the magnitude of early differences are small, however, it is possible that disparities are less pronounced prior to the onset of SUD, which would support model C from Figure 1. However, the delay discounting meta-analyses (MacKillop *et al*, 2011; Amlung *et al*, 2017) also indicate small effect sizes associated with SUD in adults populations, which may be consistent with model A from Figure 1, where differences between SUD and control remain constant throughout the progression of SUD. Longitudinal studies are needed to clarify the trajectory of decision-making patterns across the course of SUDs.

Abstinence may affect decision-making. Two studies using the IGT found that decision-making deficits lingered in alcoholics following one year (Körner *et al*, 2015) and six years of abstinence (Fein *et al*, 2004), showing no evidence of recovery. In contrast, heroin users who had been abstinent longer performed better on the IGT (Zhang *et al*, 2011). Those who had been abstinent for a month had better scores than those abstinent for only three days and, remarkably, individuals abstinent for 2 years no longer differed from control subjects. Delay discounting studies have reported similar evidence of recovery, as current users of heroin, methamphetamine, nicotine and marijuana all showed greater rates of discounting relative to controls, but ex-users and controls did not differ (Bickel *et al*, 1999; Bretteville-Jensen, 1999; Johnson *et al*, 2010). These findings suggest that some portion of decision-making deficits can be attributed to active drug use, but these deficits may be partially reversible following abstinence, which would be consistent with the recovery trajectory from Figure 1, potentially supporting model C. It remains to be seen whether rate of recovery differs by drug of abuse.

Reducing decision-making deficits may be an important target for treatment. For example, in a study of abstinent heroin dependent individuals on methadone maintenance, weekly assessments showed that frequency of risky choices on a task increased in the weeks leading up to a lapse to heroin use, but decreased again after several weeks of abstinence (Konova *et al*, 2016). This suggests that decision-making patterns may track treatment progress. Many of the existing manualized therapies focus on teaching individuals to make better life decisions (Marlatt and Donovan, 2005). Although the impact of these interventions on standardized decision-making task performance has rarely been evaluated, there is some evidence that risk-taking decreases following 28-day residential treatment (Aklin *et al*, 2009). There is also evidence in abstinent users undergoing treatment that a working memory training program could reduce delay discounting rates (Bickel *et al*, 2011). It will be important to see if this finding can be replicated and whether it contributes to better treatment outcomes.

Conclusions

The literature does not support the idea of unique patterns of decision-making across substances of abuse. However, there are currently a limited number of studies with important confounding factors, thus this conclusion remains provisional. With regards to specific decision-making assessments, there is a consensus among studies using the IGT that there is no effect of drug of choice, and the delay discounting literature offers similar conclusions. There is, however, some contradictory evidence that certain drugs, such as cocaine, may be associated with greater discounting rates than nicotine (see Garcia-Rodriguez *et al*, 2013 and Moody *et al*, 2016b in Table 1, subsection “Cocaine”). Current data indicate that individuals with a family history of addiction show pre-existing differences in decision-making that may increase risk of developing an SUD. These differences may be amplified as an individual’s substance use progresses and structural and functional neuroadaptations manifest due to the neurochemical effects of the abused substance (Ungless *et al*, 2001). In some cases, as the disorder abates, so too do decision-making deficits, although the extent of the recovery remains undetermined. While these conclusions are supported by the literature, significant gaps in our knowledge remain, underscoring the need for well-designed longitudinal studies.

This review corroborates that decision-making deficits are a prominent, well-established characteristic of individuals with SUD. Accordingly, continued work toward understanding decision-making deficits stands to advance basic knowledge of the etiology of SUDs. This knowledge may be translated into therapeutic interventions that will help individuals with SUDs learn to make better choices.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Substance abusers typically show impaired decision-making relative to healthy control groups.
- Studies comparing decision-making between individuals who abused different substances were reviewed.
- Studies have not consistently demonstrated differences in decision-making as a function of drug of choice.
- Prospective studies are needed to determine the trajectory of decision-making deficits in individuals who go on to develop substance use disorders.

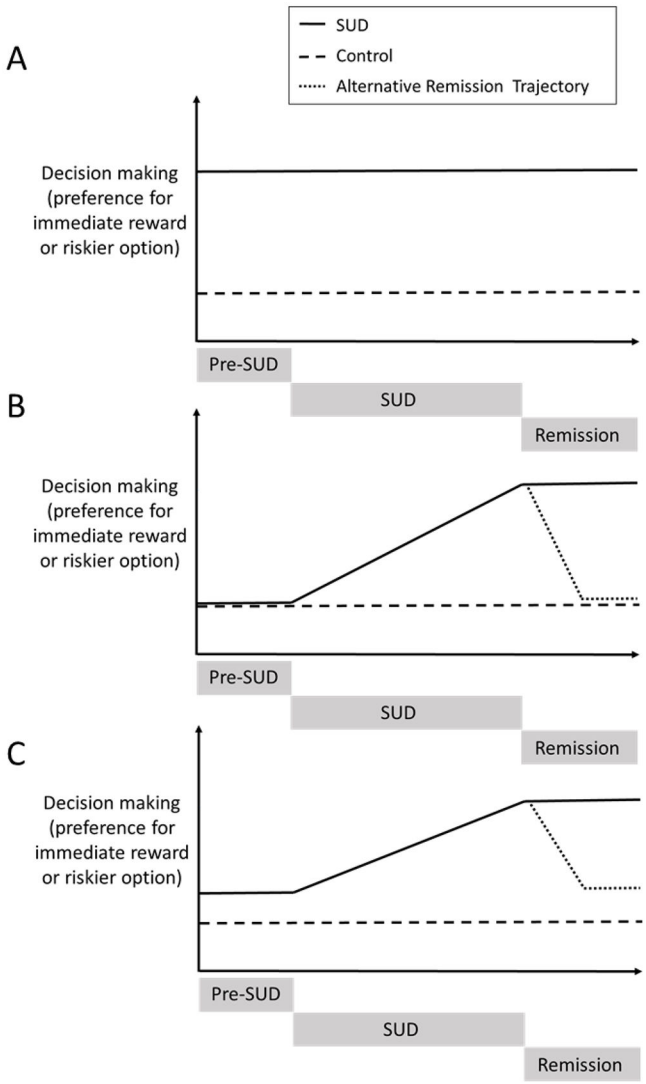

Figure 1.

This schematic depicts three possible relationships between SUD and decision-making. In panel A, an exaggerated preference for immediate rewards exists prior to the onset of SUD and likely contributes to SUD. In this possibility, it is unlikely that differences in decision-making exist across drug-type. In panel B, individuals who develop SUD do not differ from controls prior to developing a disorder. Decision-making differences coincide with the onset of their disorder, and are likely caused by substance use. The slope of the change in decision-making may differ by drug type. Remission of SUD may (dotted line) or may not (solid line) be associated with recovery of decision-making. In panel C, pre-existing differences relative to controls may contribute to the development of an SUD. Onset of SUD may exacerbate these differences. Slope of these differences may differ by drug type. Remission of SUD may (fine dotted line) or may not (solid line) be associated with recovery of decision-making.

Table 1

Studies Assessing Discounting of Delayed Monetary Rewards

Study	Substances	Group 1	N	Group 2	N	Estimated Effect Size[a]	Significant Group Difference
			Alcohol				
Kirby and Petry 2004	Opioids, Cocaine, Alcohol	Alcohol	33	Heroin	27	0.88	Yes
		Alcohol	33	Cocaine	41	0.66	No
Moallem and Ray, 2012	Alcohol, Nicotine	Alcohol + Nicotine	213	Nicotine	67	0.16	No
		Alcohol + Nicotine	213	Alcohol	107	0.31	Yes
		Alcohol	107	Nicotine	67	—	No
Taylor et al. 2016	Alcohol, Polysubstance	Alcohol	27	Polysubstance	59	0.00	No
Moody et al. 2016b	Cocaine, Alcohol, Nicotine	Alcohol	47	Nicotine	137	0.12	No
		Alcohol	47	Cocaine	28	0.19	No
			Cocaine				
Bornovalova et al. 2005	Cocaine, Opioids	Cocaine	16	Heroin	11	0.93	Yes
García- Rodríguez et al. 2013	Cocaine, Nicotine	Cocaine	17	Nicotine	30	1.18	Yes
		Cocaine + Nicotine	30	Nicotine	30	1.44	Yes
		Cocaine + Nicotine	30	Cocaine	17	0.35	No
Mejía-Cruz et al. 2016	Cocaine, Marijuana	Cocaine	77	Marijuana	44	__[b]	No
Moody et al. 2016b	Cocaine, Alcohol, Nicotine	Cocaine	28	Nicotine	137	0.63	Yes
			Opioids				
Kirby and Petry 2004	Opioids, Cocaine, Alcohol	Heroin	27	Cocaine	41	0.20	No
Robles et al. 2011	Opioids	Methadone only	30	Methadone + illicit opioids	30	<0.30	No
Karakula et al. 2016	Opioids	Heroin	106	Prescription- opioids	33	0.49	Yes
			Polysubstance				
	Polysubstance	Polysubstance	25	Nicotine	20	<0.18	No
Businelle et al. 2010		Polysubstance + Nicotine	36	Nicotine	20	<0.18	No
		Polysubstance + Nicotine	36	Polysubstance	25	<0.18	No

[a] Effect size is reported as Cohen's *d*. If this was not reported, it was calculated by a) means and standard deviations, b) test-statistics and degrees of freedom, or c) conversion from another measure of effect size.

[b] — Indicates lack of information

[c] This study compared nicotine, alcohol, and alcohol + nicotine groups using three different monetary reward magnitudes: small, medium, and large. There was no effect of group on medium or large rewards, but there was an effect of group on the small reward values, such that the alcohol + nicotine group showed steeper delay discounting relative to both the alcohol and nicotine group.

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Table 2

Risk-Taking Studies Using the Iowa Gambling Task

Study	Substances	Group 1	N	Group 2	N	Estimated Effect Size[a]	Significant Group Difference
			Alcohol				
Gonzalez et al. 2007	Alcohol, Amphetamine	Alcohol	17	Methamphetamine	16	0.63	Yes
Barry and	Alcohol, Cocaine,	Alcohol	34	Cocaine	42	0.01	No
Petry 2008	Opioids	Alcohol	34	Heroin	28	0.11	No
		Alcohol	34	Polysubstance	27	0.46	No
Cantrell et al. 2008[c]	Alcohol, Marijuana, Nicotine	Alcohol					No
van der Plas et al. 2009	Alcohol, Cocaine, Amphetamine	Alcohol	33	Cocaine	27	—	No
		Alcohol	33	Methamphetamine	38	—	No
Kornreich et al. 2013	Polysubstance, Alcohol	Alcohol	25	Polysubstance	25	—	No
			Cocaine				
Vassileva et al. 2007	Cocaine, Opioids	Cocaine	47	Cocaine + Heroin	53		No
Verdejo- Garcia et al. 2007b	Cocaine, Marijuana	Cocaine	11	Marijuana	10	—	No
Barry and Petry 2008	Alcohol, Cocaine, Opioids	Cocaine	42	Polysubstance	27	0.46	No
van der Plas et al. 2009	Alcohol, Cocaine, Amphetamine	Cocaine	27	Methamphetamine	38	—	No
Nejtek et al. 2013	Methamphetamine, Cocaine	Cocaine	41	Methamphetamine	22	0.33	No
			Opioids				
Verdejo-Garcia et al. 2007a	Cocaine, Opioids	Heroin	25	Cocaine	39	—	No
Barry and Petry 2008	Alcohol, Cocaine, Opioids	Heroin	28	Cocaine	42	0.13	No
		Heroin	28	Polysubstance	27	0.45	No
			Polysubstance				
Businelle et al 2008	Polysubstance	Polysubstance	19	Nicotine	26	__[b]	No
		Polysubstance + Nicotine	40	Nicotine	26	—	No
		Polysubstance + Nicotine	40	Polysubstance	19	—	No
Hanson et al. 2008	MDMA, Polysubstance	MDMA + polysubstance	22	Polysubstance	30	0.00	No

[a] Effect size is reported as Cohen's *d*. If this was not reported, it was calculated by a) means and standard deviations, b) test-statistics and degrees of freedom, or c) conversion from another measure of effect size.

[b] — Indicates lack of information

[c] While this study did not include separate groups for marijuana or nicotine, it compared two analyses that either adjusted for, or did not adjust for marijuana and nicotine use.