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Review

Stages of dysfunctional decision-making in addiction

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A B S T R A C T

Drug use is a choice with immediate positive outcomes, but long-term negative consequences. Thus, the repeated use of drugs in the face of negative consequences suggests dysfunction in the cognitive mechanisms underpinning decision-making. This cognitive dysfunction can be mapped into three stages: the formation of preferences involving valuation of decision options; choice implementation including motivation, self-regulation and inhibitory processes; and feedback processing implicating reinforcement learning. This article reviews behavioral studies that have examined alterations in these three stages of decision-making in people with substance use disorders. Relative to healthy individuals, those with alcohol, cannabis, stimulant and opioid use disorders value risky options more highly during the formation of preferences; have a greater appetite for superficially attractive rewards during choice implementation; and are both more efficient in learning from rewards and less efficient in learning from losses during feedback processing. These observed decision-making deficits are most likely due to both premorbid factors and drug-induced effects. Because decision-making deficits have been prospectively associated with a greater risk of drug relapse, we advocate for greater research on modulating the component stages that give rise to dysfunctional decision-making in disorders of addiction.

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1. Introduction

Optimal decision-making reflects the ability to choose the most advantageous option from a range of alternatives, considering both their short-term and long-term consequences (Bechara, 2005). For people with substance addiction, drug use is a choice with immediate positive outcomes, either through positive or negative reinforcement, but long-term negative consequences. Thus, the repeated use of drugs, even in the face of negative consequences, suggests an imbalance or deficit in the cognitive mechanisms that underlie decision-making (Redish et al., 2008). Accordingly, laboratory studies have consistently shown that individuals with substance use disorders exhibit poorer performance than healthy controls in decision-making tasks (Ekhtiari et al., 2017), and growing evidence suggests that these deficits can hamper attempts to maintain abstinence (Dominguez-Salas et al., 2016).

Decision-making impairments can be both cause and consequence of substance use disorders. Some of the traits linked to substance use vulnerability, such as reward-sensitivity and impulsivity, contribute to poorer performance in decision-making tasks (Verdejo-Garcia et al., 2008). Similarly, the harmful effects of chronic drug use on frontal-striatal and limbic brain systems have been shown to produce or exacerbate deficits in cognitive control processes that contribute to

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decision-making, such as working memory (Albein-Urios et al., 2012; Vonmoos et al., 2014).

In this review, we discuss decision-making impairments in the context of a unified model of decision-making (Coutlee and Huettel, 2012; Ernst and Paulus, 2005). This working model assumes that decision-making is instantiated by the integration of an array of cognitive control processes. Based on this premise, decision-making involves at least three stages, namely: *preference formation*, *choice implementation*, and *feedback processing*, and each of these stages encompasses a range of cognitive control processes (see Table 1 for operational definitions). The preference formation stage involves information sampling and valuation processes that contribute to assessment of reward and risk (e.g., weighing the anticipated rewards and risks of drug-taking behavior versus alternative pleasures or abstinence/recovery (Verdejo-Garcia and Bechara, 2009). The choice implementation stage requires the allocation of motivational resources; the inhibition of competing actions; and self-regulation to override other options with similar subjective values (Levine et al., 2000; Strait et al., 2014). For example, adolescents have been shown to ascribe similar values to drugs and natural rewards (Doremus-Fitzwater et al., 2010). Finally, the feedback processing/learning stage encompasses at least three outcome-evaluation processes: motivational valence (attention to gains versus losses), recency (weighting more recent versus earlier outcomes), and consistency between the history of feedback and subsequent choices (Ahn et al., 2016).

This article reviews the decision-making deficits observed in people with substance use disorders, with a focus on the cognitive processes noted above. Specifically, we review behavioral studies of cognitive deficits relating to the stages of: (i) preference formation, (ii) choice implementation, and (iii) feedback processing. It is important to note that although we present the findings in the above order, this is not necessarily the order in which these stages occur during decision-making, which is more likely to be an iterative process involving all three stages (e.g., feedback processing following one decision may precede preference formation for the next). We also discuss the implications of decision-making deficits for addiction treatment, and the treatment approaches that could modify decision-making dysfunction.

2. Formation of preferences

When confronted with a choice, people develop a preference for one option over another by computing the subjective value of each option. In economic terms, the link between the objective (intrinsic) value of a reward and its subjective desirability is described by a 'preference function' that is inferred through choice behavior (Kable and Glimcher, 2007). Recently, substantial attention has been focused on the neural correlates of how subjective valuations, or preference functions, are encoded in the brain. A large body of data show that subjective valuation is subserved by a network of subcortical and cortical areas – including the ventral striatum and the medial prefrontal, cingulate and orbitofrontal cortices (Chong et al., 2017; Clithero and Rangel, 2014; Kable and Glimcher, 2007; Levy and Glimcher, 2011; Padoa-Schioppa and Assad, 2006; Peters and Buchel, 2009; Rushworth and Behrens, 2008). Many of these areas are affected in people with substance use disorders, and deficits across this network may drive the altered subjective valuation of action/reward outcomes in addicts (see, for example, Section 3) (Bolla et al., 2003; Fishbein et al., 2005; Morales et al., 2012; Thompson et al., 2004).

The cognitive and affective processes involved in the valuation of reward and risk have been examined using several tasks that putatively tap into three domains. First, tasks of reflection impulsivity measure the amount of information participants require before making a choice (Clark et al., 2006). Second, those measuring decision-making under risk require participants to choose between options with explicit information about their outcomes. Finally, studies examining decision-making under conditions of ambiguity assess individuals' choices between options whose outcomes are uncertain (Brand et al., 2006) (Table 1).

Classic examples of tasks that measure reflection impulsivity include the Information Sampling Task and the Beads Task. Studies that have applied these tasks on individuals with substance use disorders (e.g., binge drinkers and chronic users of cannabis, cocaine, amphetamines and opiates) typically show that such individuals are satisfied to use less information to make their decisions relative to healthy controls (Banca et al., 2016; Clark et al., 2006; Stevens et al., 2015). These results suggest that people with substance use disorders are more prone to tolerate uncertainty and risk during formation of preferences.

Several tasks have been used to examine decision-making under risk. These include the Coin Flipping Task, the Cups Task, the Balloon Analogue Risk Task, the Randomized Lottery Task, and the Cambridge Gamble Task. A consistent finding across a broad range of substance use disorders (e.g., alcohol, cannabis, cocaine and opiates) is that those individuals prefer risky over safe alternatives (Brand et al., 2008; Brevers et al., 2014; Fishbein et al., 2007; Hanson et al., 2014; Wittwer

Table 1
Description of the stages and processes involved in decision-making, and the cognitive measures to assess them.

Decision-making stage/constructs	Component processes	Definition	Measures
Preference formation	Reflection	The collection of sufficient information about decision options	Information Sampling Task Beads Task
	Uncertainty evaluation	The valuation of decision options with ambiguous outcomes	Iowa Gambling Task
	Risk evaluation	The valuation of decision options with known outcomes involving potential rewards and losses	Coin Flipping Task Cups Task Balloon Analogue Risk Task Randomized Lottery Task Cambridge Gambling Task
Choice implementation	Response initiation	The allocation of motivational resources to selected choices	Effort-Expenditure for Reward Task[a]
	Self-regulation	The capacity to restrain and override motivational tendencies	Delay discounting
	Cognitive inhibition	The ability to control or suppress suboptimal responses	Go/No-Go Task Stop-signal Task Strategy Application Task
Feedback processing	Reward and punishment learning	The ability to incorporate prediction errors to guide future behavior	Iowa Gambling Task Reversal Learning Task Bandit Task
	Memory	The ability to access the history of recent and distant outcomes	Iowa Gambling Task Reversal Learning Task Bandit Task
	Consistency	The ability to reliably integrate ongoing feedback into subsequent decisions	Iowa Gambling Task Reversal Learning Task Bandit Task

[a] This task also incorporates aspects of preference formation, as individuals have to evaluate the subjective value of investing effort.

et al., 2016). Some of these studies have shown that risk-taking in drug users is particularly elevated when high gains are at stake, suggesting that reward sensitivity plays an important role in risk preference (Brand et al., 2008; Brevers et al., 2014). In addition to reward sensitivity, risk preference is clearly impacted by the ability to hold online the relative value of available options. Indeed, risk-taking behavior has been associated with lower working memory capacity in chronic users of alcohol (in the Coin Clipping and Cups Tasks; Brevers et al., 2014; Brand et al., 2006). Risk-taking behavior has shown to be affected by the severity of individuals' drug use in multiple tasks (e.g., the Balloon Analogue Risk Task, the Randomized Lottery Task and the Cambridge Gamble Task; Fishbein et al., 2007; Hanson et al., 2014; Wittwer et al., 2016).

Finally, chronic users of alcohol, cannabis, stimulants and opiates exhibit disadvantageous decision-making under ambiguity. This has been most consistently shown by deficits in the Iowa Gambling Task (IGT) (Dom et al., 2006; Grant et al., 2000; Loeber et al., 2009; Verdejo-Garcia et al., 2007a, b; Vonmoos et al., 2013). Similar to the affected decision-making processes under risk, poorer performance in the IGT has been associated with heavier alcohol and drug use and other severity indices, such as the number of detoxifications experienced (Loeber et al., 2009; Verdejo-Garcia et al., 2007a; Vonmoos et al., 2013). However, poorer IGT performance is also associated with personality traits, such as higher levels of impulsivity and antisocial characteristics (i.e., poor empathy) (Cantrell et al., 2008; Dom et al., 2006; Miranda et al., 2009; Tomassini et al., 2012). Indeed substance users have blunted valuation of both social and non-social rewards (Tobler et al., 2016). Lower affective sensitivity (i.e., a higher emotional threshold) can contribute to their preference for high reward/high punishment options in the IGT (Goudriaan et al., 2005). However it is important to note that the IGT is a complex task that includes aspects of preference formation (i.e., high reward/high punishment options are superficially more attractive), as well as aspects of feedback processing and learning (Fellows, 2007) (see Section 4).

3. Choice implementation

This stage comprises the processes required to allocate a response to an option (i.e., action selection). They include response initiation, self-regulation and cognitive inhibition (Ernst and Paulus, 2005). Response initiation refers to the allocation of motivational resources to selected choices (Rushworth et al., 2005) – for example, directing sufficient motivational resources to the addiction recovery process. Changing drug taking behavior requires motivation to perform an array of new activities such as seeking support and replacing drug-related behaviors with new behavioral repertoires. The allocation of motivational resources is compromised in substance users, such as chronic users of alcohol, cocaine, methamphetamine and opiates, who have high levels of clinical apathy (Albein-Urios et al., 2013; Pluck et al., 2012; Verdejo-Garcia et al., 2006). The fact that people with substance use disorders are motivated to seek drugs while being apathetic in other domains is consistent with the Incentive Sensitization Model of addiction (Robinson and Berridge, 2008). This model suggests that the motivational systems of individuals with substance use disorders are particularly energized in response to drug cues. Selective energization to drug cues occurs at the cost of motivation for alternative reinforcers.

Recently, several research groups have developed methods to quantify motivation by operationalizing it as the amount of effort participants are willing to invest for particular rewards (Chong et al., 2015, 2017; Treadway et al., 2009). For example, the Effort-Expenditure for Reward Task (EEfRT) measures the willingness to allocate effort to both hard and easy tasks as a function of reward (Treadway et al., 2009). In a recent study, individuals who received acute cannabinoids administration were less willing to invest effort for reward. Interestingly, however, chronic cannabis users were willing to invest equal amounts of effort for reward compared to controls (Lawn et al., 2016). More research is needed to characterize these motivational processes objectively in other substance use disorders. Such research can provide interesting insights about the development of decision-making deficits, as *increased* reward sensitivity has been linked to vulnerability for substance use disorders, whereas drug use is thought to *decrease* reward sensitivity and induce apathy. However, a challenge in exploring motivation in people with substance use disorders is that common psychiatric comorbidities, such as depression or schizophrenia, are independently associated with symptoms of apathy (Chong and Husain, 2016). These strong associations pose a challenge in disentangling the motivational deficits secondary to drug use, versus those caused by a concurrent psychiatric disorder.

A second aspect of choice implementation is self-regulation, defined as the ability to restrain and override temptation. An example of this is delay discounting, which requires participants to choose between a smaller, more immediate reward, versus a larger reward that can only be obtained after a longer delay (Bickel et al., 2014; Kable and Glimcher, 2007). A robust finding is that humans tend to discount the subjective value of the larger, later reward by the delay required to obtain this reward. Delay discounting provides a particularly useful example of a computational model of subjective value in addiction. Delay discounting has been consistently found to be best described by a hyperbolic function: $V_d = R / (1 + kD)$, where V_D is the discounted subjective value of an outcome, R is the (undiscounted) reward on offer, D is the delay to reinforcement, and k is a subject-specific discounting parameter, which indexes an individual's propensity to temporally discount future rewards. Such computational models typically show that the k-values of individual subjects are higher in people with substance use disorders relative to those without (i.e., that they discount the value of later rewards to a greater extent than controls) (Amlung et al., 2016). The clinical importance of heightened delay discounting in substance users is that they are more likely to be impulsive; less likely to override immediate urges and temptations; and more likely to discount commodities other than monetary rewards in a similar way (e.g., drugs).

Ultimately, choice implementation requires the inhibition of competitive courses of action, and the alignment of intentions and actions. Typically, response inhibition is measured by the Go/No-Go Task, which measures the ability to refrain from action initiation (reviewed in Smith et al., 2014), and the Stop-signal Task, which measures the ability to inhibit an ongoing action (Monterosso et al., 2005). A large body of literature indicates that chronic users of alcohol and stimulants have deficits in cognitive inhibition as measured by these two tasks. These deficits are clinically relevant, as substance users tend to make responses without forethought of their consequences, for example, approaching drug use hotspots during treatment.

The ability to align intentions with actions can be measured with strategy-application tasks. In these tasks, there is an overarching goal but participants are free to select the best strategy to achieve this goal (Levine et al., 2000). Participants' main task is to gain points or to complete a set of tasks, and the best strategy is to concentrate the effort in the most valuable items (e.g., the items that give more points or the tasks that count in the final tally). In this context, people with substance use disorders are able to identify the best possible strategy to complete the task, but are unable to implement the behaviors needed to deploy that strategy (Valls-Serrano et al., 2016b; Verdejo-Garcia et al., 2007a). These findings suggest that individuals with substance use disorders have cognitive control deficits that limit their ability to translate goals into appropriate courses of action.

4. Feedback processing

Finally, feedback processing refers to how behavior is shaped by the outcomes of previous experiences. Computational models of reinforcement learning attempt to link prediction errors at a cellular level to behavioral outcomes, and have great potential in helping to understand addictive behavior. For example, reinforcement-learning models predict that addiction is associated with a malfunction of the valuation circuitry, such that inappropriate values are assigned to particular behavioral acts or mental states (Paulus, 2007; Redish, 2004; see also Section 2). Computational models of reinforcement learning and/or of subjective valuation may therefore be particularly relevant for understanding how subjective valuation in addiction is altered by disordered feedback processing (Rangel et al., 2008).

The cognitive mechanisms contributing to feedback processing and learning in decision-making have been assessed using computational models of the Iowa Gambling Task (IGT) and probabilistic choice tasks, including the Reversal Learning Task (RLT) and the Bandit Task (Busemeyer and Stout, 2002; Ekhtiari et al., 2017). Computational models of the IGT have shown that chronic cannabis users exhibit more efficient learning from rewarding outcomes and less efficient learning from punishing outcomes. Furthermore, such users rely more on recent (versus past) outcomes, and their choices are generally less aligned with outcomes (Fridberg et al., 2010). Similar deficits have been observed in chronic users of stimulants. For example, people with cocaine use disorder display greater learning from rewarding outcomes and poorer consistency in their choices (Stout et al., 2004). People with amphetamine use disorder have also shown a dose-related effect of stimulant use on learning from rewarding stimuli (Ahn et al., 2014). Both cocaine and methamphetamine users show a higher tendency to win/stay in probabilistic choice tasks such as the Bandit Task and the RLT (Harle et al., 2015; Moreno-López et al., 2015).

Moreover, duration of stimulant use has been significantly associated with poorer performance in the RLT, especially following changes in reward contingencies (Fernández-Serrano et al., 2011). These findings suggest that, in cannabis and stimulant users, enhanced motivational evaluation of reward outcomes and poorer consistency between predictable outcomes and choices contribute to poorer decision-making. However, in chronic users of opiates, computational models of the IGT indicate that their feedback processing deficits are linked to lower attention to losses, or impaired loss aversion (Ahn et al., 2014). This finding is consistent with results obtained with the RLT, where users of opiates were more likely to “chase losses” following repeated negative feedback (Myers et al., 2016). Together, these data suggest that impaired feedback processing may significantly affect adaptive decision-making in populations with substance use disorders, and that these impairments may be driven by greater attention to gains; less attention to losses; and poorer consistency between choices and their probable outcomes.

5. Research challenges

Decision-making deficits have been consistently associated with lower adherence to treatment and higher risk of relapse (Dominguez-Salas et al., 2016; Stevens et al., 2014). Therefore, the cognitive deficits reviewed above have important implications for treatment matching, and for development of novel interventions that improve clinical outcomes by ameliorating decision-making deficits. Nevertheless, some aspects of the relationship between decision-making and treatment outcomes require further investigation.

For example, key processes of decision-making, such as motivation and response initiation, have not been investigated at all in the context of treatment outcomes given the lack of appropriate measures (Chong et al., 2016). New, objective measures of effort-based motivation are well suited to identify alterations in subjective valuation of rewards, which are thought to drive individual differences in goal-driven decision-making (Chong et al., 2015; Chong et al., 2016; Treadway et al., 2012; Westbrook et al., 2013). These differences may be relevant for identifying people who are less likely to adhere to treatment, or more likely to benefit from rehabilitation strategies focused on their motivational state. Given the link between motivation and self-control (Robinson and Berridge, 2008) effort-based motivation and decision-making measures might be particularly useful to identify patients at higher risk of relapse.

Critically, clinical research in the field of addiction has not tended to acknowledge the separate cognitive stages and processes involved in decision-making. Future research would benefit from assessing and targeting these unique decision-making processes, to determine their relative weighting and clinical relevance. Of course, such research is not without its methodological challenges. For instance, some of the existing behavioral measures of decision-making lack construct specificity and test-retest reliability (Hulka et al., 2014). A classic example of poor construct specificity is the IGT, which taps into multiple stages of decision-making (Buelow and Suhr, 2009; Fellows, 2007). To address this limitation, mathematical models have been developed to tease apart the processes involved in the IGT and other complex decision-making measures (Ahn et al., 2016). The limitations of test-retest reliability have been linked to the high sensitivity of these tasks to state and context fluctuations (Buelow and Suhr, 2009; Fernández-Serrano et al., 2011). Therefore, they could be addressed by improving our understanding of the impact of context on decision-making, as done in animal studies (Kim et al., 2015).

In addition, a key aspect in need of further research is ecological validity: how can we create research settings that reflect the naturalistic contexts in which drug related behaviors occur? Treatment failure and relapse obviously occur in naturalistic contexts and suboptimal conditions, such as elevated stress or social isolation. Therefore, studies are needed to bridge laboratory-based findings and the real world. In addressing this gap, future studies would benefit from interrogating both interoceptive, environmental and social contexts (Ekhtiari et al., 2017). For example, are decision-making deficits modulated by the nutritional state or the sleep problems of individuals with substance use disorders? Are they modulated by the time of the day; the salience of the environmental cues; or by social context? With regard to the latter question, recent studies have shown that some of the cognitive/affective deficits driving decision-making deficits in person-centered paradigms are also relevant to social decision-making deficits in individuals with addiction. For example, lower emotional reactivity to moral dilemmas is linked to more utilitarian choices among people with alcohol use disorder (Carmona-Perera et al., 2013). Similarly, lower emotional reactivity to social gaze is associated with orbitofrontal cortical deficits and smaller social networks among people with cocaine use disorder (Preller et al., 2014).

In summary, further research is needed to more closely relate treatment outcomes to impairments of particular stages of decision-making in the context of social and environmental cues.

6. Treatment options

A practical implication of the link between decision-making deficits and poorer treatment outcomes is that we can improve clinical outcomes by applying decision-making interventions. More research is still needed to identify which stages and processes are more tightly related to clinical outcomes, as noted above. However, such research could help determine if future therapies should focus on particular stages of decision-making, and will foster the development of specific approaches.

An alternative approach consists in applying holistic interventions that tap into the different stages of decision-making. Goal Management Training (GMT) is a cognitive remediation intervention that trains some of the cognitive control processes involved in decision-making, such as response initiation, self-regulation and feedback monitoring (Levine et al., 2011). GMT also contains a specific module on decision-making, which focuses on the coordination of these cognitive processes to achieve complex goals. This approach seems to be optimal in the context of a unified model of decision-making, as this training targets both the individual processes and their integration. Two trials have shown a significant improvement in decision-making in individuals with chronic use of alcohol, stimulants and heroin enrolled in this intervention relative to those that are enrolled in their usual treatment regimens. This change was reflected as improved performance in the Iowa Gambling Task (to measure preferences/feedback) and the Information Sampling Task (to measure preferences) (Alfonso et al., 2011; Valls-Serrano et al., 2016a). In keeping with a unified model, these results suggest that improvements achieved through the training of other components, such as self-regulation and feedback monitoring, can effectively modify preferences, for example, by reducing the appeal of choices linked to actions that become more controlled and monitored (Bickel et al., 2016; Verdejo-Garcia, 2016). These preliminary findings also confirm the basic premise that targeted cognitive training can optimise decision-making skills, although whether these cognitive gains translate into clinical outcomes such as abstinence from drugs remains unclear.

Additional cognitive interventions with the potential to improve decision-making include working memory training, which may increase the ability to hold choice-outcome representations online during preference formation; contingency management, which exploits the link between reward-based motivation and decision-making; and mindfulness and acceptance-based therapies, which strengthen self-regulation skills (reviewed in Manning et al., 2016; Verdejo-Garcia, 2016). More research regarding the influence of environmental and social contexts on decision-making deficits is needed to clarify the potential of novel technology-based interventions, such as virtual reality (e.g., virtual reality assisted cue-exposure therapy) or life-logging (using self-monitoring devices such as mini-cameras or actigraphy to identify antecedents of poor decisions and provide tailored feedback to prevent these decisions), for clients with addiction. Research is also needed on cognitive enhancement of decision-making through pharmacological and brain stimulation tools (Sofuoglu, 2010).

7. Conclusion

People with substance use disorders exhibit significant deficits in cognitive processes that underlie complex decision-making. Such deficits include: lower risk- and higher reward-sensitivity during preference formation; lower motivation, self-regulation and cognitive inhibition during choice implementation; and perseveration and greater learning from reward during feedback processing. Deficits in decision-making processes are relevant for identifying substance users at risk of poor treatment outcomes, but who are also more likely to benefit from cognitive interventions that address decision-making deficits. Goal Management Training is a promising cognitive control training intervention as it has shown to improve decision-making performance in substance users. In addition, working memory training, contingency management and third-generation psychotherapies (e.g., mindfulness, acceptance and commitment therapy) tap into relevant component processes in decision-making, such as motivation and self-regulation. More research is needed to gain a better understanding the role of context in the decision-making deficits of individuals with substance use disorders. Alterations in internal context (nutritional deficits, sleep deprivation, stress) and external context (presence of environmental cues, other people) might significantly modulate decision-making abilities in substance users. This knowledge may also inform the development of novel technology-based interventions, such as virtual reality or life-logging assisted interventions.

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