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Invited review

The behavioral- and neuro-economic process of temporal discounting: A candidate behavioral marker of addiction

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ABSTRACT

Addiction science would benefit from the identification of a behavioral marker. A behavioral marker could reflect the projected clinical course of the disorder, function as a surrogate measure of clinical outcome, and/or may be related to biological components that underlie the disorder. In this paper we review relevant literature, made possible with the early and sustained support by NIDA, to determine whether temporal discounting, a neurobehavioral process derived from behavioral economics and further explored through neuroeconomics, may function as a behavioral marker. Our review suggests that temporal discounting 1) identifies individuals who are drug-dependent, 2) identifies those at risk of developing drug dependence, 3) acts as a gauge of addiction severity, 4) correlates with all stages of addiction development, 5) changes with effective treatment, and 6) may be related to the biological and genetic processes that underlie addiction. Thus, initial evidence supports temporal discounting as a candidate behavioral marker. Additional studies will be required in several areas for a more conclusive determination. Confirmation that temporal discounting functions as a behavioral marker for addiction could lead to 1) a screen for new treatments, 2) personalization of prevention and treatment interventions, and 3) the extension of temporal discounting as a behavioral marker for other etiologically similar disorders.

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1. Introduction

Modern behavioral economic and neuro-economic approaches consider addiction to function, in part, as a possible valuation disorder wherein normal decision-making mechanisms become dysfunctional, resulting in pathological reward processing (Bickel et al., 2012a,b). Pathological valuations stemming from this aberration distort decision-making and lead to 1) overvaluing immediate, drug-associated stimuli and 2) undervaluing longer-term rewards (Bickel et al., 2007; Schultz, 2011). Temporal discounting, considered a measure of one's location on the continuum of impulsive decision-making to self-control, may represent the interaction of these valuation systems and their associated neural networks (Bickel et al., 2007). Substantial evidence has demonstrated that addicted individuals grossly undervalue (i.e., discount) future rewards relative to immediate rewards (see below). Moreover, excessive discounting among those with an addiction is associated with clinically important phenomena such as poor treatment outcome and relapse (see below).

Temporal discounting, at a behavioral level, refers to the intertemporal reward preferences often characterized by a decrease in reward value as a function of the delay to its receipt (Ainslie, 1975; Rachlin and Green, 1972). Procedurally, these methods often pit a smaller, more immediate reward against a larger, more delayed reward. In some procedures, choice amounts are titrated until there is no preference between the immediate and delayed reinforcers; this value is referred to as the indifference point. Identifying the indifference points across a range of delays allows the plotting of an indifference curve. From such a curve, the rate at which a reinforcer decreases in value as a function of the delay to its receipt can be estimated. The shape of the resulting curve has been shown in a wide variety of subjects and conditions to approximate a hyperbola (Mazur, 1987) and can be characterized by the equation

$$V_d = V/(1 + kd).$$

In this equation, V_d is the present discounted value of the reinforcer, V is the objective value of the reinforcer, k is an

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empirically derived constant that reflects the rate of discounting, and *d* is the temporal delay to the delivery of the reinforcer (Mazur, 1987; Nevin and Rachlin, 1986).

There are several discounting procedures that have been used in the literature. In addition to variants of the adjusting procedure described above, temporal discounting has been examined with tasks that arrange other sequences of questions, questionnaires, and single-item choice assessments (Bradford, 2010; Kirby et al., 1999; MacKillop, 2013). Not surprisingly, these procedures, although all measuring preferences for smaller sooner versus larger delayed rewards, have been referred to with a variety of different names including delay of gratification, delay discounting, impulsive choice, intertemporal choice, and time preference. Moreover, quantifications of the resulting data are diverse. Although the single-free-parameter hyperbolic model described above is widely used, other models including two-free-parameter models, hyperbola-like, and exponential-power models have been used (Myerson and Green, 1995; Yi et al., 2009). Additional measures include area under the curve and proportion of the choices allocated to the smaller-sooner choice (Mitchell et al., 2005; Myerson et al., 2001). Across these procedural and analytical variations, the methods and measures with greater resolution are more responsive to addiction-related differences (MacKillop et al., 2011).

In this paper, we consider whether temporal discounting, a neurobehavioral process derived from behavioral economics, further explored with neuroeconomics, and used to understand addiction via early and sustained support by NIDA, may function as a potential or candidate behavioral marker of addiction (Bickel et al., 2007). To explore its candidacy, we will review the rapidly expanding research on temporal discounting in addiction with an emphasis on human studies, and examine the extent to which this measure may function as a behavioral marker. According to Duka et al. (2011), a behavioral marker is more than a risk factor or a mere correlate of disease progression if it also reveals facets of the disorder's mechanism, tracks treatment outcomes, and suggests novel avenues for treatment development. In order to explore the relationship of temporal discounting to addiction, as well as its status as a candidate behavioral marker, we will examine (1) if temporal discounting reflects the clinical course of addiction, (2) the relationship of temporal discounting and treatment outcomes in addiction, and (3) the biological components of excessive temporal discounting in addiction (Duka et al., 2011; Frank and Hargreaves, 2003; Wiedemann, 2011).

Although we will review the status of temporal discounting as a potential behavioral marker in addiction, we acknowledge that the relationship between temporal discounting and addiction has not been extensively explored in all aspects of addiction research. Therefore, the determination of temporal discounting as a behavioral marker is still incomplete in several areas and awaits additional study. Moreover, we will not review the relationship between addiction and other distinct measures that have been characterized as measures of the multi-faceted construct of impulsivity, and only briefly discuss the role executive function has on discounting, as these have been reviewed elsewhere (e.g., Bickel et al., 2012a; de Wit, 2009; Perry and Carroll, 2008).

2. Distinguishing the drug dependent from controls

To serve as a useful behavioral marker, temporal discounting should sufficiently distinguish whether individuals have a current drug dependence disorder. Research comparing temporal discounting rates among current users and community controls has repeatedly shown that those with a drug dependence disorder have a comparatively higher average discount rate. The first published account of greater discounting of delayed rewards was conducted among a group of opioid-dependent participants (Madden et al., 1997). The opioid-dependent group in that study was found to discount delayed money more than controls. More specifically, among controls the delayed hypothetical $1000 lost 50% of its absolute value when the delay was approximately 37 months, while among the opioid-dependent group the same monetary amount lost half its value in only 4.5 months. Subsequent research with additional groups of opioid-dependent participants has since replicated this result (Kirby and Petry, 2004; Kirby et al., 1999; Madden et al., 1999; Odum et al., 2002; Vassileva et al., 2011). This observation extends beyond opioid-dependent participants. Populations that use nearly every common drug of abuse have been shown to discount delayed rewards more rapidly than appropriate controls. This is the case for individuals dependent on alcohol (Bjork et al., 2004; Bobova et al., 2009; Finn and Hall, 2004; Mitchell et al., 2005; Petry, 2001, but see Kirby and Petry, 2004), cigarettes (Baker et al., 2003; Bickel et al., 1999, 2008; Businelle et al., 2010; Johnson et al., 2007; Mitchell, 1999; Odum et al., 2002; Reynolds et al., 2009, 2004; Rezvanfard et al., 2010), cocaine (Bickel et al., 2011a; Camchong et al., 2011; Coffey et al., 2003; Heil et al., 2006; Kirby and Petry, 2004; Moeller et al., 2002), and methamphetamine (Monterosso et al., 2007). The only commonly abused drug dependence disorder that has been tested and shown to be unassociated with increased discount rates is marijuana dependence (Johnson et al., 2010). While most researchers have examined monetary discounting in relation to substance abuse, cigarette smokers have also been shown to discount delayed health gains at a greater rate than controls (Baker et al., 2003; Odum et al., 2002), suggesting that the delayed negative health-related consequences of smoking may be less impactful to cigarette smokers. Several studies examining discounting of several commodities have shown that the rate of discounting is often correlated across commodities (Odum, 2011a,b), but further research is needed comparing discounting of non-monetary rewards in drug-dependent and control populations.

Overall, a consistent finding observed in this section is that those with addiction discount money more than controls. This pattern of findings has generality across most drugs of abuse and is evident across different sampling techniques, settings, and measurement approaches used in these studies.

3. Prediction of entrance to drug use

Few studies have examined whether the rate of delay discounting predicts the likelihood that an individual will use or become dependent on a drug of abuse. This is likely due to the difficulty with measuring this relationship. As one's discount rate is possibly altered by continued drug use (see above), the relationship between delay discounting and drug use onset can only be reliably and accurately measured by assessing delay discounting rate before any drug use occurs and following up at a later date to ascertain which individuals eventually used or abused a drug. To date, only one study has assessed this relationship in humans (Audrain-McGovern et al., 2009a), with another reporting on the relationship between a similar construct (delay of gratification) and later drug use (Ayduk et al., 2000). Both are described below.

The only reported study to directly measure whether a high discount rate predicts whether someone goes on to use or abuse a drug of abuse found a positive relationship between discount rate and subsequent initiation or increased use of cigarettes among high school students (Audrain-McGovern et al., 2009b). A questionnaire version of the delay discounting task (The Monetary Choice Questionnaire, Kirby et al., 1999), and smoking behavior were assessed