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Interrelationships between marijuana demand and discounting of delayed rewards: Convergence in behavioral economic methods

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ABSTRACT

Background: Distinct behavioral economic domains, including high perceived drug value (demand) and delay discounting (DD), have been implicated in the initiation of drug use and the progression to dependence. However, it is unclear whether frequent marijuana users conform to a "reinforcer pathology" addiction model wherein marijuana demand and DD jointly increase risk for problematic marijuana use and cannabis dependence (CD).

Methods: Participants ($n = 88$, 34% female, 14% cannabis dependent) completed a marijuana purchase task at baseline. A delay discounting task was completed following placebo marijuana cigarette (0% THC) administration during a separate experimental session.

Results: Marijuana demand and DD were quantified using area under the curve (AUC). In multiple regression models, demand uniquely predicted frequency of marijuana use while DD did not. In contrast, DD uniquely predicted CD symptom count while demand did not. There were no significant interactions between demand and DD in either model.

Conclusions: These findings suggest that frequent marijuana users exhibit key constituents of the reinforcer pathology model: high marijuana demand and steep discounting of delayed rewards. However, demand and DD appear to be independent rather than synergistic risk factors for elevated marijuana use and risk for progression to CD. Findings also provide support for using AUC as a singular marijuana demand metric, particularly when also examining other behavioral economic constructs that apply similar statistical approaches, such as DD, to support analytic methodological convergence.

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1. Introduction

Ease of accessibility to inexpensive marijuana may be a substantial risk factor for elevated use, similar to risk factors that have been linked with excessive alcohol consumption (Murphy and MacKillop, 2006). As initiation and use of marijuana increase, there will be a concomitant increase in the number of individuals who develop cannabis use disorder (CUD). It is imperative that salient predictors of CUD and level of use be identified in the wake of the normative and legal shift concerning marijuana.

The propensity to initiate and maintain substance use has been linked with impulsivity (de Wit, 2009; Guy et al., 1994). Elevated impulsivity is characterized by poor decision making and diminished ability to foresee and evaluate negative consequences (Adinoff et al., 2007). Impulsivity is a complex and multi-faceted behavioral domain (Courtney et al., 2012; Cyders and Coskunpinar, 2011; Stahl et al., 2014), however, key components of impulsivity can be captured via the examination of precise behavioral constructs. Delay discounting (DD), characterized by deficits in self-regulation, is one such measure of impulsivity, and fits into a framework of behavioral economic processes. Behavioral economics is ideally suited to the conceptualization of the progression of substance use and dependence as it endeavors to integrate internal processes operating within a substance user with external factors and influences in the environment (Bickel et al., 2014). In addition, substance demand, characterized by perceived drug

value, is a related behavioral economic process that may putatively facilitate understanding of initiation and maintenance of substance use.

DD paradigms reveal an individual's intertemporal reward preference profile, namely, their preferred choice with respect to the conflict between smaller rewards obtainable in the short-term (e.g., drug of choice), set against larger or superior rewards accessible at a given future time (e.g., future positive life outcomes; MacKillop, 2013). With regard to substance use, the inability to perceive increased value in superior future rewards may explain loss of control over drug use, a key element of drug dependence (Bickel and Marsch, 2001). Consequently, substance users frequently disregard previously set limits when the prospect to use a preferred substance arises. It has been consistently shown that substance use disorders tend to be significantly related to steep DD processes (MacKillop et al., 2011). Individuals with an array of addictive disorders display significantly greater discounting for preferred substances including tobacco (Johnson et al., 2007) and alcohol (Petry, 2001), as compared to control groups.

Compared to other frequently misused substances, the relationships among DD, level of marijuana use, and the presence of CUD have been less clear. Johnson et al. (2010) investigated DD among marijuana-dependent individuals and control participants and found no significant difference in discounting, but did report a trend toward elevated discounting in the marijuana-dependent group. Furthermore, among college students, participants' age at first marijuana use has been negatively correlated with DD, with earlier onset of marijuana use being related to elevated DD (Kollins, 2003). Acute administration of delta(9)-tetrahydrocannabinol (THC), the main psychoactive constituent of marijuana, to marijuana users produced no significant effects on DD (McDonald et al., 2003; Metrik et al., 2012). Consequently, more research is required to determine whether a relationship between marijuana use and DD exists.

Substance demand, or the perceived value of a given drug, can be assessed by examining performance on a drug purchase task. Demand is the quantitative relationship between use and cost (Hursh et al., 2005). Participants indicate how much they would be willing to pay for their preferred drug at increasing levels of price. Laboratory models permit assessment of several behavioral economic substance demand indices, including intensity (substance amount consumed at zero cost), P_{max} (price at maximum expenditure), O_{max} (total peak expenditure), breakpoint (cost whereby consumption is suppressed to zero), and elasticity of demand (rate at which consumption decreases as price increases). Studies consistently confirm the existence of significant relationships between indices of drug demand and substance use disorders. For example, indices of tobacco cigarette demand have been linked with increased nicotine dependence (Chase et al., 2013; MacKillop et al., 2008; Murphy et al., 2011), and alcohol demand metrics have been significantly related to alcohol problem severity and level of alcohol consumption (MacKillop et al., 2010; Murphy et al., 2009; Murphy and MacKillop, 2006). Furthermore, indices of marijuana demand have been related to cannabis dependence (CD) symptom count and self-reported marijuana craving (Aston et al., 2015), as well as level of use (Aston et al., 2015; Collins et al., 2014) and cue-elicited craving (Metrik et al., 2016).

Substance demand can be characterized by five distinct behavioral economic indices, but moderate to high correlations among indices are common. Furthermore, while each demand index explains a unique facet of the drug's individualized perceived value, it may be problematic from a statistical perspective to include all five metrics in the same formal analysis due to potential for Type I error and multicollinearity (Amlung et al., 2015). To address this, Amlung et al. (2015) successfully employed an area under the curve (AUC) analysis to calculate an index of demand for the alcohol

purchase task, generating a single metric that was significantly correlated with the individual focal indices. AUC may be particularly advantageous in the analysis of relative drug value because it incorporates the full volume of reported demand, in essence, integrating all metrics. Moreover, utilizing AUC to represent substance demand allows for clear methodological convergence with the DD literature wherein AUC is used to capture DD performance (Amlung et al., 2015).

Standardization of measurement and analytic approaches facilitates comparability of data across studies and enables replication of findings. In this regard, convergence in analytic methodology in behavioral economics is particularly significant as a central priority is improved understanding of the distinct and dual influences of DD and substance demand within a conceptualization of addiction known as "reinforcer pathology" (Bickel et al., 2014, 2011). Reinforcer pathology is defined as the joint effects of two constituent processes: (a) the persistently high valuation of a reinforcer (i.e., demand), and/or (b) the excessive preference for the immediate acquisition or consumption of a commodity despite long-term negative outcomes (i.e., DD; Bickel et al., 2014, 2011). Behavioral economics has suggested that individuals with substance use disorders may consistently experience an interplay between demand and DD, specifically by exhibiting high personal valuation of their preferred substance while also displaying a preference toward receiving and using it immediately. Moreover, it has been posited that these two processes may synergistically interact to contribute to reinforcer pathology (Bickel et al., 2011).

While the interplay between substance demand and discounting may be of chief importance (Bickel et al., 2011), the presence of a relationship between these two behavioral economic constructs in the literature has been equivocal, and it has yet to be determined whether these are related or independent components of the reinforcer pathology conceptualization of addiction. Elevated levels of substance demand and DD are posited to be recurrent etiological markers in the progression of drug use and the development of substance use disorders (Bickel et al., 2014). In this regard, a study conducted by MacKillop et al. (2010) concluded that both high demand for alcohol and elevated DD were associated with increased alcohol use disorder severity. While demand and DD are purported to be correlated with severity of dependence, the relationship between substance demand and DD is unclear. Teeters and Murphy (2015) found no bivariate relationship between indices of alcohol demand and DD in a study evaluating the relationships among demand, discounting, and driving after drinking. Furthermore, Amlung et al. (2013) also found no bivariate relationship between demand and discounting in a study examining alcohol demand and impulsivity in the context of combined alcohol and caffeine consumption. MacKillop and Tidey (2011) investigated demand for tobacco cigarettes and DD in a study examining nicotine dependence among smokers with schizophrenia. The schizophrenia group significantly differed from the control group with respect to demand for cigarettes, however, there were no group differences in DD. Moreover, the association between marijuana demand and DD has not yet been investigated. Further research is necessary to evaluate the theoretical premise of reinforcer pathology in the progression and maintenance of substance use disorders.

In the current study, we sought to test whether frequent marijuana users conform to a reinforcer pathology model of addiction by examining the joint influence of marijuana demand and DD. We also sought to examine potential interactions between marijuana demand and DD to determine whether these variables display synergistic or additive roles in contributing to elevated marijuana use and dependence symptoms. In addition, we examined the relationship between DD and marijuana demand by assessing the bivariate relationship between demand as assessed by an AUC anal-