

DELAY AND LOSS OF SUBJECTIVE VALUE

DEMORA Y PÉRDIDA DE VALOR SUBJETIVO

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Abstract

Delay discounting, the observed decrease in the value of a reward as a function of delay, is reliably found in humans and laboratory animals under a wide range of conditions and with an equally wide variety of rewards. Importantly, higher rates of hyperbolic discounting have been observed in drug-using individuals compared to controls. Despite the overwhelming support for the association between rate of delay discounting and drug use, it is still not clear if a higher rate of delay discounting predicts drug use, if drug use affects delay discounting rate, or if a third, still unidentified, variable predicts both. The aim of this article is to present and discuss evidence regarding the relationship between rate of delay discounting and drug use, and its potential implications to the prevention, detection, and treatment of substance abuse.

Key words: delay discounting, impulsivity, subjective value, choice, drug abuse, addiction severity.

Resumen

El descuento por demora, el decremento observado en el valor del reforzamiento en función de la demora, se observa confiablemente en humanos y animales de laboratorio bajo una gran cantidad de condiciones y para una gran variedad de recompensas. De manera importante, las tasas más altas de descuento hiperbólico se han encontrado en usuarios de drogas, al compararse con controles. A pesar del amplio apoyo a la asociación entre la tasa de descuento y uso de drogas, aún no es claro si una tasa alta de descuento predice el uso de drogas, si el uso de ellas afecta la tasa de descuento, o si, una tercera variable predice ambos. El objetivo de este estudio es presentar y discutir la evidencia respecto a la relación entre tasa de descuento y uso de drogas, y sus implicaciones potenciales a la prevención, detección y tratamiento del abuso de sustancias.

Palabras clave: descuento por demora, impulsividad, valor subjetivo, elección, abuso de drogas, severidad de la adicción.

Drug dependent individuals often behave impulsively, choosing smaller rewards associated with drug use over presumably larger but delayed rewards such as good health, freedom from incarceration, or good family relations. The loss of a reward's value as a function of delay is known as *delay discounting*.

Delay discounting (DD) is a robust phenomenon observed consistently in humans and laboratory animals (Bickel et al., 1999; Green et al., 1994; Mazur, 1987; Rachlin et al., 1991; Richards et al., 1997; Reynolds, 2006b; Rodríguez and Logue, 1998; Woolverton et al., 2007). In general, research on DD has shown that the *subjective* value (utility, in economic terms) of an objectively defined reward (money, for example), decreases as delay between the choice response and the reward increases (Rachlin and Green, 1972). This relationship between delay and value of a reward appears to hold for humans in general and, in addition, a growing number of studies show that drug users consistently discount the value of delayed rewards at a higher rate than individuals who don't use drugs. For example, compared to community controls, a higher rate of DD has been observed in cigarette smokers (e.g., Bickel et al., 1999; Dallery and Raiff, 2007; Reynolds, 2006a; Reynolds, 2006b; Yoon et al., 2007), drinkers (e.g., Field et al., 2007; Petry, 2001; Vuchinich and Simpson, 1998), and users of various illicit drugs (e.g., Kirby et al., 1999; Madden et al., 1997; Madden et al., 1999; Petry and Casarella, 1999). However, most of that evidence derives from correlational or quasi-experimental studies; therefore, despite the overwhelming support for the association between rate of DD and drug use, it is still not clear if higher rate of DD predicts drug use, if drug use affects DD rate, or if a third, still unidentified, variable predicts both. The aim of this essay is to present and discuss evidence regarding the relationship between rate of DD and drug use, and its potential implications to the prevention, detection, and treatment of substance abuse.

Delay Discounting

The field of delay discounting grew out of operant intertemporal choice research (Ainslie, 1974; 1975; Rachlin and Green, 1972). In 1987, Mazur found that when pigeons choose between a smaller amount of food after a short delay and a larger

amount of food after a longer delay, their choice behavior can be optimally described by a hyperbolic model:

$$v_d = V/(1+kd) \quad (1)$$

where v_d is the value of the delayed reinforcer, V is the value of the delayed reinforcer, d is the duration of the delay, and k is an empirically derived constant proportional to the rate of delay discounting (DD). Thus, the higher the value of k (the delay discounting rate), the larger the loss of subjective value of V per unit of delay.

Laboratory studies with human subjects sometimes estimate DD rate by direct exposure to contingencies of reinforcement where the magnitude of the reinforcer and delay are systematically manipulated, as is done in animal studies (Reynolds, 2006a; Lane et al., 2003). However, most studies on human subjects use the *questionnaire method* developed by Rachlin and collaborators (e.g., Rachlin and Green, 1972; Rachlin, Rainieri, and Cross, 1991), where subjects are asked to choose between hypothetical rewards in the frame of hypothetical delays. Rachlin, Rainieri, and Cross (1991), for example, asked subjects to choose between a fixed amount of cash (\$1000) they would hypothetically receive after some delay (e.g., 1 month) and various amounts of cash (between \$1 and \$1000) they would hypothetically receive immediately. This procedure allowed the authors to find self reported *indifference points*, or the subjective value of \$1000 after a series of delay intervals. The discounting functions thus obtained can be optimally described by hyperboloid models like Mazur's (1987, Equation 1), and more complex models (Killeen, 2009; McKechar et al., 2009) with additional parameters to address individual variables and sources of hyperbolic utility discounting. In general, hyperbolic models are preferred over traditional exponential models because they adequately describe the reversal in preference that often occurs during the delay (Ainslie, 1975).

Myerson and collaborators (2001) proposed a distribution-free method to calculate amount of DD based on the area under the discounting curve (AUC; Fig. 1). The method does not assume a constant rate of devaluation over time and instead involves adding the areas of the trapezoids delimited by relative delay values (on the abscissa) and indifference points (on the ordinate); accordingly, a

higher AUC represents lower DD. Myerson's method is sometimes preferred because although the hyperbolic model fits group data very well, individual data often do not show such good fit. In addition, indifference points tend to have non-normal distributions and are not amenable to parametric tests without further transformation, whereas AUC is more likely to be normally distributed.

sumed that the indifference point is close enough to the switching point that either the switching point or the average amount between the switching point and the next immediate reward value are accepted as valid IP estimates. Once a series of IP have been obtained, the delay discounting rate is estimated by non linear regression using the model's equation.

This method to estimate the relative value of a

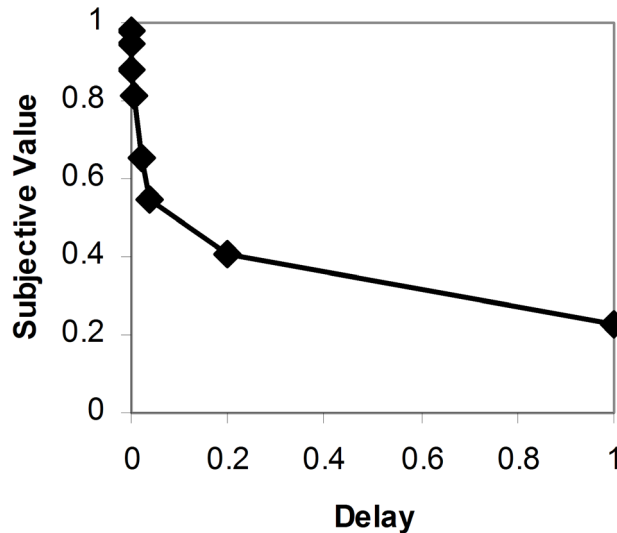


Figure 1. A delay discounting function connecting a series of indifference points obtained for \$1000 at delay intervals between 6 hours and 25 years.

Estimating Relative Subjective Value

The general strategy to determine relative value initially proposed by Rachlin and Green (1972) has been to present each subject with a series of binary choices. The trials have the general form: What would you rather have, X amount of dollars right now or Y amount of dollars in D days? The magnitude of the delayed reward (X) and the delay interval (D) are held constant while the magnitude of the immediate reward (Y) is systematically varied between trials until the subject shows indifference (no preference) between the two options. Strictly speaking, the indifference point (IP) would be the combination of values the subject chooses 50% of the time. In practice, however, it is frequently as-

reward derives from psychophysics where, in order to estimate perceptual thresholds, a dimension of a physical stimulus such as its intensity or frequency is systematically varied while the subject is asked to report perceived changes (see Gescheider, 1997). The reader may be familiar with the method optometrists use to determine the appropriate magnification level of eye glasses. In that case, the patient is asked to look into a foroptor (an optic refractor where each lens can be independently varied) and choose which of two lenses yields the clearest image. One of the lenses is fixed (at the patient's old gradation, for example) while the magnification of the second one is increased (or decreased) until further changes in magnification no longer enhance

the patient's perceived quality of the image. When this method is used to estimate DD, subjects are guided to report the *subjective* value of a delayed reward (preference) in relation to *objective* (quantitative) values of delay and reward until subjects no longer show preference for a particular combination of values. The resulting indifference point is considered a good estimate of the subjective value of the delayed reward. Similar methods have been used to estimate value of rewards with varying probability (Richards et al., 1999), altruistic choices as a function of social distance to the subject (Jones and Rachlin, 2006), the subjective value of alternative medical treatments (Chapman and Elstein, 1995), and the subjective value of past events (Yi et al., 2006).

Estimation of Delay Discounting Rate

The loss of value of a reward as a function of delay to the reward is a robust phenomenon that has been observed under very diverse conditions. For example, hyperbolic delay discounting of reinforcement has been observed in pigeons (Mazur, 1987; Rodríguez and Logue, 1988), rats (Richards et al., 1997), monkeys (Anderson and Woolverton, 2003; Woolverton et al., 2007), and humans (e.g., Rachlin et al., 1991). Hyperbolic delay discounting has been observed in relation to food (Lagorio and Madden, 2005), water (Richards et al., 1997), sucrose (Farrar et al., 2003); cartoon viewing (Navarick, 1998), real and hypothetical money (Johnson and Bickel, 2002), hypothetical cigarettes (Bickel et al., 1999), hypothetical heroin (Madden et al., 1999), and hypothetical alcohol (Petry, 2001). Regarding methods of estimation, hyperbolic DD has been observed in laboratory animals when either the reinforcer delay (Mazur, 1987) or the reinforcer magnitude is varied in concurrent schedules (Richards et al., 1997).

With human subjects, hyperbolic DD has been observed in tasks with either a fixed (Rachlin et al., 1991) or variable number of trials (Johnson and Bickel, 2002; Robles and Vargas, 2007); a predetermined (Rachlin et al., 1991) or adjustive series of values (Johnson and Bickel, 2002; Robles and Vargas, 2007); a short or log series of trials (Lane et al., 2003); with reward values presented in ascending, descending or random order (Epstein et al., 2003; Johnson and Bickel, 2002; Petry and Casarella, 1999; Rachlin et al., 1991; Richards et

al., 1997; Robles and Vargas, 2007); with tasks involving forced trials (Lagorio and Madden, 2005); with direct exposure to the contingencies of reinforcement (Lagorio and Madden, 2005; Lane et al., 2003; Reynolds, 2006a); with repeated measures (Lagorio and Madden, 2005), with manual and computerized tasks (Epstein et al., 2003; Rachlin et al., 1991; Johnson and Bickel, 2002; Robles, 2001; Robles and Vargas, 2007; 2008), and a number of other variants (for comprehensive reviews of the delay discounting literature see Bickel et al., 2006; Green & Myerson, 2004; and Reynolds, 2006b).

In summary, it is important to note that in the laboratory hyperbolic DD has been observed without exception in an increasingly large set of circumstances.

However, it is also important to note that the few studies that have directly compared methods of DD estimation have found significant differences in the estimated *amount* of DD for individual subjects, sometimes within a single session. Because such within-subject differences have been observed when other factors remained (or were expected to remain) constant, it has been concluded that they were due to variations in the methods of estimation.

Contextual Factors

Epstein et al. (2003) found differences in DD rate depending on whether the assessment task was manual or computerized. The study showed that significantly higher rates are estimated when the computerized method is used, particularly at the longest delays. It is difficult, however, to know why such differences occurred because there were other procedural variants between the manual and computerized methods that could have affected the results. For example, the computerized task used the adjustive method for determining the immediate reward values between trials (which depend on the specific choices a subject makes), while the manual task had a fixed number of trials and a predetermined series of immediate reward values (Kirby et al., 1999).

Kowal, Erisman, and Bickel (2007) compared two computerized algorithms to estimate DD rate: the *decreasing adjustment* method (Du et al., 2002) and the *double-limit* method (Richards et al., 1997). In within-subjects comparisons Kowal found that the decreasing adjustment method yields higher DD estimates than the double-limit method. It is possible that the double-limit method might pro-

duce lower DD rates by eliminating mechanical errors during the choice response, or by eliminating inconsistent choices, or, more likely, by a combination of both. More research is needed to identify the relative contribution of those factors.

Robles and Vargas (2007) compared within subjects two computerized algorithms that differed in the order of presentation of the immediate rewards (ascending, descending, or random). In that study, presenting the 240 trials in random order led to higher DD rates, longer assessment sessions, and characteristically different response time (RT) distributions, compared to either the ascending or descending order of presentation. RTs were significantly shorter with the ascending and descending order of presentation. In turn, the random order yielded RTs that were negatively correlated with the difference between the immediate and delayed rewards. And regardless of the presentation order, the longest RT in each delay series corresponded with the trial in which indifference was observed. These data suggest that subjects took longer to choose on trials where the subjective value of the options was most similar, and that during the randomized series subjects were required to ponder the value of the options in a given trial independently from the previous trials. The hypothesis that the difficulty in choosing between the two options varies from trial to trial is supported by McClure et al. (2004). McClure found that RT were consistently longer on trials in which the choice was more difficult; that is, where the difference between the optional rewards was 25% or less. Furthermore, Chabris et al. (2008b) showed that RT can be reliably used to identify indifference points and estimate DD rate.

Assessment methods in which the number of trials depends on the individual choices each subject makes allow for individuals to respond in such a way as to minimize the duration of the assessment task (a potential reward). Therefore, to explore the effect that such contingency might have on estimated DD rate, Robles and Vargas (2008) gave subjects control over the number of trials in the assessment task. In that study, all subjects completed two computerized tasks: the *full* task with a fixed series of 240 trials (8 delay and 30 immediate reward values), and the *abbreviated* task (either ascending or descending) in which once a subject showed indifference, the rest of the trials in the delay series were

omitted. An important difference between the full and abbreviated tasks is that while in the former the number of trials is fixed, in the later the number of trials in the task depended on the subject's choices. Specifically, with the abbreviated method the sooner the subject showed indifference (switched between the immediate and delayed rewards), the smaller the number of trials in that series and the shorter the assessment session as a whole. However, switching sooner during the *ascending* abbreviated task led to lower rates of DD than switching later in the series, while switching sooner during the abbreviated *descending* task led to higher DD rates than switching later. That is, if subjects were to choose in such a way as to minimize the duration of the session they would show lower DD rates with the descending abbreviated task and higher DD with the ascending abbreviated task compared with the full task. The resulting data suggest that minimizing the session duration was not a significant factor determining choice in the abbreviated task since both methods led to similar DD rates within subjects. However, order of presentation of the immediate rewards produced differences on all three measures: 1) DD rates were significantly higher with the descending order; 2) a significantly higher proportion of AUC was concentrated around the indifference point with the descending order; and 3) the correlation between DD rates estimated with the full and abbreviated tasks was lower for the group that experienced the immediate rewards in descending order. Because in that study the comparison between orders of presentation was made between groups, and there was no reason to expect that order of presentation would have a significant effect, a new study (Robles et al., 2009) directly compared the effect of order of presentation of the immediate rewards within subjects in a single session. The results from that study were consistent with our previous observations showing that for individual subjects the estimated rate of DD depended on the order of presentation of the immediate rewards: higher with descending values, and lower with ascending values. In addition, only a moderate correlation was observed between the DD rates estimated with both methods.

It is still not clear why order of presentation of the stimuli would affect DD rate. However, it is possible, that, as shown earlier, during DD tasks subjects

not only respond to the values presented in a given trial, but also compare current reward and delay values to those seen in previous trials (Lockhead, 2004; Robles and Vargas, 2007; Robles et al., *submitted*; Scholten and Read, 2009). Specifically, it is possible that choices between the two hypothetical amounts of cash might be affected by the context of the (ascending or descending) sequence being used. For example, the descending sequence begins with the best possible outcome (the maximum amount of money available immediately) where participants choose between \$1000 now and \$1000 after some delay; so, we expect most subjects to choose the immediate outcome. Then, subsequent choices in the delay series offer successively poorer outcomes for choosing the immediate reward. On the other hand, the ascending sequence begins with the worst outcome for choosing the immediate reward (the minimum amount of money) where participants choose between \$1 now and \$1000 after some delay; so, most subjects choose the delayed outcome. Then, subsequent choices in the delay series offer increasingly better outcomes for choosing the immediate reward. Although identical choices are available to the subject in both procedures, the *perceived* worsening of the outcomes in one case (a decreasing immediate amount) may lead to early switching and the *perceived* improvement of the outcomes in the other (an increasing immediate amount) may lead to switching later in the series. In both cases, however, the hyperbolic model of DD describes the indifference points equally well.

Another contextual variable potentially responsible for the differences in DD observed in this study is the magnitude of the immediate and delayed rewards to which subjects are exposed. It has been reliably demonstrated that humans discount smaller hypothetical delayed rewards at higher rates than larger delayed rewards, which is known as the *magnitude effect* (see Grace and McLean, 2005; Green et al., 1997). In this study, although the delayed reward was always \$1000, subjects were exposed to either large immediate rewards (descending sequence) or small immediate rewards (ascending sequence) first. Since the series ended when subjects showed indifference, during most delay series subjects were exposed only to either the larger or the smaller immediate rewards, depending on the order of presentation. The magnitude effect would pre-

dict that discounting rates should be greater in the ascending sequence, which is consistent with our data. Further research is needed to assess whether the observed differences in DD are related to the magnitude effect or some other factor. Scholten and Read (2009) recently developed the *trade-off model* based on the hypothesis that choices in a given trial are not treated independently of previous choices by the subjects. Their model accommodates in a psychologically consistent way many of the abnormalities derived from considering the choices as independent from each other, such as the magnitude effect, and the effects of order of presentation described above.

Taken together, direct comparisons of methods of DD estimation suggest that the various assessment tasks incorporate local contextual variables that significantly affect the resulting values. Therefore, a common conclusion of these studies is that despite the significant correlation between DD rates estimated with the various methods, the resulting values cannot be directly compared.

Impulsiveness and Self-Control

Choosing a smaller immediate reward over a larger delayed reward is considered *impulsive*. As Herrnstein (1977) put it, "We call behavior impulsive when it might not have occurred at all if its long-range consequences had been given full weight" (p. 121). In that sense, choosing the immediate reward of drug use over health, freedom, family, or career may be considered impulsive.

Law, religion, science and other social institutions recommend—or demand—to forgo many forms of immediate gratification and embrace the ostensibly more important long-term consequences of our behavior, from better health to eternal salvation. But for most other animals any delay in the possession or consumption of a reward (food, water, and mate) involves the risk of losing it and, in the long run, loose critical opportunities for individual and group survival. So, perhaps not surprisingly, every human study on intertemporal choice has found varying degrees of hyperbolic discounting; showing that just like pigeons, rats and monkeys, we tend to prefer rewards now better than later. The remaining question is: why do some individuals devalue delayed rewards more than others? As behavior scientists we investigate how an individual's delay discounting

rate relates to his/her environment and to the rest of his/her behavior. Specifically, is it more likely for an impulsive person to have drug problems? Does drug use make a person more impulsive? Can DD rate be changed by psychotherapy or education? Is DD rate a relatively stable personality trait?

Drug Administration and Drug Abstinence

An important indicator of the causal links between DD and drug addiction may be the observed quantitative relationship between DD rate and acute drug deprivation and drug administration. If observed, a covariation between those variables would indicate that DD rate is sensitive to local environmental and physiological conditions and therefore amenable to pharmacological or psychological treatment. Several studies have documented such relationship, although taken together the results seem inconclusive. For example, it has been shown that acute alcohol administration can either decrease, increase, or have no effect on DD rate (Ortner et al., 2003; Poulos et al., 1998; Reynolds et al., 2006; Richards et al., 1999). Similarly, it has been shown that acute amphetamine administration can both decrease (de Wit et al., 2002; Helms et al., 2006; Winstanley et al., 2003) or increase DD rate (Evenden and Ryan, 1996). On the other hand, save for cocaine, for which consistent increases in DD rate have been observed, results from the chronic administration of various stimulant drugs has also produced inconsistent results (Setlow et al; 2009). In assessing those results it is important to note that the DD assessment procedures used in the various studies have differed along several dimensions, as have the drug doses tested. Therefore more research appears necessary to understand the apparently contradicting effects of acute and chronic drug administration on DD rate.

On the other hand, it has been shown that acute *deprivation* of drugs affects the DD rate of drug-dependent individuals. For example, Giordano and collaborators (2002) found that opioid dependent patients treated with buprenorphine showed a higher DD rate when it was estimated under mild opioid deprivation (before receiving their medication dose) than when it was estimated once they had received their buprenorphine dose.

Addiction Severity

We noted earlier that it is not entirely clear how DD

rate, impulsiveness, drug use, and other variables are functionally related to one another. However, there are several studies indicating that the magnitude of an individual's DD rate varies consistently with the severity of his/her drug problems. For example, in two studies, Vuchinich and Simpson (1998) compared light social drinkers with problem drinkers, and with heavy social drinkers, and found higher rates of delay-discounting in heavy social drinkers and problem drinkers than in light social drinkers. Bretteville-Jensen (1999) compared active injecting amphetamine and/or heroin abusers with past abusers of amphetamine and/or heroin and non using controls, and found that both, active and past abusers discounted the value of delayed monetary rewards more than the controls; and in addition, their group of active abusers discounted delayed rewards more than past abusers. Petry (2001) compared active alcoholics with abstinent alcoholics and with control subjects without a history of alcohol dependence on their rate of discounting of money (\$1000 and \$100), and alcohol (150 and 15 bottles of an alcoholic beverage) as a function of delay. Petry's study showed that the two groups of alcoholics discounted money at higher rates than the control group. In addition, with exception of the \$1000 condition, active alcoholics discounted at a higher rate than the alcohol-abstinent group. In other words, in three out of four comparisons, the most rapid discounting was observed in active, followed by abstinent alcoholics, followed by controls. Then, in a study comparing DD rate among controls and drug users, Kirby and Petry (2004) found that DD rates were increasingly higher for controls, abstinent heroin users, and active heroin users. Taken together, these cross-sectional studies suggest that DD rate and drug use may be related in one of three ways. DD rate may either *a*) change as a function of severity of the substance use, increasing when the drug abuse problems are more severe and decreasing as a consequence of abstinence, *b*) be a preexisting condition predicting the likelihood of drug use and/or recovery from drug use, or *c*) result from an interaction of both processes.

In support of the second proposition, some prospective studies have shown that preexisting differences in delay discounting rate may play a defining role in recovery from substance use. For example, Tucker and collaborators (Tucker et al.,

2002; Tucker et al., 2006; Tucker et al., 2009) using the Alcohol-Savings Discretionary Expenditure (ASDE) index found that allocation of monetary expenditures to either alcoholic beverages or savings -which presumably reflects relative preference for immediate vs. delayed rewards- predicted abstinence from alcohol in nontreated problem drinkers at the 2-year follow-up. In addition, data pooled from three studies using the ASDE index revealed that the index incrementally predicted future rates of abstinence from alcohol in recently resolved treated and nontreated problem drinkers (Tucker et al., 2009). Regarding smokers, a number of studies show that preexisting DD rate can predict abstinence following cessation treatment. Krishnan-Sarin and collaborators (2007) found that scores on the experiential delay discounting test (EDT, Reynolds and Schiffbauer, 2004) predicted abstinence from smoking in adolescents who participated in a cessation program, although scores on Kirby's delay discounting measure (Kirby et al., 1999) did not. Recently, MacKillop and Kahler (2009) found that, among treatment seeking smokers (who were also heavy drinkers), delay discounting rate predicted the number of days to first relapse to cigarette smoking after cessation treatment, independently of degree of nicotine dependence. Similarly, Yoon and collaborators (2007) found that the individual rate of DD predicted postpartum relapse to cigarette smoking among women who had discontinued smoking during pregnancy. Importantly, the study also showed that DD rate did not change over time regardless of their smoking status at 24 weeks postpartum. Finally, a prospective longitudinal study was recently published on the relationship between baseline DD rate and the probability of taking up smoking among a large cohort of volunteers followed from 15 to 21 years of age. In that study, Audrain-McGovern and collaborators (2009) found that degree of DD was relatively stable when measured repeatedly over 3 years; that higher DD rate at baseline predicted a heightened probability to take up smoking; and that having taken up smoking did not affect DD rate. To our knowledge, theirs is the first prospective study clearly showing DD rate acting as a stable subject variable predicting initiation of substance use, rather than changing as a consequence of it.

On the other hand, some studies have not found

differences in DD rate associated with abstinence. For example, a recent study that measured discounting rate for marijuana and hypothetical cash in self-reported current marijuana dependents, former marijuana dependents, and controls found no significant differences in DD rate between the groups (Johnson et al., 2010). Also, Kirby and Petry (2004) compared groups of self-reported 14-day abstinent and current users, and found lower DD rate among abstinent opiate abusers compared with active users, but did not find differences between abstinent alcoholics and abstinent cocaine users compared to active alcohol and cocaine users. Then, Heil and collaborators (2006) compared DD rate among cocaine dependent patients who were either currently using or had maintained abstinence from cocaine for 30 consecutive days, as well as a group of non-using community controls. Their study showed no differences in discounting rate between cocaine using and cocaine abstinent subjects although, consistent with previous research, both groups showed higher rates of DD than the group of community controls. Taken together, these studies show, as Heil points out, that abstinence of up to 30 days from cocaine may not have a sufficient effect on delay-discounting rate to be detectable, or that abstinence from cocaine or alcohol for up to 30 days may not be stable enough to be predicted by a higher pre-existing DD rate.

To address a similar question Robles and collaborators (submitted) compared a group of methadone maintenance patients who had remained abstinent from illegal drugs for 24 months (opioids, cocaine, benzodiazepines, and THC) with a group of methadone maintenance patients who had continued using illegal drugs, and a group of volunteers without a history of drug abuse. The groups were compared on addiction severity, DD rate, trait impulsivity, and IQ. The results showed no differences in DD rate between the drug abstinent and the drug using patients. However, consistent with previous reports, the DD rate of both groups of patients was significantly higher than that of controls. Similar results were observed in relation to impulsivity scores: while the two groups of patients did not differ from each other, they showed higher impulsivity scores than the group of controls. These results are unique in that they show that groups of patients that clearly differed in the degree of addiction severity,

both behaviorally and based on Addiction Severity Index (ASI) scores, did not differ in DD rate. Specifically, these results show DD rate as independent of the level of clinical recovery (defined as confirmed drug abstinence and lower ASI drug and alcohol scores) and personal level of stability (defined as consistent adherence to drug treatment and lower legal, familiar, and psychiatric ASI scores) of the patients.

Finding that addiction severity differed between the two groups of patients while DD rate and trait impulsivity did not suggest that these indicators were not affected by efficacious methadone maintenance treatment. In that sense, these results support a view of DD rate as a relatively stable individual characteristic like trait impulsivity, more than a behavioral state sensitive to local physiological and environmental changes (Odum and Bauman, 2009).

In summary, a number of studies show a direct relationship between addiction severity and delay discounting rate, but at least three cross-sectional and one longitudinal studies found no relation between these variables. Here, again, the methods used to assess DD as well as the populations and substances of abuse vary between studies. Therefore it is difficult to reach a definitive conclusion at this point.

Cognitive Factors

Impulsiveness has been defined as the tendency to act and decide without proper regard for the long-term consequences of those acts. It is reasonable to assume, then, that properly pondering the long-range consequences of our behavior requires adequate cognitive skills and an environment suitable to such decision making, the lack of which would lead to errors and impulsive choices. Supporting this hypothesis, some studies have found that IQ scores correlate negatively with DD rate (de Wit et al. 2007; Shamosh and Gray, 2008; Reynolds et al., 2009). Shamosh and Gray (2008) conducted a meta-analysis of 24 studies on the relation between IQ score and DD rate. Their analysis found a significant negative relation between IQ score and DD rate in every study, independently of the tests used to measure IQ, and independently of the method used to estimate DD. Moreover, a study by de Wit et al. (2007) with a large sample of healthy adults showed that both DD rate and nonplanning

impulsiveness correlated negatively with IQ scores independently of the subjects' socioeconomic status and educational attainment. In addition, it has been shown that deficits in working memory are associated with higher impulsiveness (Bechara and Martin, 2004; Hinson et al., 2003), and that interfering with concentration during assessment of DD leads to increases in the estimated DD rate (Upton et al., 2009).

Summary and Conclusions

Delay discounting, the observed decrease in value of a reward as a function of delay, is reliably found in humans and laboratory animals under a wide range of conditions and an equally wide variety of rewards. Importantly, higher rates of hyperbolic discounting have been observed in drug-using individuals compared to controls. But despite the overwhelming support for the association between rate of DD and drug use, it is still not clear if higher rate of DD predicts drug use, if drug use affects DD rate, or if a third, still unidentified, variable predicts both.

While some studies have shown that acute and chronic drug administration increase DD rate, others have shown decreases or no change in DD rate. On the other hand, mild drug deprivation has been found to increase discounting. These results suggest that local physiological states derived from drug administration and abstinence *can* affect the estimated rate of DD; although how and when that happens is still unknown.

Similarly, the results on the relation between DD rate and addiction severity are inconclusive. While some studies show a direct relationship between these variables, suggesting that more severe drug problems are associated with higher DD rate, others show DD rate as independent of the individual's drug problem. These results suggest that after a history of substance use, consistent abstinence *may* determine a decrease in DD rate; although how and when that happens is still unknown.

Alternatively, there is increasing evidence that the preexisting rate of DD can predict drug use. For example, a study by Perry and collaborators (2006) found that, in rats, a higher DD rate is predictive of more rapid acquisition of and more frequent cocaine self-administration. Similarly, Marusich and Bardo (2009) found that higher rates of DD

at baseline predict higher frequency of low-dose methylphenidate self administration in rats. And Wilhelm and Mitchell (2009) showed that, in inbred rats, breed was an important predictor of DD rate. Taken together, these studies show that, at least in rats, genetic differences between individuals and strains are associated with degree of DD which in turn predicts drug self-administration. In human subjects, as described above, a longitudinal study showed that while higher DD rate was predictive of taking up smoking in teenagers, having started smoking did not change their DD rate. These studies suggest that an individual's DD rate can predict (perhaps determine?) drug use. Therefore, it is important to note that correlational studies showing an association between DD and drug use do not exclude the possibility that the higher DD rate observed in drug users might have been a preexisting condition. Thus, the evidence in support of DD rate as a relatively stable personal characteristic leading to drug use, while still inconclusive, is gaining support.

Intelligence and local variables affecting cognition (e.g., memory deficits and low concentration) appear to be important factors affecting DD rate in humans. IQ scores remain relatively stable over the lifespan and may influence DD rate as a preexisting condition to drug use. However, to the extent that a lower DD rate depends on the ability to properly ponder future events, it may be possible to teach individuals (particularly children) to choose in less impulsive ways.

The large body of evidence on how DD rate relates to impulsiveness and drug use clearly shows that we are dealing with an important and fundamental phenomenon. Not only has excessive DD been observed in drug users, pathological gamblers and mental patients, but a relation has been suggested between DD rate and a variety of health behaviors including frequency of exercise, obesity, unsafe sex, and use of safety belts (Daugherty and Brase, 2010; Chabris et al., 2008a). On the other hand, the multiple gaps in our knowledge, and the methodological complexities associated with accurately estimating DD reveal a challenging road ahead. Many inconsistencies in the evidence may be due to variations in the experimental conditions under which DD observations have been made, and to the almost exclusive use of correlational and

quasi-experimental designs, which do not properly address causation. But, in our eyes, more research is warranted in the form of longitudinal and randomized controlled studies.

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