

Understanding Addiction as a Pathology of Temporal Horizon

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The seemingly irrational behavior exhibited by individuals with addiction may be understood by considering their temporal horizon. In this paper, we reviewed published literature and current research concerning how delay discounting, a measure of temporal horizon, has been employed to understand addiction. Specifically, studies of delay discounting among addicted individuals and other psychiatric populations, current controversies in the delay discounting literature, and new developments were reviewed. Addicted individuals discount the long-term consequences of their behavior at a higher rate than matched controls. Current controversies illustrate the need for continued research. Given the rising interest in using delay discounting to understand addictive behaviors, in terms of both overt behavior and at the level of brain activity, we believe research in this field will continue to produce substantial progress for the next several years.

Keywords: temporal horizon, delay discounting, impulsivity, neuroeconomics, trait, state

Addiction is a serious public health problem that is projected to cost over \$245 billion to the US economy annually (NIDA InfoFacts: Costs to Society, 2005). One of the greatest challenges in understanding addiction is the seemingly irrational behavior exhibited by those affected. For example, it is hard to understand why an individual who knows about the risk of contracting a life-threatening disease would choose to use a hypodermic needle that some other individual has just used to inject drugs. We believe that such behavior and other persistent problems among individuals with addiction may be understood by considering their temporal horizon. Consider a study from our group where we asked opioid-dependent individuals and matched controls to complete a story that started: "After awakening, Bill began to think about his future. In general, he expected to..." The specific events that each participant used to complete their story were not important. Instead we were interested in the time frame of their story. Opioid-dependent individuals referred to a future of nine days on average, while the controls referred to a future of 4.7 years (Petry, Bickel, & Arnett, 1998). This striking difference becomes a lens by which to view the behavior of the addicted. If one's temporal horizon entails only the next nine days, then considering the long-term consequences of sharing injecting equipment is not relevant because the consequences of those actions fall beyond that temporal view. In that regard, these consequences may be discounted such that they are for all intents and purposes non-existent.

Our view is that the seemingly irrational behavior of addicted individuals may be usefully considered as an extreme and continuing constriction of temporal horizon. In this paper, we will review how the behavioral economic concept of delay discounting has been employed to understand addiction. We will then review the extant literature on the discounting behavior among individuals who exhibit addictive behaviors, followed by examination of whether the extreme discounting among addicted individuals is a state or trait, and consideration of whether extreme temporal discounting is reflective of impulsivity or temporal horizon. Finally, we will examine the implications of using discounting to understand addiction in the new scientific field of neuroeconomics.

Delay Discounting

Discounting of delayed reinforcers refers to the observation that behavioral effects of a reinforcer are modulated by the delay to its receipt (Logue, 1988). Said another way, the value of a delayed reinforcer is discounted (reduced in value or considered to be worth less) compared to the value of an immediate reinforcer. Indeed, discounting of delayed rewards seems intuitive because most individuals would prefer a reinforcer (e.g., \$1,000) now rather than that same reinforcer later (Kirby, 1997). The degree of discounting has been considered to be a measure of the continuum between impulsivity and self-control.

Studies examining delay discounting in human subjects typically employ procedures similar to those used in psychophysical experiments (Richards, Mitchell, de Wit, & Seiden, 1997). Psychophysical procedures typically present participants with a standard stimulus and then present them with a stimulus that is adjusted until they consider the two stimuli to be equivalent (Stevens, 1975). Similarly, procedures used in delay-discounting experiments present subjects with a choice between a standard larger-later reward (e.g., \$1,000 delivered in 1 year) and an immediate reward whose magnitude is adjusted until the participant subjectively considers the two rewards to be of approximately equal worth (e.g., Green, Fry, & Myerson, 1994). This point of equivalence is the indifference point for that particular delay interval. When indifference points are obtained for a variety of delays, an indifference curve may be plotted. Indifference curves permit empirical determination of the shape of the discounting function and the rate at which delayed rewards are discounted.

Economics has traditionally assumed that the shape of the discounting function was exponential; that is, for each unit of time that constitutes the delay to delivery, the value of a reward decreases, or is discounted, by a fixed proportion (Kirby, 1997). However, exponential discounting has not been empirically supported by behavioral research conducted with nonhuman and human subjects. Instead, these studies demonstrated that the shape of the delay-discounting function was hyperbolic (e.g., Madden, Bickel, & Jacobs, 1999; Richards, Zhang, Mitchell, & de Wit, 1999). Hyperbolic discounting refers to the devaluation of delayed rewards proportional to their delay (Ainslie & Haslam, 1992); that is, for each unit of time that constitutes the delay to delivery, the reward's present value decreases by an increasingly smaller proportion (Kirby, 1997).

The discounting rate can be calculated by applying the following hyperbolic-decay equation developed by Mazur (1987):

Equation 1

$$v_d = \frac{V}{(1 + kd)}$$

In Equation 1, v_d is the present discounted value of a delayed reward (i.e., the indifference point), V is the objective value of the delayed reward, k is an empirically derived constant proportional to the degree of delay discounting (i.e., discounting rate), and d is delay duration. Empirically determined indifference curves have been demonstrated to be hyperbolic. Equation 1 has been found to accurately model empirically determined hyperbolic discounting functions (accounting for more than 85% of the variance) when food is used with nonhumans (Rodriguez & Logue, 1988) and real and hypothetical money are used with human subjects (Green, et al., 1994; Johnson & Bickel, 2002; Kirby, 1997; Kirby, Petry & Bickel, 1999; Madden, Begotka, Raiff, & Kastern, 2003; Madden, Petry, Badger, & Bickel, 1997; Myerson & Green, 1995; Rachlin, Raineri, & Cross, 1991). Given the utility of Equation 1 and that the discounting of delayed rewards has been demonstrated across species, it seems reasonable to assume that delay discounting is an evolutionarily conserved behavioral process (Bickel & Johnson, 2003; Daly & Wilson, 2005).

Delay Discounting and Addictive Behaviors

Tobacco Dependence

Nine studies examined delay discounting among cigarette smokers. In Bickel, Odum, and Madden's (1999) examination of discounting among cigarette smokers and matched controls, cigarette smokers discounted a hypothetical \$1,000 more than matched controls, and cigarette smokers discounted hypothetical \$1,000 worth of cigarettes more than hypothetical money (see Figure 1). Mitchell (1999) replicated some of these results by showing that smokers discounted real money more than controls. In the third study, Reynolds (2004) combined and re-analyzed data from two of his studies (the 4th and 5th) that examined discounting among adolescent and young adult smokers (Reynolds, Karraker, Horn, &

Richards, 2003; Reynolds, Richards, Horn, & Karraker, 2004). He hypothesized that if a high rate of discounting was a predisposing factor for smoking, then there would not be differences between adolescent and young smokers on discounting measures. Alternatively, if smoking more cigarettes daily resulted in greater discounting, then young adult smokers should discount more than adolescents. The results supported the latter hypothesis, and showed that number of cigarettes consumed was correlated with the rate of delay discounting. In these re-analyses, discounting was also greater in current smokers than those who never smoked.

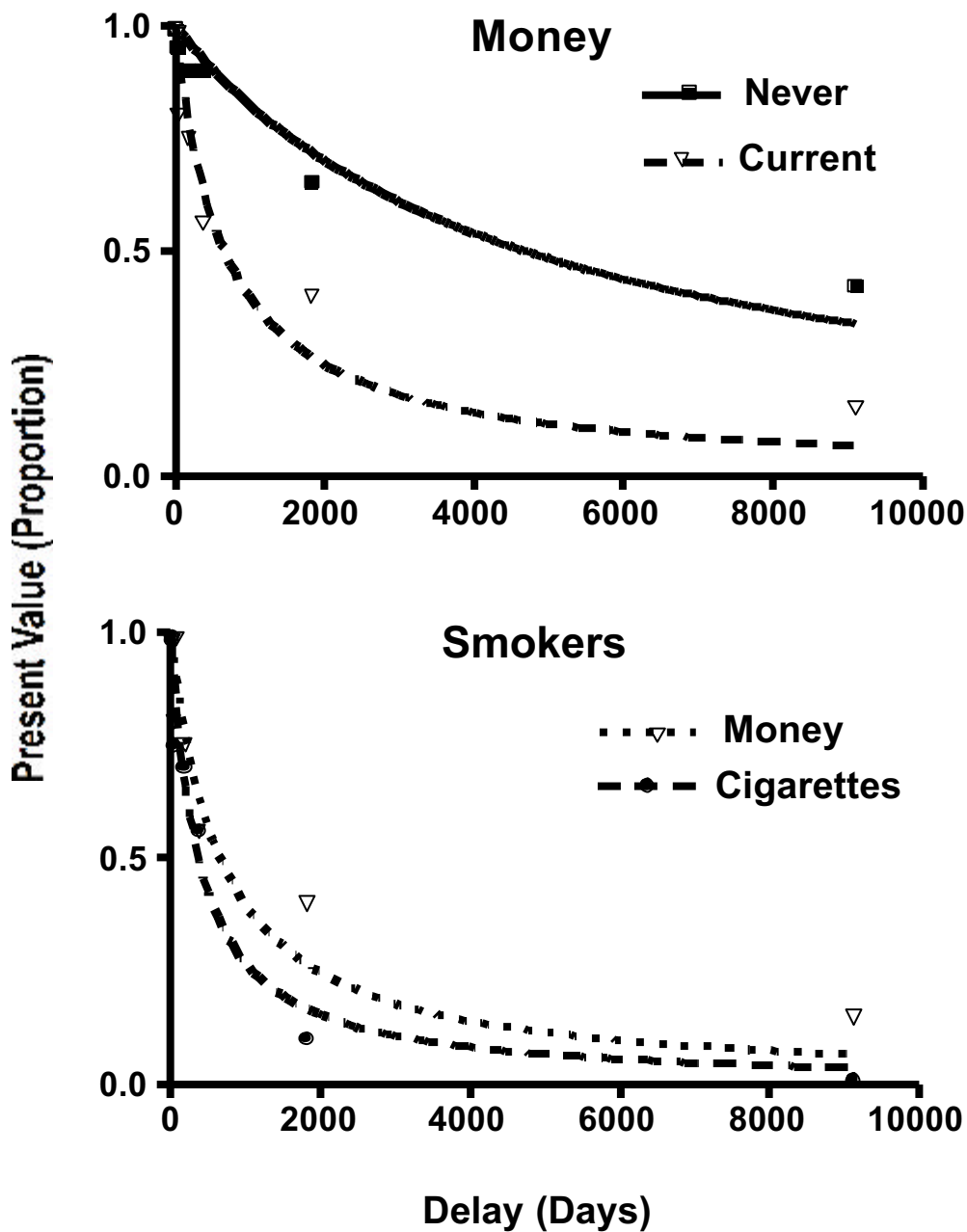


Figure 1. The top panel presents hyperbolic discounting functions for money among current smokers and never smokers. The bottom panel presents discounting functions for money and cigarettes among current smokers. Points represent median indifference points and lines represent the best-fitting functions calculated using non-linear regression. Adapted from Bickel et al., 1999.

In the sixth study, Baker, Johnson, and Bickel (2003) comprehensively compared discounting of cigarette smokers to matched controls. This study examined discounting of hypothetical monetary gains and losses at three magnitudes (\$10, \$100, and \$1,000); real money rewards at two magnitudes (\$10, \$100); gains and losses in hypothetical health at one magnitude; and, in smokers only, gains and losses of cigarettes at three magnitudes. This study repeated each measure one week later to assess its stability. Thus, this study allowed a comparison of real vs. hypothetical money and an assessment of the reliability of the measures and the magnitude and sign effects. The magnitude effect refers to the inverse relationship between the objective magnitude of the delayed reward and the degree of discounting (Chapman, 1996). For example, the discount rate would be higher for a choice between \$10 now and \$15 in one year than for a choice between \$1,000 now and \$1,500 in a year. The sign effect refers to the observation that rewards are discounted at a higher rate than are comparably valued losses (e.g., Thaler, 1981). Thus, participants would prefer a smaller immediate loss to a larger delayed loss (e.g., Loewenstein, 1988), though exceptions have been reported (Shelly, 1994). The results of this study demonstrated that cigarette smokers discounted all magnitudes of all commodities more than matched controls (Baker et al., 2003). Second, real money and hypothetical money were not significantly different (replicating prior results). Third, the results were replicated when participants were re-tested one week later (see also Simpson & Vuchinich, 2000, who replicated discounting of money at one-week intervals in non-dependent individuals). Fourth, the magnitude and sign effects were observed across commodities and participant groups. Fifth, this study demonstrated that health outcomes were discounted hyperbolically with clear evidence of the magnitude and sign effects. These findings support the notion that discounting by humans is applicable to a wide variety of reinforcers.

The greater discounting observed among cigarette smokers was evident across different magnitudes of three types of reinforcers (cigarettes, money, and health), suggesting that higher rates of discounting among smokers may be associated with more than just the drug of dependence. The effect observed with health discounting was also observed in a seventh study (Odum, Madden, & Bickel, 2002). The eighth study examined the relationship between discounting of monetary rewards and the number of cigarettes smoked and nicotine consumed. The researchers reported that greater discounting was associated with more cigarettes smoked and greater nicotine consumption. They did not detect an overall difference in discounting between smokers and controls. However, given that the group of smokers in that study included individuals who both smoked and discounted very little (Ohmura, Takahashi, & Kitamura, 2005), the failure to detect a difference may have resulted from limited statistical power. In the ninth study, Mitchell (2004) examined the effects of 24-hour abstinence from tobacco smoking on discounting. In addition to money discounting, an interesting variant of the discounting procedure was employed in which smokers chose between cigarettes now or money later. Relative to usual smoking, 24 hours of smoking abstinence resulted in greater discounting of the immediate cigarette vs. later money choices, but had no effect on the discounting of money. The absence of the effect of brief abstinence on money vs. money choice is inconsistent with a prior comparable study conducted with opioid-dependent individuals (Giordano, Bickel, Loewenstein, Jacobs, Marsch, & Badger, 2002) in which brief abstinence increased discounting in heroin vs. heroin and money vs. money choices.

Opioid Dependence

Five studies compared the delay discounting of opiate abusers and matched controls. In the first study by Madden and colleagues (1997), participants chose between hypothetical monetary rewards available

immediately or following a delay. Delayed rewards were \$1,000, and the immediate amount was adjusted until choices reflected indifference. The participants also chose between immediate and delayed heroin, using the same procedures. The amount of delayed heroin was derived by estimating the local street value of heroin, and then determining how much heroin could be purchased with \$1000. Across the opiate-dependent and control participants, the hyperbolic discounting equation accounted for 80% to 99% of the variance. Opiate-dependent participants discounted money at higher rates than controls, and discounted heroin more than money. Differences between opioid-dependent individuals and matched controls have also been found when real rewards were available (Kirby et al., 1999). In this study, participants were matched on several demographics including age, gender, and education. Participants were informed before the delay-discounting task that they had a one in six chance of receiving the reward that they had chosen on a randomly selected trial. Distributions of discounting were compared between the opioid-dependent and matched controls. The rate of discounting for opioid-dependent individuals was significantly greater than the rate of discounting in matched controls. Overall, discounting rates of opioid-dependent individuals were about twice that of the matched controls.

In the third study, Bretteville-Jensen (1999) investigated the discounting of hypothetical money among actively injecting heroin and amphetamine users, ex-users, and matched controls. The participants were asked to imagine they had a winning lottery ticket, worth 100,000 Norwegian Kroner (Nkr; approximately \$14,600 in US dollars). Then they were asked to decide how much money someone would have to give them now for the winning ticket if it was going to be paid out now, in one week, or after one year. Actively injecting users discounted the payment delayed by one year more than former users and former users discounted more than matched controls. In addition, 20% of the active users reported that they would have sold the winning ticket for less than 100,000 Nkr when the payment was delayed by only one week. In comparison only 2% of matched controls and 4% of former users would have accepted a loss with this delay.

Two additional studies (the 4th and 5th) examined delay discounting among heroin abusers and matched controls. In the first of these studies, delay discounting among several drug-abusing populations was compared to matched controls. Participants chose between immediate or delayed money gains, health losses, and losses of freedom (Petry, 2003). Hypothetical delayed money gains were \$100 and \$1,000. In health choices, participants were asked to imagine they had a disease that would produce negative symptoms for one year after a delay of 25 years. They were then asked to estimate the longest time period they would tolerate the negative symptoms now to avoid the onset of the symptoms 25 years from now. Similarly, for freedom losses the participants were asked to imagine they were sentenced to serve a one-year sentence in jail after a 25-year delay and then to estimate the longest time period they would serve now to avoid the sentence 25 years from now. Results indicated that heroin abusers discounted money, health, and freedom at higher rates than matched controls (Petry, 2003). Across the drug-abusing and control participants, the hyperbolic discounting equation accounted for 91% to 96% of the variance. In a related study, discounting of delayed monetary rewards was examined with heroin abusers and matched controls when there was a 1 in 6 chance of receiving a reward from a randomly selected trial (Kirby & Petry, 2004). Reward size was varied from \$25 to \$85 dollars. Active heroin users discounted delayed monetary rewards at over six times the rate of matched controls. In this study, discounting of delayed rewards was a function of both delay and amount. That is, larger rewards did not tend to be discounted as much as smaller rewards (i.e., the magnitude effect) and rewards with a short delay did not tend to be discounted as much as rewards following a long delay (i.e., hyperbolic discounting).

Alcohol Dependence

Five studies have explored the relationship between delay discounting and alcohol abuse. Vuchinich and Simpson (1998) compared discounting of delayed hypothetical rewards of \$1,000 and \$10,000 among heavy drinkers and light drinkers and among heavy drinkers with alcohol problems and light drinkers.

Discounting values were consistently higher for heavier drinkers than for lighter drinkers. Because distributions of discounting values were not normally distributed, the authors presented average discounting values for the 25th, 50th, and 75th percentile of light drinkers vs. heavy drinkers. At each percentile, the heavy drinkers discounted at a higher rate than the light drinkers. When heavy drinkers with problems were contrasted with light drinkers in this same manner these differences were exaggerated.

In the second study, Petry (2001a) examined delay discounting among alcoholics, currently abstinent alcoholics, and matched controls. Participants chose between immediate or delayed hypothetical monetary gains of \$100 and \$1,000. The participants also chose between immediate and delayed alcohol. At all magnitudes of alcohol, alcoholics had the highest discounting rates, currently abstinent alcoholics showed moderate discounting rates, and matched controls showed the lowest discounting rates. For monetary gains, the same pattern was found at the \$100 magnitude, but the differences were negligible at the \$1000 magnitude. Alcoholics and control participants discounted delayed \$100 gains at almost twice the rate that they discounted delayed \$1000 gains. Interestingly, the former alcoholics did not show this magnitude effect.

The third study compared delay discounting among abstinent alcoholics and matched controls (Bjork, Hommer, Grant, & Danube, 2004). Participants chose between an immediate reward and a standard \$10 delayed reward, and received a randomly selected reward from one of their choices. Discounting was significantly higher in the abstinent alcoholics than in the matched controls for delays ranging from 7 to 365 days. Overall, the rate of discounting was 4 times greater for abstinent alcoholics than controls. Post-hoc analyses, which took into account severity of alcoholism (e.g., co-occurrence of psychiatric dysfunction, parental history of alcoholism), did not detect significant differences in discounting. One potential issue of concern with this secondary analysis was that only male participants were considered.

In the fourth study, Petry, Kirby, and Kranzler (2002) compared delay discounting among healthy males and females with or without parental histories of alcoholism. Overall, the differences in discounting between individuals with or without parental histories of alcoholism were negligible. However, when females' delay discounting performances were viewed separately, parental histories of alcoholism were associated with higher rates of discounting. This pattern was not identified for the discounting rates of the male participants. Interestingly, discounting rates among females with parental histories of alcoholism were similar to discounting rates among males.

In a related fifth study (Kirby & Petry, 2004), discounting of delayed monetary rewards was examined with alcohol abusers and matched controls when there was a 1 in 6 chance of receiving a reward from a randomly selected trial. Reward size was varied from \$25 to \$85 dollars. Active and currently abstinent alcohol users discounted delayed monetary rewards at rates that were not significantly different from matched controls. However, given that Kirby and Petry's (2004) heterogeneous group of alcohol abusers included individuals who had a large range of usage patterns, from binge-drinking to daily use, the failure to detect a difference may have resulted from limited statistical power.

Cocaine Dependence

Four studies compared delay discounting among cocaine abusers and matched controls. In the first study, Coffey, Gudleski, Saladin and Brady (2003) examined delay discounting of hypothetical \$1000 money gains among cocaine abusers and matched controls. Delay discounting of \$1000 worth of cocaine among cocaine abusers was also examined. Cocaine abusers in this study met the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994) criteria for cocaine dependence. Overall, cocaine abusers discounted the value of hypothetical money gains at a higher rate than matched controls. In addition, cocaine was discounted at a higher rate than money among

cocaine abusers.

In a second related study, delay discounting among cocaine and heroin abusers was compared to delay discounting among matched controls. Participants chose between hypothetical immediate or delayed, money gains (\$100 and \$1000), health losses, and losses of freedom (Petry, 2003). Cocaine abuse was defined as use of cocaine at least eight times per month with loss of control and reports of drug related problems. Results indicated that cocaine and heroin abusers discounted money, health, and freedom at higher rates than matched controls. Cocaine and heroin abusers discounted hypothetical \$100 money gains more steeply than \$1000 money gains. Discounting of hypothetical losses of freedom and health showed lower discounting than hypothetical money gains. However, as Petry (2003) noted, this may be related to a sign effect. That is, losses may be discounted at a different rate than gains. In a third study, Kirby and Petry (2004) examined the discounting of delayed monetary gains with cocaine abusers and matched controls. Active and currently abstinent cocaine users discounted delayed monetary rewards at rates that were higher than matched controls.

The fourth study examined delay discounting of a hypothetical \$1,000 reward among current cocaine users, currently abstinent ex-cocaine users, and matched controls. Current and ex-users were currently in treatment for cocaine dependence. For a participant to be qualified as an ex-user, the participant was required to have reported not using cocaine in the past 30 days. To qualify as a current-user, participants were required to have reported using cocaine in the past 30 days. Current and ex-cocaine users discounted at higher rates than matched controls. Significant differences in discounting between current and ex-cocaine users were not found (Heil, Johnson, Higgins, & Bickel, 2005). Perhaps, extreme discounting is either an enduring trait or the time course for reversal is longer than one month.

Gambling

Four studies have examined delay discounting among pathological gamblers. In the first study (Alessi & Petry, 2003), discounting of delayed rewards was regressed on several variables in a population of gamblers. Severity of gambling was a successful predictor of discounting rates. However, other demographics such as, age, gender, and years of education were not predictors of discounting rates. The second study (Dixon, Marley, & Jacobs, 2003) compared delay discounting among pathological gamblers and matched controls. Gamblers discounted significantly more than the matched control participants. Across the pathological gamblers and control participants, the hyperbolic discounting equation accounted for 93% to 89% of the variance.

Two studies (the 3rd and 4th) examined comorbid gambling and drug abuse. Petry and Casarella (1999) examined delay discounting for hypothetical \$1,000 gains among drug abusers with and without gambling problems, and matched controls. Drug abusers with gambling problems discounted delayed rewards more than either of the other two groups. Second, Petry (2001b) compared patterns of delay discounting among pathological gamblers with and without drug abuse problems to patterns of delay discounting among matched controls. Pathological gamblers with drug abuse problems discounted delayed rewards significantly more than the other two groups. The results of these two studies support findings that suggest risk-taking populations (e.g., heroin addicts) may contain sub-populations (e.g., needle sharing heroin addicts) that show particularly high rates of delay discounting (Odum et al., 2000).

Other psychiatric disorders

Three studies have examined delay discounting among individuals with other psychiatric disorders. Most recently, we conducted a study (Gatchalian, Yi, Johnson, Baker, & Bickel, in prep.) of discounting for delayed monetary rewards (\$10, \$100 real and \$10, \$100, \$1000 hypothetical) among participants with and without depression. Rates of discounting were higher among depressed participants compared to

non-depressed participants. The second study (Petry, 2002) compared discounting of delayed hypothetical rewards of \$100 and \$1,000 among substance abusers with or without antisocial personality disorder (APD), and matched controls. Substance abusers discounted rewards at a higher rate than non-substance abusers. Substance abusers with APD discounted delayed outcomes at a higher rate than substance abusers without APD.

The third study (Crean, de Wit, & Richards, 2000) compared rates of delay discounting between two sub-groups of an outpatient psychiatric population (i.e., participants with high or low impulsivity). Rates of delay discounting were higher among patients that demonstrated high levels of impulsive behavior than for patients that exhibited low levels of impulsive behavior. Rates of delay discounting were not significantly correlated with other measures of impulsivity (with the exception of their measure of probability discounting).

Summary

In this section, 29 studies were reviewed that examined delay discounting among several groups. Several general patterns of importance to the general theme of this paper emerged from this review. First, delay discounting was higher in drug-abusing groups than in matched control groups. Second, delay discounting was higher in currently drug-abusing groups than in currently abstinent groups of ex-abusers. Third, sub-groups within currently drug-abusing groups that tend to engage in particularly high rates of delay discounting can be identified. The next section of this paper addresses empirical evidence of delay discounting as a measure of a trait (i.e., a static characteristic) and/or a state (i.e., a variable condition).

Current Controversies

Discounting: State or Trait

The existing literature provides mixed evidence concerning whether delay discounting can be best described as either a state (i.e., a variable condition) or a trait (i.e., a static characteristic). At this time, the evidence does not suggest that delay discounting can be exclusively described as either a state or a trait; however, certain studies in isolation do seem to provide evidence for delay discounting as either a state or a trait. Evidence that delay discounting can be changed following abstinence offers an indication that delay discounting is a state. Evidence that delay discounting rates predict an increased probability of drug use offers an indication that delay discounting is a trait. Here we will review the literature to illuminate the evidence supporting arguments from both sides of this controversy. First, we will review four representative studies that examined cross-sectional data concerning abstinence and rates of delay discounting in ex-users. Second, two studies that examined within-subject deprivation data among current drug users will be reviewed. Finally, a non-human animal study that suggests a possible role for delay discounting, as a trait, in determining the future probability of drug use will be analyzed.

In the first cross-sectional study, Bickel et al. (1999) examined delay discounting in current, never-, and ex-smokers who were matched on demographic categories that have previously been shown to influence delay discounting. Ex-smokers reported being abstinent for at least one year before the study. Bickel and colleagues found that ex- and never-smokers discounted delayed rewards less than current smokers. Differences in discounting among ex- and never smokers were not statistically significant. The second study (Petry, 2001a) examined delay discounting among recently abstinent (at least one month) alcohol-dependent individuals, current alcohol-dependent individuals, and controls. Abstinent alcoholics discounted money at a rate that was lower than rates among current alcoholics and higher than discounting rates among controls. In the third study, Bretteville-Jensen (1999) compared delay-discounting rates among current, ex, and never-users of heroin and amphetamine. In this study, the researchers did not ask participants how long they were abstinent. Similar to the pattern of results

reported by Petry, ex-injectors of heroin and amphetamine were found to discount money at lower rates than current users and at higher rates than never users.

In a recent paper (the fourth study), delay discounting was assessed in currently using and recently abstinent cocaine-dependent outpatients and non-drug-using matched controls (Heil et al., 2005). Delay discounting among currently using cocaine-dependents did not differ significantly from discounting among recently abstinent users; however, combined both groups discounted at a higher rate than matched controls. The authors suggested that the short duration of abstinence (i.e., 30 days) might explain the lack of a significant difference between the cocaine-dependent groups.

The results from the four cross-sectional studies we reviewed did not provide clear evidence to conclude whether or not drug use and/or abstinence from drug use affects rates of delay discounting. One possible interpretation of the evidence is that delay discounting can be described as a state that may be affected by drug use. However, even if this interpretation is accepted, suggesting that drug use may increase rates of delay discounting or that abstinence may have a decreasing effect on rates of discounting seems to be a matter of semantics. Further, because these studies were cross-sectional in nature, alternative interpretations of these findings can also be used to argue that discounting is a trait. That is, individuals who have low discounting rates may have had greater success in achieving abstinence.

Given the limitations of cross-sectional data, it is not surprising that researchers have conducted studies in which drug use was experimentally manipulated and delay discounting was measured multiple times among the same participants. For example, the first study in this line of research utilized a within-subject design in which rates of delay discounting among opiate-dependent outpatients maintained on buprenorphine (a pharmacotherapy for the treatment of heroin and other opiate dependence) were measured under satiated and deprived conditions (Giordano et al., 2002). Giordano and colleagues reported that opioid-dependent outpatients discounted delayed heroin and money gains more steeply during deprivation conditions (i.e., five days after receiving a quintuple buprenorphine dose) than during satiation conditions (i.e., 2 hours after receiving buprenorphine). Mitchell (2004) conducted the second study in this line of research, examining the effects of nicotine deprivation on rates of delay discounting for money and cigarettes among cigarette smokers. Results of this study revealed that deprivation affected discounting rates, but only when the choices were drug-related. In other words, preference for immediate money over delayed money did not change as a function of short-term nicotine deprivation; however, preference for immediate cigarettes over delayed money increased under deprived conditions relative to satiated.

Although at present the literature on the effects of deprivation status on delay discounting is limited, the findings from the available two studies indicate that short-term deprivation increases rates of delay discounting among drug-dependent individuals. Additional research employing prospective within-subject designs, in which discounting is measured pre- and post-abstinence, seems advisable given the paucity of studies examining this topic. This research may provide valuable insight into the directional relationship between drug use and discounting rates and may determine whether treatment itself has an impact on rates of delay discounting.

One study investigated the role of delay discounting in determining the probability of future drug use in non-human animals (Perry, Larson, German, Madden, & Carroll, 2005). The authors measured rates of delay discounting for food rewards among female rats. Based on delay discounting performances, individual rats were categorized into low or high impulsivity groups. In the second part of the experiment, the two groups were exposed to training sessions for cocaine self-administration. Seventy-seven percent of the rats within the high-impulsivity and only 25% of the rats within the low-impulsivity groups met criteria for acquisition.

The evidence from Perry et al.'s (2005) study can be interpreted as evidence that delay discounting is a stable characteristic (i.e., a trait) that can be used to predict the acquisition of drug use. However, similar to the cross-sectional studies reviewed above, the results of this study are open to multiple interpretations. As Perry and colleagues noted, other factors could covary with, or underlie, group differences in discounting. If an environmental factor covaried with discounting, then the results from this study could support the argument that delay discounting is a trait.

In summary, the argument for delay discounting as a state is supported by evidence that short-term deprivation appears to increase rates of delay discounting and long-term abstinence appears to be related to lower rates of delay discounting. The argument for delay discounting as a trait is supported by evidence that measures of delay discounting predict future acquisition of drug use. After illuminating the current evidence from both sides of the controversy, it cannot be decisively concluded whether delay discounting should be considered primarily a state or a trait, and perhaps it is both.

Discounting: Impulsivity or Temporal Horizon

An additional controversy within the delay discounting literature is whether delay discounting can be best described as a measure of impulsivity or temporal horizon. Impulsivity has typically been described as acting without conscious thought or consideration of consequences. Delay discounting has often been identified as a behavioral measure of impulsivity. Indeed, numerous studies have examined the relationship between delay discounting and various traditional measures of impulsivity, such as the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1978) and the Barratt Impulsiveness Scale (Barratt, 1985). Previously, measures of temporal horizon (e.g., Stanford Time Perception Inventory, Zimbardo, 1992; Future Time Perspective, Wallace, 1956) have been considered to be corollary measures of impulsivity (see Bickel & Marsh, 2001 for review). However, recent evidence challenges the view that delay discounting is a measure of impulsivity and suggests that discounting may be more accurately described as a measure of temporal horizon.

In one representative study, Odum et al. (2000) assessed delay discounting for money and heroin among opioid-dependent individuals who share needles and opioid-dependent individuals who do not share needles. The Eysenck Personality Questionnaire was administered to both opioid-dependent groups. Delay discounting of money was significantly greater among opioid-dependent needle-sharers than among opioid-dependent individuals who do not share needles. The two groups did not differ significantly on the impulsivity subscale of the Eysenck Personality Questionnaire. The discordance between measures of delay discounting and impulsivity suggests that delay discounting may not be a direct measure of impulsivity. One possibility is that delay discounting can be more accurately understood as a measure of temporal horizon.

Temporal horizon can be generally thought of as a window of time over which reinforcers are integrated. The following two scenarios illustrate the relationship between temporal horizon and the value of reinforcement. Imagine eating a single bite of pizza now, followed by another bite 30-s later, followed by a third bite in another 30-s. Now imagine consuming the same overall amount of pizza with each bite being consumed 24 hours apart. The greater subjective value of the first scenario suggests that reinforcers have effects that are not integrated over an unlimited duration of time. Importantly, viewing delay discounting as a measure of temporal horizon also suggests that the subjective value of a previous reward should decrease as it becomes more remote in a way that is similar to the discounting of rewards that are delayed.

A recent study that supports a temporal-horizon interpretation of delay discounting was conducted by Yi, Gatchalian, and Bickel (in press). Yi et al. examined discounting of past monetary gains and losses as well as discounting of future monetary gains and losses. Overall, discounting of future outcomes and past

outcomes produced similar results. Past discounting data were orderly and followed the same principles as future discounting (i.e., hyperbolic discounting, the magnitude effect, and the sign effect). While impulsivity does not appear to offer an explanation for the way that past events are valued, temporal horizon may explain the discounting of both past and future outcomes. Replication of these results is necessary, and like the state or trait controversy, the controversy of whether discounting is a measure of impulsivity or of temporal horizon remains to be further clarified.

The Neuroeconomics of Discounting: A New Development

The literature on delay discounting has grown extensively in recent years and has contributed to understanding addictive behaviors. A new development in delay discounting research is known as the Neuroeconomics of Discounting. Neuroeconomics is a multi-disciplinary approach to the study of how economic behavior is related to neuronal processes and structures. The observation that eight out of 50 abstracts presented at the 2005 conference of the Society for Neuroeconomics mentioned delay discounting exemplifies the current interest in this area of research. McClure, Laibson, Loewenstein, and Cohen (2004) conducted a study published in *Science* where the neural correlates of delay discounting among non-drug-using participants were examined. The results revealed that 1) the limbic system (i.e., a part of the brain generally believed to be involved in emotion and reinforcement) was preferentially activated when subjects chose immediate options, and 2) the prefrontal cortex (i.e., a part of the brain generally believed to be involved in planning and abstract thinking) showed activation regardless of the length of delay. Many questions remain to be answered in future studies. For example, do drug-dependent and non-drug-abusing individuals show different patterns of brain activation during delay discounting procedures? Do drug-dependent individuals show different patterns of brain activation during delay discounting procedures when they are drug-satiated and drug-deprived? Among drug abusers, are there different patterns of brain activation when discounting delayed money versus when discounting delayed drugs?

Conclusions

The present review of how delay discounting has been used to understand addiction demonstrates that this topic has generated significant interest among researchers. Recent research has continued to provide evidence that addicted individuals discount the long-term consequences of their behavior at a higher rate than matched controls. These findings can be used to understand the harmful behavior of addicted individuals. It remains to be determined whether there are procedures that can directly change rates of discounting and whether such procedures would be useful in therapy. A review of current controversies further illustrated the need for continued research in this area. Clarification of these controversies might challenge conventional views on how variables are categorized (e.g., state vs. trait) and may require a subtle and interactive view. Given the current interest in using delay discounting to understand addiction, in terms of both overt behavior and at the level of brain activity, we believe the next several years will continue to produce substantial progress in this field.

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