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Discounting of Past Outcomes

Richard Yi, Kirstin M. Gatchalian, and Warren K. Bickel
University of Arkansas for Medical Sciences

Drug use, abuse, and addiction are common behavioral manifestations of impulsiveness. A useful and popular laboratory analogue of impulsiveness is temporal discounting. Temporal discounting refers to the reduction in the present, subjective value of outcomes that are temporally distant in the future. The extensive literature on temporal discounting indicates hyperbolic discounting, the magnitude effect, and the sign effect. It is possible that the same principles may apply to other dimensions of psychological distance, including past temporal distance. The purpose of the present study was to examine the possibility that outcomes in the past are discounted hyperbolically and at a similar rate to outcomes in the future. The magnitude and sign effects were also examined in past discounting. Indifference points of college students were determined from a paper-and-pencil questionnaire of future and past discounting. The results demonstrate that humans discount temporally distant past outcomes similarly to future outcomes. Discounting of the future and past are qualitatively and quantitatively similar; discounting of past outcomes is orderly, hyperbolic, and consistent with most empirical observations from studies of future discounting, including the magnitude and sign effects. The present study indicates that the discounting of past outcomes is a quantifiable phenomenon, and the results are similar to observations from the established future-discounting literature. Past discounting may be of use in the study of drug-dependent and other impulsive populations. Implications of a relationship between future and past discounting are discussed.

Keywords: temporal discounting, impulsivity, choice

Impulsiveness is a construct composed of many factors including risk taking, behavioral disinhibition, and an inability to delay gratification (Evenden, 1999; Monterosso & Ainslie, 1999). As such, there is no single, widely accepted definition of impulsiveness. However, many definitions do share two common features: lack of deliberation and undesirable consequences (Evenden, 1999). Given these features, behavioral manifestations of impulsiveness include violence (Cherek, Moeller, Dougherty, & Rhoades, 1997), sexual compulsion (Bancroft & Vukadinovic, 2004), pathological gambling (Petry, 2001b), drug use (Dawe, Gullo, & Loxton, 2004), and a variety of other behaviors that result in negative outcomes (Hollander & Rosen, 2000). Much of the behavioral study of drug use has focused on impulsiveness, and particularly the inability to delay gratification, as a possible causal factor in use and dependence. This approach conceptualizes drug use as an inability to delay the immediate gratification of drug consumption in lieu of the delayed and diffuse gratification (improved health, job performance, social relationships, etc.) that results from nonuse. A quantitative explanation for the inability to delay gratification is high temporal (future) discounting. Future discounting refers to the reduction of the present subjective value of an outcome as a function of temporal distance in the future. Future discounting is a growing and important research area in part because of its ability to unify theoretical approaches that may be applied to diverse psychological phenomena (such as delay of gratification; Green & Myerson, 2004) and their behavioral manifestations (such as drug use). Future-discounting procedures have been successfully used with a variety of drug-using or drug-dependent populations (see Bickel & Marsch, 2001, for a review).

Because rate of future discounting is believed to be a measure of impulsiveness, future-discounting procedures have been used to differentiate drug-using or drug-dependent (and thus more impulsive) and control populations. Numerous drug-using populations have been found to be more impulsive than control populations with future-discounting procedures and include those who are dependent on cocaine (Coffey, Gudleski, Saladin, & Brady, 2003), are dependent on opioids (Kirby, Petry, & Bickel, 1999; Madden, Petry, Badger, & Bickel, 1997), have a drinking problem (Petry, 2001a; Vuchinich & Simpson, 1998), and smoke cigarettes (Baker, Johnson, & Bickel, 2003; S. H. Mitchell, 1999).

In these studies of future discounting, the present subjective value (indifference point) of an outcome that is temporally distant in the future is determined in a choice proce-

Richard Yi, Kirstin M. Gatchalian, and Warren K. Bickel, Department of Psychiatry, College of Medicine, University of Arkansas for Medical Sciences.

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Correspondence concerning this article should be addressed to Richard Yi, Department of Psychiatry, College of Medicine, University of Arkansas for Medical Sciences, 4301 West Markham Street, #843, Little Rock, AR 72205-7199. E-mail: ryi@uams.edu

dure. Participants are asked to choose between an outcome (usually hypothetical money) available at some point in the future and a smaller outcome available immediately. By adjusting the value of the immediately available outcome while keeping other variables constant, an indifference point is determined. This procedure is repeated over a range of delays to receiving the future outcome, and the rate at which the future outcome loses its subjective value (discounting rate) is determined. Economic analyses of future discounting assume that the rate of discounting is exponential, where the reduction in value is proportional at each unit of time:

$$v_d = Ve^{-kd}. \quad (1)$$

In this equation, v_d is the discounted value of an outcome, V is the undiscounted value, d is the delay, and k is a discounting parameter that provides a measure of the degree to which the value of a reward is discounted. A high discounting parameter indicates greater discounting and more impulsiveness. Mazur's (1987) hyperbolic model of future discounting, in contrast, assumes that the proportional reduction in value decreases as delay increases:

$$v_d = \frac{V}{1 + kd}. \quad (2)$$

Comparisons of these models of discounting have consistently found that the hyperbolic model accounts for a greater proportion of the variance than the exponential model in human and nonhuman animal studies of intertemporal choice (e.g., Kirby, 1997; Kirby & Marakovic, 1995).

The extensive literature on future discounting indicates that some findings are consistently observed across variations in procedure, population, and so forth. As stated above, Mazur's (1987) hyperbolic equation, where the relative decline in subjective value decreases as delay increases, has proven to be a superior model of discounting behavior to the exponential equation. A second common finding is the magnitude effect, in which large-magnitude outcomes are discounted less than small-magnitude outcomes. A third common finding is the sign effect, in which positive outcomes (gains) are discounted more than negative outcomes (losses). Green and Myerson (2004) and Frederick, Loewenstein, and O'Donoghue (2003) have offered good reviews of the general findings in studies of future discounting.

Another procedure that has consistently differentiated drug-dependent participants and control participants is Bechara's Gambling Task (Bechara et al., 2001; Grant, Contoreggi, & London, 2000; Whitlow et al., 2004). In this procedure, developed by Bechara, Damasio, Damasio, and Anderson (1994), choosing large, risky alternatives leads to an overall loss and choosing small, less risky alternatives leads to overall gain. One explanation offered for poor performance in this task is the inability to learn from past experiences (Bechara, Damasio, Damasio, & Lee, 1999; D. G. V. Mitchell, Colledge, Leonard, & Blair, 2002), and particularly from past punishment (loss) for choice of the risky alternatives. A synthesis of the future discounting and Gambling Task literature suggests that both expectations for the future and learning from the past are important factors (or minimally covariates) in the behavior of drug-dependent individuals.

Trope and Liberman's (2003) general theory on the consequences of temporal distance of future events is consistent with this implication. They offer the insight that the same principles that affect future events of temporal distance can apply for other distance dimensions such as spatial and social distance and, important for the purposes of this article, past temporal distance. The idea that social distance is influenced by the same principles as temporal distance in the future has already received some indirect support. An extensive body of literature indicates that identity within a common group (and thus reduced social distance) increases cooperation in social dilemmas (e.g., Brewer & Kramer, 1986; Kollock, 1998; Kramer & Brewer, 1984); cooperation in social dilemmas is positively correlated with self-control in future discounting (Harris & Madden, 2002; Yi, Johnson, & Bickel, 2005)

The purpose of the present study was to determine if the discounting of outcomes of temporal distance in the past is similar to the discounting of outcomes of temporal distance in the future. A long-term program of research examining discounting in drug dependence requires direct study of drug-dependent populations as well as the exploration of other phenomena that may be germane in the study of discounting: Discounting of outcomes in the past may prove to be a good example of the latter. In the present study, we examined discounting of past outcomes in a normal population and whether discounting of past outcomes shows the same profile of effects observed with future discounting. Specifically, we tested for (a) hyperbolic discounting as compared with exponential discounting, (b) the magnitude effect, and (c) the sign effect.

Method

Participants

Twenty-eight college students between 18 and 35 years of age were recruited from a subject pool in the department of psychology and received credit in an introductory level class for participation. One participant failed to complete the study. The mean age of the remaining 27 participants was 19.9 years (9 men, 18 women).

Materials

A paper-and-pencil test of future and past discounting was used to obtain indifference points in this choice procedure. Directions were written on the top of each page of the questionnaire and expressed the time condition (future or past), sign (gain or loss), magnitude of the delayed amount ($10 or $1,000), and temporal distance (1 day, 1 week, 1 month, 6 months, 1 year, or 5 years). Two columns of hypothetical money amounts were listed below the directions. The right column (standard amount) contained 40 rows of a fixed sum of money (depending on the magnitude condition). The left column (adjusting amount) listed ascending or descending sums of money in 2.5% increments of the alternative in

the right column. Participants were directed to compare the two alternatives in each row of the questionnaire and mark an *X* next to the preferred alternative. Furthermore, participants were directed to attend to the directions on the top of each page of the questionnaire, as the amount of hypothetical money and temporal distance would change over the course of the experiment. The time, sign, and magnitude conditions were blocked to facilitate participant recognition of the condition.

Directions for the future discounting condition directed participants to choose between two alternatives occurring in the future. In the future–gains condition, participants chose between receiving a sum of money following a specified delay (standard amount) and a different sum of money in 1 hr (adjusting amount). In the future–losses condition, participants chose between losing a sum of money following a delay or a different sum in 1 hr. Directions for the past discounting condition directed participants to choose between two alternatives having occurred in the past. In the past–gains condition, participants chose between having received a sum of money at some point in the past and a different sum 1 hr in the past. In the past–losses condition, participants chose between having lost a sum of money at some point in the past and a different sum of money 1 hr in the past. The losses condition was identical in all respects to the gains condition with the exception of the words *lose* or *having lost* replacing the words *receive* and *having received*.

Procedure

Following the informed consent procedure, participants were given the opportunity to ask questions. The experimental session began when all questions were answered and participants reported understanding the choice procedure. Participants completed all experimental procedures in one 1-hr experimental session. Gains in the sign condition always preceded losses, and temporal distances were presented in random order. Indifference points were obtained for each participant in both the ascending and descending adjusting amounts conditions. The time (future–past and past–future), magnitude ($10–$1,000 and $1,000–$10), and adjusting amounts order (ascending–descending and descending–ascending) were counterbalanced.

Results

The indifference point of each questionnaire sheet was calculated as the mean of the largest adjusting value in which the standard alternative was preferred and the smallest adjusting value in which the adjusting alternative was preferred. The indifference point for each delay at each level of the time, sign, and magnitude conditions was calculated as the mean of the indifference points from the ascending and descending adjusting amounts. Overall, data obtained from the future and past discounting conditions were very similar. Median indifference points were used to compare the exponential (Equation 1) and hyperbolic (Equation 2) discounting equations. The hyperbolic model accounted for a substantially higher proportion of the variance than the exponential model, with R^2 approximately 13% and 14% higher in the future and past conditions, respectively. The plot of median indifference points and fit to Equation 2 are shown in Figure 1. Discounting parameters from this model are used in analyses of discounting rate. Natural-logarithm transformations were conducted on discounting parameters to normalize a skewed distribution and allow for parametric analyses.

A repeated measures analysis of variance was calculated on transformed discounting parameters with time (future, past), magnitude ($10, $1,000), and sign (gains, losses) as independent variables (see Figure 2). Analysis of discounting parameters in the future ($M = -7.06$) and past ($M = -6.56$), $F(1, 26) = 1.21$, $p > .05$, discounting conditions revealed no significant difference. The same result was found in an analysis of indifference points in the future ($M = .71$) and past ($M = .68$), $F(1, 26) = 1.78$, $p > .05$, and further confirmed with analysis of area-under-the-curve (AUC; Myerson, Green, & Warusawitharana, 2001) measures, $F(1, 26) = 0.03$, $p > .05$. Table 1 shows the Spearman correlation matrix with discounting parameters. All correlations were positive, with most of them (82%) significant at $p = .05$. Noteworthy are the very high correlations between the comparable future–past conditions (i.e., future and past $1,000 gains, etc.). With one exception (between future and past discounting for $10 gains), the relevant future–past correlations are the highest found in the matrix, and all are statistically significant at $p = .01$.

Overall, the magnitude effect was observed with discounting parameters. Across the time and sign conditions, the small-magnitude outcomes ($M = -6.41$) were discounted more than the large-magnitude outcomes ($M = -7.23$), $F(1, 26) = 7.37$, $p < .05$. No magnitude effect was observed in the future condition, $F(1, 26) = 0.99$, $p > .05$, though one was found in the past condition, $F(1, 26) = 8.43$, $p < .05$. The absence of the magnitude effect in the future condition was due to a nonsignificant difference with future losses, $F(1, 26) = 0.68$, $p > .05$, concealing a significant difference with future gains, $F(1, 26) = 11.96$, $p < .05$. A significant difference was observed in an analysis of indifference points from the small- ($M = .64$) and large-magnitude conditions ($M = .76$), $F(1, 26) = 39.46$, $p < .05$. This result was confirmed with analysis of AUC measures, $F(1, 26) = 29.33$, $p < .05$.

Overall, the sign effect was not observed with discounting parameters. Rates of discounting in the gains ($M = -6.42$) and losses conditions ($M = -7.17$), $F(1, 26) = 1.90$, $p > .05$, were not significantly different. However, an analysis with only future-discounting data found the sign effect, $F(1, 26) = 6.02$, $p < .05$. No difference was observed in the same analysis with past-discounting data, $F(1, 26) = 0.01$, $p > .05$. Analysis of indifference points also indicated no overall difference between gains and losses, $F(1, 26) = 0.29$, $p > .05$. However, AUC measures did indicate a sign effect, with greater discounting of gains than losses, $F(1, 26) = 5.07$, $p < .05$. Similar to analyses with discounting parameters, the sign effect was observed in the future condition, $F(1, 26) = 5.76$, $p < .05$, but not in the past condition, $F(1, 26) = 1.48$, $p > .05$.

Though goodness-of-fit measures were mostly similar between future and past discounting conditions, the degree of similarity depended on the sign condition. R^2 from the past and future discounting conditions were similar for gains, $F(1, 26) = 2.31$, $p > .05$, but a significant difference

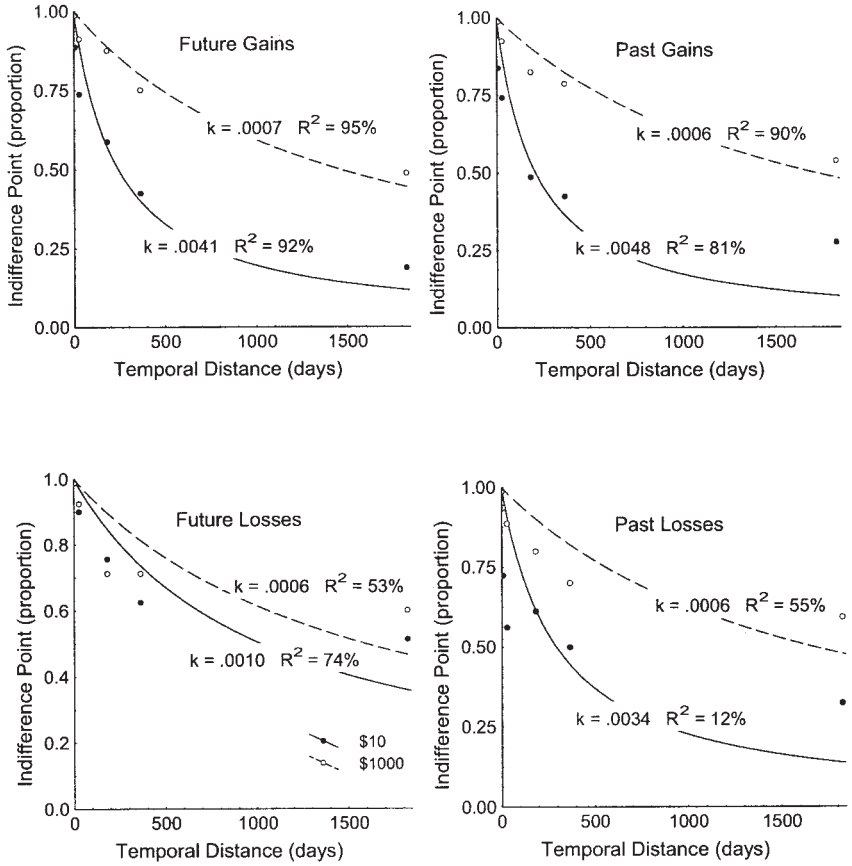

Figure 1. Hyperbolic discounting rates (see Mazur, 1987) obtained from median indifference points from the \$10 (solid circles) and \$1,000 (open circles) conditions. The present subjective values (*y*-axis) as a function of temporal distance (*x*-axis) are plotted.

was observed for losses, with lower R^2 in the past discounting condition, $F(1, 26) = 6.22$, $p < .05$. This was primarily due to the difference between fits for future and past discounting for \$10, $F(1, 26) = 6.04$, $p < .05$. No significant differences were observed in any other comparisons of goodness of fit.

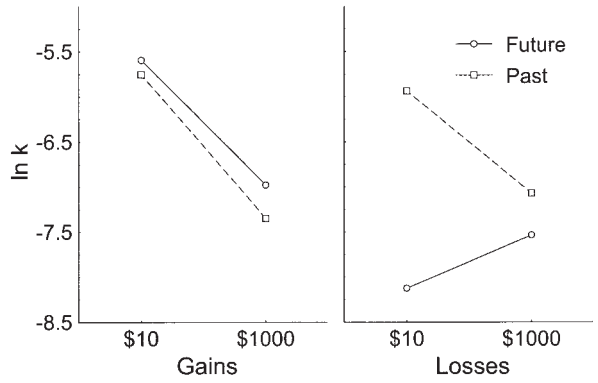

Figure 2. Mean discounting rate following natural-logarithm transformations for future and past conditions.

Discussion

The present experiment introduces a new topic in the behavioral study of choice and impulsiveness: past discounting. Though extensive work has been conducted to examine the manner in which individuals discount an outcome that will occur in the future, we know of no research that has examined the quantitative discounting of outcomes in the past. The evidence of past discounting as a measurable behavioral phenomenon is bolstered by a pattern of results similar to that obtained from studies of future discounting.

First and foremost, the shape of the discount function for the past is very similar to discounting for the future. This is indicated by analyses with both hyperbolic discount rates and AUC measures. As expected, the hyperbolic model of discounting provided a better fit to future discounting data than did the exponential model. This is a replication of studies that have compared the two models of discounting (e.g., Kirby, 1997; Kirby & Marakovic, 1995). For the most part, the rate of discounting and goodness-of-fit measures obtained from the hyperbolic model in comparable future and past conditions were very similar. The single exception exists between future and past losses for \$10, where both *k*

Table 1
Spearman Correlations Between Discounting Parameters Obtained From Each Condition

Condition	1	2	3	4	5	6	7	8
1. Future Gain $10	—	.71**	.44*	.50**	.27	.54**	.28	.39*
2. Future Gain $1K		—	.53**	.53**	.34	.64**	.45*	.33
3. Future Loss $10			—	.64**	.39*	.71**	.71**	.58**
4. Future Loss $1K				—	.18	.38	.63**	.76**
5. Past Gain $10					—	.77**	.62**	.42*
6. Past Gain $1K						—	.68**	.47*
7. Past Loss $10							—	.75**
8. Past Loss $1K								—

* $p < .05$. ** $p < .01$.

and R^2 were dissimilar. This could be a real effect or largely due to a single aberrant result; indifference points for $10 losses at 1-month temporal distance (see bottom right panel of Figure 1) were unusually low and are responsible for the relatively poor fit. Exclusion of that indifference point, for instance, decreases the k to .0026 ($\ln k = -5.95$) and increases R^2 to 62% with median indifference points. Inconsistency of choice (where the indifference point for 1 month is less than the indifference point for 6 months) in the $10 past–losses condition occurred in 7 out of 27 participants with an average of 4.4 participants across all conditions between the 1- and 6-month temporal distances. This suggests that the low indifference points for $10 at the 1-month temporal distance in the past–losses condition may simply be due to an atypical data point. Analysis of AUC measures, which are less influenced by this atypical data point, indicates no such differences between the future and past conditions; a comparison of AUC measures of future and past $10 losses is not statistically significant, $F(1, 26) = 1.30$, $p > .05$. This is the only discrepant finding between discount rates and AUC measures.

The magnitude effect was observed in the future–gains condition but not in future losses. Though the magnitude effect is a robust finding in studies of temporal discounting (Green & Myerson, 2004), our review of the literature reveals that this is primarily found in studies involving rewards (gains), and similar findings for losses are very limited if not completely absent. We are aware of two studies that have determined discounting rates for gains and losses at multiple magnitudes (Baker et al., 2003; Yi et al., 2005). In these studies, a statistically significant magnitude effect was observed only in the gains condition; no magnitude effect was observed in the discounting of losses. Furthermore, a preliminary review of currently unreported data from our laboratory indicates no magnitude effect for losses. In the absence of studies reporting a magnitude effect for losses, the present results are consistent with the literature. The sign effect was observed in the present study in the future discounting condition, and this is also consistent with previous literature (Baker et al., 2003; Murphy, Vuchinich, & Simpson, 2001). The indifference points from the 1-month delay for past losses (discussed above) are at least partially responsible for the lack of sign effect in the past condition. Further study and replication are necessary to determine the reliability and cause of the absence of a sign effect in past discounting.

A final important finding is the high correlations observed with discounting parameters (see Table 1) across the time, magnitude, and sign conditions. The vast majority of correlations involving at least one past discounting condition were statistically significant, similar to correlations between future discounting conditions such as magnitude, commodity, and sign in previous research (Yi, Baker, Johnson, & Bickel, 2006). Like future discounting, data obtained from past discounting may be able to differentiate populations that differ in impulsiveness. Degree of future discounting has been found to covary with variables thought to be related to impulsiveness, including age (Green, Fry, & Myerson, 1994), gambling status (Alessi & Petry, 2003), drug dependence (Bickel & Marsch, 2001), and clinical classification of impulsiveness (Crean, de Wit, & Richards, 2000). Similar results for future and past discounting across the entire spectrum of relevant variables would further validate past discounting as a measurable, behavioral phenomenon. The results obtained in the present study suggest that this is a possibility given that three of the four direct correlations of future and past discounting parameters (e.g., $1,000 future gain and $1,000 past gain) were significant at $p = .01$. These correlations indicate that those participants who steeply discount the future are likely to steeply discount the past. Conversely, those who steeply discount the past are likely to steeply discount the future.

The similarities in the pattern of results in future and past discounting support Trope and Liberman's (2003) contention that the same principles that affect future events of temporal distance apply to past events of temporal distance. This is also consistent with Rachlin's (2000) proposal that estimates of time left in delay-of-gratification studies is an increasing function of time already elapsed. Rachlin cited the example of waiting for a bus:

> The only possible basis for their estimation of how long they have to wait is how long they have already waited. Where waiting time is completely unpredictable, as at the bus stop and delay-of-gratification experiments, we would expect estimates of time left to vary directly with time elapsed. The longer you have waited for the bus, the longer you expect to wait. As time goes by, therefore, the larger reward recedes farther and farther into the distance. (p. 47)

An implication of this hypothesis is that an individual's projection of the future mirrors that individual's perception of the past. If this were the case, the rate of decline in subjective value of an outcome would be similar as the

outcome moves temporally further in the future and the past. This is consistent with the observed results.

There are some potential weaknesses of the present study. First is the use of hypothetical outcomes. Use of hypothetical outcomes allowed for examination of past discounting (which would not be possible with real rewards). Furthermore, discounting for real and hypothetical money rewards shows no systematic differences (Lagorio & Madden, 2005) and correlates highly (Johnson & Bickel, 2002; Madden, Begotka, Raiff, & Kastern, 2003). Nevertheless, participants may behave differently if outcomes were real. A second potential weakness of the present study is the use of college students; they are not representative of the population and the results may not be generalizable. We believe, however, that the use of college students as representative of the general population is justified in the present study because it attempts to understand a basic, behavioral process that is maintained across populations (e.g., discount rates change as a function of age but hyperbolic discounting is maintained throughout); there is little a priori reason that past discounting in other populations would not share the features observed in the present study. Nonetheless, examination of the topic may be appropriate in the future.

A third weakness is participant compensation with course credit. This could have resulted in participant indifference between the time conditions and, thus, the similar effects of future and past discounting. We believe that participant indifference cannot account for the similarities in the future and past discounting. The magnitude and sign effects as well as a systematic decrease in subjective value as a function of temporal distance were observed in the present study. Given the overall pattern of results, participants would have had to practice a selective indifference to the time condition and to the exclusion of the other conditions. We believe this is unlikely. Furthermore, because the order in which the future and past conditions were presented was counterbalanced, half of all participants were exposed to the past discounting condition first. Indifference in these instances would mean that participants discounted future outcomes in accordance with how they discounted past outcomes.

A fourth potential weakness is how participants might have interpreted the discounting of the past. For instance, an individual might perceive of their current status (e.g., how much money they have now) as the outcome of the past discounting. If in fact individuals examined outcomes in the past with their current status as the outcome, there should be no difference as a function of outcome value or duration of time because the outcomes remain the same. Instead, the present experiment reveals a systematic manner of discounting similar to the discounting of the future, with discounting of the past nearly an identical mirror image of the discounting of the future in many cases. This suggests that individuals either interpreted current status as changing as a function of their choices in the past discounting condition (e.g., have more money now as a result of the past choice) or that there is a component of the choice that depends on a nonrational preference (e.g., emotional preference for one choice or another). Finally, the replication of the sign effect in the future condition with its absence in the past condition is an issue that requires consideration. This may be an aberrant finding unique to this data set or may indicate a difference between future and past discounting; replication of this topic is required.

The present experiment used a novel discounting procedure to demonstrate that individuals discount the past. The similarity between data observed for past discounting and the well-established literature on future discounting is compelling. An implication of this similarity is that a direct and influential relationship may exist between the two. Does the discounting of the past affect the rate of discounting of the future? Conversely, does discounting of the future affect the rate of discounting of the past? The former case is similar to the proposition of Rachlin (2000) and has the significant implication that changing an individual's perception of the past may affect future discounting. The scientific exploration of such a relationship could have broad influence in the study of behavior in general and drug dependence in particular. Regardless of the existence of a causal relationship between discounting of the future and past, the topic of past discounting can be applied in established areas of future discounting. Differentiation of drug-dependent populations from control populations on past discounting procedures would not only confirm the validity of past discounting as a real and quantifiable phenomenon but offer new and interesting implications for the nature of the disorder.

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