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DELAY DISCOUNTING AND PERFORMANCE ON THE PRISONER'S DILEMMA GAME

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Participants' rates of delay discounting and percentage of defections on the prisoner's dilemma game were studied in a within-subjects correlation study. Thirty-one participants completed a discounting exercise involving choices between immediate and delayed monetary rewards. Each participant then played 40 trials of the prisoner's dilemma game against a computer opponent using a tit-for-tat playing strategy. A one-tailed Pearson's test of correlation revealed a significant positive relationship between the participants' rates of delay discounting and their percentage of defections on the prisoner's dilemma game. These data support the contention that high delay discounting is related to defecting against an opponent playing tit-for-tat on the prisoner's dilemma game.

Impulsivity has been defined as the choice of a smaller, less delayed reinforcer over a larger, more delayed reinforcer. Self-control, conversely, has been defined as the choice of a larger, more delayed reinforcer over a smaller, less delayed reinforcer (Rachlin & Green, 1972). Impulsivity has been linked to a number of behavioral problems, including drug abuse (Alcock & Grace, 1988; Madden, Petry, Badger, & Bickel, 1997) and alcoholism (Herrnstein, Lowenstein, Prelec, & Vaughan, 1993).

The degree to which delayed reinforcers are discounted in value (delay discounting) may help in understanding impulsive and self-control choices (Green, Fry, & Myerson, 1994). Specifically, when choosing between a smaller-sooner and a larger-later reinforcer, an impulsive choice will occur if the value of the delayed reward is discounted so much that its present value (i.e., how much it is worth right now) falls below that of the smaller-sooner reinforcer. However, if the delayed reinforcer is discounted to a lesser degree, its present value will exceed the smaller-sooner alternative, and a self-control choice will be made.

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A number of researchers have examined delay discounting in human (e.g., Rachlin, Raineri, & Cross, 1991) and nonhuman (e.g., Mazur, 1987) subjects. In a typical experiment involving nonhumans (e.g., Richards, Mitchell, De Wit, & Seiden, 1997), the animal is given repeated choices between a larger reinforcer delivered following a delay (e.g., 100 μl of liquid following a 4-s delay) and an adjusting-amount reinforcer delivered immediately. The immediate alternative is adjusted until the animal is indifferent between the two rewards. The amount of the adjusted reward at this indifference point provides the present (discounted) value of the delayed reward. Similar procedures have been employed with humans. Participants typically choose between a large hypothetical reward delivered after a delay (e.g., $1,000 delivered in 1 year) and an immediate reward that is adjusted in amount until an indifferent point is reached (Rachlin et al., 1991).

When indifferent points are obtained across a range of delays, the equation proposed by Mazur (1987) can be used to quantify the degree of delay discounting:

$$v_d = A/(1+kd). \tag{1}$$

In Equation 1, v_d is the present discounted value of a delayed reward (i.e., the current subjective value of the reward), A is the amount (magnitude) of the delayed reward, k is an empirically derived constant proportional to the degree of delay discounting, and d is the duration of the delay. Equation 1 is a hyperbolic discounting function and empirical evidence from animal (e.g., Mazur, 1987) and human studies (e.g., Madden, Bickel, & Jacobs, 1999; Myerson & Green, 1995; Rachlin et al., 1991) favors this function over an exponential function derived from normative economic theory.

The prisoner's dilemma game is a popular model of social interaction and conflict situations (e.g., Axelrod, 1980; Baefsky & Berger, 1974). The prisoner's dilemma game involves two players who must independently choose to either "cooperate" or "defect." The consequence of each choice depends on the choice made by the other player. A typical set of consequences employed in this literature is shown in Table 1 (McClintock & McNeel, 1966). When both players cooperate, they receive a moderate payment (3 points each). When both defect, they receive a smaller amount (2 points each). When one player cooperates and the other defects, the cooperator earns the lowest possible payment (1 point), while the defector earns the highest payment (4 points).

Table 1

Reward Matrix for the Prisoner's Dilemma Game

	Player 1 Cooperates	Player 1 Defects
Player 2 Cooperates	3 Points Earned By Player 1 3 Points Earned By Player 2	4 points Earned By Player 1 1 Point Earned By Player 2
Player 2 Defects	1 Point Earned By Player 1 4 Points Earned By Player 2	2 Points Earned By Player 1 2 Points Earned By Player 2

The optimal strategy in a prisoner's dilemma game depends, in part, on the number of choice trials that will be played. In a one-choice game (akin to the original prisoner's dilemma in which two prisoners must independently decide to cooperate with their partner in crime, or confess to the police), an individual player can, on average, earn more by defecting (2 or 4 points, $M = 3$) than by cooperating (1 or 3 points, $M = 2$). Thus, defecting is considered the optimal strategy (e.g., Macey & Skvoretz, 1998). The optimal strategy in an iterated (multi-trial) game, however, depends on the strategy of the opponent. Pure defection is the optimal response against an opponent playing a noncontingent (random) strategy (Rapoport & Chammah, 1965). If the opponent plays a tit-for-tat strategy (always copying the player's last move), however, the optimal pattern is to cooperate on every trial (Green, Price, & Hamburger, 1995). Defecting against a tit-for-tat opponent may earn the player 4 points on one trial (if the opponent has cooperated), but when the opponent defects on the next trial, the player earns either 1 point (by cooperating) or 2 points (by defecting). Consistently defecting earns 2 points per trial, compared with the 3 points per trial earned by consistent cooperation.

The choice between cooperating and defecting in an iterated tit-for-tat prisoner's dilemma game represents a number of common social dilemmas—for example, the conflict between the interests of an individual and those of the group containing the individual (e.g., Hardin, 1968) the development of interpersonal trust (e.g., Quigley-Fernandez, Malkis, & Tedeschi, 1985) and the conflict between immediate and delayed outcomes (Rachlin, 1997). With respect to the latter, an interesting choice exists after the player defects against an opponent playing the tit-for-tat strategy. Choosing to defect on the next trial will earn the player 2 points, while cooperating will result in 1 point. However, choosing to cooperate means that the opponent will do the same on the next trial; cooperating from this point forward will result in 3 points per trial. Thus, the player must choose between a smaller, sooner reward (2 points now) and a larger, later reward (1 point now and 3 points on all subsequent trials). Rachlin (1997) has suggested that individuals who demonstrate self-control are more likely to cooperate when playing the prisoner's dilemma game against a tit-for-tat opponent. Conversely, individuals who greatly discount the value of delayed reinforcers (i.e., those making impulsive choices) are more likely to defect, and thereby choose the smaller-sooner reward.

Evidence supporting Rachlin's (1997) hypothesis was gathered by Green et al. (1995). In this study, pigeons played a series of prisoner dilemma games against a computer opponent using a tit-for-tat strategy. Prior research has shown that pigeons are highly impulsive animals (e.g., Kagel & Green, 1987) and should, therefore, employ a defection strategy in the prisoner's dilemma task. Despite the fact that the animals could earn three pellets per trial if they consistently cooperated, they consistently defected (one pellet per trial). Consistent with Rachlin's hypothesis, the pigeons may have defected because the immediate consequence of defecting (one pellet) exceeded the immediate consequence of cooperating (zero pellets) *and* the delayed consequence of cooperating (3 pellets on the next trial). Green et al. suggested that this inability of future consequences to affect the pigeons' behavior may have led to their consistent defections.

The present study examined the relationship between delay discounting and defections in a tit-for-tat prisoner's dilemma game with a less impulsive species: humans (Rodriguez & Logue, 1988). Delay discounting was assessed using the procedures developed by Rachlin et al. (1991) and was quantified using Equation 1. The degree of discounting (parameter k from Equation 1) was correlated with percentage of defections in a 40-trial prisoner's dilemma game. Consistent with the hypotheses of Green et al. (1995) and Rachlin (1997), we hypothesized that degree of delay discounting would be positively correlated with defections.

Method

Participants

Thirty-one college students (9 male) ranging in age from 18 to 23 (mean = 19.36) participated. Students were recruited by placing posters around campus. Students were excluded from participating if they were colorblind, had taken more than an introductory psychology course, reported regular use of cigarettes or alcohol (four or more times per week), engaged in binge drinking (five or more drinks per sitting), or used any illegal drugs. Participants were treated in accordance with APA ethical guidelines (APA, 1992).

Materials

Sessions were conducted in a room containing a table, two chairs, and an IBM computer. The discounting exercise was performed at the table with the researcher sitting across from the participant, and the prisoner's dilemma game was played on the computer.

Monetary rewards, and delays to these rewards, were printed on separate 3 x 5 index cards and placed in separate piles on the table. The set of monetary rewards were: $10.00, $9.90, $9.60, $9.20, $9.00, $8.50, $8.00, $7.50, $7.00, $6.50, $6.00, $5.50, $5.00, $4.50, $4.00, $3.50, $3.00, $2.50, $2.00, $1.50, $1.00, $0.80, $0.60, $0.40, $0.20, $0.10, $0.04, and $0.02. The delays were 6 hours, 2 days, 1 week, 2 weeks, 1 month, 2 months, 6 months, and 1 year.

Procedure

Discounting exercise. The session began by the experimenter reading aloud the following instructions:

> I'm going to ask you to make some decisions about which of two rewards you would prefer. One of the rewards will always be available right now, and the other will only be available after you

> have waited for some period of time. For example, I might ask you to choose between $550 delivered today and $800 delivered in two years. The actual amounts of the rewards will be much less than this. We will do this with eight sets of rewards and each time the delay to one of the rewards will be different. For example, in the second set I might ask you to choose between some amount of money delivered today and $800 delivered in 10 years.
>
> The choices you make are completely up to you. Please select the option that you prefer, not what you think I might want you to prefer. I do not expect you to choose one particular reward over another. Just choose the reward you really want.
>
> For each set of rewards, I will record the amount of money that the delayed rewards seem to be worth to you. At the end of the session I will put all of your preferences (that is, how much each of the delayed rewards is worth to you) into a hat and you will pull one out. Whichever reward you select is the one that you will get, so every choice you make is potentially going to determine how much money you will earn. If you happen to select a delayed reward, we will mail you a check so it arrives on the exact day you are supposed to get it. If you happen to select a reward delivered today, we will write you a check as soon as the reward has been selected. Because you don't know which of the eight different rewards you will randomly select, you should make all of your choices as though you are really going to get each reward.

In the discounting exercise, the first choice was always between $10.00 delivered immediately and an equal amount of money following a 6-hr delay. After the participant pointed to the reward he or she preferred (the immediate reward in all cases), the immediate reward was decreased to the amount shown on the next card ($9.90). This sequence continued through the entire deck of immediate rewards, regardless of the participant's choices. When the participant switched from the immediate to the delayed reward, the value of the last immediate reward chosen was recorded. When the end of the deck of immediate rewards was reached, the process was repeated in reverse order with the researcher recording the first immediate reward selected. The average of the two recorded values was taken as the indifference point, at which the immediate and delayed rewards were of equal subjective value. Delays were increased for all participants following each complete progression (forward and backward) through the immediate rewards. These procedures were repeated with the same reward type at each of the delays.

Prisoner's dilemma task. Following the discounting component, participants used the computer to play the prisoner's dilemma game. This task, like the delay discounting task, was played with the possibility of earning a real reward ($40 awarded to the participant earning the most points). After sitting at the computer, a table similar to Table 1 was presented to the screen. Instead of listing the players as Players 1 and 2, they were identified as "human player" and "computer player." To avoid biasing participants' choices, the words "Cooperates" and "Defects" were replaced with "Red" and "Green," respectively. Because only the participant received points, the number of points the computer earned was not shown on the screen. Instructions printed below this display described the point earnings following different choices made by the participant and computer.

Next, the computer quizzed participants to ensure they understood the number of points they would earn during three different choice scenarios (e.g., the participant chooses red and the computer chooses red). After the participants had successfully completed this quiz, the on-screen instructions continued:

> Before you make a choice, the computer will choose a color. After you choose, the computer will show you what it chose and will give you the appropriate number of points (according to the table above). The computer's strategy is to copy you. That is, if you select green, the computer will choose green at the next opportunity. Likewise, if you select red, then the computer will choose red next time. Thus, you can always predict what the computer will choose next (it will be what you chose last time). When you understand the computer's strategy, describe it to the research assistant sitting behind you.

Participant awareness of the computer's strategy from the beginning was important because leaving it to the participant to discover the strategy would have introduced between-subject variability (participants would have discriminated the pattern of computer choices at different points in the session). Upon successfully explaining the computer's strategy (participants all accomplished this without additional instructions), they completed 40 trials of the prisoner's dilemma game.

At each trial, the table of choices and point earnings was presented in the upper portion of the screen. Below this, three rectangles were presented. The left and center rectangles were red and green, and their positions switched at each trial. Trials began when the computer simulated making a choice; the computer made random tones for 1 s while the color of the right rectangle was randomly varied every 50 ms. Above this rectangle was written "Computer's Choice" and the rectangle appeared black after the simulated choice. Then the text "Choose a Color" appeared above the left and center rectangles. Participants selected the red or green rectangle by clicking on it with the computer mouse. After making a decision, participants were shown the computer's choice (always the color the participant had chosen on the previous trial, except in the case of the first trial when the computer chose red/cooperate) and how many points they had earned. To ensure that participants attended to the points earned, they were required to press the left mouse button once for each point earned. At each press, a point was added to their cumulative number of points shown at the bottom of the screen. After a 10-s intertrial interval, the next trial began.

Upon completion of the prisoner's dilemma game, the participant randomly selected either a delayed or immediate monetary reward. Eight "delayed reward" tokens and eight "immediate reward" tokens were mixed together. Each token corresponded to one of the eight different delay periods from the discounting exercise. If a "delayed reward" token was selected, the participant was mailed a $10.00 check at the end of that token's delay period. In the event that a 6-hr or 2-day delay was selected, the experimenter met the participant at the lab after the delay had elapsed. If an "immediate reward" token was selected, the participant was given a check for the amount of money previously established as the indifference point at that delay period. Finally, participants signed a form agreeing not to discuss their experiences in the study with others. The entire session lasted approximately 1 hr.

Data collected from 4 participants were discarded because the participants apparently misunderstood the choices given them (demographics of these individuals not included above). These participants provided responses that indicated monetary rewards were either not discounted with increasing delays, or were discounted more at shorter delays. Asking these participants to describe the rewards they were choosing and the delay values involved did not result in delay discounting. Further instructions or questioning of these participants was deemed inappropriate because these interactions may have systematically affected the degree of discounting.

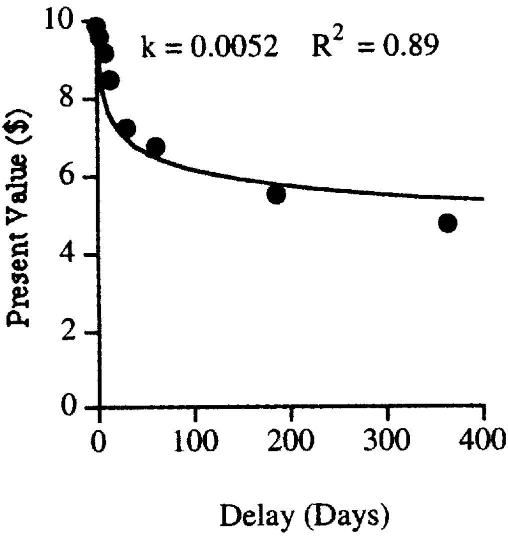

Figure 1. Median monetary indifference points as a function of delay on the discounting exercise. *K* refers to the resulting discounting parameter when a nonlinear regression was fit to the indifference points, while R^2 refers to the percentage of variance accounted for by the hyperbolic discounting function.

Results

Figure 1 shows median indifference points at each of the eight delays, the nonlinear regression function fit to these median values, and the resulting discounting parameter (*k*) and percentage of variance accounted for by the hyperbolic discounting function. The regression function was fit using Delta Graph graphics software using Equation 1. Delays to each reward were expressed as days in estimating the degree of discounting. Data shown in the figure represent the value of the immediate rewards when participants were indifferent between the immediate and delayed rewards. The hyperbolic discounting function provided an excellent fit of these data, accounting for 89% of the variance. Table 2 shows *k* and R^2 values for individual participants. The individual and median *k*-values were in the range typically reported with human participants (Kirby, 1997) and the R^2 values ranged from 0.23 to 0.98 (median = 0.78).

Table 2

Individual Participants' Discounting Parameter (*k*) and R^2 Values Derived from Choices Made in Discounting Exercise and Percentage of Defections Made on Prisoner's Dilemma Task

Participant	*k*	R^2	Percentage of Defections
1	0.0464	0.96	80
2	0.0024	0.91	63
3	0.0039	0.85	53
4	0.0105	0.73	85
5	0.0725	0.97	100
6	0.0177	0.78	28
7	0.0038	0.59	0
8	0.0059	0.78	5
9	0.0007	0.79	20
10	0.0011	0.40	15
11	0.0009	0.72	40
12	0.1069	0.98	63
13	0.0475	0.94	93
14	0.0046	0.58	15
15	0.0002	0.91	20
16	0.0109	0.80	63
17	0.0014	0.68	48
18	0.0056	0.80	10
19	0.0073	0.97	15
20	0.0198	0.94	13
21	0.0040	0.52	30
22	0.0041	0.78	18
23	0.0258	0.45	23
24	0.0062	0.96	3
25	0.0032	0.52	45
26	0.0080	0.88	0
27	0.0086	0.80	18
28	0.0376	0.62	38
29	0.0371	0.26	25
30	0.0010	0.23	13
31	0.0030	0.74	50

Because *k* values were not normally distributed, they were log transformed before being correlated with percentage of defections on the prisoner's dilemma task. Figure 2 shows this correlation. A one-tailed Pearson's test of correlation revealed a significant positive relation between the log *k* values (mean = -2.19, *SD* = 0.64) and percentage of defections (mean = 34.75, *SD* = 27.85) on the prisoner's dilemma game ($r = 0.415$, $p = 0.01$).

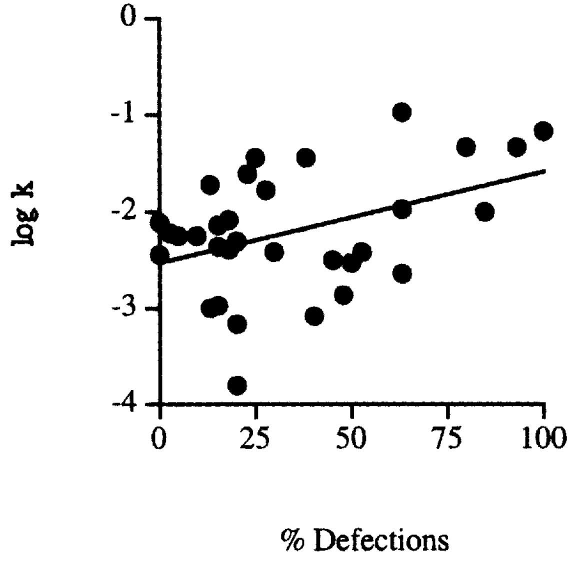

Figure 2. Scatterplot of participants' percentages of defections on the prisoner's dilemma game and respective log *k* values from the discounting exercise.

Discussion

Participants discounted the value of delayed monetary rewards and, with few exceptions, the hyperbolic discounting function (Equation 1) provided a good fit of these data. Although several participants defected at nearly every opportunity in the prisoner's dilemma task, most cooperated on the majority of choice trials. Log transformed discounting parameter values (*k*) were positively correlated with defections on the prisoner's dilemma game. That is, when participants played against a computer opponent that employed a tit-for-tat strategy, impulsive participants (i.e., those with high *k* values) were more likely to choose to defect.

As noted by Green et al. (1995) and Rachlin (1997), the contingencies of reinforcement in a tit-for-tat prisoner's dilemma game provide the player with a series of "self-control" vs. "impulsive" choices. The player behaves impulsively by defecting because the points earned on the present trial are small relative to the points that may be obtained on the trial following cooperation and at the end of the game by cooperating on every trial. The present findings support this comparison and suggest that individuals who most discount the value of delayed consequences will be unlikely to cooperate in the prisoner's dilemma.

Our findings are also consistent with those reported by Green et al. (1995) who demonstrated that pigeons, a species that greatly discounts future consequences, consistently defected in a tit-for-tat prisoner's dilemma game. Green et al. reported that pigeons' choices were affected by the amount of food that could be earned on the present trial alone, suggesting that the value of future outcomes were sufficiently discounted so that they could not compete with the reinforcer available for defecting now. Rachlin (1995) has noted that discounting is attenuated when a series of choices are made before the consequences are delivered and a similar manipulation may improve pigeon cooperation in the prisoner's dilemma.

One potential limitation of our study is the fixed order in which conditions were conducted (the delay-discounting task always preceded the prisoner's dilemma game). Perhaps asking participants to report the subjective value of delayed hypothetical rewards (discounting task) sensitized them to the temporal delay characteristics of the prisoner's dilemma game. If completing the discount task somehow biased participant's subsequent behavior, then we might expect the distribution of defection scores (i.e., the percentage of trials in which participants defected) to be systematically shifted in one direction or another (predicting direction of this shift is difficult because differential consequences were not arranged dependent upon behavior in the discounting task). Although most participants cooperated often in the prisoner's dilemma game, a number of subjects either always or often defected. This suggests that if condition order affected behavior in the prisoner's dilemma game, the effect was either small or unsystematic between participants.

The relation between discounting delayed consequences and defecting in a sequence of prisoner's dilemma choices was discussed as early as 1970 by Shubik, who proposed that future consequences were weighted less in the decision to cooperate or defect than are current consequences. According to Shubik's model, future consequences are discounted at a constant rate. If, for example, the discounting rate was 0.5, then the consequence of the current choice retains it full value, the consequence of the next trial is discounted by 50%, the outcome of the third trial is discounted by 75%, and so on. According to this model, and consistent with our findings, individuals who weigh future consequences little in making a decision are more likely to defect.

Research conducted in the delay discounting literature, however, has demonstrated that the shape of the discounting function is not as simple as Shubik (1970) proposed. Instead, humans (e.g., Myerson & Green, 1995; Rachlin et al., 1991) and animals (e.g., Mazur, 1987) appear to discount future consequences according to a hyperbolic function (Equation 1). Thus, if delay discounting is the mechanism underlying prisoner's dilemma defections, then an adequate quantitative model of defecting must incorporate hyperbolic discounting.

A model that may prove useful to this end was proposed by Mazur (1986) to quantify the extent to which pigeons discounted a series of up to three delayed food rewards:

$$v_d = \Sigma\ (A_i / 1 + kd_i), \tag{2}$$

where v_d is the present value of the series of outcomes obtained by defecting (cooperating), A_i is the reward amount obtained by defecting (cooperating) on the i^{th} trial, k is the degree of discounting, and d is the delay to the i^{th} reward. Thus, the present value of a sequence of defections or cooperations is the sum of discounted values of these delayed outcomes; and preference is determined by relative values.

Applying Equation 2 to the prisoner's dilemma choices made by our participants would be inappropriate because discounting parameters (k values) derived from the discounting task would have to be used to estimate the degree to which delayed points in the prisoner's dilemma task were discounted. Studies examining human discounting of monetary rewards suggest that discounting can vary greatly when different reward amounts are used (e.g., Myerson & Green, 1995), so comparing monetary rewards with points that had only a loose association with money seems inappropriate. Equation 2 also cannot be used to account for predominant defections in the Green et al. (1995) pigeon study because degree of discounting (k) was not reported in that study. Further research with nonhuman subjects in which discounting of prisoner's dilemma outcomes is quantified is required to evaluate the utility of Equation 2 as a model of iterated prisoner's dilemma choices.

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