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The relationship between behavioral measures of self-control: temporal discounting and the single-player iterated prisoner's dilemma

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The Relationship Between Behavioral Measures of Self-Control: Temporal Discounting and The Single-Player Iterated Prisoner’s Dilemma

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Psychology by Shawn R Charlton

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2006
The dissertation of Shawn R Charlton is approved, and it is acceptable in quality and form for publication on microfilm:

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Chair

University of California, San Diego

2006
DEDICATION

To Veda for constant inspiration and support, to my parents, Robert and Linda Charlton, for teaching me to appreciate the beauty of knowledge and the wonder of discovery, and to Carl Cheney for his friendship and introducing me to a natural science view of behavior.
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ABSTRACT OF THE DISSERTATION

The Relationship Between Behavioral Measures of Self-Control: Temporal Discounting and The Single-Player Iterated Prisoner’s Dilemma

by

Shawn R Charlton

Doctor of Philosophy in Psychology

University of California, San Diego, 2006

Professor Edmund Fantino, Chair

Behavior analytic discussions of self-control have focused on temporal discounting as the primary index of self-control behavior. In this measure, choice between discrete, mutually exclusive, delayed outcomes is observed. The outcome of this self-control measure is well described by hyperbolic models of intertemporal choice. In the last ten years, a second measure of self-control has been developed, the single-player iterated prisoner’s dilemma. This measure is based on a series of choices between two discrete outcomes, one of which is larger in the immediate trial, but leads to a lower overall payout while the smaller immediate outcome leads to a higher overall payout. Recent theoretical and empirical reports suggest that while the two self-control measures are unique, the same process modeled by hyperbolic discounting may also influence performance in the single-player prisoner’s dilemma.
To test this possibility, six experiments compared the correlation between performance on temporal discounting tasks with performance in iterated prisoner’s dilemma games. Results from these experiments suggest that: (1) previous reports of a correlation between hyperbolic discounting and performance on the iterated prisoner’s dilemma are replicable, but (2) this correlation is not a universal characteristic of these tasks. Rather, the relationship between the two measures is dependent on specific experimental parameters. Further explorations of the necessary parameters found that the relationship between discounting and performance on the iterated prisoner’s dilemma is influenced by the type of IPD game, type of discounting task, and the probability of reciprocation used in the IPD game.
The behavior analytic literature defines a self-control situation as one in which there is a choice between a larger, more delayed outcome and a smaller, less delayed outcome. A choice of the larger, more delayed outcome is termed self-control, while a choice of the smaller, sooner outcome is considered impulsive (Domjan, 2003; Herrnstein, Rachlin & Laibson, 1997; Logan & Fantino, 1979; Mazur, 2006; Navarick & Fantino, 1976; Rachlin, 1995a). Within the human operant literature hyperbolic discounting of delayed outcomes has traditionally provided a strong measure of self-control behavior (Ainslie, 1992; Green & Myerson, 1993, 2004; Logue, 1988). However, over the last ten years a second measure, based on the single-player iterated prisoner’s dilemma, has been proposed as a second index of self-control behavior (Baker & Rachlin, 2001, 2002; Rachlin 2000, 2002).

In the temporal discounting measure, participants are presented with a series of choices between discrete outcomes available after a series of delays. For example, a participant may be asked to choose between $100 in 1 week or $90 today and then between $100 in 1 week and $50 today. The distribution of these choices provides a profile of how the passage of time impacts the effectiveness of the target outcome as a reinforcer. This index is called the discount rate (Critchfield & Kollins, 2001).

In the single-player iterated prisoner’s dilemma, participants make repeated choices between two options, cooperate or defect, each associated with two possible
outcomes (such as $2 or $4 for defect and $1 or $3 for cooperate). The outcomes are arranged such that a choice to defect always provides a greater outcome than a choice to cooperate on the immediate trial, but lower overall earnings. On the other hand, while choosing to cooperate costs on the current trial, continued cooperation produces greater overall earnings. For example, in a standard application of this game, a participant would be provided the choice between $4 and $3 (defect/cooperate). If $4 were selected, the next choice offered would be between $2 and $1 (defect/cooperate). Each choice of $2 would result in this same choice between $2 and $1 being presented while a choice of $1 would result in the presentation of the $4 and $3 pair. A choice of $3 (cooperate) would lead to the continued presentation of the $4 and $3 dyad. If the game outlined above were played for 100 trials the difference in overall outcome would be between $300 for all cooperation and $200 for all defect. The index of self-control produced by this measure is the proportion of cooperation choices across a defined number of trials.

Each of these measures provides a view of the self-control process. However, recent theoretical discussions have questioned whether the index of behavior provided by temporal discounting and the index provided by the single-player prisoner’s dilemma represent two separate types of self-control behavior or are measures of the same underlying self-control process. In order to address this question in depth, a review of these measures is required.

The Hyperbolic Discounting Measure of Self-Control

At the heart of the hyperbolic discounting measure of self-control is the idea that the value, or utility, of an outcome decreases as a function of its temporal
distance (Chung, 1965; Chung & Herrnstein, 1967; Williams, 1976). For example, a
$100 check you receive today is worth more to you than a $100 check you are
scheduled to receive in a month. A frequently used (and arguably one of the most
successful) quantitative model of this relation is that of Mazur (1987):

$$V_p = \frac{V}{1 + kd}$$

(Equation 1)

In this model, the current value, $V_p$, of a commodity is a function of the
absolute value of the commodity, $V$, divided by the constant 1 plus the free parameter,
$k$, times the delay to the outcomes availability, $D$. The constant 1 in the denominator
allows the delayed value of the commodity to approach the absolute value of the
commodity as delay approaches 0. The free parameter $k$ is included as an individual
index of temporal sensitivity. The larger this value, the greater the reduction in value
as delay is increased.

A unique characteristic of this hyperbolic model is that the rate at which the
commodity loses value is inconsistent across time. For example, with a discount
parameter of $k = 0.1$, a commodity that is worth $100 today would lose 9.1% of its
value after a delay of 1 day. 8.3% between day 1 and day 2, and 7.7% between day 2
and 3.

This inconsistency in discount rate can be contrasted with the standard
economic model of discounted utility, the exponential decay model (Lancaster, 1963;
Meyer 1976; Samuelson, 1937; see Frederick, Loewenstein, & O’Donoghue, 2002,
for a general review and history). This model is normative in the sense that discount
rates are consistent across time periods. The exponential decay model can be written
as:
\[ V_p = Ve^{-kD} \quad (Equation \ 2) \]

The components of this model are the same as in the hyperbolic decay model. That is \( V_p \) is the present value of a commodity, \( V \) is the absolute value, \( k \) is the discount rate, and \( D \) is the delay to receipt of the commodity. Using the same demonstration of this model as used for the hyperbolic model, assume that \$100 is delayed across a three day window with a discount rate of \( k = 0.1 \). The loss of value from no delay to a delay of 1 day is 9.5\%, between day 1 and day 2 the loss in value is 9.5\%, and between day 2 and day 3 the loss in value is 9.5\%. As long as a constant (1 day in this case) is added to the delay, the relative loss in value will remain constant.

This difference in consistency becomes particularly salient in the modeling of a self-control choice. As defined previously, a self-control choice occurs whenever a smaller-sooner outcome (SS) and a larger-later outcome are offered. Consider the self-control choice of \$100 available in 100 days (LL) and the impulsive choice of \$60 available in 80 days (SS). This example uses a discount rate of \( k = 0.05 \). (The following example is shown graphically in Figure 1). When this choice is first offered (\( D = 100 \) days) the value of the LL choice is: \$16.67 according to Equation 1 and \$0.67 according to Equation 2. The value of the SS outcome is \$12.00 and \$1.10. According to the hyperbolic discounting model, preference would be toward the LL outcome as its value is greater than the SS outcome (\$16.67 > \$12.00). According to the exponential decay model, preference would be for the SS outcome as its discounted value is greater than that of the LL outcome (\$1.10 > \$0.67). When the delay to the LL outcome is only 30 days (10 days to SS), the predicted value of the
SS and LL outcomes, according to the hyperbolic discounting equation, is equal: $40 = $40. According to the exponential model, preference is still for the SS outcome over the LL outcome: $36.39 > $22.31. For the remaining 10 days until the SS outcome becomes available, the hyperbolic discounting model predicts preference for the SS outcome over the LL outcome. In summary, the inconsistency in discount rate allowed by hyperbolic discounting (Equation 1) predicts a preference reversal in self-control situations while the exponential model allows no such reversal.

The preference reversal prediction of the hyperbolic discounting model is empirically well established. In two of the first operant tests of self-control (the first test of self-control was Fantino, 1966), Rachlin and Green (1972) and Ainslie (1974) demonstrated that when pigeons are provided an opportunity to choose (commit to) the LL outcome while the delay to the LL and the SS outcome is still great, they will do so. However, if given this same option when the delay to the SS and LL is shorter, the same pigeons choose the SS outcome on as many as 95% of the trials (Ainslie, 1974). Green, Fisher, Perlow, and Sherman (1981) showed that when the delays preceding both a SS outcome and a LL outcome were short, pigeons were impulsive, even when this meant missing more than two-thirds of the available reinforcers. However, when a constant delay was added to both choice options, preference switched to the LL outcome and a greater proportion of the available reinforcers were obtained (for other examples of preference reversals, see Ainslie & Herrnstein, 1981; Kirby & Herrnstein, 1995). While the examples given above target animal models of the preference reversal effect, this phenomenon is also well established in human populations (see Green, Fristoe, & Myesrson, 1994; Kirby & Herrnstein, 1995).
The research on preference reversals not only showed an inconsistency in choice behavior, they also suggested a mechanism for increasing self-control. If an irreversible choice is made in favor of the LL outcome when both choices are distant, the change in preference that occurs when the SS option looms closer cannot be acted upon. This idea of a commitment response introduced by Ainslie (1974) and Green and Rachlin (1972) is an oft researched and cited method for increasing self-control (Ainslie, 1992, 2001, 2005; Domjan, 2003; Green & Rachlin, 1996; Logue, 1988; Mazur, 2006; Pierce & Cheney, 2004; Rachlin, 1995a).

In addition to accurately modeling preference reversals, the hyperbolic model has been shown to have a variety of other strengths. It has been sown that Equation 1 provides a better fit (as measured by variance accounted for, or $R^2$) to empirical data than does the exponential model in Equation 2 (for a selection of these studies see: Green, Myerson, & McFadden, 1997; Kirby, 1997; Kirby & Marakovic, 1996; Kirby & Santiesteban, 2003; Madden, Bickel, & Jacobs, 1999; Rachlin, Raineri, & Cross, 1991; Simpson & Vuchinich, 2000). This advantage of the hyperbolic model has been shown to hold across species (Green & Myerson, 2004; Rodriguez and Logue, 1998).

Research has also shown that changes in the parameters of the discounting task produce systematic changes in discount rates. Frederick, et. al. (2002) reviewed a sample of economic studies of the discounting rate and found that when the delays studied were less than one year, changes in the length of delay greatly influenced the observed discount rates. Once this temporal window extends beyond a year, no further effect was observed. Green and Myerson (2004) provide a similar review of
the effect of increasing the magnitude of the delayed outcome in which increases in
the size of the delayed outcome decrease the rate of discounting. In a growing body
of evidence, Odum and Rainaud (2003), Odum, Baumann, and Rimington (in press),
Estle, Green, Myerson, and Holt (in press), and Charlton and Fantino (in preparation)
have shown that the rate at which a commodity discounts is a function of
characteristics of the commodity as well as the individual. Other factors have also
been shown to effect the rate of discounting: age (Green, Fry, & Myerson, 1994;
Green, Myerson, & Ostaszewski, 1999a), income level (Green, Myerson, Lichtman,
Rosen, & Fry, 1996) and personality characteristics such as sensation seeking and
impulsivity (Ostaszewski & Karzel, 2005) are several examples.

It has also been recognized that hyperbolic discounting functions play a role in
substance abuse (Bickel & Marsch, 2001; Bickel & Johnson, 2003a) and impulse-
control disorders (Ainslie & Haendel, 1983; Critchfield & Kollins, 2001; Petry,
2001a; Raineri & Rachlin, 1993). In support of this proposal, an extensive literature
demonstrates that discounting rates vary across populations with different drug abuse
patterns. For example differences in discount rates have been observed between:
problem drinkers, heavy drinkers, and social drinkers (Vuchinich & Simpson, 1998);
current, never, and ex-smokers (Bickel, Odum, & Madden, 1999; also Baker, Johnson,
& Bickel, 2003, for current and never-smokers); non-drug abusing, non-pathological
gamblers, non-drug abusing, pathological gamblers, and drug-abusing, pathological
gamblers (Petry, 2001b); heroin addicts and non-drug using controls (Kirby, Petry,
and Bickel, 1999); and cocaine-dependent individuals and non-substance dependent
matched controls (Coffey, Gudleski, Saladin, & Brady, 2003). In all of these cases,
the consumption of drugs of abuse was associated with an increase in the discounting parameter, \( k \).

Finally, observations that hyperbolic discounting models also describe the loss in value when the probability of receiving an outcome varies led to an initial belief that probability discounting and delay discounting shared a similar underlying process (Prelec & Loewenstein, 1991; Rachlin, Brown & Cross, 2000; Rachlin, Castrogiovanni, & Cross, 1987; Rachlin, Raineri, & Cross, 1991; Rachlin & Siegel, 1994; Richards, Zhang, Mitchell, & de Wit, 1999). However, recent evidence suggests that discounting across delay and across probability are separate processes (Green & Myerson, 2004). For example, the magnitude effect, the observation that discount rates change as the magnitude of the delayed outcome varies, is reversed for probabilities (larger commodities are probability discounted more rapidly than smaller commodities: Du, Green, & Myerson, 2002; Green, Myerson, & Ostaszewski, 1999b; Green, Myerson, Holt, Slevin, & Estle, 2004; Myerson, Green, Hanson, Holt, & Estle, 2003;). The rate of probability discounting shows a continuous increase with amount while changes in rate of temporal discounting tend to stabilize for magnitudes greater than $25,000 (Green, Myerson, & McFadden, 1997).

The extensive empirical support for hyperbolic discounting has been generated through a variety of different techniques. Much of the original research was collected using human free operant procedures (Forzano & Logue, 1994; Kirk & Logue, 1996; Logue, Forzano, & Tobin, 1992) in which the human participant is placed in front of a response panel with various buttons and levers. In these studies, food and liquid reinforcers were typically used and reinforcers were delivered.
immediately (see Mazur, 1998, for a general review of these methods). Over the past
decade, and across most of the substance abuse literature, discounting has more
frequently been measured with a psychophysical-like titration procedure. In this
procedure, participants are presented a series of outcomes and asked to make a choice
at each level of an immediately available outcome. The comparison choice is a
delayed outcome of a set magnitude. The point at which the participant changes from
a choice of the immediate outcome to a choice of the delayed outcome is interpreted
as the crossover point, or \( V_p \), for that combination of delay and magnitude. This
general procedure has been validated across dozens of studies (see the section on drug
abuse and discounting for references) and across both real and hypothetical outcomes
(Johnson & Bickel, 2002).

The stability of observed discount rates across species, populations, and
experimental procedures, has established this as a valid measure of self-control and
impulsivity. Additionally, the breadth of empirical support behind this model makes
it a strong starting place for investigations of real world self-control problems (such
as drug abuse and risky behaviors). As hyperbolic discounting is well integrated with
Herrnstein’s Matching Law (Herrnstein, 1961; Herrnstein, Rachlin, & Laibson, 1997;
Rachlin, 2006) its function as a general process of choice behavior is anticipated.
Indeed several authors have suggested that hyperbolic discounting is not only a
functional measure of self-control behavior, but also a general process of choice
behavior that provides evolutionary advantages (Bickel & Johnson, 2003b; Herrnstein,
Rachlin, & Laibson, 1997; Williams, 2005).

The Single-Player Prisoner’s Dilemma Measure of Self-Control
While temporal discounting as a measure of self-control is a mature field of research, the single-player iterated prisoner’s dilemma (SP-IPD) is the infant offshoot of a colossal literature. The SP-IPD is a special case of the Prisoner’s Dilemma (PD), a social dilemma first formulated by Flood and Dresher (Poundstone, 1992). The PD has influenced theoretical and empirical ideas across the breadth of the biological and social sciences (for recent reviews see: Barash, 2004; Colman, 1995, 2003; Osborne, 2004; Poundstone, 1992; Von Vugt, 1998) and has generated models of general behavior such as cooperation, competition, trust, suspicion, threats, promises, commitments, environmental problems, and political interactions (Colman, 1995; Cartwright, 2001).

The Prisoner’s Dilemma is a game in which the rational solution is at odds with the solution that is mutually better for the players. In a typical PD game (Figure 2, A), players are presented with the choice to either cooperate (C) or defect (D). Each player makes this choice independently, but the outcome of the game is a function of both choices. There are four possible outcomes in the game: player 1 and player 2 can each cooperate (CC), player 1 can defect while player 2 cooperates (DC), player 1 can cooperate while player 2 defects (CD), and both players can choose to defect (DD). As shown in Figure 2, a choice to defect always provides an outcome with a superior utility to that available for cooperation. As such, both players have a strong incentive to defect. However, mutual defection provides an option that has lower utility (2) than that provided by mutual cooperation (3). Thus, the dilemma: individually - defection is best, mutually - cooperation is best.
While defection is the rational choice in a single round PD, Axelrod and Hamilton (1981) argued that if the game were repeated between players there might be an incentive for the development of cooperation (Cartwright, 2001). The modification suggested by this idea, the iterated prisoner’s dilemma (IPD) has become a dominant force in theoretical and empirical investigations of cooperation among unrelated animals as it provides a general model for the study of reciprocal altruism (Trivers, 1971). Of specific interest in this work has been the tit-for-tat strategy (Axelrod, 1984). In this strategy, the player’s first move is to cooperate. From this point, the player reciprocates the move of player 2 on trial (N – 1). In this way, tit-for-tat both rewards cooperation and punishes defection, both components critical to the evolution of cooperation (Cosmides & Tooby, 2005; Cummins, 2005). The tit-for-tat strategy won Axelrod’s (1984) original IPD tournament despite not winning a single round (but it never lost by more than a small margin, Cartwright, 2001). Some authors have criticized the IPD as a model of reciprocal altruism as the plays occur simultaneously (Bertram, 1982; Barret, Dunbar, & Lycett, 2002), rather than sequentially. In responding to this criticism, Boyd (1995) demonstrated that the critical component in IPD games is not the simultaneous occurrence of choice but the level of reciprocation and the availability of a time period between cheating and retaliation (the importance of reciprocation is similarly supported by Komorita, HIlty, & Parks, 1991; Komorita & Parks, 1994; Komority, Parks, & Hulbert, 1992).

Although the rational strategy is to defect on a single trial PD, an interesting observation is that humans playing both a one-trial PD and the IPD game tend to violate rationality by cooperating (Colman, 2003; Cummins, 2005). This is
particularly true when a mechanism exists not only to detect cheaters, but also to punish them (Fehr, Gächter, 2002; Fehr, Fischblacher, & Gächter, 2002). Recent evidence has even demonstrated that people will actively choose situations in which cheaters are punished over situations where no such punishment is used (Henrich, 2006). Evolutionary psychologists have interpreted these findings as evidence of a general mechanism and need for cheater detection (Cosmides & Tooby, 2005).

The single-player iterated prisoner’s dilemma (SP-IPD) is a specific subclass of the Iterated Prisoner’s Dilemma in which player 1 and player 2 are the same individual. Brown and Rachlin introduced this version of the PD in 1999. Like the IPD, the SP-IPD is played multiple times across the same group of players. The outcome for each trial is determined by the participant’s current choice, Trial N, and their previous choice, Trial N - 1 (See panel B of Figure 2). This sequential game uses the same dilemma as the PD: during each trial, a choice of defection pays off better than a choice to cooperate, but over the long-run, choosing to cooperate pays off better.

Rachlin introduced the SP-IPD game as a general model of Teleological Behaviorism (1992, 1995b, 2000, 2002). In this theoretical description of behavior, the meaning of an individual response is defined by its relationship to overall patterns of behavior. Accordingly, a self-control situation arises when there is a conflict between the preference for a long-term pattern and a preference for the outcome of a shorter activity. For example, the stereotypical individual on a diet values the long-term pattern of being at a target weight over the long-term pattern of being overweight. However, they also value the current enjoyment of a high caloric meal.
over a healthier option. Consistency with the desired long-term pattern requires the sacrifice of a more preferred immediate outcome. In this form, the teleological view of self-control is an individualized version of the Prisoner’s Dilemma.

The development of the SP-IPD was influenced by a series of experiments on temporal patterning in utility maximization and self-control (Herrnstein, Loewenstein, Prelec, & Vaughn, 1993; Kudadjie-Gyamfi, & Rachlin, 1996, 2002; Rachlin, 1995b, 2000; Tunney & Shanks, 2002). In these experiments, participants make repeated choices between two options, A and B. Both options provide reinforcers at the same probability and magnitude, but the delay associated with each choice is different. The delay to delivery of an outcome is decided by a simple rule such as (Kudadjie-Gyamfi & Rachlin, 2002): Delay to A = N + 3; Delay to B = N; and N = the number of A choices over the last 10 trials. These rules create a set of contingencies in which the delay to A is always three seconds longer than the delay to B. However, each choice of the short delay adds 1 second to both delays. The continued choice of B would result in a 10 second delay to outcome B and a 13 second delay to A. However, continued choices of A result in only a 3 second delay to A. These studies found a general bias toward the more immediate outcome over the long-term pattern. Manipulations by Kudadjie-Gyamfi & Rachlin (2002) and Tunney & Shanks (2002) found that changes in the level of instructions provided and the magnitude of the outcomes, respectively, increased the overall level of long-term choices. As with Rachlin’s Teleological theory of self-control these procedures are a direct approximation of the dilemma created in the prisoner’s dilemma.
Silverstein, Cross, Brown, & Rachlin (1998) conducted the first direct experimental approximation to the single-player iterated prisoner’s dilemma (SP-IPD) in an experiment looking at the effect of prior SP-IPD exposure to the tit-for-tat strategy on performance during the two-player IPD. Participants played an IPD against an experimenter playing a fixed strategy and then against another research participant. One of the strategies played by the experimenter was tit-for-tat. Under this condition, the two-player IPD becomes a single-player IPD as the outcomes experienced by the participant are directly caused by the participant’s own behavior. Participants in this group cooperated on 59% of the last 8 trials. This was significantly higher than for subjects playing against a research assistant who played an all cooperate, all defect, or random strategy.

As noted previously, the formal introduction of the SP-IPD was in 1999. As a follow-up to the findings from Silverstein, et. al. (1998), Brown and Rachlin (1999) were interested in how performance on a one-player PD would transfer to a two-player IPD. In the one-person game, participants chose between four boxes, each of which produced both a number of nickels and a key. The key indicated which of the boxes the participant could open on the next round. The color of the key was correlated with the choice on the previous round. The two boxes opened with the “cooperate” key were of a higher value than the boxes that could be opened with a “defect” key. However, for each choice pair, the box containing the greatest number of nickels produced a “defect” key while the box with fewer nickels produced a “cooperate” key. In this experiment, the research assistant was only involved in resetting the boxes after each trial, creating a true single-player iterated prisoner’s
dilemma. Participants cooperated on between 48% and 58% of the trials (depending on condition). In a second experiment where the magnitude of outcomes for each choice was increased, cooperation increased to between 75% and 77%. In both of these experiments, cooperation on the two-player game, regardless of prior experience with the one-player game, was below 50%.

In both Silverstein, et. al. (1998) and Brown & Rachlin (1999) a condition was included in which trials were presented in groups rather than individually. In these conditions, participants would make their choices for the next n trials prior to seeing the choices made by the participant. After the choices were made, all of the plays by each participant were shown and the total tally for that group of trials was calculated. In each of these experiments, the grouping of trials resulted in a significant increase in the number of cooperation choices in a two-payer game.

The third study of the SP-IPD examined the impact of the probability of reciprocation on cooperation in a repeated prisoner’s dilemma (Baker & Rachlin, 2001). This experiment tested performance on an IPD game in which the computer played either a straight tit-for-tat, reciprocated on 75% of the trials, or played a random strategy. For both the tit-for-tat and 75% reciprocation conditions, cooperation is the optimal strategy. The tit-for-tat condition was directly analogous to a self-control situation. Results from these experiments indicated a high level of cooperation at both the tit-for-tat and 75% reciprocation conditions when the computer’s probability to cooperate is signaled (through the use of colored spinners at the top of the display screen), a decrease in cooperation at the 75% reciprocation level when the probability of reciprocation is unsignalled, and a similar decrease in the
75% condition when the computer is replaced by an unknown other (although the unknown other was actually still the computer). The finding that changes in probability of reciprocation impacts the overall level of cooperation is consistent with general theories of cooperation (Komorita, Hilty, & Parks; 1991; Komorita & Parks, 1994; Komorita, Parks, & Hulbert, 1992) and the idea that cooperation under uncertainty was highest when signals of this uncertainty were present is consistent with the conception of cheater detection (Cosmides & Tooby, 2005).

In a review of these first three SP-IPD studies, Rachlin, Brown, and Baker (2001) determined that the critical determinant of both social cooperation and self-control was the conditional probability of “…if I cooperate now, will others cooperate (or will I cooperate) in the future?” (italics from original). In situations of self-control, this question translates into a general calculation of how likely it is that in the future, you will also choose in favor of the long-term pattern over the short-term benefit. For individuals with high levels of impulsivity, this probability is low. Additionally, each of the three SP-IPD studies reviewed by Rachlin, et. al. (2001) had a similar suggestion for handling periods of potentially low reciprocation: make choices in bundles.

In the fourth study of the SP-IPD with human participants, Fantino, Gaitain, Meyer, and Stolarz-Fantino (2006) investigated the effect of lengthening the delay between choice trials on cooperation using the same SP-IPD procedure as Baker and Rachlin (1999). Silverstein, et. al. (1998) had previously proposed that increasing the length of the time between trials (the intertrial interval, or ITI) would decrease the level of cooperation as it would interfere with the development of a pattern of
responding. However, in the first experiment of Fantino, et. al, the opposite effect was found. In the second experiment of this report, it was found that inserting a filler task into the ITI (a simple puzzle) eliminated the gains in cooperation observed when the ITI was increased without the filler. The increase in cooperation as the ITI increases was taken as evidence that the longer ITI facilitated the discrimination of the contingencies.

These four studies represent almost all the existing empirical research on the single-player iterated prisoner’s dilemma measure of self-control (the final three papers will be discussed in the following section). Two issues of particular importance are revealed by this review. First, the SP-IPD does appear to be an analog of the general IPD as performance in the single-player is influenced by the same variables as the IPD (i.e., probability of reciprocation, signals of cooperation). The similarity between single-player and multi-player versions of the IPD can provide a powerful research model as the reduction from two to one players reduces the number of uncontrolled and interacting variables involved in the prisoner’s dilemma (Fantino, 2004). Fantino, et. al. (2006) highlight the importance of this control as small parametric manipulations (changing the length of the ITI by 5 to 15 seconds) can have significant impacts on performance in the SP-IPD.

Second, and of more importance, it is notable that the SP-IPD is linked to self-control behavior in theory only. In the four studies reviewed above, all of the tests were conducted with undergraduate students with no known variance on any self-control or impulsivity dimensions. This can be contrasted with the temporal discounting literature where the link between self-control and discount rates has been
extended from the laboratory to the real world. In the SP-IPD literature, it has been demonstrated that changes in the probability of reciprocation cause changes in the overall level of cooperation (Baker & Rachlin, 1998; Fantino, et. al, 2006). In the temporal discounting literature it has been shown that changes in discount rate are reliably correlated with risky choice behaviors (Odum, Madden, Badger, & Bickel., 2000; Petry, 2001a) and changes in drug consumption patterns (Baker, et. al., 2003; Petry, 2001b). In short, the current status of the SP-IPD is as a fascinating model of behavior under complex contingencies that is theoretically linked to self-control.

Temporal discounting is an established measure of self-control behavior. (Of course, temporal discounting was once where SP-IPD is currently)

**Temporal Discounting and the Single-Player Iterated Prisoner’s Dilemma**

In the previous review of the SP-IPD much of the theoretical framework of the measure was not presented. The relation between the SP-IPD and Rachlin’s ideas of Teleological Behaviorism (1992, 1995a, 2000, & 2002) were outlined, but this is a relatively new theoretical explanation of how the SP-IPD relates to self-control. A much older and more developed theoretical link is between the SP-IPD and temporal discounting.

Before going into the theoretical link in detail, it should be pointed out that for the SP-IPD to be of any interest at all, human behavior must be prone to intertemporal inconsistency. If human behavior were perfectly rational, an individual choosing to cooperate in the first trial of the SP-IPD would choose to cooperate in the second round and on through infinity. Just as the dilemma in the interpersonal prisoner’s dilemma is caused by uncertainty over the upcoming play by the other player, the
dilemma in intrapersonal dilemmas (Read, 2001; Read & Roelofsma, 1999) is caused by uncertainty within the individual concerning future performance. A model of the similarities and differences between interpersonal dilemmas such as the PD and the IPD and intrapersonal dilemmas such as the SP-IPD is presented in Figure 3. In panel (A) an interpersonal dilemma is displayed in which the individual (self) is interacting with 8 other agents (selves). The double arrows indicate that the behavior of these individuals is reciprocal in the sense that the behavior of each agent is influencing and being influenced by the other agents. The only information shared by these agents is through these interactions. In panel (B) the 8 agents are now represented as inside the individual (self) and are extended across time. Each agent is still influenced by the other agents, but in a more sequential pattern (Agent T1 will influence T1 who will influence T2, and so forth). Note that while the agents are within the individual, not all information is shared. As the agents are separated by temporal space, there is uncertainty concerning both the state of the agent and external forces this agent may encounter. The basic premise of the theoretical link between temporal discounting and the SP-IPD lies in the inconsistency and unpredictable nature of these intrapersonal agents.

The path leading to a discounting theory of PD performance began in 1970 when Shubik suggested that future consequences are weighted less than are present choices to cooperate or defect in a prisoner’s dilemma. In this original proposal, the discount rate between choices was constant. Fourteen years later, Axelrod (1984) extended this original idea by suggesting that the utility of each move in a prisoner’s dilemma was a product of the utility associated with the current move and successive
moves. Future moves, however, conveyed less utility, as weighted by a discounting parameter, $w^T$, where $T$ is the trial number. This model agreed with that of Shubik in form, but assumed a constant decrease in value across trials.

It was Ainslie (1992, 2001, & 2005) who first argued that the intertemporal inconsistencies created by hyperbolic discounting could be viewed as creating an internal prisoner’s dilemma played by successive motivational states. As each of these states would be a different temporal distance from the potential choice outcome, each would value the outcome differently. This theoretical link has been proposed directly (Ainslie 1992, 2001, & 2005) as well as indirectly in general descriptions of intrapersonal dilemmas (Read & Roelofsma, 1999; Read, 2001)

Rachlin (1997 & 2000) furthered this description by suggesting that individuals with high discounting rates would value the long-term pattern of outcomes in a prisoner’s dilemma task less and would therefore be more likely to defect. Along a slightly different route, Stephens, Nishimura, and Toyer (1995) suggested that a general failure to observe the development of stable cooperation in animals playing multi-player iterated prisoner’s dilemma games could be attributed to two processes: error and discounting rate (also Stephens, 2000).

Up to this point, the theoretical link between discounting and the SP-IPD has been purely theoretical. However, some recent studies have interpreted their results as consistent with this theoretical model. Green, Price, and Hamburger (1995) tested pigeons on a series of iterated prisoner’s dilemma tasks where the computer played several different strategies (tit-for-tat, all cooperate, all defect, chicken, and random) and found that behavior was consistently controlled by the immediate consequences
rather than long-term outcomes. The authors suggested that this could be the product of strong discounting rates observed in pigeons (Kagel & Green, 1987; since: Rodriguez and Logue, 1988; Green, Myerson, Holt, Slevin, & Estle, 2004).

In a more direct test of this relationship, Stephens, McLinn, and Stevens (2002, 2006), tested blue jays in a two-player iterated prisoner’s dilemma context where the play of the one bird was forced to conform to either a tit-for-tat strategy or a random strategy and the play of the other bird was used as the dependent measure. The presentation of outcomes in this study was either immediate or accumulated across several choices prior to presentation (this accumulation is similar to the patterning used by Baker & Rachlin, 2001, 2002; Rachlin, Brown, & Baker, 2001; Silverstein, et. al., 1998). The grouped delivery of pellets was used because pilot studies by this research team as well as various other reports indicated that clumping of trials prior to the presentation of earned outcomes decreases the observed rate of discounting (Ainslie, 1992 & 2005; Ainslie & Monterosso, 2003; Stephens 2000). The jays in the accumulated condition cooperated significantly more than did those in the immediate condition. As with Green, et. al. (1995), this finding was interpreted as evidence that discount rates do influence the overall level of cooperation on a prisoner’s dilemma type task.

The work by Stephens, et. al. (2002) is particularly interesting as it demonstrates a possible functional link between discounting and the SP-IPD. Patterning of trials has been seen as a type of soft commitment (Rachlin & Siegel, 1994; Siegel & Rachlin, 1995; Rachlin, 1995, 2000, & 2002) in which an individual uses some type of psychological or motivational device to create a link to the self-
control response. Ainslie (1992, 2001) suggested that one type of these commitment devices is to imagine every choice as the selection of several of the same kind (if I choose to cooperate now, I must do so for the next 10 trials). In this way, the overall value of each choice is increased. Soft commitment is the SP-IPD analog of the commitment procedures demonstrated in the temporal discounting work (Ainslie, 1974; Green and Rachlin, 1972).

Direct Tests of the Theoretical Link Between Discounting and the SP-IPD

The preceding section ended with a demonstration that commitment is a functional method of increasing the frequency of self-control choices in both temporal discounting procedures and SP-IPD games. However, the preceding section still did not present any direct comparison of the relationship between discounting and cooperation on the SP-IPD. The three SP-IPD studies that were not addressed in the overview of this literature provide the first attempt at establishing this link empirically. Each of these reports presents participants with both a temporal discounting task and an iterated prisoner’s dilemma task and then looks at the correlation between performance on each of these tasks. A negative correlation is expected between proportion cooperation on the SP-IPD and discount rate. In essence, individuals with a higher discounting rate (less self-control) should emit fewer cooperation responses than those with a lower discount rate.

Harris and Madden (2002) conducted the first direct look at discounting and the SP-IPD. Participants in this experiment were first presented a standard version of the temporal discounting titration procedure with a temporal window, or length of delay from the shortest to the longest delay, of 6 hours to 1 year and a delayed
magnitude of a hypothetical $10. The IPD game was completed second by all participants. In this experiment, the computer played tit-for-tat. The outcomes in the IPD procedure ranged from $1 to $4 (the same as Baker & Rachlin, 2001). Each participant completed 40 trials of this game and then their proportion defection on the 40 trials was compared to their observed discount rate from the temporal discounting procedure. Across 31 participants, a correlation of $r = 0.41$ ($p = 0.01$) was observed between discount rate and proportion defections.

The second exploration of a correlation between discount rate and cooperation with human participants was conducted by Yi, Johnson, and Bickel (2005) and involved a more extensive series of procedures. This study also involved undergraduate students. However, each participant was asked to complete two prisoner’s dilemma games and four temporal discounting measures. The experiment was spread across two sessions with one game and two discounting tasks presented each session. The two prisoner’s dilemma games were presented in the same manner with the participant making a choice between a button labeled Defect on one side of the screen and a button labeled Cooperate on the other side of the screen. Participants were told the other player was the computer, but no details concerning the computer’s strategy were provided. The computer played either a tit-for-tat or a random strategy. After completing the IPD game, participants completed a series of discounting tasks in which they chose between outcomes delayed from 1 day to 25 years and with delayed magnitudes of $10, $100, and $1,000. After completing the temporal discounting task for gains, they repeated the same procedures, but with a $10, $100, or $1,000 loss after the specified delay. Whether the tit-for-tat or the
random strategy presented as the IPD game in the first session was alternated across participants, as was the presentation of the gains and loss conditions of the temporal discounting measure. However, the IPD game always preceded the completion of any temporal discounting tasks. All outcomes in this experiment were hypothetical.

The results indicated statistically significant negative correlations between discount rate for gains and proportion cooperation and between discount rates for losses and proportion cooperation. As the results in this experiment were presented in terms of proportion cooperation rather than proportion defect, the results are consistent with those from Harris and Madden (2002). Novel to this experiment was the finding that a stronger correlation existed between the discount rate for losses and proportion cooperation than for the discount rate for gains and proportion cooperation. Also, the results found no correlation between discount rate and proportion cooperation when playing against a random strategy. This is consistent with the ideas put forth by Ainslie (1992) and Rachlin (2000, 2002) as self-control on the prisoner’s dilemma is limited to the strict reciprocity condition in that each subsequent choice confronted by an individual is a direct product of their past choices.

A second experiment included in Yi, et. al. (2005) tested the relationship between probability discounting and cooperation in an IPD game. The experimental design was identical to that used in the previous test of delayed discounting and cooperation, but used probability in place of delay. Unlike the first experiment, no statistically significant correlations were identified between probability discounting and cooperation in any of the conditions.
The final investigation of a relation between discounting and cooperation in the prisoner’s dilemma was an extension of Yi, et. al. (2005) to a non-student population. In this study, Yi, Buchahalter, Gatchalian, and Bickel (2006) tested 31 intranasal opioid dependent individuals on both a temporal discounting task and an iterated prisoner’s dilemma during the intake for a clinical treatment study. The temporal discounting task and the IPD game were the same as that used by Yi, et. al. (2005), but the parameters of the discounting task were changed. The temporal window still ranged from 1 day to 25 years, but only two values of gains were tested, $1,000 and $10,000. The IPD game used the tit-for-tat strategy for all participants and the range of outcomes was from $5 to $25. As with the previous studies, all outcomes were hypothetical and all participants completed the TD task first, followed by the IPD game. Results from this study replicated those from Harris and Madden (2002) and Yi, et. al. (2005) in that a significant negative correlation between the measured discount rate and proportion cooperation was identified.

In summary, the studies of Harris and Madden (2002), Yi, et. al. (2005), and Yi, et. al. (2006) agreed that the theoretical link between discounting and cooperation held at least enough to produce a moderate correlation between the two self-control measures. The range of correlations between discount rate and cooperation reported across these studies was from $r = -0.29$ to $r = -0.65$.

**How Robust is the Relationship Between Temporal Discounting and the SP-IPD?**

Harris and Madden (2002), Yi, et. al. (2005) and Yi, et. al. (2006) established a general link between temporal discounting and cooperation on the SP-IPD. This link is of theoretical interest to the SP-IPD procedure in that it ties the SP-IPD
procedure to an established model of self-control. For the temporal discounting procedure this link is of importance as it ties the temporal discounting literature to the extensive study of the iterated prisoner’s dilemma. From an applied perspective, this is of particular interest as a link between discount rates and performance on the IPD could provide further insight into how the abuse of substances interferes with regular behavioral functioning.

The goal of the remainder of this report is to explore just how robust a relationship exists between temporal discounting and the iterated prisoner’s dilemma by conducting a parametric analysis of the variables that influence the relationship between these measures. Across the six experiments presented in the next 3 chapters, most of the parameters that have been shown to influence discounting rate: the length of the temporal window, the magnitude of the delayed outcome, and the type of outcome commodity in the temporal discounting procedure are varied in a comparison of how these impact the correlation between discounting and the SP-IPD. The parameters that have been shown to impact performance on the SP-IPD are also varied: probability of reciprocation, type of player, information concerning the computers probability of reciprocation, and the magnitude of the commodities used as the outcomes in the IPD procedure. This wide study of the parameters of these tasks and how they influence the observed correlation can both indicate how robust this phenomenon is and highlight possible areas for future emphasis in looking for the functional relationship between temporal discounting and cooperation in the SP-IPD.

In addition to exploring the direct correlation between these measures, two novel comparisons are made. In the first, performance on the SP-IPD and individual
discount rates are compared to the score of a general measure of self-control that has been shown to be highly related to trait models of self-control and various real world benefits of self-control (grade point average, quality of interpersonal relationships, etc.). This test was included in order to explore the possibility that either temporal discounting or performance on the SP-IPD might also be an indicator of more general constructs of self-control (Tangney, Baumesiter, & Boone, 2004).

The novel task added to the second experiment is the Sharing Game developed by Fantino & Kennelly (Fantino, Stolarz-Fantino, & Kennelly, 2005). This game was designed as a measure of resource allocation between individuals under a non-competitive context. This task has generated a series of interesting findings, and it was asked how distribution of resources on the Sharing Game might be related to performance on temporal discounting and/or the SP-IPD.

Both the Tangney, et. al. (2004) general self-control task and the Sharing Game were included to see if temporal discounting or SP-IPD measures of self-control would be related to these more general measures of behavior. However, they also served a second purpose. Looking at how two measures that are correlated interact with a third measure is a possible method for identifying the relationship between the two variables of interest. This is akin to the process of triangulation where the identification of how an object relates to multiple known spatial points allows for an exact localization of the object.
The experiments presented in this chapter extend the findings of Harris and Madden (2002), Yi, et. al. (2005), and Yi. et. al., (2006) by exploring the generality of the observed relationship between the rate of temporal discounting and cooperation on prisoner’s dilemma tasks by: (1) comparing the relationship between temporal discounting (TD) and cooperation in four different IPD contexts, (2) comparing the relationship between TD and IPD performance to a third behavioral game, and (3) evaluating the relationship between TD, IPD, and a general paper-and-pencil based test of self-control. These extensions should help determine the robustness of the relationship between temporal discounting and IPD performance.

Experiment 1

Participants completed one of four IPD tasks. Half of the participants completed a single-player game and the other half completed a simulated two-player version. In both tasks, the participant played with a computer that was programmed to play tit-for-tat. Participants in the single-player game saw the outcome of their choices only. In the multi-player game, the computer’s choice, total score, and most recent outcome were also presented. A manipulation similar to this was employed by Baker and Rachlin (2001) and found no change in terminal level of cooperation between the single-player and multi-player games. However, in their “alone” conditions, information concerning the computer’s choice was presented. It is
possible that this extra information changed the task. On the other hand, Brown and Rachlin (1999) and Fantino, Gaitan, Meyer, and Stolarz-Fantino (2006) presented their tasks as true SP-IPD games in that no information concerning the computer was presented on the screen. Is there a functional difference between these two tasks? If so, does this difference impact the relationship between discounting and cooperation on the IPD games?

Each of the IPD groups was subdivided into either an instructed or discovery group. In the discovery group, participants were told the specifics of the IPD game, but no information was provided concerning how the computer would choose its move. For the instructed group, a detailed description of the tit-for-tat strategy was provided. As a variety of studies have suggested that rule-governed behavior is less sensitive to local contingencies, it is possible that performance on the IPD tasks could also be sensitive to how the instructions are presented (Fantino, Kanevsky, & Charlton, 2005; Kudadjie-Gamfi & Rachlin, 2002; Hayes & Ju, 1998; Kaufman, Baron, & Kopp, 1966; Lippman & Meyer, 1967; Luchins & Luchins, 1994). If behavior is influenced by the instructions provided, would this have an impact on the relationship between discounting and cooperation?

The manipulation of instructions provided to the participants during an IPD procedure represents a novel test within the SP-IPD literature. One previous experiment explored a somewhat similar manipulation. In Silverstein, et. al. (1998) participants played first against a confederate using a pre-planned strategy and then against other participants (who had also played an experimenter with a set strategy in the first round). The results of this experiment indicated an initial impact of previous
experience, but a gradual convergence to no difference between the groups regardless of instructional pre-exposure (Kudadjie-Gyamfi & Rachlin, 2002, present a similar finding with a different procedure). The authors interpret this as evidence of a shift from rule governed to contingency shaped behavior. However, no study has yet looked at how the rule-governed versus contingency-shaped distinction impacts performance on a multi-player and a single-player IPD task.

The final element of this experiment was the inclusion of the general self-control measure developed by Tangney, et. al. (2004). This measure is a trait measure of self-control targeting both general behavioral outcomes and personality dimensions. The inclusion of this measure in the current experiment was designed to allow a comparison between discounting rates, cooperation on the IPD, and score on a general measure of self-control. This comparison allows for an evaluation of how behavioral measures relate to general models of self-control.

The Tangney, et. al. (2004) measure was selected as it is a broad based measure of self-control. A validation study of this measure demonstrated that the Total Self-Control Scale (TSCS) correlates with behavioral aspects of self-control (grade point average, alcohol use, family relations, anger management, psychopathology) as well as personality traits (conscientiousness, agreeableness, self-esteem, empathy). Follow-up investigations using this measure have further demonstrated its value as general index of real-world self-control (Duckworth & Seligman, 2005; Finkenauer, Engels, & Baumeister, 2005; Gailliot, Schmeichel, & Baumesiter, 2006; Goodson, Buhi, & Dunsmore, 2006; Trumpeter, Watson, & O’Leary, 2006).
1.1 Method

1.1.1 Participants

Response data from 237 UCSD undergraduate students were analyzed (out of 250 participants). Data from 13 participants was excluded due to a failure to complete all three tasks. Participants were recruited from undergraduate psychology courses and were given one-hour of experimental credit for their participation.

1.1.2 Testing Apparatus and Location

Experimental sessions were conducted at individual PC computers. The majority of participants completed the task in a room with four computers separated by cardboard privacy dividers. A small number of participants completed the tasks in one of two small rooms with only a single PC. No demographic data was collected on the participants and no record of testing location was made.

1.1.3. Experimental Procedure

Each participant was randomly assigned to one of eight conditions (Table 1). The presentation of the IPD and discounting task was fully counterbalanced.

Upon arrival at the laboratory, a research assistant directed the participant to a computer terminal. The computer presented the instructions and all experimental procedures.

Temporal-discounting task

Individual discounting rates were estimated using a computerized presentation of the psychophysical titration procedure (Vuchinich & Simpson, 1998; Odum and Rainaud, 2003). In this procedure, two virtual index cards are shown on the computer screen, one on the left side of the screen and the other on the right side (see Figure 4).
The card on the left displays a money amount ranging from $100 to $1 (US) that is available right now (Appendix A). The card on the right was a constant $100. The delay to availability of the amount on the right ranged from 1 week to 25 years (Appendix A).

The participant clicked directly on the preferred choice. After a valid response, the image of the non-selected card disappeared from the screen for two seconds. During the first second, the selected card was visible. During the final second, neither card was shown. The next trial started with the presentation of both cards, each updated to reflect the current choice options. After all 26 monetary values for a given delay were presented, the length of delay to the $100 on the right of the screen increased and the amount available immediately returned to $100. This cycle continued for all 7 delay periods (a total of 182 choices). After completing all delays with decreasing amounts, the procedure restarted, with the delayed outcome starting at $1 and increasing to $100 for all seven delays.

The following instructions were centered in the top portion of the screen throughout the entire procedure:

The two values below represent two hypothetical rewards. Your task is to identify which of the two rewards you would prefer to receive. While the rewards are hypothetical and you will not be receiving any of the chosen outcomes, we ask you to choose AS IF you were going to receive the outcome. The reward you choose should represent the outcome you prefer. There are no right answers to this task.

The card on your left represents, and always will represent, a reward that you would receive TODAY.

The card on your right represents a reward that would be available to you after the amount of time indicated below the reward amount.
Please click directly on the amount of reward that you would prefer. When you make a selection, the non-selected reward will disappear for a few seconds and then both reward values will return, updated with the new values.

Iterated Prisoner’s Dilemma

Participants were presented a screen dominated by a 2 x 2 table. The two choice buttons were placed directly above this table. The button above column 1 was labeled ‘A’ and the button above column 2 was labeled ‘B’. The participant’s last choice and current total were displayed immediately above the choice options (Figure 4). Points were used as the outcome commodity. The point distribution was: 1 (defect-cooperate), 2 (defect-defect), 5 (cooperate-cooperate), 6 (cooperate-defect). The possible outcomes were presented inside the individual cells of the table.

Once a choice was selected, the non-selected choice button disappeared, a colored box displayed around the current outcome, and the current total was adjusted. After three seconds, the box was removed, both response buttons were presented, but inactive, and the last choice display was updated. One second later, the response keys activated. All participants completed 99 trials of the IPD procedure. Each trial lasted a minimum of 4 seconds. If a choice response occurred prior to the end of the four-second window, the response button deactivated, but the outcome was not displayed until the end of the four-second interval. If a response were not made until after the 4-second window, a response was immediately registered and the results displayed. Throughout the experiment, a textbox in the upper-left hand corner of the screen read “waiting for your response…” until a choice was selected. At this point, it was updated to read “you have responded”. The procedure described above applied to all participants, regardless of IPD condition.
For participants in the multi-player condition, a second set of buttons, ‘C’ and ‘D’, respectively, were placed to the left of rows 1 and 2. The last play and current total for the computer displayed to the immediate left of these buttons (Figure 6). During the feedback delays, the button corresponding to the computer’s choice deactivated and the non-selected button disappeared. A textbox displayed in the upper-left corner read, “Waiting for computer’s move…” during the first four seconds of a trial and, “Computer has responded,” after this.

For both the SP-IPD and the MP-IPD discovery groups, the instructions read:

For this portion of the experiment, you will be playing a simulation in which the goal is to:

**EARN AS MANY POINTS AS POSSIBLE**

Points are earned by choosing either the A or the B button at the top of the game matrix. The option that you choose will determine which of the two columns your points will come from (either the column with 6 points on the top and 2 points on the bottom or the column with 5 points on the top and 1 point on the bottom). The point value that you will receive for each cell of the matrix is identified with red font.

The exact number of points you receive will be determined by the column you choose and the row that the computer chooses. The computer is playing a set strategy and makes its choice on each trial without "knowing" what your choice is.

The possible outcomes for each trial are as follows:

- If you choose column A and the computer chooses row C you will earn 5 points
- If you choose column A and the computer chooses row D you will earn 1 point
- If you choose column B and the computer chooses row C you will earn 6 points
- If you choose column B and the computer chooses row D you will earn 2 points
For the instructed group, the following paragraph was added to the end of the instructions:

The strategy the computer is programmed to play is known as tit-for-tat. According to this strategy, the computer will use your choice on the previous trial as its choice on the current trial. That is, if you chose A on the last trial, the computer will choose C on this trial and if you chose B on the last trial, the computer will choose D on this trial.

Total Self-Control Scale (TSCS)

Participants completed the full 36-question Total Self-Control Scale developed by Tangney et. al., (2004). Each question was displayed individually on the computer screen. Participants responded by clicking on one of five buttons. Each button was labeled with a number, ranging from 1 to 5. Instructions indicated that a response of 1 indicated they did not agree with the statement and 5 indicated they did agree. Once a click was recorded, the question was removed and the next question presented.

1.2 Results

Individual discounting rates \(k\) were calculated using non-linear regression and the standard hyperbolic discounting function (Equation 1). The subjective value for each of the seven delays was calculated as the last choice of the immediate outcome prior to a crossover to the delayed outcome for the decreasing magnitude conditions and as the first choice of the immediate outcome for the increasing magnitude choices. The average of these values was used to calculate the discount function. A natural-logarithm transformation normalized the fitted \(k\) parameters.

Although the discounting procedure did not differ between groups, a 2 x 2 x 2 (IPD x Instruction x Order) ANOVA tested for between group differences. As
anticipated, no differences were observed for IPD or Instructions. However, a significant difference was found between groups based on order of presentation, F(1, 234) = 4.0385; p < 0.05; $\eta_p^2 = 0.017$). When the TD measure was presented first, the observed median discount rate was 0.0133 ($QR = 0.0022$ to 0.0356). When the discounting measure followed the IPD measure, the observed median discount rate increased to 0.0217 ($QR = 0.0052$ to 0.0785). Overall, groups completing an IPD game prior to the discounting measure showed an increased preference for the more immediate outcome during the temporal discounting task. The median variance accounted for (VAC), a measure of the goodness of fit, was 0.90 ($QR = 0.61$ to 0.96). Table 2 presents the median discount rates for all 8 groups.

In the IPD task, a choice of the left column was scored as cooperate and a choice of the right column was scored as defect. The proportion cooperation was calculated as the total cooperate choices divided by total trials. The completed IPD trials were arranged into three blocks of 33 trials (Figure 7). A 2 x 2 x 2 x 3 (IPD x Instructions x Order x Block) repeated measures ANOVA was conducted on the proportion cooperation from each block. The three blocks of trials were the within-subject factors. A main effect of IPD, F(1, 229) = 32.846; p < 0.0001; $\eta_p^2 = 0.125$, was the only significant main effect. Between the two IPD games, mean proportion cooperation was 0.424 (SEM = 0.022) for the multi-player IPD game and increased to 0.601 (SEM = 0.021) for the single-player IPD game.

The within-subject tests across blocks of IPD trials found a significant difference between blocks, F(2, 458) = 104.249; p < 0.0001; $\eta_p^2 = 0.313$, with a monotonic increase in mean proportion cooperation from 0.415 (SEM= 0.013) for
block 1, to 0.513 (SEM = 0.018) for block 2, and finally to 0.610 (SEM = 0.019) for block 3. Pair-wise comparisons showed a significant difference between each of these blocks ($p < 0.0001$ for all pairs). Two interactions were also found to be significantly different: Block by IPD: $F(2, 458) = 5.544; p < 0.01; \eta_p^2 = 0.024$, and Block by Instructions: $F(2, 458) = 3.481; p < 0.05; \eta_p^2 = 0.015$.

The Block x Instruction and Block x IPD interactions were explored by conducting three separate 2 x 2 ANOVAs, one for each block of trials (with IPD and Instruction as the factors). For the first block, main effects of IPD, $F(1, 233) = 41.840; p < 0.0001; \eta_p^2 = 0.15$, and Instruction, $F(1, 233) = 10.937; p < 0.001; \eta_p^2 = 0.045$, were observed with mean proportion cooperation greater for the SP-IPD games than the MP-IPD games (0.501 and 0.328, respectively) and for the Instructed groups than the Discovery groups (0.459 and 0.370, respectively). In block 2, a main effect of IPD, $F(1, 233) = 37.2850; p < 0.0001; \eta_p^2 = 0.138$, was identified but there was no effect of Instruction $F(1, 233) = 2.2820; p = 0.132$. As with block 1, the block 2 mean proportion cooperation for the SP-IPD game was greater than for the MP-IPD game (0.625 and 0.401, respectively). The third block of trials was similar to the second block with no main effect of Instruction, but a significant effect of IPD, $F(1, 233) = 11.776; p < 0.001; \eta_p^2 = 0.048$. As with block 1 and block 2, the mean proportion cooperation for the SP-IPD game was greater than for the MP-IPD game (0.677 and 0.544, respectively). These findings suggest that the impact of the IPD context, whether single-player or multi-player, was consistent across all 99 trials with greater cooperation in the single-player games. However, the effect of providing instructions on the tit-for-tat strategy was localized to the first block of trials with the
mean proportion cooperation between the instructed and discovery groups being significantly different only during the first 33 trials.

For the Total Self-Control Scale (TSCS), no main effects were observed for IPD, Instruction, or Order. The mean score for the measure was 113 (SD = 16.1261). This mean was compared to the observed mean of 114.47 (SD = 18.81) from Tangney, et. al. (2004) and the test failed to achieve statistical significance. The possible range of scores on this scale is 36 to 180.

Correlations were calculated between overall IPD score, IPD Blocks, the log transformed discounting parameter ($k$), and total score on the TSCS. Due to the observed differences between the four IPD types and proportion cooperation and the order of presentation and observed discounting parameter, correlations were computed independently for each IPD type and order of presentation (8 groups in all). As shown in Table 3, only three correlations reached significance: discounting rate and the last block of trials for SP-IPD(D) when IPD was presented first ($r = -0.3696$, $p < 0.05$), discounting rate and SP-IPD(I) when TD was presented first ($r = -0.3692$, $p < 0.05$), and discounting rate and TSCS in the SP-IPD(I) first group ($r = 0.5144$, $p < 0.001$). Of 32 comparisons between TD and the various IPD measures, 24 of the 32 (75%) were in the anticipated negative direction. The correlations between the behavioral measures and the TSCS are shown in Table 4.

The SP-IPD(I), TD first group was the most similar of all the groups to Harris and Madden. The observed correlation between discount rate and overall proportion cooperation for this group was non-significant, but in the anticipated direction and close to the magnitude reported by Harris and Madden with a current correlation of $r$
= -0.2919 and a reported correlation by Harris and Madden of $r = -0.415$. The correlation for the last 33 trials, however, was very similar with $r = -0.3692$ ($p < 0.05$). The condition most similar to Yi, et. al. (2005), the SP-IPD(D) with IPD first group, produced an overall correlation of $r = -0.2798$ and a last block correlation of -0.3696, $p < 0.05$. Yi, et. al., reported a correlation of $r = -0.37$, $p < 0.05$.

1.3 Discussion

In the two conditions most similar to previously published reports, this experiment replicated the findings of Harris & Madden (2002) and Yi, et. al. (2005) by producing statistically significant correlations between observed discount rate and proportion cooperation on the last block of IPD trials. The findings of Harris and Madden (2002) were confirmed by the observed significant correlation between discount rate and proportion cooperation in the SP-IPD(I), TD first group (Table 3, fifth column, fifth row). The findings of Yi, et. al. (2005) were confirmed by the observed significant correlation between discount rate and proportion cooperation in the SP-IPD(D), IPD first group (Table 3, fifth column, second row).

Outside of these two significant correlations, the remaining six groups failed to produce any significant correlations between discount rate and proportion cooperation (Table 3). Although the results of Brown and Rachlin (1999) and Silverstein, et. al. (1998) showed a significant change in performance between the single-player and the two-player games, the lack of an observed correlation between discount rate and proportion cooperation in the multi-player games is intriguing. The contingencies in effect for the multi-player games did not differ from those for the single-player groups. The only difference was the presentation of the computer’s
choices and score. One possible explanation for the lack of an observed correlation is that the correlation between cooperation in a multi-player IPD game and discount rate is masked by the added complexity of a multi-player context.

A second intriguing result was the interaction between instruction type and the correlation between discount rate and proportion cooperation. When the IPD game came first, the discount rate for the SP-IPD discovery group was correlated with performance on the IPD task, however no correlation was observed between cooperation in the SP-IPD instructed game and discount rate. When the IPD game was presented second, the correlation between discount rate and cooperation in the IPD instructed group was statistically significant, but the correlation between cooperation in the SP-IPD discovery group and discount rate was not. This finding is difficult to explain. However, a possibility is that when SP-IPD(D) follows the TD task the relationship is initially obscured by uncertainty concerning the contingencies of the game and by the time this uncertainty is overcome, performance is being controlled by variables other than the individual discount rate. In the TD second SP-IPD(D) group, the contingencies of the IPD are understood by the time the TD task is completed so this initial confusion would not interfere. Further empirical work is required for these possibilities to be more than conjecture.

Neither the IPD tasks nor the discount rate correlated with the TSCS measure of Tangney, et. al. (2004, Table 4). The mean of 113 and SD for this measure was similar to that of 114.47 reported by Tangney, et. al., suggesting that the computer based administration of this procedure produced reliable results. While no direct link between these measures was presupposed, there have been various reports that the
discount rate is correlated to personality traits related to impulsivity (Coffey, et. al., 2003; Baker, et. al., 2003, Kirby, et. al., 1999; Vuchinich & Simpson, 1998). One possible explanation for the lack of correlation between discount rate suggested by Bickel, Odum, and Madden (1999) is that temporal discounting is a process involved in self-control but separate from, the parallel influence of personality. This conclusion was based on a finding of a significantly reduced impulsivity score (based on the Eysenck Personality Questionnaire) for ex-smokers as compared to current and never smokers, but no difference in discount rate between never and ex-smokers and a significant increase in discount rate for the current smokers. Joireman, Strathman, and Balliet (2006) propose a similar relation between personality measures of self-control and temporal discounting in their Consideration of Future Consequences model. Both personality and temporal discounting are included in this model as determinants of behavioral regulation, but their effect is through separate causal pathways. The strong positive correlation of $r = 0.5144$ ($p < 0.01$) between discount rate and the TCS in the SP-IPD(I), IPD first group (Table 3 and Table 4 – last column, first row) is odd, but consistent with the positive correlation of $r = 0.2774$ ($p > 0.05$) observed between the last block of the IPD game and discount rate (Table 3 – fifth column, IPD Last, first row). Whether this warrants further investigation is unclear.

The results of the secondary goals of this experiment are worth noting. All four IPD games showed a monotonic increase in proportion cooperation across the three blocks of trials. The context of the IPD game had a significant impact on performance with greater cooperation in the single-player IPD game than the multi-
player IPD game, despite differing only in terms of whether the computer’s score and plays were displayed or only the participant’s information during the single-player game (see Figure 5 and Figure 6). This framing effect (Kahneman & Tversky, 1982; Tversky & Kahneman, 1981, 2004) was consistent across all three blocks with mean proportion cooperation always greater for the single-player game. The difference in cooperation between the two-games was most likely tied to different response patterns in the initial trials as the overall trend for both games across all three blocks was toward increased cooperation. As in Kudadjie-Gyamfi & Rachlin (2002) and Silverstein, et.al. (1998), the initial impact of the differential rules was statistically significant with the instructed groups cooperating more frequently than the discovery groups on the first block of trials. However, this difference in cooperation was localized to the first block of trials with no significant difference between instruction groups in either block 2 or block 3.

In summary, Experiment 1 had 5 main findings: (1) the group in which an instructed SP-IPD game followed the temporal discounting procedure confirmed Harris and Madden by producing a statistically significant negative correlation between discount rate and proportion cooperation on the last block of IPD trials, (2) the experimental group in which a discovery SP-IPD game preceded the completion of the TD task confirmed Yi, et. al. (2005) by producing a statistically significant negative correlation between discount rate and proportion cooperation on the last block of trials, (3) a significant effect of IPD context on proportion cooperation was observed with increased cooperation in the single-player context over the multi-player context in all 3 blocks of IPD trials, despite no difference in the underlying
contingencies. This effect was constant across all three blocks, (4) A local effect of instruction type was observed with the a higher mean proportion cooperation for the instructed group on the first block of trials, and (5) an increase in discount rate was observed when the IPD games preceded the presentation of the discounting measure, independent of whether the IPD game was instructed or discovery and independent of an observed correlation between discount rate and cooperation in the IPD game. For the final finding, this is the first time an impact of completing an IPD game on discount rates has been observed. However, experiment 1 was also the first experiment to present the IPD and TD tasks in counterbalanced order.

Experiment 2

This experiment was conducted at the same time as Experiment 1. The discounting parameters and the prisoner’s dilemma task are to the same as those from the single-player instructed, SP-IPD(I), condition from the previous experiment. This task was included as it approximated that of Harris and Madden (2002).

Experiment 2 provides a novel test of the relationship between discounting and cooperation by using Critchfield and Atteberry’s (2003) quick-adjusting procedure to determine discount rates and including a third behavioral measure, the Sharing Game.

The Critchfield and Atteberry (2003) quick-adjusting procedure uses a non-monotonic “step” algorithm that requires a maximum of six choices per delay to determine an indifference point. The change in discounting task allows a comparison between different methods of determining the subjective values of outcomes.
However, it was included in this experiment in order to reduce the time required to complete the three behavioral measures.

Edmund Fantino and Art Kennelly’s Sharing Game was introduced in this experiment as a third behavioral task (Fantino, Stolarz-Fantino, & Kennelly, 2005; Fantino, Gaitan, Kennelly, & Stolarz-Fantino, 2006). This game involved the distribution of money between two players. Each trial presented two distributions of money with one distribution biased toward the participant and the other distribution biased toward the other player. For example, one distribution was $5 for the participant and $3 for the other while the second distribution was $7 for the participant and $9 for the other. For the participant, the task involved choosing which distribution to accept. Various pairs of distributions were presented during the procedure. Each distribution of money contained an optimal choice in which both the participant and the other received more money and a non-optimal choice in which both received less money. In the optimal choice the other received more money than the participant. In the non-optimal choice the participant received more money than the other participant. The participant made all the choices and the identity of the other participant was unknown. The distribution pairs were presented such that three response patterns emerged: (1) Optimal for both participants, but “giving” more to the other, (2) non-optimal, but providing equal sums for both participants, and (3) sub-optimal, but providing more money for the participant. Performance on the sharing game was compared to individual discount rates and performance in the IPD game.
Unlike experiment 1, the current experiment included two distinct sample populations. The first sample was recruited to the study and completed the experiment in the same manner as experiment 1. The second sample was drawn from San Diego Mesa College and completed the experiment in a novel context.

In summary, the current experiment: (1) tested the correlation between temporal discounting and cooperation in the IPD directly as did Experiment 1, (2) compared individual discounting rates and performance on the iterated prisoner’s dilemma with performance on the Sharing Game, and (3) compared performance across two subject samples.

2.1 Methods

2.1.1 Participants

Participants from UCSD were recruited using the same process as in Experiment 1.

Participants from San Diego Mesa College (Mesa) were recruited by general announcement to behavior science classes. No scheduling was required as the experiment was self-guided. Most participants were provided extra credit for their participation, based on individual instructor discretion.

2.1.2 Testing Apparatus and Location

The UCSD sample used the same equipment and setting as Experiment 1.

The Mesa sample used PC computers in an open access computer lab.

2.1.3 Experimental Procedures
For the UCSD sample, the interactions of the research staff with participants were identical to those from Experiment 1. The same computer interface and instructions were provided as in Experiment 1.

The Mesa sample completed the experiment in an open access computer lab of approximately 150 computers. The staff of the computer lab provided general instruction sheets, but had no other scheduled interactions. Eighteen computers had the testing program loaded and could be used at the same time for completing the task. The computers were not separated from the remainder of the lab and no restrictions were placed on who could use these computers. At the end of the experiment, participants received a receipt of participation.

The three behavioral tasks were counterbalanced. The six possible groups are shown in Table 5. Participants were assigned randomly to a group. Demographics were collected at the end of the experiment. The testing program for the Mesa sample was identical to that used by the UCSD sample.

Temporal Discounting Procedure

The screen layout of the temporal discounting procedure did not differ between Experiment 1 and Experiment 2 nor did the timing of events during the procedure or the instructions provided to participants. How the choice outcomes were decided for each choice stage formed the only functional difference. Figure 8 illustrates the decision-structure used to assign values for each trial. The subjective value associated with each pattern of choices is the number outside the stop cell for that pattern. This procedure is a computer-based version of the procedure used by Critchfield and Atteberry (2003). Pilot work showed that the rates of discounting
observed by the psychophysical titration procedure used in experiment 1 and the quick adjusting procedure employed in the current experiment produced highly correlated results ($r = 0.748, p < 0.0001$, for a comparison between a delayed magnitude of $100 and a temporal window of 1 week to 25 years), but the quick-adjusting procedure produced slightly higher discounting rates.

Single-Player Iterated Prisoner’s Dilemma

The prisoner’s dilemma task used in this experiment was the Single-Player IPD-Instructed, SP-IPD(I), group of Experiment 1. In this procedure, participants only saw their choice, their outcome, and their score. The computer played a straight tit-for-tat strategy. The outcome for each choice was a quantity of points ranging from 1 to 6 (see Figure 5 for the exact payoff matrix).

The Sharing Game

The screen layout during the Sharing Game is illustrated in Figure 9. Participants indicated their choice by clicking either the “A” or the “B” button. Upon making a selection, both buttons deactivated, and a yellow box surrounded the selected distribution for 5 seconds. After 5 seconds the box disappeared and the distributions updated. In total, 26 pairs of distributions were presented. The presentation of trials was randomized for each participant. Whether the optimal choice presented as option A or B was varied across choice pairs. The 11 choice pairs and how they were scored are presented in Table 6.

Participants were presented two clusters of choices. For the first six choices, pairs 1 through 6 from Table 6 were presented. Each pair was presented once. These distributions differed from those presented in trials 7 through 26. A generosity score
(GS) was calculated for each participant based on these first six questions. This score was calculated by assigning one point for a choice of the option that was equitable when an option to be selfish was also presented or generous when an opportunity to be equitable was also presented. The following equation was used to calculate the GS, where 1 point was assigned any time the condition evaluated as true and 0 when it evaluated as false:

\[ GS = (Q1 = A) + (Q2 = A) + (Q3 = B) + (Q4 = A) + (Q5 = A) + (Q6 = B) \]

Using this formula produced an index from 0 to 6 for each participant. The higher the score the more frequently the participant chose the option that provided a greater outcome for the other player.

After completing the first six trials, participants received information that each pair of distributions would be presented twice. Pairs 7 through 11 from Table 3 were presented during this portion of the game. Order of presentation was randomized. Each pair was presented twice in succession. This type of presentation allowed for an equity strategy (more for one on each trial, averaging out to the same total outcome). After all five pairs were presented once, the order of presentation was randomized, and the pairs were presented a second time. The scoring for each pair is listed in the proportion optimal section of Table 6. The possible score for the 20 trials presenting choice pairs 7 through 11 ranged from 0 to 20. A 0 indicated constant choice of the lower outcome for both individuals, a 10 indicated an equitable distribution of points and a 20 indicated choice of the optimal amount on all trials.

2.2 Results
219 UCSD undergraduates participated in the experiment (63% Female). The average age for participants was 20.19 for females and 21.22 for males (significantly different, $t(1) = -2.44; p < 0.05$). The age and distribution of gender between the six groups did not differ, $F(5, 219) = -1.5785, p = 0.16$, and, $\chi^2(5, 219) = 3.49, p = 0.62$, respectively.

340 Mesa college students participated in the experiment (64% Female). The average age for participants was 23.72 (6.63) years. The distribution of gender across the 6 groups did not differ: $\chi^2(5, 340) = 3.526, p = 0.6195$. The age of participants across groups did not differ: $F(5, 340) = 1.1742, p = 0.3215$.

A comparison of the UCSD and Mesa participants found these samples were similar. The distribution of gender across the two samples was not significantly different: $\chi^2(2, 557) = 0.599, p = 0.4388$. The distribution of gender across the six groups did not differ for either of the samples. The distribution of participants across the groups was not different between the two samples: $\chi^2(5, 559) = 8.766, p = 0.1188$. The only observed demographic category on which the two samples differed was the average age of participants (UCSD = 20.56; Mesa = 23.72; $t(556) = 7.806, p < 0.0001$).

Individual discounting rates were fit to Equation 1 using nonlinear regression (Table 7). This process determined a discounting rate for 547 of the 556 total participants. The natural logarithm transformation normalized the discounting rates and these normalized rates were used in all comparisons. A $2 \times 2 \times 6$ ANOVA (school x gender x group) on the log-transformed discounting rates failed to find a significant difference between the six groups, $F(5, 546) = 0.394, p = 0.853$. The
failure to observe a difference in discount rate based on order of presentation did not agree with the results from Experiment 1. For experiment 1, it was found that presenting the IPD games prior to the temporal discounting game increased the level of impulsivity. For the current experiment, order of presentation had no observed effect.

Proportion cooperation for both gender, \( F(1, 546) = 3.887, p = 0.049, \eta^2_p = 0.007 \), and school, \( F(1, 546) = 3.875, p = 0.50, \eta^2_p = 0.007 \) were at the required level of significance. The median discounting rate was less steep for females at 0.0300 \((QR = 0.00 - 0.24)\) than for males at 0.065 \((QR = 0.009 - 0.306)\), suggesting less impulsivity among the female participants than the males. The median observed discounting rates were slower for the UCSD sample, \( k = 0.0280 \ (QR = 0.0044 - 0.2103) \), than for the Mesa sample, \( k = 0.0600 \ (QR = 0.00 - 0.29) \). The slower discounting rate observed for the UCSD participants suggests less impulsivity for this group compared to the Mesa participants. The pooled median discounting rate of 0.05 \((QR = 0.00 - 0.27)\) was higher for the current experiment than the observed median discount rate for Experiment 1 \((0.0171, QR = 0.0031 \text{ to } 0.0494)\). This is consistent with the findings of the pilot study. The median variance accounted for (VAC) across the UCSD and Mesa samples was 0.859 \((QR = 0.456 - 0.946)\) and 0.815 \((QR = 0.158 - 0.934)\), respectively.

As in experiment 1, cooperation choices were tallied for the first 33 trials, the middle 33 trials, and the last 33 trials and converted to proportions. A 2 x 2 x 6 x 3 repeated measures ANOVA with school, gender, group, and block as the 4 factors tested for significant differences. The within-subjects tests identified a significant
difference between blocks: $F(2, 1070) = 238.211, p < 0.0001, \eta_p^2 = 0.308$, with a monotonic increase in mean cooperation from 0.57 (0.21) for block 1 to 0.67 (0.23) for block 2 and finally to 0.74 (0.22) for block 3. Pair-wise comparisons found all three blocks to be significantly different, $P < 0.0001$ for all pairs. This increasing monotonic trend was similar to that observed between blocks in experiment 1. Between-subject effects tests failed to find a significant difference between gender or group. A significant difference was found between the Mesa and the UCSD sample: $F(1,535) = 22.924, p < 0.0001, \eta_p^2 = 0.041$, with a higher overall level of cooperation for the UCSD sample than the Mesa sample (0.71 and 0.63, respectively). The monotonic increase in mean proportion cooperation across Blocks is listed in Table 7. Figure 10 illustrates the increased cooperation for the UCSD sample compared to the Mesa sample. The proportion cooperation for the UCSD sample was higher than for the Mesa sample for all 3 blocks. Both sample groups showed a similar monotonic increase across blocks.

The Sharing game produced two scores: (1) the proportion optimal which was calculated as the total optimal choices on trials 7 through 26 (choices pairs 7 through 11, Table 6) divided by 20 and (2) the proportion generous which was calculated as the total number of optimal choices from trials 1 through 6 (choice pairs 1 through 6, Table 6) divided by 6. Two 2 x 2 x 6 ANOVAs (school x gender x group) tested proportion optimal and GS. For proportional optimal, no main effect was found for gender. The mean proportion optimal for females and males was 0.64 (0.24) and 0.67 (0.28), respectively. Significant effects of school, $F(1, 556) = 8.625, p < 0.01, \eta_p^2 = 0.016$, and group, $(5, 556) = 54.442, p < 0.0001, \eta_p^2 = 0.338$, were observed. The
proportion optimal was greater for UCSD (0.69, SD = 0.26) than Mesa (0.62, SD = 0.25). Across the six groups, the observed mean proportion optional was: 0.82 (0.26), 0.52 (0.13), 0.77 (0.29), 0.82 (0.23), 0.50 (0.16), and 0.51 (0.15) for groups 1 through six respectively (the order of behavioral task presentation for each group can be seen in Table 5).

A visual analysis of the mean proportion cooperation across the six groups suggested two clusters of scores. Proportion optimal for groups 1, 3, and 4 ranged between 0.77 and 0.82. For groups 2, 5, and 6, proportion optimal ranged from 0.50 to 0.52. Pair-wise comparison confirmed these two clusters with all comparisons between groups 1, 3, and 4 and groups 2, 5, and 6 being significantly different with \( p < 0.0001 \) (for example, group 1 and 2, group 3 and 5, and so forth, Figure 11). All comparisons within groups 1, 3, and 4 and within groups 2, 5, and 6 were non-significant with \( p = 1.000 \) for all comparisons (for example, group 1 and 3, group 2 and 5, and so forth). For ease of discussion, groups 1, 3, and 4 are identified as Cluster 1 while groups 2, 5, and 6 are identified as Cluster 2. The three Cluster 1 groups had a mean proportion optimal of 0.80 (0.2674) while the mean proportion optimal for Cluster 2 was 0.5011 (0.1497).

The ANOVA on proportion optimal also identified a significant interaction between gender and group: \( F(5, 556) = 2.434, \ p < 0.05, \ \eta^2_p = 0.019 \). A Tukey HSD test comparing all possible pairs of the 12 Gender x Group means revealed a similar pattern of clusters was responsible for the observed gender by group interaction. That is, no significant differences were observed between the six Gender x Group means for the three Cluster 1 groups of 1, 3, and 4. No significant differences were found
between the six Gender x Group means for the Cluster 2 groups of 2, 5, and 6. However, significant differences were found between the means of all three Cluster 1 groups and all three Cluster 2 groups for all gender x group pairs.

A review of the order of presentation for the behavioral tasks across the 6 groups revealed that for all three Cluster 1 groups, the temporal discounting procedure preceded the Sharing Game. For all 3 Cluster 2 groups, the temporal discounting task followed the Sharing Game. For example, group 4 presented the temporal discounting task followed by the Sharing Game and then the SP-IPD task. The observed mean proportion optimal for this group was 0.82. For group 2 the single-player IPD task was presented followed by the Sharing Game and then the temporal discounting task. In this group, the mean proportion optimal was 0.51. Table 7 presents the mean proportion optimal for each group across schools and Figure 11 presents a visual view of these means. Across all comparisons, the mean proportion optimal is greater whenever the temporal discounting task is presented prior to the Sharing Game.

While proportion optimal was strongly impacted by the order of behavioral task presentation and school, the results of the 2 x 2 x 6 ANOVA on proportion generous found no significant differences between schools, gender, or group. For example, the mean proportion generous for the UCSD sample was 0.54 (0.20) and for Mesa it was 0.55 (0.22). Between females and males, the proportion generous was 0.53 (0.20) and 0.56 (0.24), respectively. Finally, the pooled mean cooperation for Cluster 1 (groups 1, 3, and 4) and for Cluster 2 (groups 2, 5, and 6) was 0.55 (0.22) and 0.54 (0.21), respectively.
Pearson correlations were calculated between: proportion cooperation on block 1, block 2, block 3, the log-transformed discounting parameter, the proportion optimal from the Sharing Game measure, and the proportion generous from the GS score. Due to the significant effect of presentation order on the proportion optimal for the Sharing Game and the significant differences in proportion cooperation and proportion optimal observed across schools, correlations were calculated separately for each school and for Cluster 1 (groups 1, 3, and 4) and Cluster 2 (groups 2, 5, and 6). Table 8 presents the correlations.

In general, performance on the behavioral measures was not correlated and the relations observed between the measures differed across the two samples. Outside of the within-task IPD correlations, only eight significant correlations developed. Two of the significant correlations were between proportion optimal and proportion generous. The correlation between proportion optimal and proportion generous for Mesa Cluster 1 was $r = 0.446$ ($p < 0.01$). For the UCSD Cluster 1 participants, the correlation between proportion optimal and proportion generous was $r = 0.390$ ($p < 0.01$). The correlation between proportion optimal and proportion generous was non-significant for both the Mesa and the UCSD Cluster 2 participants. The third significant correlation was observed between proportion optimal and proportion cooperation for the first block of SP-IPD trials for Mesa Cluster 2 ($r = 0.165, p < 0.05$). The fourth significant correlation was observed between proportion optimal and proportion cooperation on the last block of trials for UCSD Cluster 1 ($r = 0.197, p < 0.05$). The fifth significant correlation was also observed in Mesa Cluster 2 in which proportion generous was negatively correlated with discount rate ($r = -0.225, p$
The sixth significant correlation was between proportion generous and proportion cooperation \( (r = 0.197, p < 0.05) \) on the last block of SP-IPD trials in UCSD Cluster 1.

The final two significant correlations were between discount rate and proportion cooperation. These critical correlations ranged from \( r = -0.200 \) to \( r = 0.1200 \). The two significant correlations were \( r = -0.200 \) for the correlation between the last block of IPD trials and the observed discounting parameter for Cluster 1 at UCSD and \( r = -0.156 \) between the first block of trials and the discount rate for Cluster 2 at Mesa. Although not significant, eight of the twelve correlations between cooperation and discounting were in the anticipated negative direction.

Correlations for group 3, the most closely analogous to Harris and Madden (2002) as the temporal discounting task preceded the SP-IPD game, were analyzed for both schools (Table 9). For the UCSD sample, the correlation between proportion cooperation and log-transformed discounting for group 3 was \( r = -0.323 \) \( (p = 0.059) \) for Block 3. For the Mesa sample, the correlations between discounting and proportion cooperation on the last block was \( r = 0.093 \) \( (p > 0.05) \). Harris and Madden (2002) reported a significant correlation of \( r = 0.41 \) \( (p = 0.01) \). In experiment 1, when the temporal discounting procedure preceded an instructed SP-IPD groups the observed correlation was \( r = -0.3692 \) \( (p < 0.01) \) for the last block of trials and discounting rate. The observed correlation for UCSD group 3 on Experiment 2 was similar in magnitude to both the correlation for Harris and Madden and Experiment 1, but was non-significant
Experiment 1 suggested that order of presentation influenced the observed correlation between discount rate and proportion cooperation with a non-significant correlation when an instructed SP-IPD game preceded the temporal discounting measure and a significant correlation when the instructed SP-IPD game followed the discounting measure. To assess this previous finding, a comparison of the observed correlations for group 1 was conducted. This is the only group where IPD is presented first followed by the discounting measure. The results from experiment 1 predict no correlation between discount rate and proportion cooperation when the tasks are presented in this order. The observed correlations between discounting, proportion cooperation, proportion optimal, and proportion generous by participants in group 1 are shown in Table 9. The only significant correlations (outside of the within-measure correlations for IPD blocks) were observed between proportion cooperation on the last block of IPD trials and proportion generous for both samples. For the UCSD sample, proportion optimal was significantly correlated with proportion cooperation in the first block, second block, and third block of IPD trials with \( r = 0.526 (p < 0.01) \), \( r = 0.566 (p < 0.01) \), and \( r = 0.421 (p < 0.05) \), respectively (Table 9, first 3 rows of the last column of the UCSD Group 1 section). Proportion generous was just above the level of significance when compared to proportion optimal \( (r = 0.325, p = 0.053) \). For the Mesa group 1 participants, proportion optimal was significantly correlated with proportion cooperation for the middle block of IPD trials \( (r = 0.277, p < 0.05) \) and proportion generous \( (r = 0.297, p < 0.05) \).

For the critical correlations between cooperation on the blocks of IPD trials and discounting rate in group 1, the range of these correlations for both UCSD and
Mesa was from $r = -0.045$ to 0.215. None of these correlations were significant. The failure to observe a significant correlation between cooperation and discount rate in group 1, where the SP-IPD game preceded the temporal discounting measure, was consistent with the failure to observe significant correlations between cooperation and discounting rate when the SP-IPD game preceded the temporal discounting task in Experiment 1 (group 3: Table 3, IPD first section, Single-Player Instructed columns 3, 4, and 5). Despite the significant correlations discussed above, the general finding for this group was that proportion cooperation and discount rate were not correlated when the SP-IPD game preceded the temporal discounting task, consistent with the findings from experiment 1.

2.3 Discussion

Overall, discount rate and proportion cooperation were not correlated. Across the two sample groups and the two clusters within each sample group, a total of 12 correlations between discount rate and cooperation were observed. Of these, only two were statistically significant (Mesa Cluster 2 block 2 and discount rate and UCSD Cluster 1 block 3 and discount rate, $r = -0.156$ and $r = -0.200$, respectively). For group 3, the group most analogous to Harris and Madden (2002), the UCSD sample approximated the Experiment 1 finding of a significant correlation between discount rate and cooperation when the SP-IPD task followed the discounting task, but was not statistically significant ($r = -0.323$: Table 9, column 5 of the UCSD group 3 section).

The similarity of the results from group 3 to those from the existing literature and the dissimilarity of the results from the remaining groups from this literature
suggest that the inclusion of the Sharing Game significantly interfered with the correlation between discount rate and proportion cooperation. For example, the correlation between discount rate and cooperation for the three IPD blocks in UCSD Cluster 2 (Table 8, fourth section), where the Sharing Game preceded the temporal discounting task, ranged from \( r = 0.1210 \) for the first block to \( r = 0.0180 \) for the last block. In contrast, the UCSD Cluster 1 participants (Table 9, section three), where the temporal discounting task preceded the Sharing Game, a correlation of \( r = -0.149 \) for the first block of IPD trials to \( r = -0.200 \) (\( p < 0.05 \)) for the last block of trials was observed. For the one group in which the temporal discounting task was presented first followed by the SP-IPD procedure then the Sharing Game, the observed correlations across the three blocks were: \( r = -0.245 \), \( r = -0.201 \), and \( r = -0.323 \).

The conclusion is particularly interesting given the strong impact of the discounting task on the Sharing Game with a shift of nearly 30% in proportion optimal observed when discounting preceded the Sharing Game. In the UCSD sample, the increase in observed proportion cooperation for the Cluster 1 participants occurred concurrent with an increase in the correlations between all three behavioral measures (Table 8, Columns 5, 6, and 7, UCSD Cluster 1 section). However, as the increase in proportion optimal on the Sharing Game between Cluster 1 and Cluster 2 occurred independent of any change in observed discount rate between the experimental groups, this shift can be best interpreted as a product of completing the discounting procedure rather than as an interaction between individual discount rates and proportion optimal on the sharing game. The possibility that the task rather than individual discount rates influenced the proportion optimal was further supported by
the lack of a significant correlation between proportion optimal and discount rate for either the UCSD Cluster 1 participants or the Mesa Cluster 1 participants ($r = -0.057$ and $r = 0.079$, respectively; Table 8).

Another finding of interest is that the Mesa sample showed a decrease in proportion cooperation and in proportion optimal compared to UCSD. These observed differences in response patterns between the UCSD and the Mesa sample are best explained as a product of the data collection procedures. As in experiment 1, the UCSD participants were required to complete the experiment in a research laboratory with a research staff present and interacting with the participant. The Mesa sample, however, completed the behavioral tasks using a self-guided procedure in a public access computer lab with no research staff present. Despite these differences in overall mean, the increasing trend in proportion cooperation for the IPD game was similar across schools. Also, the increased proportion optimal for Cluster 1 (groups 1, 3, and 4) and Cluster 2 (groups 2, 5, and 6) on the Sharing Game were identical for both the Mesa and UCSD sample. Despite these similarities in trend between the two schools, almost all correlations are weaker and less systematic for the Mesa participants (Table 8 and Table 9). With the significant differences in proportion cooperation and proportion optimal between the UCSD and Mesa sample, it is noteworthy that the difference in observed discount rate was relatively small between the two schools ($k = 0.028$ and $k = 0.06$, respectively).

In general, the evidence from the current experiment presents a strong argument in favor of the context specificity of the relationship between the discount rate and performance on an IPD task. As discussed previously, in the Cluster 2
groups where the Sharing Game presented prior to the temporal discounting measure, no significant correlations were observed. In the highly similar Experiment 1 group 3, where temporal discounting is the first task followed by the SP-IPD game, a nearly significant correlation was observed between discount rate and proportion cooperation \( (r = -0.323) \). This finding is highly similar to the correlation observed for group 3 of Experiment 1 in which the temporal discounting task was similarly presented prior to the SP-IPD task \( (r = -0.3692) \). Also consistent with Experiment 1(group 5), when an instructed, single-player IPD task preceded the temporal discounting task, non-significant correlations were observed \( (r = 0.093 \) for the last block of IPD trials for UCSD group 1). In summary, for any group in experiment 2 in which the IPD, instructed game preceded the temporal discounting task or the Sharing Game was inserted between the temporal discounting task and the IPD game the correlation between cooperation on the IPD game and discounting rate was disrupted.

**General Discussion**

The primary goal of the two experiments reported in this chapter was to extend the finding that a negative correlation exists between individual discounting rates and performance on the iterated prisoner’s dilemma, as reported by Harris and Madden (2003) and Yi, et. al. (2005, 2006), to: (1) different IPD contexts, (2) different PD instructions, (3) a novel TD testing procedure, (4) a global measure of self-control, and (5) a new behavioral game, the Sharing Game. The experiments were moderately successful in achieving these extensions. Specifically:

(1) Different IPD Contexts: discount rates and performance on the IPD task are correlated in the single-player IPD, but not the multi-player IPD.
(2) Within the single-player IPD groups, discount rates and performance on the IPD task are correlated when a discovery IPD precedes the temporal discounting measure and when an instructed IPD follows the TD measure (this second finding was replicated in Experiment 2). This finding is consistent with Yi, et. al. (2005) as their task was a SP-IPD, discovery game presented before the TD measure and with Harris and Madden (2002) as their task was an instructed SP-IPD game that followed the TD measure.

(3) The observed difference in discount rate between experiment 1 and experiment 2 was consistent with the findings of the pilot study comparing the two TD methods. Despite not reaching a level of statistical significance, the correlations between the comparable groups found a similar pattern in the correlation between discount rate and cooperation. This suggests the relationship between discounting and cooperation on the SP-IPD is robust across temporal discounting measures.

(4) Discount rate, cooperation on IPD games and the TSCS (Tangney, et. al., 2004) are not correlated.

(5) Neither proportion optimal nor proportion generous from the Sharing Game is correlated with individual discount rates or with proportion cooperation on the SP-IPD game. However, selection of the optimal choice in the Sharing Game is quite sensitive to the order of task presentation and is highly influenced by prior exposure to a temporal discounting task. The increased proportion optimal when the temporal discounting task preceded the Sharing Game might result from an increase in sensitivity to the value of money caused by completing the temporal discounting task. During the temporal discounting task, participants are asked to directly compare
pairs of monetary outcomes and then identify which outcome they prefer. In the Sharing Game participants choose which of a pair of outcomes they prefer to receive and which of a pair of outcomes they prefer the other participant to receive. An increased sensitivity to the value of money caused by the temporal discounting task could serve to increase the salience of personal outcomes in relation to the social comparisons in the Sharing Game.

In general, the two experiments in this chapter support the general finding that a relationship exists between rate of temporal discounting and performance on the single-player prisoner’s dilemma task. However, this is not a general characteristic of these tasks. Rather this relationship is dependent on specific parametric arrangements. The nature of these arrangements is a topic that will be addressed in depth in Chapter 4.
III

Replication

The inconsistent correlations between discount rate and cooperation on the IPD games observed in Experiment 1 and Experiment 2 suggest that the relationship between discounting and cooperation on the iterated prisoner’s dilemma is not a general characteristic of these procedures. Rather, the ephemeral nature of the observed correlations indicated that there are specific parametric and/or procedural requirements for the tasks to be related.

Although Experiment 1 and the UCSD sample from Experiment 2 replicated the general findings of Harris and Madden (2002) and Yi, et. al. (2005), they failed to produce correlations of a similar magnitude. As the procedures between these four experiments differed along multiple dimensions, this could be the product of a number of factors. However, the lack of consistent correlations observed in the Mesa sample from experiment 2 suggests a possible explanation. In Harris and Madden (2002) and Yi, et. al. (2006) the research team is much more involved in the experiment than for either the UCSD sample or the Mesa sample. For Yi, et. al. (2006), which produced the strongest correlations for monetary gains of all the experiments, the participants completed the experiment during the intake interview for a clinical treatment. In Harris and Madden (2002), a research assistant administered the temporal discounting task rather than the computer-based presentation used in Experiment 1 and Experiment 2. It is possible that the
relationship between temporal discounting and prisoner’s dilemma is at least weakly influenced by the social context in which the experiment is delivered.

In order to establish the impact of the social context on the observed relation between discount rate and cooperation on and IPD game, a procedural replication of Harris and Madden (2002) was conducted. During this experiment, the Harris and Madden temporal discounting and SP-IPD procedures were mimicked and the same parametric values were employed. However, the temporal discounting task was presented via a computer, as in Experiment 1 and Experiment 2, rather than a research assistant as in the original experiment of Harris and Madden (2002). Maintaining the parameters of the experiment constant while manipulating the social context of the temporal discounting task provided at least a rough estimate of the role of social variables.

In addition to providing insight into the role of the social context, this replication was designed to provide a baseline that was demonstrably similar to the results of Harris and Madden. With this baseline, it would be possible to vary the parameters used in the temporal discounting task and the IPD in an examination of how parametric changes influence the magnitude of the observed relationship between discount rate and cooperation.

**Experiment 3**

This experiment replicated Harris and Madden (2002) with the exception of using a computer-based temporal discounting task rather than having a research assistant interact with the participant during this measure. The results provided an insight on the role of the social context in the relationship between discount rates and
cooperation. The results were also used as a baseline for the experiments in chapter 4.

3.1 Method

3.1.1 Participants

As with Experiments 1 and 2, UCSD undergraduates enrolled in psychology courses participated in this experiment. Course credit was provided as compensation for participation.

3.1.2 Testing Apparatus and Location

The location and computers from experiment 1 and experiment 2 were utilized.

3.1.3 Experimental Procedures

The initial interactions between researcher and participant were similar to Experiment 1 and Experiment 2. Upon presentation at an available computer, participants completed a computerized version of the temporal discounting task from Harris and Madden (2002) and an SP-IPD task similar to that used in their experiment. With the exception of the computer-based temporal discounting task in lieu of a face-to-face interactive temporal discounting measure, this experiment is a replication of Harris and Madden (2002).

The order of presentation of the experimental tasks remained constant throughout the experiment. Participants completed the discounting procedure then the IPD. At the end of the IPD procedure, a brief demographics survey was provided.

Temporal Discounting Procedure

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1 It should be noted that this replication was initiated prior to the publication of Yi, et. al. (2005) and Yi, et. al. (2006).
The screen layout and the participant's interaction with the program were comparable to Experiment 1 and Experiment 2. The procedure used a psychophysical titration process in which 28 choices were made between a small monetary quantity available immediately and a larger amount available after a delay. Between choices, the amount of immediate money available either decreased or increased monotonically from $10 to $0.02 and from $0.02 to $10, respectively. Each cycle began at $10, decreased to $0.02, and then increased back to $10 (see Appendix A for exact values). During the cycle of decreasing values, the first switch from the immediate to the delayed option was recorded. During the cycle of increasing value, the opposite occurred. The indifference point, or subjective value of the delayed commodity, was calculated as the average between the value recorded during the decreasing cycle and the value recorded during the increasing value cycle.

When both cycles completed, the delay to the larger amount increased. Eight delay values ranged from 6 hours to 1 year (see Appendix A for exact delays). Delay values presented in increasing order and one down-up cycle completed per delay. After all delays, the task ended and the next phase began.

Prior to beginning the IPD task participants reviewed the following modification of Harris and Madden’s (2002) instructions:

The computer is 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, the computer might ask you to choose between $500 dollars today and $800 in 3 months. The computer will do this for eight sets of rewards and each time the delay to one of the rewards will be different. For example, in the second set the computer might ask you to choose between some amount of money delivered today and $800 in delivered in 10 years.
The choices you make are completely up to you. Please select the option that you prefer. There are no correct answers on this task. Just choose the reward you really want.

For each set of amounts, the computer will record the amount that you selected. All your choices will be for hypothetical money. You will not be receiving any of the amounts of money that you choose today. However, we ask you to imagine that you were going to actually receive the money. In fact, it is best if you pretend that at the end of your participation today all of your chosen outcomes is going to be placed in a hat and you could select one at random. If you select an immediately available amount, you will be given that amount immediately. If you select a delayed amount, a check will be sent to you so that it will arrive after the specified time. As you would not know what outcome you will receive from this procedure, it is particularly important that you make each choice as if you were actually going to receive it. Again, you will not receiving any actual money today, but you should be making each choice as if it were real.

The Single-Player Iterated Prisoner’s Dilemma

The payoff matrix, with the trial (N – 1) choice presented first and the trial N choice presented second was: Defect-Cooperate, $1, Defect-Defect, $2, Cooperate-Cooperate, $3, and Cooperate-Defect, $4.

Prior to the presentation of the IPD procedure, participants were instructed on game play, the payoff matrix, and the tit-for-tat strategy. Once finished with the instructions, participants answered the following questions:

1. If you choose RED and the computer chooses GREEN, how much money would you earn?

2. If you choose GREEN and the computer chooses GREEN, how much money would you earn?

3. If you choose GREEN and the computer chooses RED, how much money would you earn?
(4) If you choose RED and the computer chooses RED, how much money would you earn?

(5) If you chose RED on the previous trial, what would the computer choose on the current trial?

(6) If you chose GREEN on the previous trial, what would the computer choose on the current trial?

Upon completion, participants clicked a button labeled Click here to check your answers. If all six answers were correct, the IPD procedure was presented. If some answers were not correct, the quiz returned. The answers remained present with a prompt to review the instructions, revise the answers, and resubmit the quiz. This procedure continued until all answers were correct.

Figure 12 illustrates the IPD screen layout. Clicking on one of two colored squares at the bottom of the screen represented a choice response. The red and green squares appeared to the left and right of a black square. At each trial, the side changed on which red and green presented. The computer’s choice appeared on the center square. The start of each trial was signaled by the center square flashing red and green for 3 seconds. During this time a label beneath the center square read “Computer is Choosing…”. After three seconds the center square turned black and the label changed to “Human Player is Choosing…”. At this point, the program waited for the participant to respond. Following a response, the center square turned red or green, based on the participant’s choice on trial (N-1). A yellow border presented around the Money earned this round label, input box, and button. Finally, the amount of money earned on the current trial appeared in the center box. A click
to the *Collect Money* button was required for point aggregation. After all money was collected, a ten second timeout, or inter-trial interval (ITI), was initiated. The status was listed as *Preparing the next round...* The red-green flashing center box signaled the start of a new trial. The procedure repeated for 40 trials.

3.2 Results

Non-linear regression using Equation 1 provided individual discount rates across the eight delays. The natural-log transformed values were used in all statistical calculations. The total proportion cooperation was calculated as the number of red (cooperate) choices divided by the total number of trials.

Seventy-one participants completed the experiment. Of these, 55 (77%) were female and the average age was 20.23 (1.49) years. The mean number of attempts on the IPD quiz was 1.65 (1.35). The mode and median were both 1 attempt. A non-parametric Spearman’s rho correlation between attempts on the quiz and discounting rate showed no relation ($r = 0.029$), but a relation was found between attempts on the quiz and proportion cooperation on the IPD task ($r = -0.298$, $p < 0.002$).

The behavioral data approximated Harris and Madden (2002). The median observed discounting rate was 0.0052 ($QR = 0.0014$ to 0.0594). The log-transformation of these discounting rates resulted in a mean discount rate of -3.488 (2.235). The observed median for the current data set was nearly identical to that observed by Harris and Madden (0.0052), but the mean and standard deviation differed from that reported by Harris and Madden (-2.19, SD = 0.64; $z = 38.179$, $p < 0.001$). A t-test of gender on log-transformed discounting rates failed to find a significant difference, $t(64) = -0.597$, $p = 0.555$. 
The mean proportion cooperation was 0.71 (0.238). This mean was slightly higher than that reported by Harris and Madden (mean = 0.6525, SD = 0.2785; \( z = 1.459, p = 0.1446 \)). A t-test of gender on proportion cooperation revealed a significant difference between genders, \( t(69) = -2.189, p < 0.05 \). The mean proportion cooperation for females was 0.668 (0.241) and for males was 0.797 (0.211).

The correlation between log-transformed discounting rate and proportion cooperation during the IPD for the entire sample was \( r = -0.3689 \) (\( p < 0.01 \)). As proportion cooperation differed between gender, separate correlations were conducted between females: \( r = -0.4072 \) (\( p < 0.01 \)), and males \( r = -0.3825 \) (\( p = 0.0961 \), \( n = 20 \)). All of these correlations were similar to the level reported by Harris and Madden of \( r = -0.415 \), \( p = 0.01 \) (note: the direction of their original correlation has been reversed as it was based on proportion of defections and this experiment's results were based on proportion cooperation).

3.3 Discussion

The correlation between discount rate and cooperation observed in the current experiment approximated those of Harris and Madden (2002). This finding suggested that the change in social context did not have a significant impact on the outcomes of Experiment 1 and the UCSD sample of Experiment 2. The similarity between the results of experiment 3 and Harris and Madden suggested these data were appropriate as a baseline for the parametric manipulations of chapter 4.

General Discussion
While the difference observed in the Mesa sample could still be the product of a changed social context, the result from experiment 3 suggests that the variability observed in Experiment 2 was not the product of the social context for the UCSD sample. The outcome produced in Experiment 3 will be used as the comparison data for each of the experiments in chapter 4.
IV

Exploration

Experiment 1 and Experiment 2 confirmed the relation between discount rate and performance on IPD games. They also demonstrated that this relationship is context specific. Experiment 3 replicated the findings of Harris and Madden (2002) and provided a baseline correlation similar to that observed by Harris & Madden. The experiments in this section were concerned with better defining the limits of the relationship between temporal discounting and IPD performance.

In experiment 4 seven groups were tested under different temporal discounting and IPD parameters. The combinations of parameters explored encompassed those from Experiment 1, Experiment 2, Yi, et. al. (2005), and Yi, et. al. (2006). The results from these groups provided a basic understanding of the variables influencing the relationship between discount rate and cooperation.

In experiment 5, performance on a single-player IPD, a two-player IPD, and individual discount rates are compared.

In experiment 6, the impact of changing the probability of reciprocation in a SP-IPD, discovery game is explored.

Experiment 4

Using the baseline correlation provided by Experiment 3, the current experiment utilized the Experiment 3 procedures to explore the impact of parametric changes on the relationship between discount rate and performance on the SP-IPD.
4.1 Methods

4.1.1. Participants

UCSD undergraduates were recruited from the Department of Psychology human participants research pool. Arrival at the laboratory and initial interactions were identical to experiment 3.

4.1.2. Testing Apparatus and Location

This experiment utilized the same equipment and location as the previous experiments.

4.1.3. Experimental Procedure

The experiment employed the procedure from Experiment 3 with the same order of presentation, instructions, and interface. Figure 13 provides a visual summary of the parameters used for each of the 8 experimental groups.

Group A: The data from Experiment 3 were used for this group. No new participants were studied. The temporal discounting procedure varied from 6 hours to 1 year with a delayed magnitude of $10. The prisoner’s dilemma presented values from $1 to $4.

Group B: Experiments 1 and 2 used points rather than money as the outcome in the IPD procedure. This group tested the possible role of commodity type in the IPD by using points rather than money. The temporal discounting procedure still used money as the delayed value.

Group C: Discounting research showed that changes in the magnitude of the delayed outcome influence the observed rate of discounting, a finding known as the magnitude effect. This group increased the delayed outcome from $10 to $100 in
order to test the influence of the magnitude effect on the correlation between discount rate and cooperation. The results from Yi, et. al. (2005) and Yi, et. al. (2006) suggest that the magnitude of the commodity should not have a significant impact on the observed correlation. That is, the magnitude of the delayed commodity should affect discount rate and cooperation in the IPD game to approximately the same degree.

Group D: Research has also shown that discounting rates fluctuate between commodities. For this group, the discounted commodity was changed from money to iTunes downloads ($0.99). Music has been shown to discount at a higher rate than does money (Charlton & Fantino, In preparation). This is a novel comparison.

Group E: This group examined the impact of lengthening the temporal window, by using delays from 1 year to 25 years. In order to make this group a replication of Experiment 1, $100 was used as the magnitude of the delayed outcome. The critical comparison for this group is with group C as both groups have the same magnitude of delayed commodity in the temporal discounting procedure and the same magnitude of commodities in the IPD game. The only parametric difference between group C and group D is the length of the temporal window.

Group F: This group replicated Yi, et. al., (2005) by increasing the delayed outcome to $100, the temporal window to 1 week to 25 years, and the IPD payoffs to (trial N-1 / Trial N): Defect/Cooperate = $5, Defect/Defect = $10, Cooperate/Cooperate = $20, Cooperate/Defect = $25. A critical comparison is with group E.
Group G: Fantino, et. al. (2006) found that increasing the ITI increases cooperation. This group tested this ITI effect and how it relates to the relationship between IPD and TD by using a 30 second ITI between IPD trials.

Group H: This group reversed the order of delay presentation from Group A. This group tested the possibility that the initial delay value serves as a temporal anchor for future choices.

4.2 Results

551 participants completed the experiment. The number of participants per group and descriptive statistics for the groups are shown in Table 10. A Chi-square test failed to find a difference in distribution of participants across the eight groups, $\chi^2(7, 551) = 3.0771, p = 0.8792$. There were 386 female participants and 165 male participants. A chi-square between groups revealed no difference in distribution of gender between the eight groups, $\chi^2(7, 551) = 7.799, p = 0.3506$. The average age of participants was 20.23 years. A one-way ANOVA found an overall difference in ages between groups: $F(7) = 3.3266, p < 0.001$. A follow-up Tukey HSD test revealed a difference in age between Group A and Groups E and G. As the difference in mean age between these groups was approximately 1.5 years, the difference was not sufficient to impact the results. As the distribution of gender between the groups did not differ, results were pooled across gender and further testing was conducted using one-way ANOVA with group as the factor and either proportion log-transformed discount rate or proportion cooperation as the dependent variable.

Table 10 shows the median discount rates, interquartile ranges, and VAC. An ANOVA on the observed discounting parameter revealed an overall difference
between groups: $F(7, 538) = 3.170 \ p < 0.01$. Follow-up tests using Dunnett’s t-test for comparisons between Group A, and the seven experimental groups found no group to be significantly different from the comparison group. In order to determine the origin of the main effect, a Tukey’s HSD tested all possible pairs. Three pairs were found to be significantly different: Group D v. Group E, Group D v. Group F, and Group D v. Group H. As groups E, F, and H did not differ significantly from any groups other than D, it was determined that group D, which used music as the choice commodity rather than money, was the source of the main effect. Removing Group D from the ANOVA resulted in a non-significant finding: $F(6, 475) = 1.979, \ p = 0.67$.

The mean proportion cooperation for the IPD games are displayed in the right half of Table 10. A one-way ANOVA revealed a significant difference in proportion cooperation between the groups: $F(7, 550) = 4.066, \ p < 0.001$. Only Group G differed from the comparison group A (Dunnet’s t-test). Group G differed from the other test groups in that a 30 second timeout, or ITI, separated each choice trial. A follow-up Tukey HSD test of all possible pairs revealed five pairs that were significantly different, with all pairs differing from Group G: Groups B, C, D, E, and H. Removing Group G from the ANOVA produced a non-significant finding: $F(6, 479) = 1.068, \ p = 0.381$. The increased cooperation observed in group G is consistent with the findings of Fantino, et. al. (2006).

The statistical tests revealed that with the exception of two groups (D and G) the groups did not differ from each other in terms of observed discount rate or proportion cooperation. The assumption can be made that differences in observed
relationship between discounting and cooperation are a product of the parametric change.

The observed correlations for each group are shown in Figure 14 and Table 10.

4.3 Discussion

The outcome for each group is discussed below:

**Group B:** The change from money to points in the IPD did not have a significant impact on the correlation between discount rate and cooperation.

**Group C:** The increased magnitude of the delayed outcome should have decreased the observed discount rate in comparison to A (Green & Myerson, 2004; Yi, et. al., 2005) While a statistically significant difference was not observed, the change occurred in the expected direction. Increasing the size of the delayed reward blunted the observed relation between discount rate and cooperation, but it was still significant at the p < 0.05 level.

**Group D:** As previous research (Charlton & Fantino, In preparation) demonstrated a higher discount rate for music than money, it was anticipated that this group would produce a higher discount rate than Group A. This was not the case (p = 0.130), but the direction of change was in the predicted direction. Group D did have a significantly higher discount rate than groups E, F, and H. Changing the commodity type in the TD procedure nearly eliminated the observed correlation, $r = -0.0865$ ($p = 0.5005$).

**Group E:** Although this group approximated Experiment 1 and 2, the observed correlation between discounting and IPD performance was $r = 0.0897$ ($p = 0.4701$). It is uncertain why this relationship is so low.
Group F: This group replicated Yi, et. al. (2005). The correlation observed was significant, but weaker than observed in the original study.

The difference in discount rate observed between Group E and Group F and their counterparts, Experiment 1 and Yi, et. al. (2005) suggests a similar source of interference in each of these groups. One possibility is that the range of delays is not quite equivalent to that used by Yi, et. al. The temporal window in their experiment was 1 day to 25 years. This possibility does not fully explain the lack of a correlation in group E, but provides a reasonable explanation for the difference observed in Group F. More will be said about this possible anchoring effect with group H. A second possibility is that the similar condition in Yi, et. al. (2005) was inflated by having been presented in close temporal proximity to a larger delayed outcome ($1,000).

Group G: This group successfully replicated the results of Fantino, et. al. (2006) by showing a significant increase in cooperation as the ITI increased. In addition to improving performance on the IPD task the inclusion of an ITI eliminated the relationship between discounting and cooperation. This is consistent with the idea that increasing the time between trials changes the IPD from a motivation problem to a cognitive problem.

Group H: Despite using the same delay window and producing similar discount rates, the reversed presentation of the delayed values eliminated the relationship between discount rate and cooperation. In comparison with Group F, this suggests that the increased initial delay value introduces a bias in perception of the discounting task.
The primary goal of the current experiment was to explore the robustness of the observed correlation between discount rate and proportion cooperation on a single-player iterated prisoner’s dilemma using the confirmed procedure from experiment 3. A secondary goal was to identify what experimental parameters might influence the correlation between these measures.

Of the seven experimental groups in the current experiment, three statistically significant negative correlations were observed (Group A is not included in this tally as it is a carryover from Experiment 3). The correlation remained significant as the type of outcome in the IPD procedure changed (from money to points), as the magnitude of the commodity in the IPD increased (from a maximum of $4 to a maximum of $25), and as the magnitude of the delayed commodity increased (from $10 to $100).

Initial clues emerged regarding the nature of the relationship between discounting and cooperation. The lack of a significant correlation when the delayed commodity in the temporal discounting task was changed to iTunes downloads rather than money (group D) suggests that similarity between the target commodities of each task is a critical variable.

Group B also addresses the possibility that commodity type matters. This group changed the target commodity of the IPD game from money to abstract points and only a small change in correlation was observed. If commodity type influences the relationship, this correlation in Group B should differ from that observed in group A. Perhaps the two commodities did not differ enough. Points earned in an experiment are not directly consumable, but must be exchanged for other
commodities. This function is highly similar to money. Indeed, Odum, et. al. (In press), Estle, et. al. (In press), and Charlton and Fantino (in preparation) all argue that commodities that require exchange prior to consumption are unique from those that are directly consumable. If the assumption is made that both points and money gain value through exchange for other commodities, then these commodities might be functionally equivalent and the change from points to money might be one of degree, not kind.

At least one piece of evidence suggested that a decrease was expected in the relationship between discounting and cooperation similar to that between group A and group B. Yi, et. al. (2005) found that a change from a $10 gain to a $100 gain resulted in an increase in the correlation between discount rate and cooperation (from -0.27 to -0.37, the second correlation is statistically significant). The correlation observed in Group C ($100 delayed commodity; \( r = -0.263 \)) also changed in strength as compared with group A ($10 delayed commodity; \( r = -0.369 \)). But, this result is a reverse effect of Yi, et. al. (2005) where an increase in magnitude resulted in an increased strength of the observed correlation.

A comparison of the correlations observed in Groups C, E, and F suggested that changes in the length of the temporal window may affect the relation between discounting rate and cooperation in a manner similar to the magnitude effect observed between groups A and C. Though similar in mean discount rate and mean proportion cooperation, there is a substantial difference in observed correlation from Group E (\( r = 0.090 \)) to Groups C (\( r = -0.263, p<0.05 \)) and F (\( r = -0.226, p < 0.05 \)). When the width of the temporal window increased from 1 year (Group C) to 25 years (Group E)
while the magnitude of the outcome in the IPD procedure was held constant, the observed correlation changed direction and went from significant (Group C) to non-significant (Group E). When the longer temporal window was maintained (Group E) and the value of the outcomes in the IPD procedure increased, as in Group F, the correlation reversed and achieved a level of statistical significance. A similar effect occurred between Group A and Group C when the magnitude of the delayed outcome was changed from $10 to $100, but the temporal window and the values of the IPD procedure were maintained constant the observed correlation between discount rate and cooperation decreased in strength. These findings suggest an interplay between temporal window, magnitude of delayed outcome, and the outcome values in the IPD game. Specifically, as the temporal window increases, the magnitude of either the IPD outcomes or the delayed commodity must also increase in order for the correlation between discount rate and cooperation in the IPD game to go unchanged.

Group H provides a final piece of evidence supporting this hypothesis that the correlation between discount rate and cooperation is dependent on a “match” between the parameters of the procedures. In this group the order of presentation for the delays in the temporal discounting procedure was reversed. This allowed a test of how the size of the initial delay affects the relationship between the two measures. Changing the order of presentation for the delays did not change the observed discount rate, but it did have a substantial impact on the observed correlation ($r = 0.168$). As with increasing the overall width of the temporal window, as in group E, starting the temporal discounting procedure with a long delay while the magnitude of
outcomes in the temporal discounting procedure and the IPD game are relatively small, appears to disrupt the correlation between discount rate and cooperation.

The increased cooperation and decreased correlation observed in Group G are interesting. In this group, the temporal window was maintained at 1 year and the magnitude of the delayed outcome was $10, similar to group A. However, the length of the ITI between trials was increased from 10 seconds to 30 seconds. The explanation forwarded by Fantino, et al. (2006), argued that as the time between trials increases, more time is available to consider the contingencies, resulting in the adoption of a more optimal strategy. Indeed, Fantino, et al., demonstrated that the inclusion of a distracting task (completing a simple puzzle) during the ITI eliminated the facilitating effect of the increased ITI. A similar contemplation of the contingencies in this group may have changed this from a self-control to a cognitive task.

While correlations do not imply causation, the comparisons from this experiment suggest that a relationship between discounting and the prisoner’s dilemma will be observed when there is (1) a functional match between the target commodities in both procedures, (2) a similarity in magnitude, and (3) increases in magnitude are matched by increases in delay.

Experiment 5

Concurrent with experiment 4, a separate participant group completed both a one-player and a two-player IPD task. While the results from experiment 1, Brown and Rachlin (1999), and Silverstein, et al. (1998) suggest that performance on a multi-player task is not related to discounting rates the theoretical path from the
standard IPD to self-control on the SP-IPD involves interpersonal dilemmas. As discussed previously the single-player IPD developed as a special case of the general IPD in which the participants involved in the interaction are assumed to be “inside” the player. The individual discounting rate is interpreted as an index of how likely future selves are to cooperate with each other across time. As social interactions are also mediated via the probability of reciprocation, discounting rates may play a role in this type of behavior.

5.1 Methods

5.1.1 Participants

Participants were drawn from those registered to participate in Experiment 4. Sampling from the group planning to complete Experiment 3, ensured that the samples came from the same population. The same protocols and procedures were used with handling these participants as with other participants in the study.

The first two participants arriving for the study were assigned to the group condition. No constraints were placed on gender or matches between the two genders playing the game.

5.1.2 Location and apparatus.

During the periods when the experiment was conducted, two of the rooms used in Experiments 1 through 4 were tasked to this experiment. These rooms allowed for two participants to be in a separate room from each other and yet have an unobstructed view of the research assistant conducting the experiment.

5.1.3 Experimental Procedures
Participants completed two distinct sections: (1) the discounting task followed by the single-player iterated prisoner’s dilemma as used in Experiment 3, also group A or experiment 4, and (2) the two-player iterated prisoner’s dilemma game. The order of these sections was determined randomly, by computer, prior to the start of the experiment.

The Discounting Task and Single-Player Iterated Prisoner’s Dilemma

The discounting task and the prisoner’s dilemma were the same as used in experiment 3. The discounting task was always presented first. As in the previous experiments, the computer played a straight tit-for-tat procedure.

The Two-Player Iterated Prisoner’s Dilemma

Each participant was seated in one of two small testing rooms facing toward the door. The two rooms were adjacent to each other. The research assistant sat at a table outside the two rooms so as to be visible by both participants. The participants could not see one another during the task. Each participant was provided a clipboard with an attached scoring sheet and two plastic poker chips, one red and one white. When prompted by the research assistant, the participant showed one of the two chips. To the side of each participant, a table contained an example of the payoff matrix and an instruction sheet:

For this portion of your participation, you and another participant will be completing the same condition. The other participant is in the room next to you and the research assistant will be situated outside the room where both of you can see them.

During the experiment, each of you will be making a choice between a red token and a white token. You will indicate a choice by showing the token to the experimenter when asked. Please hold the token so that the experimenter can clearly see what choice you made. While you will not be able to see the token chosen by the other participant,
your points for each choice trial will be a function of the token color you chose and the token color chosen by the other participant. The rules for determining your total points are as follows (also shown on the attached table):

If you choose RED and the other participant chooses RED: 2 points for you (2 for other).
If you choose RED and the other participant chooses WHITE: 6 points for you (1 for other).
If you choose WHITE and the other participant chooses RED: 1 points for you (6 for other).
If you choose WHITE and the other participant chooses WHITE: 5 Points for you (5 for other).

You will have multiple opportunities to make this choice.

Following each choice, please record what color you chose as well as the points you earned on the data sheet.

The research assistant started each trial by asking, “Ready” and then, after a short pause of one to two seconds, stating, “Okay, choose”. At this point both participants showed their selected color for the current trial. Once both choices had been signaled, the research assistant presented one of four cards indicating how many points each participant earned on the current trial. The assistant also recorded the outcome of the choice trial on the computer. This cycle continued for 40 trials, but the data sheet seen by participants had lines for 100 trials.

5.2 Results

A total of 126 participants were tested with 80% (n = 101) female and 20% (n = 25) male. The distribution of gender across the single-player first and two-player first order of presentation groups was not significantly different: \( \chi^2(1, 126) = 0.052, p = 0.8198 \). These participants were divided between 63 pairs, with the following gender arrangements: 42 (67.7%) were female-female pairs, 17 were mixed pairs (one male, one female; 27.0%), and 2 (3.2%) were male-male pairs. The distribution of
gender-arrangements did not differ between order of presentation groups: \( \chi^2(1, 126) = 2.1799, p = 0.3363 \). The average age of participants was 20.03 years. Age did not differ between the order of presentation groups: \( t(126) = 0.372, p = 0.7102 \), or by gender: \( t(126) = 0.785, p = 0.4339 \).

The median discount rate was 0.05 \((QR = 0.01\) to \(0.28)\). The variance accounted for (VAC) for this data set was extremely poor with a median of 0. As the discounting equation did not provide a good fit for the current data set, the area under the curve (AUC) statistic was calculated for each participant (Myerson, Green, Warusawitharana, 2001). This measure is a non-theoretical index of discounting that has been shown to correlate well with discount rates produced by a non-linear fit of Equation 1. The mean AUC for the current data set was 0.5263 (0.2676). The individual AUC measures were highly correlated with the log-transformed discount rates, \( r = -0.9418, p < 0.0001 \). The negative correlation is anticipated as a greater area under the curve indicates a slow loss of value as delay increases. A 2 x 2 ANOVA of gender and order on log-transformed discount rate and on AUC failed to find any significant main effects or interactions.

A 2 x 2 x 2 repeated measures ANOVA tested the effects of gender and order of presentation on performance in the two game types. A significant effect of game type was observed: \( F(1, 122) = 34.457, p < 0.001, \eta^2_p = 0.220 \) with an increase in mean cooperation from 0.51 (0.32) for the two-player IPD game to 0.76 (0.25) for the single-player IPD. No interactions between game type, gender, or order reached the level of statistical significance. The between-subjects tests found no main effects of gender or order.
As indicated above, the mean level of cooperation varied between the one-player game and the two-player game, but the order in which the games were presented did not impact the level of cooperation in either task. This finding is consistent with that of Brown and Rachlin (1999). The mean level of cooperation for the single-player IPD game was 0.7609 (0.2510). This mean was significantly higher than that observed for group A of Experiment 4: Mean = 0.710, SD = 0.238, $z = 2.409$, $p < 0.05$. The temporal discounting task and the single-player IPD game were identical between the current experiment and group A of experiment 4. The mean proportion cooperation on the two-player game was 0.5115 (0.3179).

Correlations were calculated between log-transformed discount rate, proportion cooperation on the single-player game, and cooperation on the two-player game. The correlations were separated by order (Table 11). When the single-player game was presented first (the actual order was discounting measure, single-player IPD, then multi-player IPD), a significant correlation was observed between discounting rate and proportion cooperation on the single-player IPD ($r = -0.2558$, $p < 0.05$) and between proportion cooperation on the single-player IPD and the two-player IPD ($r = 0.3888$, $p < 0.001$). The correlation between proportion cooperation on the two-player IPD and discount rate was not significant ($r = -0.023$). When the two-player game was presented followed by the discounting procedure, and then the single-player IPD, no significant correlations were observed. The observed correlation between discount rate and proportion cooperation in the single-player IPD was $r = -0.0617$. The observed correlation between proportion cooperation on the single-player and on the two-player game $r = 0.1110$. Finally, the observed
correlation between proportion cooperation in the two-player IPD and discount rate was \( r = -0.0205 \). This same pattern of correlations was observed using the AUC in place of the log-transformed discount rate.

As contingencies in a two-player IPD are more complex than those of a single-player IPD, several additional tests were conducted. Participants were ranked based on observed discount rank. The resulting distribution was broken into thirds (\( n = 41 \)) and those members in the top third (lowest discounters) were assigned a rank of 1, those in the middle a rank of 2, and the final third a rank of 3 (the highest discounters). A one-way ANOVA was conducted on the proportion cooperation during the two-player IPD game for the three groups and no significant difference was observed: \( F(2) = 0.688, p < 0.505 \).

In order to test for interactions between the discount rate for the two players, the rank of the two players in the pair were then compared and an independent-samples t-test was conducted on the proportion cooperation in the two-player IPD by the pairs who were both low-discounters (both ranked 1) and where both members were high discounters (both ranked 3). No difference was found between these groups: \( t = 0.082, p = 0.935 \).

As a general measure of reciprocation, the correlation between proportion cooperation for player 1 and proportion cooperation for Player 2 was calculated. For those pairs who participated in the single-player game before the two-player IPD, the correlation between proportion cooperation for both players was: \( r = 0.9195, p < 0.0001 \). When the two-player game was completed first, the correlation between the proportion cooperation for the two players was: \( r = 0.7191, p < 0.0001 \). Using a
Fisher $z$-transformation these correlations were found to be significantly different: $z = 3.48, p < 0.001$.

Finally, the impact of the first play on the overall level of cooperation was examined. The frequency of cooperation on the first play was not affected by the order of presentation: $\chi^2 = 2.551, p = 0.1525$, and the probability of starting with either a cooperate or a defect response did not differ from 0.50 for either group. A 2 (order of presentation) x 2 (first play) ANOVA was conducted on the participant’s overall level of cooperation based on whether the second player’s first move was to cooperate or defect. A significant main effect of first play was found: $F(1, 125) = 12.3271, p < 0.001$. Consistent with the previous finding, no effect of order of presentation was observed and the interaction between order of presentation and first play was not significant. The mean proportion cooperation across all 40 trials by player 1 when player 2 started with cooperation was 0.61 (0.33). When the second player opened with a choice of defect, the mean proportion cooperation across all 40 trials was 0.41 (0.27).

5.3 Discussion

As suggested by the finding of no systematic correlations between discount rate and proportion cooperation for the multi-player condition of experiment 1 and the random strategy IPD condition of Yi, et. al. (2005), this experiment found no evidence for a relationship between rate of temporal discounting and level of cooperation in a two-player IPD game. However, level of cooperation on the single-player IPD game and level of cooperation in the two-player game were related..
Additionally, the outcome of the two-player game was strongly impacted by their opponents first move of the game.

**Experiment 6**

A possible reason for the lack of correlation between performance on the two-player game and observed discount rate is that the second player does not perfectly reciprocate the moves made by the participant. Under these conditions, the choices made by the participant became less introspective as cues other than personal choice history are now important. Of the groups tested in experiments 1, 2, 3, and 4, the computer was programmed to play a tit-for-tat strategy of perfect reciprocation or p(R) = 1.00. To date, only one experiment looked at the impact of p(R) on the correlation between discount rate and cooperation. Yi, et. al. (2005) tested participants at either p(R) = 1.00 or P(R) = 0.50. Consistent with findings from previous studies in which the probability of reciprocation was changed (Baker & Rachlin, 2001; Fantino, et. al., 2006), Yi, et. al., observed that proportion cooperation decreased with the decrease in probability of reciprocation. The observed relationship between cooperation and discount rate also decreased with no significant correlations being observed in the p(R) = 0.50 condition (at this value, defection is optimal as the move made by the computer is independent of the move made by the participant).

Experiment 6 aimed to replicate and extend the finding of Yi, et. al. (2005). In this experiment, five groups were tested, each with a different p(R). The probabilities of reciprocation used in this experiment were p(R) = 1.00 (tit-for-tat, cooperation optimal), 0.75 (cooperation optimal), 0.50 (random), 0.25 (defection
optimal) and 0.0 (reverse tit-for-tat, defection optimal). As in experiment 5, participants completed the same discounting and IPD game as in group A (experiment 3, 4). Also, participants completed a single-player IPD game identical to the single-player iterated prisoner’s dilemma – discovery (SP-IPD(D)), group from experiment 1.

In addition to the five p(R) groups, the current experiment presented one of two outcomes as the choice commodity in the SP-IPD(D) game. Participants were presented either $1, $2, $5, or $6 in the IPD game (identical to experiments 1 and 2) or 1, 2, 5, or 6 iTunes downloads. Studies have demonstrated that music is discounted at a higher rate than money (Charlton & Fantino, in preparation; unpublished data collected by the author). This change in commodity type was included as a more direct test of the relationship between discount rate and proportion cooperation. If higher discount rates between individuals are associated with decreased cooperation, it was hypothesized that the higher discount rates observed for hypothetical music would lead to decreased cooperation. The choice of iTunes downloads was selected as each download is approximately $1 ($0.99).

This experiment had several goals. First, Yi, et. al. (2005) demonstrated that when there is no correlation between a participant’s choices on the IPD game, as in p(R) = 0.50, the relationship between discounting and cooperation disappears. However, they did not explore what would happen to this relationship when the correlation was weakened, as in p(R) = 0.75 or 0.25. Also, under the condition p(R) = 0.00, there is a direct inverse relationship between the participant’s choices and outcomes on the IPD. The optimal strategy in this condition is to defect on every trial
as the computer would respond by cooperating and the maximum outcome would be received. In the P(R) = 0.25, and 0.00 conditions where the optimal strategy is to defect, the observed correlations between discounting and cooperation would be expected to reverse. That is, if lower discount rates are facilitating the development of the long-term effective strategy in an IPD game then those with lower discount rates should defect more when p(R) is at 0.25 and 0.00.

Second, experiment 1 found that when the SP-IPD(D) condition preceded the discounting task, there was a significant correlation between discount rate and cooperation. This is the only example so far of a correlation between these two measures when the IPD game precedes the discounting task. The procedure in experiment 6 presented the SP-IPD(D) condition prior to the discounting condition in order to verify this earlier finding. The IPD game following the discounting procedure was the same instructed task as used in experiments 3 – 5.

Third, in addition to verifying the results of experiment 1, this order of presentation permitted a test of the relationship between the two IPD games used in the various experiments of this report. In the p(R) = 1.00 group, both the initial IPD task and the second IPD task are replications of the procedures used in experiment 1 and 2 and experiments 3 – 5 of this report, respectively. This allows for a direct comparison of performance on each of these tasks by comparing how performance on the SP-IPD(D) task correlates with performance on the Harris and Madden IPD task. As illustrated in Figures 5 and 12, the two tasks differ in that the SP-IPD task used in experiments 1 and 2 presented a true single-player IPD in which only information concerning the participant’s outcomes was presented. In the Harris and Madden
(2002) procedure as used in experiments 3 – 5, each trial is presented as a play between the computer and the participant and the computer’s choices are shown. While it has been demonstrated that the difference in observed correlation from experiment 1 and 2 can be at least partially explained by differences in the parameters used in the discounting and IPD tasks, a direct comparison of performance on the two tasks will help clarify the role of the different IPD games in changing the observed correlations.

Finally, the use of commodities with different discount rates in the IPD game allows a direct test of how the discount rate of the commodity is related to cooperation.

6.1 Methods

6.1.1 Participants

Sampling and recruitment followed the same procedure as previous experiments.

6.1.2 Testing apparatus and location

The same equipment and location as in experiments 1 – 5 were employed.

6.1.3 Experimental procedures

Participants first completed the single-player IPD task from experiments 1 and 2 (Figure 5). No signal was provided regarding the probability of reciprocation, p(R), being used by the computer. The p(R) being used by the computer was assigned at random. Following each choice trial, the computer selected a random number between 0 and 1. When this number was less than the assigned p(R) for the given group, the computer copied the player’s choice from the previous trial. When this
number was greater than the assigned \( p(R) \), the computer made the opposite move. For the \( p(R) = 0.00 \) group, the computer always made the opposite play. The commodity used in the IPD procedure was also selected at random. The money and music conditions differed only in the label used inside the IPD matrix. For money, each number was preceded by a dollar sign. For the music condition, the words “iTunes downloads” were written immediately below the numbers in each cell. This game lasted for 60 trials.

Following the completion of the SP-IPD(D) procedure, participants were presented the same task as from experiment 3 (Figure 12).

6.2 Results

A total of 168 participants completed the experiment. The average age of participants was 20.20 (1.51) years. The average age between probability of reciprocation, \( p(R) \), groups and commodity types did was not different. 63% of participants were female. The distribution of gender did not differ between \( p(R) \) groups or commodity type.

The median observed discount rate was 0.07 (\( QR = 0.02 \) to 0.47). This median was slightly greater than observed in experiment 3 (0.02), but the interquartile range is quite similar (\( QR = 0.01 \) to 0.411). A 2 (commodity) x 5 (\( p(R) \)) ANOVA on the log-transformed discounting rate found no main effects of commodity, \( F(1, 157) = 0.203, p = 0.653 \), or probability of reciprocation: \( F(4, 157) = .817, p < 0.516 \).

The proportion cooperation on the Harris and Madden IPD game was 0.7695 (0.2167). This was significantly greater than the mean proportion cooperation of 0.710 (0.238) that was observed in experiment 3: \( z = 3.24, p < 0.0012 \). A 2 x 5
ANOVA (commodity x p(R)) found no main effects of commodity type: $F(1, 167) = 1.507, p = 0.221$, or probability of reciprocation: $F(4, 167) = 1.308, p < 0.269$.

Similar to experiment 1 and 2, the 60 trials from the SP-IPD(D) procedure were separated into 3 blocks. The proportion cooperation was calculated for each block (Figure 15). A repeated measures $2 \times 5 \times 3$ ANOVA (commodity x p(R) x blocks) revealed a non-significant effect of commodity: $F(1, 158) = 1.249, p = 0.265$, a significant effect of p(R), $F(4, 158) = 34.432, p < 0.0001, \eta_p^2 = 0.466$, a significant within-subject difference across blocks: $F(2, 158) = 5.224, p < 0.01, \eta_p^2 = 0.032$, and a significant block x p(R) interaction: $F(8, 158) = 11.778, p < 0.0001, \eta_p^2 = 0.230$.

Pairwise comparisons found a significant difference between p(R) = 1.00 and all other groups ($p < 0.0001$ for all pairs), but a non-significant difference between p(R) = 0.75 and p(R) = 0.50 and between p(R) = 0.25 and p(R) = 0.00. All other pairs were significantly different. The p(R) by block interaction was explored by conducting five separate repeated measures ANOVAs with blocks as the only factor. A significant effect of blocks was found for p(R) = 1.00: $F(2, 36) = 29.053, p < 0.001, \eta_p^2 = 0.447$. Pair-wise comparisons found all three blocks to be significantly different (block 1 vs. block 2 and block 3: $p < 0.0001$; block 2 vs. block 3, $p < 0.05$).

A main effect of blocks was observed for p(R) = 0.25: $F(2, 33) = 3.373, p < 0.05 \eta_p^2 = 0.093$. However, pair-wise comparisons failed to find any significant differences between individual pairs of blocks (the first block and last block were nearly significant at $p = 0.061$). Finally, a main effect of block was observed for p(R) = 0.00: $F(2, 30) = 4.838, p < 0.011, \eta_p^2 = 0.139$. Pairwise comparisons found a difference between the first block and the last block ($p < 0.05$) and no other
significant differences. No main effect of blocks was observed for $p(R) = 0.75$ or $p(R) = 0.50$. The relationship between $p(R)$ and block is shown in Figure 15.

The correlation between discount rate and proportion cooperation on the experiment 3 IPD game from this experiment pooled across all five experimental groups was $-0.1576, p < 0.05$. As there was a significant difference in proportion cooperation across the SP-IPD(D) game from the current experiment, correlations were calculated separately for each probability of reciprocation group. These correlations can be seen in Table 11.

In general, the correlation between discounting and the SP-IPD(D) task that preceded the temporal discounting measure was stronger than the correlation between the Harris & Madden game (H & M game) that followed the discounting measure, although these correlations did not typically achieve statistical significance. The correlation between the SP-IPD(D) game and discounting was negative for the two groups where cooperation was optimal and positive for the three groups ($p(R) = 0.50, 0.25,$ and $0.00$) where defection was optimal. The only statistically significant correlation between proportion cooperation on the SP-IPD(D) game and discount rate occurred in the $p(R) = 0.50$ group and was $r = 0.356, p < 0.05$. The correlation between these two measures was lowest for the $p(R) = 0.75$ and 0.25 groups.

The correlation between discount rate and the H & M game ranged from 0.004 to $-0.293$. This correlation was highest for the $p(R) = 0.75$ group at $r = -0.293, p = 0.110$. For $p(R)$ groups 1.00, 0.75, and 0.50, the correlation between proportion cooperation on the H & M game was negative. For the final two groups, the correlation was $r = 0.004 (p = 0.984)$ and $r = -0.074 (p = 0.697)$. 
The correlation between proportion cooperation on the two IPD games ranged from 0.569 ($p < 0.0001$) for the $p(R) = 1.00$ group to $r = -0.528$ ($p < 0.01$) for the $p(R) = 0.00$ group. The observed correlation was positive for both groups (1.00 and 0.75) where cooperation was optimal and reversed to negative for the three groups where defection was optimal (0.50, 0.25, and 0.00).

6.3 Discussion

The inclusion of an IPD task prior to the presentation of the temporal discounting task both confirmed the Experiment 1 finding of a significant correlation between discount rate and proportion cooperation on a discovery IPD game when the IPD game is presented first and disrupted the correlation between discounting and the IPD game that followed. This effect was similar to including the Sharing Game in Experiment 2. The strongest correlation produced between discount rate and the Harris and Madden IPD game was for the $p(R) = 0.50$ group where the correlation was $-0.293$ ($p = 0.110$). This observed correlation could be viewed as evidence of the interaction between the SP-IPD(D) and H & M games. Under a $p(R) = 0.50$, there is no direct link between the participant’s behavior and the outcome they receive. For the other four groups, however, there is a link between performance and outcome. As there is no difference in the measured discount rate and proportion cooperation on the H & M game, but systematic shifts in correlation between discounting and proportion cooperation on the H & M game were observed, it seems likely that the prior completion of the SP-IPD(D) was the source of the interference.

The first goal of experiment 6 was to extend the finding of Yi, et. al. (2005) that changing from a tit-for-tat, $p(R) = 1.00$, strategy in the preceding SP-IPD(D)
The game would eliminate the correlation between proportion cooperation and discount rate. Unfortunately, the results did not replicate this effect. Changing the p(R) to 0.50 did change the strength of the correlation, but by increasing it to \( r = -0.356 \) \((p < 0.05)\) rather than decreasing it. While this is different from the general results reported by Yi, et. al. (2005), it is not overly different from their test group with $10 gains in the temporal discounting measure. For this group the correlation across the first 30 trials was \( r = -0.44 \) \((p < 0.05)\), but dropped to \( r = -0.03 \) over the last 30 trials. The overall correlation for this group is \( r = -0.19 \). These correlations are similar enough in pattern to suggest that the difference between these groups is not a sign of a substantial difference between the outcomes of the two experiments, but can rather be attributed to the differences between the two procedures.

A comparison across the five p(R) groups produces a trend that was not studied by Yi, et. al. (2005). The range in strength of correlations for the p(R) = 1.00, 0.50, and 0.00 groups was small: -0.289 to 0.356. The change in sign between the two correlations was anticipated as the optimal strategy shifted from cooperation to defection across these two groups. The similarity in observed strength of correlation is interesting as these three groups have the most straightforward relations to the participant’s behavior. For the two groups in which the relationship is more complicated, the correlations are \( r = -0.158 \) and 0.146. Although these are substantially weaker than those observed for the p(R) = 1.00, 0.50, and 0.00 groups, the directions of the correlations are consistent with the optimal strategy for each of these groups.
Another systematic pattern of correlations was observed between proportion cooperation on the SP-IPD(D) and the temporal discounting measure. When the optimal strategy was to cooperate, both of the observed correlations were negative (group $p(R) = 1.0$ and $0.75$). When the optimal strategy shifted to defect, the signs of the correlations between discounting and proportion cooperation switched from negative to positive. This pattern suggests that individuals with lower discount rates have a slight tendency to perform more optimally in IPD games by cooperating when this is best and defecting when this is more optimal.

A similar pattern of correlations is evident in the comparison between proportion cooperation on the SP-IPD(D) game and proportion cooperation on the Harris and Madden game in the results from the present experiment. For these two games, the correlation at $p(R) = 1.00$ was $r = 0.584$ ($p < 0.01$) and for the $p(R) = 0.00$ group the correlation was $r = -0.528$. The transition from these two extremes was systematic with the correlation becoming monotonically more negative. The change in sign for these correlations occurred concurrent with the change in strategy from cooperation to defection.

The second goal of this experiment was to verify the finding from experiment 1 that when the IPD game preceding the temporal discounting task is presented without any description of the tit-for-tat strategy there will be a correlation between proportion cooperation on this task and the subsequently measured discount rate. The results from the $p(R) = 1.00$ group supported this proposal. The correlation between proportion cooperation on the SP-IPD(D) game and discount rate was $r = -0.289$ ($p = 0.098$). For the experiment 1 SP-IPD(D), IPD first group, the observed correlation
was -0.2798 for the overall proportion cooperation and discount rate. For both of these groups, the correlation was strongest across the last block of trials ($r = -0.3696$, $p < 0.05$, for experiment 1 and $r = -0.327$, $p = 0.059$, for the p(R) = 1.00 group of experiment 6). Interestingly, this same effect was nearly mirrored in the p(R) = 0.00 group. For this group, the correlation between proportion cooperation on the SP-IPD(D) game and discount rate was $r = 0.353$ ($p = 0.055$). Both of these correlations were stronger than Experiment 2 Cluster 2, where the instructed SP-IPD game preceded completion of the temporal discounting task, correlations between cooperation on the IPD game and discount rate for either the Mesa or UCSD sample ($r = -0.075$ and $r = 0.0180$, respectively). These correlations are also stronger than that observed for the discovery, single—player IPD group presented following the temporal discounting task in experiment 1 ($r = 0.0666$).

The third goal of experiment 6 was to demonstrate the relationship between the SP-IPD games used in experiment 1 and 2 and the Harris and Madden (2002) based games used in experiments 3, 4, and 5. In the condition where the two games are the most similar, p(R) = 1.00, the correlation between proportion cooperation on the two games was $r = 0.569$ ($p < 0.0001$). The strong similarity between the two games suggests that while some difference in observed correlation between experiment 1 and 2 is attributable to the difference in procedures, the different procedures did not substantially contribute to these differences.

Finally, experiment 6 used both money and iTunes downloads as the target commodity in the IPD game in order to test for a difference in proportion cooperation when the target commodities were each associated with different rates of discounting.
No evidence of a difference in proportion cooperation as a function of the discounting rate of the target commodity was found. As the inclusion of a commodity other than money as the outcome of a single-player iterated prisoner’s dilemma was a novel comparison, no studies exist with which to compare this outcome.

**General Discussion**

The aim of the three experiments in this section was to explore how changes in the parameters of the discounting measure and the IPD game influenced the observed correlation between these measures. This systematic manipulation of variables would provide clarity as to the discordant findings between Harris and Madden (2002), Yi, et. al. (2005), Yi, et. al, (2006), and experiments 1 and 2 of this report. This goal was achieved. The results of Harris and Madden were replicated (experiment 3). A condition similar to one reported by Yi, et. al. (2005) produced a statistically significant negative correlation (group F). When a single-player IPD, discovery group preceded the discounting task, the finding from experiment 1 of a significant correlation between proportion cooperation and discount rate was replicated (experiment 6). These results suggest that while discordant, the findings of the five experiments are replicable.

The experiments also provided some evidence of the factors that influence the strength of the relationship between discounting and cooperation. When the length of the temporal window was increased from 1 year (Group C) to 25 years (Group E), the relationship was eliminated. However, when the size of the outcomes in the IPD task increased along with the width of the temporal window, the relationship reappeared. There were no co-occurring changes in the observed rate of discounting or proportion
cooperation between these three groups. This suggests that one variable influencing the strength of relationship between discounting and cooperation is the interaction between the length of the temporal window and the magnitude of the outcomes in the IPD game.

Four other manipulations were shown to disrupt the relationship between discounting and cooperation on the IPD. First, changing the delayed commodity to one that is functionally different from the target commodity of the IPD procedure decreased the correlation, but did not change its direction. Second, increasing the delay time between choice trials increased the proportion cooperation, but eliminated the relationship between discounting and cooperation. Third, reversing the order of presentation of the delays in the temporal discounting window also reversed the sign of the observed correlation. Fourth, presenting an IPD procedure with a probability of reciprocation other than 1.00 (tit-for-tat) prior to the temporal discounting task also disrupted the correlation between cooperation and temporal discount rate for the single-player IPD game following the temporal discounting measure. Another dimension of this group of experiments was a comparison between performance on the single-player IPD and a two-player IPD. According to the results from experiment 5, discounting was not related to performance on the two-player game. Instead, cooperation on the two-player game was strongly influenced by the first play and by the proportion cooperation by both players in the single-player IPD game. Proportion cooperation was significantly elevated when the second player chose to cooperate on trial 1. Completing the single-player game prior to participating in the two-player game did not increase the overall number of individuals choosing to
cooperate on the first trial. However, completing the single-player game first significantly increased the correlation between the level of cooperation for the two participants.

Finally, experiment 6 provided evidence that changing the probability of reciprocation in the IPD game impacts the correlation between cooperation and discounting. While not achieving statistical significance in most conditions, the correlation between cooperation and discounting was shown to reverse as the strategy changed from cooperation to defection. This systematic shift in the direction of the correlation is further evidence that lower discount rates are related to more optimal performance on IPD games (when the strategy is to cooperate, a negative correlation is observed as the slower the discount rate the more likely the participant is to cooperate and when the optimal strategy is to defect, the correlation is positive as slower discount rates are associated with a lower proportion cooperation).

In summary, the three experiments reported in this chapter can be seen as providing support for a constrained relationship between individual discount rates and proportion cooperation on the single-player iterated prisoner’s dilemma game.
General Conclusions

The overarching objective of the experiments in this dissertation was to extend the general understanding of when correlations between individual discount rates and performance on iterated prisoner’s dilemma games would be observed. This goal was achieved, not by demonstrating that this relationship is a general characteristic of these tasks, but by demonstrating that it is a relationship under constraint.

The six experiments in this dissertation explored the breadth of factors shown to influence the rate of hyperbolic discounting. They also looked at the role of reciprocation, a strong determinant of behavior in prisoner’s dilemma games. These comparisons suggest that the strength of the relationship between discounting and performance on the iterated prisoner’s dilemma can be influenced by the following six categories:

1. Type of Iterated Prisoner’s Dilemma

The type of prisoner’s dilemma game influenced the strength of the observed correlation between discounting and cooperation. Experiment 1 demonstrated that when the context of the IPD suggested a multi-player prisoner’s dilemma, the correlation between discounting and cooperation was inconsistent. This same effect was observed in the two-player condition of Experiment 5. However, changing the
context to a single-player interaction had a significant impact on the observed correlations.

2. Order of the Behavioral Measures

The order of presentation of the behavioral tasks influenced the observation of a relationship between discounting and cooperation. In experiment 1, correlations were only observed when the temporal discounting measure followed a single-player, discovery group. If the temporal discounting task was presented first, it needed to be followed by the single-player instructed group in order for a significant negative correlation to emerge. In experiment 2, the strongest correlation occurred in the UCSD group that completed the temporal discounting task then the SP-IPD(I) task (group 3). On the other hand, for experiment 2 group 1, in which the SP-IPD(I) task presented first then the temporal discounting measure, a non-significant correlation was observed. In experiment 5, when the temporal discounting measure preceded the group interaction, significant correlations were observed between discounting and the single-player IPD. These correlations were not observed when the two-player interaction preceded the temporal discounting measure, despite the fact that the discounting measure came before the SP-IPD. In experiment 6, a SP-IPD(D) condition preceded the discounting measure which was followed by the SP-IPD(I). In the p(R) = 1.00 group, the correlation between the SP-IPD(D) and discounting approached significance, but the correlation between discounting and the SP-IPD(I) did not.

3. Length of Delays
Changes in the length of the temporal window used in the temporal discounting task influenced the strength of the observed correlation between discounting and the SP-IPD. The length of the delay between SP-IPD trials influenced the strength of the relationship between discounting and the SP-IPD game. In Experiment 4, when the temporal window was extended from 1 year (Group C) to 25 years (Group E) without any other adjustments, the observed correlation changed from $r = -0.2625 \ (p < 0.05)$ to $r = 0.0973 \ (p = 0.4300)$. The correlation was recovered when the magnitude of the IPD outcomes was increased: $r = -0.2264 \ (p < 0.05, \text{ Group F})$. In Group H, the absolute length of the delay was kept constant but the order of presentation was reversed. This had the effect of reversing the correlation from $r = -0.3665 \ (p < 0.001, \text{ Group A})$ to $r = 0.1676 \ (p = 0.1676, \text{ Group H})$. The addition of an ITI in Group G demonstrated that changes to the temporal parameters of the IPD game also influences the relation between the two measures.

4. Similarity in target commodity

The extent to which the commodities used in the temporal discounting task and the IPD game were similar influenced the strength of the correlation between discounting and cooperation. In Experiment 4, when a qualitatively different commodity (iTunes downloads) was inserted into the temporal discounting procedure in group D, a significant decrease in the relationship between discounting and cooperation was observed compared to group A where money was used as both the outcome commodity for the discounting procedure and in the IPD game.

5. Magnitude of the outcome commodities
The similarity in the magnitude of the commodities used in the discounting task and the IPD game influenced the strength of the correlation between temporal discounting and IPD games.

Yi, et. al. (2005) found that with a delayed magnitude of $10 in the temporal discounting task a non-significant, yet moderate, correlation was observed while at magnitudes of $100 and $1,000 in the temporal discounting task moderate and significant correlations were observed between discounting and cooperation. On the other hand, Group E of Experiment 4 failed to produce a significant correlation with values ranging from $1 to $6 in the IPD. Group F used the same general parameters, but increased the IPD values to between $5 and $25. This change produced a significant correlation between temporal discounting and cooperation. Each of these comparisons suggests that the magnitudes of the outcomes used in the behavioral measures play a role in determining the correlation between discount rates and cooperation on IPD games. The evidence from Experiment 4 suggests that both the absolute values of these commodities and the relative values (in comparison to the magnitudes of the other task, the delays, etc.) might influence the strength of the relationship between discounting and cooperation.

6. The probability of reciprocation

The probability at which outcomes in the IPD task are related to the individual behavior of the organism influenced the correlation between discount rate and proportion cooperation.

In Experiment 6 a SP-IPD(D) game preceded the temporal discounting measure. The probability of reciprocation in this game was varied from $p(R) = 1.00$
to p(R) = 0.00. A nonmonotonic effect of changes in the probability of reciprocation was observed. When p(R) was at either extreme, the correlation between discounting and cooperation approached significance. The sign of the correlation reversed as the optimal strategy changed from cooperate to defect. When the computer played a random strategy, p(R) = 0.50, a significant correlation between discounting and cooperation was observed. The sign of this correlation was in agreement with the optimal strategy.

These six categories summarize the primary findings of this series of experiments. However, they most likely do not encompass the full breadth of factors that impact the strength of the relationship between discounting and cooperation. Indeed, the relationships between Groups C, E, and F presented an interaction between delay and magnitude that is not captured by the categories presented above. However, the purpose of presenting these findings in a categorical manner was to encourage the consideration of each topic independently.

In considering the breadth of variables found to influence the strength of the relationship between discounting and cooperation, it should be noted that these findings are based on a limited range of initial questions. Even when the studies of Harris and Madden (2002), Yi, et. al. (2005), Yi, et. al. (2006), are included with the findings of this dissertation, the scope of these tests remain extremely limited. All of these experiments use similar temporal discounting procedures and present the same general types of IPD games. With the exception of one group in experiment 4 and Experiment 6, all of these tests have involved money. Most of the participants in these studies are college students performing controlled laboratory tasks. Despite the
breadth of knowledge concerning individual and group differences in discount rates, no comparisons have been made as to how these groups differ when playing iterated prisoner’s dilemma games. As with the SP-IPD game in general, the limits on the types of questions asked in studies of the relationship between discount rates and cooperation in IPD games is a product of the young state of this line of research.

To date, and optimistically counting this dissertation, only four published investigations of the relationship between discounting and the iterated prisoner’s dilemma exist. These studies have confirmed the existence of an interaction between discount rate and cooperation on IPD games. Also, they have provided a solid foundation for future investigations to build upon as they ask questions more concerned with why and when this relationship is important. For now, it is sufficient for this dissertation that the relationship between temporal discounting and cooperation on the single-player iterated prisoner’s dilemma is.
Tables

*Table 1*

*Experiment 1: Experimental Groups and Labels.* Group number, order of task presentation, IPD type, and rule used for each of the eight groups. The label given to each group provides a brief summary of each group as IPD type (Instruction Type): First Task.

<table>
<thead>
<tr>
<th>Group</th>
<th>First</th>
<th>IPD Type</th>
<th>Instructions</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TD</td>
<td>Single-Player</td>
<td>Discovery</td>
<td>SP-IPD(D): TD</td>
</tr>
<tr>
<td>2</td>
<td>IPD</td>
<td>Single-Player</td>
<td>Discovery</td>
<td>SP-IPD(D): IPD</td>
</tr>
<tr>
<td>3</td>
<td>TD</td>
<td>Two-Player</td>
<td>Discovery</td>
<td>MP-IPD(D): TD</td>
</tr>
<tr>
<td>4</td>
<td>IPD</td>
<td>Two-Player</td>
<td>Discovery</td>
<td>MP-IPD(D): IPD</td>
</tr>
<tr>
<td>5</td>
<td>TD</td>
<td>Single-Player</td>
<td>Instructed</td>
<td>SP-IPD(I): TD</td>
</tr>
<tr>
<td>6</td>
<td>IPD</td>
<td>Single-Player</td>
<td>Instructed</td>
<td>SP-IPD(I): IPD</td>
</tr>
<tr>
<td>7</td>
<td>TD</td>
<td>Two-Player</td>
<td>instructed</td>
<td>MP-IPD(I): TD</td>
</tr>
<tr>
<td>8</td>
<td>IPD</td>
<td>Two-Player</td>
<td>Instructed</td>
<td>MP-IPD(I): IPD</td>
</tr>
</tbody>
</table>
Table 2

Experiment 1: Group Outcomes for the IPD game and Temporal Discounting. The outcomes from the iterated prisoner’s dilemma (IPD) game (mean and standard deviation, SD) and the temporal discounting task (median and interquartile range, Q25 and Q75) for the eight experimental groups are presented.

<table>
<thead>
<tr>
<th>Label</th>
<th>N</th>
<th>IPD¹ Mean</th>
<th>IPD¹ SD</th>
<th>K</th>
<th>R²</th>
<th>Q25</th>
<th>Q75</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP-IPD(D): TD</td>
<td>35</td>
<td>0.5766</td>
<td>0.1672</td>
<td>0.0189</td>
<td>0.8970</td>
<td>0.0021</td>
<td>0.1186</td>
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<td>SP-IPD(D): IPD</td>
<td>30</td>
<td>0.5838</td>
<td>0.2049</td>
<td>0.0220</td>
<td>0.9260</td>
<td>0.0021</td>
<td>0.1263</td>
</tr>
<tr>
<td>MP-IPD(D): TD</td>
<td>31</td>
<td>0.3646</td>
<td>0.2841</td>
<td>0.0075</td>
<td>0.9000</td>
<td>0.0012</td>
<td>0.0678</td>
</tr>
<tr>
<td>MP-IPD(D): IPD</td>
<td>30</td>
<td>0.4199</td>
<td>0.2541</td>
<td>0.0240</td>
<td>0.8940</td>
<td>0.0098</td>
<td>0.1034</td>
</tr>
<tr>
<td>SP-IPD(I): TD</td>
<td>29</td>
<td>0.5664</td>
<td>0.2322</td>
<td>0.0062</td>
<td>0.7550</td>
<td>0.0016</td>
<td>0.0192</td>
</tr>
<tr>
<td>SP-IPD(I): IPD</td>
<td>30</td>
<td>0.6761</td>
<td>0.1937</td>
<td>0.0192</td>
<td>0.9080</td>
<td>0.0100</td>
<td>0.0479</td>
</tr>
<tr>
<td>MP-IPD(I): TD</td>
<td>26</td>
<td>0.4577</td>
<td>0.2798</td>
<td>0.0139</td>
<td>0.9200</td>
<td>0.0043</td>
<td>0.0279</td>
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<tr>
<td>MP-IPD(I): IPD</td>
<td>26</td>
<td>0.4557</td>
<td>0.2620</td>
<td>0.0126</td>
<td>0.8950</td>
<td>0.0030</td>
<td>0.0989</td>
</tr>
</tbody>
</table>
Table 3

Experiment 1: Correlations for the Log-Transformed Discount Parameter. All correlations are comparing the log-transformed discount rate with the parameter listed at the column heading. TSCS is the Total Self-Control Scale from Tangney, et. al. (2004).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>First</th>
<th>Middle</th>
<th>Last</th>
<th>Total</th>
<th>TSCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Player</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructed</td>
<td>30</td>
<td>0.0837</td>
<td>0.057</td>
<td>0.2774</td>
<td>0.1582</td>
<td>0.5144**</td>
</tr>
<tr>
<td>Discovery</td>
<td>30</td>
<td>-0.0602</td>
<td>-0.2768</td>
<td>-0.3696*</td>
<td>-0.2798</td>
<td>-0.2509</td>
</tr>
<tr>
<td>Two-Player</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructed</td>
<td>26</td>
<td>-0.0543</td>
<td>0.1435</td>
<td>-0.1102</td>
<td>-0.0039</td>
<td>-0.0704</td>
</tr>
<tr>
<td>Discovery</td>
<td>30</td>
<td>-0.2376</td>
<td>-0.0283</td>
<td>-0.1538</td>
<td>-0.1437</td>
<td>-0.3018</td>
</tr>
<tr>
<td>Single-Player</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Instructed</td>
<td>29</td>
<td>-0.209</td>
<td>-0.2224</td>
<td>-0.3692*</td>
<td>-0.2919</td>
<td>-0.0575</td>
</tr>
<tr>
<td>Discovery</td>
<td>34</td>
<td>-0.0814</td>
<td>0.022</td>
<td>0.0666</td>
<td>0.0116</td>
<td>0.1559</td>
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<tr>
<td>Two-Player</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Instructed</td>
<td>26</td>
<td>-0.0277</td>
<td>-0.0457</td>
<td>-0.0871</td>
<td>-0.0618</td>
<td>-0.178</td>
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<tr>
<td>Discovery</td>
<td>31</td>
<td>-0.1251</td>
<td>-0.0242</td>
<td>-0.0892</td>
<td>-0.0791</td>
<td>0.2219</td>
</tr>
</tbody>
</table>

* P < 0.05  
** P < 0.01
Table 4

Experiment 1: Correlations for scores on the Total Self-Control Scale. Each correlation compares total score on the TSCS with the measure listed in the column label. The \( k \) column represents the log-transformed discount rate.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>IPD - Proportion Cooperation</th>
<th></th>
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<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IPD first</td>
<td>First</td>
<td>Middle</td>
<td>Last</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Single-Player</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructed</td>
<td>30</td>
<td>0.0065</td>
<td>0.0114</td>
<td>0.0957</td>
<td>0.0445</td>
<td>0.5144**</td>
<td></td>
</tr>
<tr>
<td>Discovery</td>
<td>30</td>
<td>0.1740</td>
<td>0.3610</td>
<td>0.3320</td>
<td>0.3317</td>
<td>-0.2509</td>
<td></td>
</tr>
<tr>
<td>Two-Player</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructed</td>
<td>26</td>
<td>-0.2120</td>
<td>-0.2640</td>
<td>-0.0578</td>
<td>-0.1867</td>
<td>-0.0704</td>
<td></td>
</tr>
<tr>
<td>Discovery</td>
<td>30</td>
<td>-0.1600</td>
<td>-0.2023</td>
<td>0.0916</td>
<td>-0.0860</td>
<td>-0.3018</td>
<td></td>
</tr>
<tr>
<td>IPD first</td>
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<tr>
<td>Instructed</td>
<td>29</td>
<td>-0.1878</td>
<td>-0.2783</td>
<td>0.0362</td>
<td>-0.1341</td>
<td>-0.0575</td>
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</tr>
<tr>
<td>Discovery</td>
<td>34</td>
<td>0.1002</td>
<td>-0.2215</td>
<td>-0.1766</td>
<td>-0.1337</td>
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<tr>
<td>Two-Player</td>
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<tr>
<td>Instructed</td>
<td>26</td>
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<td>-0.1964</td>
<td>-0.1551</td>
<td>-0.2236</td>
<td>-0.1780</td>
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<td>Discovery</td>
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<td>0.0263</td>
<td>0.0311</td>
<td>0.2219</td>
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</tr>
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</table>

* \( P < 0.05 \)
** \( P < 0.01 \)
Table 5

Experiment 2: Experimental groups and order of task presentation.

<table>
<thead>
<tr>
<th>Group</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SP-IPD</td>
<td>Temporal Discounting</td>
<td>Sharing Game</td>
</tr>
<tr>
<td>2</td>
<td>SP-IPD</td>
<td>Sharing Game</td>
<td>Temporal Discounting</td>
</tr>
<tr>
<td>3</td>
<td>Temporal Discounting</td>
<td>SP-IPD</td>
<td>Sharing Game</td>
</tr>
<tr>
<td>4</td>
<td>Temporal Discounting</td>
<td>Sharing Game</td>
<td>SP-IPD</td>
</tr>
<tr>
<td>5</td>
<td>Sharing Game</td>
<td>SP-IPD</td>
<td>Temporal Discounting</td>
</tr>
<tr>
<td>6</td>
<td>Sharing Game</td>
<td>Temporal Discounting</td>
<td>SP-IPD</td>
</tr>
</tbody>
</table>

PC(T) = Proportion cooperation on all 99 trials of the single-player iterated prisoner's dilemma
PO = Proportion optimal from the last 20 trials of the Fairness Game
GS = Generosity score from the first six trials of the Fairness Game
Experiment 2: The Sharing Game. The 11 choice pairs for the Sharing Game are represented. The first six choice pairs were each presented once and were used to calculate the Generosity Score. The last five choice pairs were each presented 4 times and were used to calculate the proportion optimal. The Points column indicates how many points either a choice of A or B earned toward the Generosity Score (first 6 pairs) or towards proportion optimal (last 5 pairs).

<table>
<thead>
<tr>
<th>Choice Pair</th>
<th>Choice</th>
<th>You</th>
<th>Other</th>
<th>Points</th>
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<tbody>
<tr>
<td>Generosity Score</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>A</td>
<td>6</td>
<td>8</td>
<td>1</td>
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<tr>
<td></td>
<td>B</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6</td>
<td>4</td>
<td>0</td>
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<tr>
<td>3</td>
<td>A</td>
<td>2</td>
<td>2</td>
<td>0</td>
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<tr>
<td></td>
<td>B</td>
<td>1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>0</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
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<td>A</td>
<td>5</td>
<td>5</td>
<td>1</td>
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<td></td>
<td>B</td>
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<td>0</td>
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<td>Proportion Optimal</td>
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<td>0</td>
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<tr>
<td>8</td>
<td>A</td>
<td>5</td>
<td>4</td>
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</tr>
<tr>
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<td>B</td>
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<td>7</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>A</td>
<td>7</td>
<td>9</td>
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<td>B</td>
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<tr>
<td></td>
<td>B</td>
<td>5</td>
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</table>
Table 7

Experiment 2: Groups and Descriptive Statistics. Iterated prisoner’s dilemma (IPD) is presented as mean overall proportion cooperation, PC(T) and standard deviation (SD). Discounting data is presented as median \(k\) value, median variance accounted for, \(r^2\), and the interquartile range. Sharing game data is presented as mean proportion optimal (PO) and standard deviation (SD) across the twenty trials and the mean generosity score (GS) and standard deviation (SD).

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>PC(T)</th>
<th>SD</th>
<th>k</th>
<th>(r^2)</th>
<th>25Q</th>
<th>75Q</th>
<th>PO</th>
<th>SD</th>
<th>GS</th>
<th>SD</th>
</tr>
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<tbody>
<tr>
<td>UCSD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>36</td>
<td>0.719</td>
<td>0.203</td>
<td>0.019</td>
<td>0.889</td>
<td>0.004</td>
<td>0.063</td>
<td>0.910</td>
<td>0.205</td>
<td>3.306</td>
<td>1.370</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>0.694</td>
<td>0.191</td>
<td>0.015</td>
<td>0.846</td>
<td>0.002</td>
<td>0.155</td>
<td>0.534</td>
<td>0.107</td>
<td>3.452</td>
<td>1.091</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>0.742</td>
<td>0.186</td>
<td>0.087</td>
<td>0.770</td>
<td>0.003</td>
<td>0.571</td>
<td>0.815</td>
<td>0.299</td>
<td>3.200</td>
<td>1.256</td>
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<tr>
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<td>42</td>
<td>0.676</td>
<td>0.204</td>
<td>0.035</td>
<td>0.862</td>
<td>0.005</td>
<td>0.385</td>
<td>0.795</td>
<td>0.249</td>
<td>3.191</td>
<td>1.174</td>
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<tr>
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<td>36</td>
<td>0.700</td>
<td>0.209</td>
<td>0.080</td>
<td>0.864</td>
<td>0.011</td>
<td>0.295</td>
<td>0.531</td>
<td>0.146</td>
<td>2.944</td>
<td>1.241</td>
</tr>
<tr>
<td>6</td>
<td>39</td>
<td>0.729</td>
<td>0.217</td>
<td>0.023</td>
<td>0.833</td>
<td>0.006</td>
<td>0.224</td>
<td>0.547</td>
<td>0.156</td>
<td>3.231</td>
<td>1.202</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
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<td>0.794</td>
<td>0.000</td>
<td>0.270</td>
<td>0.757</td>
<td>0.279</td>
<td>3.353</td>
<td>1.092</td>
</tr>
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<td>66</td>
<td>0.656</td>
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<td>0.088</td>
<td>0.824</td>
<td>0.015</td>
<td>0.304</td>
<td>0.511</td>
<td>0.146</td>
<td>3.212</td>
<td>1.259</td>
</tr>
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<td>56</td>
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<td>0.169</td>
<td>0.079</td>
<td>0.800</td>
<td>0.017</td>
<td>0.280</td>
<td>0.748</td>
<td>0.281</td>
<td>3.071</td>
<td>1.360</td>
</tr>
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<td>0.792</td>
<td>0.003</td>
<td>0.277</td>
<td>0.849</td>
<td>0.218</td>
<td>3.848</td>
<td>1.475</td>
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<td>75</td>
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<td>0.489</td>
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<td>3.107</td>
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<tr>
<td>6</td>
<td>46</td>
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<td>0.189</td>
<td>0.060</td>
<td>0.782</td>
<td>0.021</td>
<td>0.936</td>
<td>0.483</td>
<td>0.142</td>
<td>3.326</td>
<td>1.076</td>
</tr>
</tbody>
</table>
Table 8

Experiment 2: Correlation coefficients for Cluster 1 and Cluster 2 by School.

<table>
<thead>
<tr>
<th></th>
<th>MESA - Cluster 1 (Groups 1, 3, and 4)</th>
<th>MESA - Cluster 2 (Groups 2, 5, and 6)</th>
<th>UCSD - Cluster 1 (Groups 1, 3, and 4)</th>
<th>UCSD - Cluster 2 (Groups 2, 5, and 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First</td>
<td>Middle</td>
<td>Last</td>
<td>k</td>
</tr>
<tr>
<td>First</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Last</td>
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<tr>
<td>First</td>
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</tr>
<tr>
<td>Middle</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Last</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**p < 0.01 (2-tailed).
*p < 0.05 (2-tailed).
First, Middle, Last = Proportion Cooperation Across Blocks
k = Log-transformed discounting parameter
PO = Proportion Optimal
PG = Proportion Generous
**Table 9**

*Experiment 2: Correlation Coefficients for Group 1 and Group 3 by school*

<table>
<thead>
<tr>
<th></th>
<th>First</th>
<th>Middle</th>
<th>Last</th>
<th>k</th>
<th>PO</th>
<th>PG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MESA - Group 1 (IPD - TD - Fair)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>1</td>
<td>0.590**</td>
<td>0.341*</td>
<td>0.215</td>
<td>0.175</td>
<td>0.043</td>
</tr>
<tr>
<td>Middle</td>
<td>1</td>
<td>0.405**</td>
<td>0.126</td>
<td>0.185</td>
<td>0.277*</td>
<td></td>
</tr>
<tr>
<td>Last</td>
<td></td>
<td></td>
<td></td>
<td>-0.025</td>
<td>0.039</td>
<td>0.079</td>
</tr>
<tr>
<td>k</td>
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<td></td>
<td>0.248</td>
<td>0.216</td>
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</tr>
<tr>
<td>PO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.297*</td>
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</tr>
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<td>PG</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MESA - Group 3 (TD - IPD - Fair)</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>1</td>
<td>0.673**</td>
<td>0.309*</td>
<td>0.066</td>
<td>0.077</td>
<td>0.073</td>
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<tr>
<td>Middle</td>
<td>1</td>
<td>0.724**</td>
<td>0.061</td>
<td>-0.012</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>Last</td>
<td></td>
<td></td>
<td></td>
<td>0.093</td>
<td>0.082</td>
<td>-0.042</td>
</tr>
<tr>
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<td>1</td>
<td></td>
<td></td>
<td>0.063</td>
<td>-0.041</td>
<td></td>
</tr>
<tr>
<td>PO</td>
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<td></td>
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<td>0.505**</td>
</tr>
<tr>
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<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UCSD - Group 1 (IPD - TD - Fair)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>1</td>
<td>0.681**</td>
<td>0.684**</td>
<td>0.024</td>
<td>0.263</td>
<td>0.526**</td>
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<tr>
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<td>1</td>
<td>0.722**</td>
<td>0.038</td>
<td>0.282</td>
<td>0.566**</td>
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<tr>
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</tr>
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<td></td>
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</tr>
<tr>
<td><strong>UCSD - Group 3 (TD - IPD - Fair)</strong></td>
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<td>1</td>
<td>0.845**</td>
<td>0.735**</td>
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<td>-0.092</td>
<td>-0.014</td>
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<td>0.025</td>
<td>0.056</td>
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</tr>
<tr>
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<td></td>
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<td>-0.323</td>
<td>0.081</td>
<td>0.263</td>
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<td></td>
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<td>-0.116</td>
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</tr>
<tr>
<td>PO</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>0.681**</td>
</tr>
<tr>
<td>PG</td>
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<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**p < 0.01 (2-tailed).**

* p < 0.05 (2-tailed).

First, Middle, Last = Proportion Cooperation Across Blocks

k = Log-transformed discounting parameter

PO = Proportion Optimal

PG = Proportion Generous
Table 10

**Experiment 4: Outcomes and Correlations.** Median discounting parameter and mean cooperation for the temporal discounting and single-player iterated prisoner’s dilemma (SP-IPD) across experimental groups and the correlation coefficient between discount rate and proportion cooperation.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Temporal Discounting k</th>
<th>25Q</th>
<th>75Q</th>
<th>r²</th>
<th>SP-IPD PC</th>
<th>SD</th>
<th>r</th>
</tr>
</thead>
<tbody>
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<td>0.411</td>
<td>0.264</td>
<td>0.710</td>
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<td>0.030</td>
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<td>0.651</td>
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<td>0.008</td>
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<td>0.038</td>
<td>0.684</td>
<td>0.243</td>
<td>-0.263*</td>
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<td>0.020</td>
<td>0.390</td>
<td>0.540</td>
<td>0.660</td>
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<td>0.005</td>
<td>0.082</td>
<td>0.846</td>
<td>0.645</td>
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<td>0.876</td>
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<td>0.009</td>
<td>0.383</td>
<td>0.294</td>
<td>0.828</td>
<td>0.203</td>
<td>-0.087</td>
</tr>
<tr>
<td>H</td>
<td>60</td>
<td>0.019</td>
<td>0.006</td>
<td>0.049</td>
<td>0.752</td>
<td>0.691</td>
<td>0.251</td>
<td>0.168</td>
</tr>
</tbody>
</table>

$k =$ Fitted Equation 1 Discount Paramater (Median)

$25Q/75Q =$ Interquartile range

$r^2 =$ Variance accounted for - VAC (Median)

PC = Proportion cooperation (Mean)

SD = standard deviation

$r =$ Pearson correlation coefficient: $k$ x PC

* $p < 0.05$

* $p < 0.01$
Table 11

*Experiment 6: Correlations Across Probability of Reciprocation.* Pearson $r$ correlations between scores on the single-player IPD – discovery group (PC – SIPD), proportion cooperation on the Harris and Madden type procedure (PC – H & M) and the log-transformed discounting parameter ($k$).

<table>
<thead>
<tr>
<th></th>
<th>$K$</th>
<th>PC - SIPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(R) = 1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC - H &amp; M</td>
<td>-0.198</td>
<td>0.569**</td>
</tr>
<tr>
<td>$k$</td>
<td></td>
<td>-0.289A</td>
</tr>
<tr>
<td>P(R) = 0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC - H &amp; M</td>
<td>-0.200</td>
<td>0.120</td>
</tr>
<tr>
<td>$K$</td>
<td></td>
<td>-0.158</td>
</tr>
<tr>
<td>P(R) = 0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC - H &amp; M</td>
<td>-0.293</td>
<td>-0.160</td>
</tr>
<tr>
<td>$K$</td>
<td></td>
<td>0.356*</td>
</tr>
<tr>
<td>P(R) = 0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC - H &amp; M</td>
<td>0.004</td>
<td>-0.351*</td>
</tr>
<tr>
<td>$K$</td>
<td></td>
<td>0.146</td>
</tr>
<tr>
<td>P(R) = 0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC - H &amp; M</td>
<td>-0.074</td>
<td>-0.528**</td>
</tr>
<tr>
<td>$k$</td>
<td></td>
<td>0.353A</td>
</tr>
</tbody>
</table>

* $p < 0.05$
** $p < 0.05$
A $p < 0.10$
Figures

Hyperbolic Discounting v. Exponential Discounting. Comparison of the divergent predictions of the Exponential Discounting model and the Hyperbolic Discounting model. The hyperbolic model, bottom graph, predicts a change in preference from the larger, later outcome to the smaller, sooner outcome at time one, $T_1$, while preference for the smaller, sooner choice in the exponential model, top graph, is consistent across all delays.
Figure 2

*Multi-Player Prisoner’s Dilemma and Single-Player Prisoner’s Dilemma Payoff Matrices.* Values indicate utilities associated with the outcome for each player. Panel (A) shows the traditional prisoner’s dilemma payoff matrix. Shaded boxes are the outcomes for Player 2 and the white boxes are the outcomes for Player 1. Panel (B) shows the single-player payoff matrix. Note that Player 1 is now Trial N and Player 2 is the previous trial, N – 1.
Interpersonal v. Intrapersonal Dilemmas. Section A illustrates an individual, self, interacting with multiple external agents, P1 – P8. Section B illustrates the same general interactions, but the agents are now internal agents across multiple time periods, T1 – T8.
Figure 4

Temporal Discounting Procedure Screen Layout. Experiments 1 – 5 used this same general screen format. Responses were indicated by clicking directly on the number of the selected outcome.
Figure 5

Single-Player Iterated Prisoner’s Dilemma Screen Layout. General screen layout used in experiments 1 – 4. Choices are signaled by clicking either the button labeled A or the button labeled B.
Figure 6

Multi-Player Iterated Prisoner's Dilemma Screen Layout. Procedure used in Experiment 1. Participants signaled their choices by clicking either A or B. The computer’s choice was indicated on C or D.
Experiment 1: IPD Outcome by Type and Group. Comparison of the three block means (error bars represent standard error of the mean) for the four IPD groups: Single-Player-Instructed, SP-IPD(I), single-player-discover SP-IPD(D), multi-player-instructed, MP-IPD(I), and multi-player-discover, MP-IPD(D).
Figure 8

Experiment 2: Quick Adjusting Temporal Discounting Decision Tree. The top box is the immediately available option and the bottom box is available after a specified delay. The numbers outside and to the right of cells indicate the subjective value for that pattern of decisions.
Figure 9

Experiment 2: The Sharing Game Screen Layout. Participants indicated their choice by clicking either on button A or B. The numbers available for each choice updated between each trial. The selected pair was temporarily highlighted with yellow.
Figure 10

Experiment 2: SP-IPD Outcome by School Across the First, Middle, and Last Block. Mean and standard error of the mean (error bars) for the 33 trial blocks across the UCSD and Mesa sample.
Figure 11

Experiment 2: Sharing Game Outcome Across Schools. Mean proportion optimal across the 20 blocks of the sharing game (error bars are represent the standard error of the mean).
Figure 12

Experiments 3 – 5: Harris and Madden IPD Procedure Screen Layout. The boxes to the right and left of the center black box vary between red and green. Participant responses are recorded by clicking on either the red or green box.
### Figure 13

**Experiment 3 – 4: Comparison Between Experimental Groups.** Each box provides the temporal discounting parameters (temporal window and delayed value) and width of ranges used in the prisoner’s dilemma task. Shaded area represents the parameter that is different from comparison group A.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temporal Window</td>
<td>6 h. - 1 y.</td>
<td>6 h. - 1 y.</td>
<td>6 h. - 1 y.</td>
<td>6 h. - 1 y.</td>
<td>1 w. - 25 y.</td>
<td>1 w. - 25 y.</td>
<td>1 y. - 6 h.</td>
</tr>
<tr>
<td></td>
<td>Delayed Value</td>
<td>$10</td>
<td>$10</td>
<td>$100</td>
<td>10 iTunes</td>
<td>$100</td>
<td>$100</td>
<td>$10</td>
</tr>
<tr>
<td></td>
<td>IPD Values</td>
<td>$1 - $4</td>
<td>$1 - $4</td>
<td>$1 - $4</td>
<td>$1 - $4</td>
<td>$1 - $4</td>
<td>$5 - $25</td>
<td>$1 - $4</td>
</tr>
</tbody>
</table>

**Legend:**
- **A:** Group A
- **B:** Group B
- **C:** Group C
- **D:** Group D
- **E:** Group E
- **F:** Group F
- **G:** Group G
- **H:** Group H

- **Temporal Window:** Time frame for the experiment.
- **Delayed Value:** Monetary value received after a delay.
- **IPD Values:** Range of points accrued in the prisoner’s dilemma task.
Figure 14

Experiment 3 – 4: Observed Correlations Between Discount Rate and Proportion Cooperation. The observed correlation and level of significance across comparison groups A – H for experiments 3 and 4.
Experiment 6: Probability of Reciprocation Across Blocks. Data points represent mean cooperation across blocks of 20 trials. Error bars are the standard error of the mean. The probability of reciprocation 0.75 and 0.50 group overlap in the center of the graph.
Appendix

Discounting values and delays used in the various experiments.

**Experiment 1 & 2**

Amount: $100, $99, $97.50, $95, $92.50, $90, $85, $80, $75, $70, $65, $60, $55, $50, $45, $40, $35, $30, $25, $20, $15, $10, $7.50, $5, $2.5, and $1

Delays: 1 week, 2 weeks, 1 month, 6 months, 1 year, 5 years, and 25 years

**Experiment 3:**

Amount: $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

Delays: 6 hours, 2 days, 1 week, 2 weeks, 1 month, 2 months, 6 months, 1 year
References


Rachlin, H., Brown, J., & Baker, F. (. (2001). Reinforcement and punishment in the prisoner's dilemma game. In D. L. Medin (Ed.), *The psychology of learning and


