January 2009

Temporal Discounting: A comparison of adjusting-amount and adjusting-delay procedures

Daniel Holt
Washington University in St. Louis

WASHINGTON UNIVERSITY

Department of Psychology

Dissertation Committee:

Leonard Green, Chairperson
Lisa Connor
Sandra Hale
Joel Myerson
Mitchell Sommers

TEMPORAL DISCOUNTING: A COMPARISON OF ADJUSTING-AMOUNT AND ADJUSTING-DELAY PROCEDURES

by

Daniel D. Holt

A dissertation presented to the
Graduate School of Arts and Sciences
of Washington University
in partial fulfillment of the
requirements for the degree
of Doctor of Philosophy

August 2009

Saint Louis, Missouri

Acknowledgements

I would like to thank Len Green and Joel Myerson for their years of support and guidance throughout my graduate training. Both have been wonderfully patient teachers and model mentors. Each, in their own way, has taught me more about science and life than words can express. I would also like to thank Tony Marcattilio for his guidance in my early academic years. Thanks also to my friends and family for their continued support during this process. The journey would not have been nearly so rich if it were not for each of their unique contributions.

Table of Contents

List of Figures

Abstract

Several experimental procedures (e.g., adjusting amount, adjusting delay) have been used to study the effect that changes in amount of and delay to a reward have on the reward's subjective value. The present series of three experiments sought to test the implicit assumption that the underlying decision-making process (discounting) is identical regardless of the procedure used, and that all would converge on similar indifference points. For each of the experiments, participants were initially tested on one of the adjusting tasks (Adjusting Immediate Amount, Adjusting Delayed Amount, or Adjusting Delay) and returned a week later to complete each of the remaining adjusting tasks. The indifference points obtained from the initial adjusting task were used as the test parameters in the other two tasks. That is, when participants completed the other two adjusting tasks, the amounts and delays experienced were identical to those from the initial adjusting task. Since, in the other adjusting tasks, the participants experience the identical amounts and delays as the initial adjusting task, specific predictions, at the level of the individual, were possible. Participants in all three experiments also completed a fully randomized version of the initial choice task. The results confirmed that, regardless of the choice task used, subjective value decreased as the delay to that outcome increased. In addition, it was found that under the adjusting-delay and the adjusting-

delayed-amount tasks, but not under the adjusting-immediate-amount task, subjective value was determined not just by the amount of the outcome or the delay to its receipt, but to some degree by the manner in which the choices are presented (i.e., the context). Therefore, when investigating intertemporal choice, the adjusting-immediate-amount procedure appears to provide the most reliable and valid estimates of indifference between immediate and delayed outcomes.

TEMPORAL DISCOUNTING: A COMPARISON OF ADJUSTING-AMOUNT AND ADJUSTING-DELAY PROCEDURES

Situations often present themselves in which a decision must be made between two outcomes, one of which is available sooner than the other. At the individual level, for example, do you invest money in a retirement plan knowing you cannot have access to the money until you retire, or do you keep the money in a savings account where the interest earned is lower but you can have immediate access? At the theoretical level a fuller understanding of the factors related to how an individual evaluates the choice alternatives and then arrives at a decision is important. That is, when careful observation of choice behavior is made and the patterns of behavior are reliable, it then becomes possible to make assertions regarding potential underlying mechanisms. Therefore, how an individual evaluates the choice alternatives and arrives at a decision are important at both the individual and the theoretical level.

When people choose between large and small rewards, or when they choose between sooner and later rewards, the choices made are relatively easy to predict: Individuals typically choose the larger reward to the smaller reward, and the sooner to the later reward. Consider, however, a choice between a smaller reward to be received soon and a larger reward to be received later. In this situation each preferred choice dimension is paired with a non-preferred choice dimension. That is, immediacy (preferred) is paired with a smaller reward (non-preferred), and delay (non-preferred) is paired with the larger reward (preferred). Predicting choice behavior in this context is more difficult and less intuitive. But why might an individual forgo the larger reward for the smaller reward? According to a discounting explanation, the present (subjective) value of a reward decreases as a function of the time until its receipt (e.g., Kagel, Battalio, & Green, 1995). In the current example, then, given enough of a delay to the larger reward, the smaller-sooner reward will be preferred. Temporal discounting is the term used by economists and psychologists to refer to the decrease in the present value of a reward as the delay to its receipt increases.

There are two bodies of literature concerning the effects of delay on choice behavior: the economic and psychological. The economic literature on temporal discounting is grounded in classic economic theory which assumes rational choice behavior on the part of the decision maker. Several challenges to the assumptions of classical economic theory with regard to time preference have been raised (e.g., Loewenstein & Prelec, 1992; Thaler, 1981). For their part, psychologists have been concerned less with underlying economic principles and macroeconomic issues and more with the development of quantitative models that accurately describe empirical findings at the individual and group level.

Economics and Time Preference

Economists have attempted empirical tests of factors related to decision-making that fall under the rubric of microeconomics (e.g., consumer behavior). In the 1940s and 1950s, for example, economists came to be interested in psychological aspects of choice behavior (for a review of the historical antecedents see Fishburn, 1988, 1989; Kahneman, 1991). One group of economists was primarily interested in how people choose what to do given uncertainty about the consequences (e.g., von

Neuman & Morgenstern, 1944). That is, these economists were interested in factors related to an individuals' decisions given assumptions of rational behavior. Instances in which individual's choice behavior deviated systematically from that predicted by classic economic theory were uncovered (e.g., Loewenstein & Prelec, 1992; Thaler, 1981).

The standard economic theoretical approach to intertemporal choice was built on the framework of the general discounting model or discounting utility model (DU). In DU, the value of a future outcome decreases exponentially as the time to its receipt increases (Samuelson, 1937) and can be expressed as,

$$U_0 = \sum \delta^t u_t \,, \qquad (1)$$

where U_o is the present value of the outcome, u_t is the utility obtained from that outcome at time t, and δ is a discount factor, assumed to be less than 1.0. There are two core assumptions associated with DU: a strong form of preferential independence and stationarity. The independence property states that if two temporal prospects, X = (x1, x2, x3, ...xn) and Y = (y1, y2, y3, ...yn), share a common outcome at a given point in time, then preference between them is determined solely by the remaining (n -1) outcomes. Put another way, preferential independence assumes that if temporal prospect X is preferred over temporal prospect Y, then the addition of temporal prospect Z should not change the ordinal relationship between X and Y.

The stationarity assumption states that if the first outcome in both X and Y is the same, x1 = y1, then preference between X and Y will be preserved by dropping the first outcome and shifting the remaining outcome by one period. This assumption implies that whenever two sequences differ in only two periods, preference between them does not depend on the common outcomes in the remaining periods. For example, Equation 1 suggests that a 1-month delay will lead to the same rate of discounting if you were choosing between this month and next month or between next year and next year plus one month.

DU is a normatively based theory (i.e., one that describes what people *should* do), but many economists would argue that it also serves as a descriptive theory (predicts what the consumer *will* do). This view has received a great deal of attention by economists (as early as Strotz, 1956) and numerous systematic inconsistencies (violations) in what people do have emerged. Loewenstein and Prelec (1992) compiled a list of such violations which include: the common difference effect, the absolute magnitude effect, the gain-loss asymmetry, and the delay-speedup asymmetry (also see Thaler, 1991), each of which is summarized below.

The common difference effect refers to the dynamically inconsistent behavior found as the delay to two outcomes increases (i.e., preference reversal). For example, given a choice between $20 today and $50 in 3 months, an individual might prefer $20 today. If a constant delay of 1 year were added to each alternative, preference might reverse to the larger reward. Preference reversals were first noted by Strotz (1956) and later systematically investigated by Ainslie (1975, 1985). Preference reversals are consistent with the view that rate of discounting decreases as the delay increases, whereas DU assumes that the rate of discounting remains constant.

The absolute magnitude effect refers to the decrease in rate of temporal discounting as a function of the amount of reward. More specifically, as the amount of reward increases, the rate of discounting decreases. This effect has been demonstrated using both hypothetical (e.g., Green, Myerson, & McFadden, 1997; Kirby, 1997; Thaler, 1981) and real (e.g., Lagorio & Madden, 2005; Johnson & Bickel, 2002) rewards. The fact that smaller amounts are discounted at a higher rate than are larger amounts violates the assumption of DU that discount rates should be the same for all amounts of rewards of the same type.

The gain-loss asymmetry refers to the finding that losses are discounted at a lower rate than are gains. Thaler (1981) asked one group of participants to imagine that they were issued a traffic ticket (the size of the fine varied from relatively small to relatively large), and then informed the participants that the fine could be paid now (at face value) or that the fine could be paid later but at an increased price (the delay of payment ranged from sooner to relatively distant). Participants were then asked to indicate the amount of money they would be willing to pay to postpone paying the traffic ticket. Thaler asked another group to imagine that they had just won a lottery, and then informed them that they could take the money now or wait until later and receive a larger amount. These participants were then asked to indicate the amount of money they would require to postpone the receipt of the winnings. Thaler found that gains (lottery win) were discounted at much higher rates than were losses (traffic ticket) of equivalent amounts, and especially so with smaller outcomes. That is, when paying the fine, participants were willing to pay proportionally more immediately (lower rate of discounting) as compared to those participants in the lottery condition where they were willing to take proportionally less immediately (higher rate of discounting). Further evidence for the gain-loss asymmetry has been obtained by Loewenstein (1988) and Benzion et al. (1989). Again, DU assumes discount rates to be the same for all types of outcomes (e.g., gains and losses).

The delay-speedup asymmetry (Loewenstein, 1988) refers to the asymmetric preference between speeding up and delaying consumption. That is, the amount an individual requires to compensate for delaying the receipt of a positive outcome by a given time interval is several times greater than the amount that same individual would sacrifice to speed consumption up by the same time interval. To illustrate this effect, consider the study by Loewenstein (1988; Experiment 3) in which high-school students were told that they were to receive a $7 gift certificate to a music store. The students were told that the expected time to the receipt of the certificate was either in one, four, or eight weeks (across different groups of students). Some students were then asked to make a choice between keeping their certificate at the originally scheduled time or trading for a larger certificate to be received later, whereas other students were asked to make a choice between keeping their certificate or trading for a smaller certificate to be received earlier. For example, some subjects were asked to make a trade-off between the size of a reward and its delayed consumption from 1 week to 4 weeks, whereas other students were asked to make a trade-off between the size of a reward and its speed-up from week 4 to week 1. In all comparisons, the mean delay consumption was at least twice the mean speed-up cost. For instance, in one condition, students would accept $1.09, on average, to delay the receipt of the $7 gift certificate from 1 week from now to 4 weeks from now, whereas they were only willing to pay $0.25, on average, to speed up the delivery of the gift certificate from 4 weeks from now to 1 week from now. That is, subjects wanted more money (approximately 4 times the money) to wait past the expected arrival point than they were willing to pay to speed up its arrival (also see Benzion et al., 1989, for similar findings). This asymmetry is problematic for DU because the pairs of choices are functionally identical.

In response to the aforementioned problems of DU, Loewenstein and Prelec (1992) proposed an alternative model that takes the form of a generalized hyperbola and is represented by

$$V = v\,(1 + k\,T)^{-b/k}, \qquad (2)$$

where V is present discounted value, v is undiscounted value, T is expected delay, and k and b are positive constants. Note that when $k = b$, the equation becomes a simple hyperbola, and when k approaches 0 the equation becomes an exponential function. The form of the hyperbola allows for temporal inconsistencies for which the exponential model (Equation 1) cannot account. That is to say, only the hyperbola allows for changing rates of discounting as a function of delay.

Psychology and Time Preference

As mentioned previously, a larger reward typically will be preferred to a smaller reward, but if one had to wait a period of time before the larger reward could be obtained, then the smaller reward might be the preferred alternative. Preference reversals make apparent the importance of an outcome's temporal aspect. For example, one might prefer to receive $100 right now rather than $120 one month from now. If, however, the choice were between $100 in one year and $120 in 13 months, one might choose the $120. Notice that preference reverses from the smaller-sooner reward to the larger-later reward as an equal amount of time is added to the receipt of both alternatives.

Preference reversals may be represented as shown in Figure 1 (e.g., Ainslie, 1975). The vertical axis represents the subjective, or discounted, value of a future reward, and the horizontal axis represents time. In this representation, the further to the left, the further in time from the rewards, and moving to the right (from T_1 to T_2) represents moving closer in time to the rewards. The heights of the bars represent the actual reward amounts. The curves show how their subjective values might change as a function of the time at which the rewards are evaluated. Such curves are termed discounting functions because they indicate how the value of a future reward is devalued with its delay. According to the representation in Figure 1, if one were offered the choice between the smaller-sooner (SS) and the larger-later (LL) rewards at time 1 (T_1), well in advance of when the smaller reward can be obtained, one would chose LL, whereas if one were offered a choice between the same rewards at time 2 (T_2), one would chose SS.

Preference reversals are a violation of the stationarity assumption that underlies the discounted utility model of classic economic theory. Preference reversals can be accounted for, however, if the form of the discounting function takes a hyperbolic form (as illustrated in Figure 1).

The results of studies with both humans and nonhuman animals show violations of the stationarity assumption and are consistent with a discounting account. For example, in a study by Green, Fisher, Perlow, and Sherman (1981), pigeons chose, by pecking illuminated response keys, between two alternatives. A peck to one response key led to a smaller-sooner food reward, and a peck to the other response key led to a larger-later food reward (see procedural schematic in Figure 2). In this procedure there were two distinct trial periods: the first period (30 s in duration) was the choice period, and the second period (10 s in duration) was the outcome period. In different conditions, the pigeons' were presented with the illuminated keys at different points in time within the 30-s choice period, and a key peck to either response key led to its respective outcome. For example, in one condition the choice opportunity was presented 25 s before the outcome period (see the top diagram in Figure2), whereas in another condition the choice opportunity was presented 5 s before the outcome period (see the bottom diagram in Figure 2).

As can be seen in Figure 3, when the choice was offered further in advance of the outcome period, analogous to T_1 in Figures 1 and 2, each pigeon strongly preferred the larger-later reward. When the choice was offered shortly before the outcome period, analogous to T_2, each pigeon demonstrated a reversal in preference, now strongly preferring the smaller-sooner reward.

Using a procedure similar to Green et al. (1981), Green, Fristoe, and Myerson (1994) observed preference reversals in humans making choices between hypothetical monetary rewards. Figure 4 shows that as the delay to both choice alternatives (i.e., $20 and $50) was increased while the interval between the two alternatives (time between receipt of the SS and receipt of the LL) was held constant (e.g., at 1 year), the percentage of participants who reversed their preference and chose the later, $50 reward increased, as predicted by the discounting account. Preference reversals, such as these, have been demonstrated over a considerable range of species (both human and nonhuman) and procedures (Ainslie & Haendel, 1983; Ainslie & Herrnstein, 1981; Green & Estle, 2003; Kirby & Herrnstein, 1995; Mazur, 1987; Rachlin & Green, 1972; Rodriguez & Logue, 1988).

According to the discounting account represented in Figure 1, preference reversals occur because the subjective value of the larger-later reward decreases more slowly as its receipt becomes more delayed than does the subjective value of the smaller-sooner reward. However, this description of the discounting of smaller and larger rewards does not greatly constrain the form of the discounting function, even though the shape of the function is assumed to underlie the preference-reversal phenomenon. Recent efforts to determine the actual form of the temporal discounting function have been motivated by a desire to better understand preference reversals, as well as by the fact that different function forms have different theoretical implications for the discounting process.

There is a growing body of research attempting to elucidate the form of the discounting function. In early work, for instance, Mazur (1987) had pigeons make choices between smaller-sooner and larger-later food rewards. Mazur used an adjusting-delay procedure to find points of subjective equivalence (indifference points) between SS and LL rewards. Specifically, Mazur presented pigeons with the choice between 2-s access to grain after a fixed delay and 6-s access to grain after a delay that systematically increased or decreased as a function of the pigeon’s previous choices. For example, if the pigeon chose 2-s access to grain delayed by 2 s, then the delay to the 6-s access to food would decrease by 1 s for the next trial. If the pigeon chose the larger (6-s access to grain) alternative, then the delay to that alternative would be increased by 1 s for the next trial. When the length of delay to the larger alternative stabilized, it was treated as the indifference point for that given set of conditions (e.g., 2-s delay followed by 2-s access to grain versus an adjusted delay value followed by 6-s access to grain). Across conditions, the delay to the 2-s access to grain was either: 0, 1, 2, 6, 10, 12, 14, or 20 s. Since all pigeons were tested across a range of conditions, several indifference points were obtained, each indifference point representing the different amount and delay of reinforcement combinations equally preferred by a pigeon.

Given the range of indifference points, Mazur (1987) was able to evaluate the descriptive ability of several quantitative models of choice that take into account reinforcers of various amounts and delays. The first model was the simple reciprocal equation, in which reinforcer value is directly proportional to its amount and inversely proportional to its delay. The equation takes the form:

$$V = A / k D , \qquad (3)$$

where V is the subjective value, A is the amount of delayed reward, D is the delay to the receipt of the reward, and k is a scaling parameter. This reciprocal equation (which follows from the generalized matching law) is appealing because it has one free parameter and presents a simple relationship between reinforcer value, amount, and delay. The free (*weighting*) parameter, k, represents rate of discounting. A large k value represents a high rate of discounting, a steeper curve, whereas a smaller k value represents a lower rate of discounting. The equation predicts that a truly immediate reinforcer will always be chosen over a later reward, regardless of their respective amounts. This problem was easily remedied by a second equation in which 1 was added to the denominator of Equation 1. The resulting equation takes the form:

$$V = A / (1 + k D) , \qquad (4)$$

and was labeled hyperbolic (Mazur, 1987, 1988).

A third model is the exponential, representative of Samuelson's (1937) standard Discounting Utility model, and which assumes a certain amount of risk inherent with any reward in which the receipt is delayed a specified period of time:

$$V = A^{-k D}. \qquad (5)$$

This "rational" model assumes a constant hazard rate, or stationarity, and leads directly to a temporal discounting function in the form of an exponential decay. A criticism of this model is that it does not, by itself, predict preference reversals unless the discounting rate for a larger amount is assumed to be lower than the discounting rate for a smaller amount (Green et al., 1981; Green & Myerson, 1993). Mazur (1987) found that the hyperbolic equation (Equation 4) better described the obtained data in his experiment than the reciprocal (Equation 3) or exponential decay (Equation 5) functions.

The iterative choice procedure of Mazur (1987), termed the *adjusting- delay procedure*, has been used to assess the present value of some distal reward across a variety of manipulations (Mazur, 1984, 1985, 1986, 1987; Mazur, Snyderman, & Coe, 1985). The adjusting-delay procedure serves to hone in on an indifference point between a smaller-sooner and a larger-later reward through systematic adjustments of the length of delay to the larger reward. For example, a subject may be presented a choice between a given smaller-sooner reward and a given larger reward where there would be a range of delays to the larger reward. Notice here that the dimension that is adjusted by the participant is the length of the delay to the larger reward, and the experimenter controls the size of the immediate reward and the size of the larger reward. As such, the dependent variable in an adjusting-delay procedure is the length of the delay to the larger reward.

The adjusting-delay procedure has proven to be an efficient method for eliciting indifference points across a range of choice parameters allowing for tests among the descriptive abilities of several models of choice (e.g., Christensen, Parker, Silberberg, & Hursh, 1998). Rodriguez and Logue (1988) employed this sort of iterative procedure as a test of the cross-species (pigeon and human) generality of temporal discounting and found that the hyperbolic model (Equation 4) well described the obtained results for both pigeon and human. Pigeons, however, tend to discount rewards at a much higher rate than humans, as indicated by the size of their discount parameter (e.g., k as found in Equation 4). Despite the differences in discount rates (k) across organisms, Rodriguez and Logue found that a hyperbolic model provided a better description of the empirical data than did the exponential decay model.

An alternative, but related, choice task, referred to as the *adjusting-amount procedure*, often is employed to determine the amount of a (usually) hypothetical reward that can be received immediately and whose amount is adjusted until it is judged approximately equivalent in value to a larger reward that is to be delivered after a given period of time (e.g., Rachlin, Raineri, & Cross, 1991; see also Green et al., 1997; Green et al., 1994). Like the adjusting-delay procedure, the adjusting-amount procedure adopts an iterative procedure that serves to hone in on the indifference value (present, subjective value). In an adjusting-amount procedure, a subject is asked to indicate the immediate (present) value of a delayed outcome. There are several adjusting-amount procedures but the two most common procedures include a paper-and-pencil task and an iterative computer program. The paper-and-pencil task requires participants to make a choice between an immediate-smaller amount and a larger-delayed amount where the size of the smaller amount varies on each subsequent choice. For example, a participant might be asked to indicate his/her preference between \$198 available immediately and \$200 available after 6 months on the first choice, and then be asked to indicate preference between \$195 available immediately and \$200 available after 6 months on the second choice, and so on.

The iterative computer program also requires participants to make a series of choices between smaller-immediate rewards and larger-delayed rewards but in this case the size of the smaller reward is adjusted based on prior choice. For example, a participant might be asked to indicate preference between \$100 available immediately and \$200 available after 6 months on the first choice and then, depending on the option selected, the size of the immediate reward would be increased or decreased. If the participant chooses \$200 in 6 months over \$100 now, the next choice would be between \$150 available immediately and \$200 in 6 months. If the participant chooses the immediate alternative on the first choice (i.e., \$100 now over $200 in 6 months), then the next choice would be between $50 available immediately and $200 in 6 months. This iterative procedure continues as a means of honing in on the size of the immediate reward that is subjectively equivalent to the larger, delayed reward.

The commonality between the adjusting-amount procedures is that the dimension that is adjusted by the participant is the amount of the immediate reward, and the experimenter controls the delay to and the size of the larger reward. As such, the dependent variable in an adjusting-amount procedure is the amount of the immediate reward. The obtained immediate amount is referred to as the subjective value because it represents the amount that is subjectively equivalent to the larger but later reward.

Data gathered via adjusting-amount procedures suggest that the hyperbolic model (Equation 4) describes temporal discounting of children, college-age, and older adults better than the exponential (Equation 5) (e.g., Green, Myerson, & Ostaszewski, 1999a). The hyperbolic equation has been shown to describe temporal discounting across large and small hypothetical rewards (e.g., Green et al., 1997), under circumstances with extreme rates of inflation (Ostaszewski, Green, & Myerson, 1998), across cultures (Du, Green, & Myerson, 2002), in terms of health (Chapman, 1996), in gamblers and addicts (e.g., Petry & Casarella, 1999), and in smokers (Mitchell, 1999). Additionally, the hyperbolic equation not only describes group average data but also accounts for discounting at the individual level when an adjusting-amount procedure is used (e.g., Green, Myerson, & Ostaszewski, 1999b; Myerson & Green, 1995).

Statement of the Problem

There are several possible approaches one could take when attempting to gain an understanding of choice behavior with regard to delayed rewards. Two typical methodologies are the adjusting-delay procedure and an adjusting-amount procedure. With an adjusting-delay procedure, the experimenter controls the size of the smaller-immediate and larger rewards, and the participant reports the length of time s/he would be willing to wait for the larger reward. With an adjusting-amount procedure, the experimenter controls the size of and delay to the larger outcome, and the participant reports the amount s/he would be willing to accept immediately. Both procedures serve to establish a point of indifference between a smaller-immediate and larger-delayed reward. Regardless of the approach used, however, the question is always the same: How does delaying a reward affect that reward's present value?

There is a tacit assumption that the underlying decision-making process (discounting) is identical regardless of the methodology used to establish the indifference points. This assumption may be based on animals' always choosing the option with the highest value (Rachlin, 1992). Although each of the methodologies, adjusting amount and adjusting delay, have demonstrated their usefulness in evaluating models of choice behavior in terms of delayed rewards, the only published research that has made a direct comparison of the procedures is in the non-human literature using pigeons (Green, Myerson, Shah, Estle, & Holt, 2007). Here pigeons were given a choice between a smaller-sooner outcome and a larger-later outcome. In different conditions of the experiment, either the size of the smaller-sooner outcome was adjusted or the length of the delay was adjusted based on the pigeon's previous choice. The purpose of both task types was to arrive at a point of indifference between the smaller-sooner and larger-later outcome. Green et al. then used these indifference points as the test parameters for the other task. That is, if a pigeon first completed the adjusting-amount task, it then completed a yoked adjusting-delay task. In the yoked adjusting-delay task the test values were yoked to the values obtained from the adjusting-amount procedure. If a pigeon first completed the adjusting-delay task, the obtained indifference points were then yoked to the adjusting-amount task. The central question was whether similar rates of discounting would be observed between the two task types. The pigeons in the Green et al. study were consistent in their rates of discounting between the task types. In spite of the finding that the same rates of discounting were obtained under both procedures, important questions still remain regarding the cross-species generality of decision making (e.g., Green, Myerson, Holt, Slevin, & Estle, 2004), and some of these questions will be discussed later. For instance, humans may be differentially affected by previous choices in ways that are different from non-humans (e.g., pigeons).

The present work further evaluates whether the indifference points obtained with adjusting-amount and adjusting-delay procedures will be quantitatively similar using equivalent amounts and delays. In other words, would an individual arrive at the same indifference point given an adjusting-amount procedure and adjusting-delay procedure under similar delay and amount parameters? This issue is not only of theoretical interest; it has implications for everyday decision making which often involves outcomes that differ on multiple dimensions, one of which includes the way in which the indifference point is obtained.

Consider the situation in which an individual is studied via an adjusting-amount procedure where the size of the immediate reward is varied. Let's say, for example, that the individual arrives at a subjective value of $940 now relative to $1000 in 2 months. That is to say, for that individual, $940 now is subjectively equivalent to $1000 in 2 months. The individual could now be studied with an adjusting-delay procedure in which the delay to the larger reward is varied. Would that individual be willing to wait 2 months for the $1000 relative to receiving $940 now? Of critical importance here is that the monetary amounts and delays are the same across the two procedures. The only difference, then, is whether the amount of the immediate reward or the delay to the larger reward is adjusted by the participant. If the decision-making process is independent of such methodological differences, then the individual should arrive at about the same indifference point (2 months in the current example).

The Current Study

In a typical discounting paradigm, participants are asked to make a series of choices between a smaller, immediate reward and a larger, delayed reward (e.g., "Would you prefer to receive $100 now or $200 in 3 months?"). In such a discounting choice paradigm there are three choice variables that can be manipulated: (1) the amount of the immediate reward; (2) the amount of the larger but delayed reward; and (3) the delay to the larger reward. The current study involves three experiments in which participants made choices between immediate smaller rewards and delayed larger rewards. For each of the experiments, each participant was tested on an adjusting task (i.e., Adjusting Immediate Amount, Adjusting Delayed Amount, and Adjusting Delay) where one choice dimension varied systematically. In each of the three experiments participants also were tested on a fully randomized choice task (explained later).

Each participant was tested in two separate sessions, each session separated by approximately one week. During the first session, participants were tested on one of the adjusting tasks. The subjective values, or indifference points, obtained from the first session's task then were used the following week as the test values in each of the remaining adjusting tasks. The goal of these experiments was to determine if, when holding the choice parameters constant, each of the varied tasks would yield similar indifference points. The distinction among the three experiments was the choice task used in the first session. In the first experiment, a group of participants first was tested on the Adjusting Immediate Amount (AIA) task and returned in approximately one week and completed the remaining two choice tasks (i.e., Adjusting Delayed Amount, ADA, and Adjusting Delay, AD); in the second experiment, another group of participants first was tested on the ADA task and returned approximately one week later to complete the remaining two choice tasks (i.e., AD and AIA); and in the third experiment, another group of participants was first tested on the AD task and returned approximately one week later to complete the remaining two choice tasks (i.e., AIA and ADA).

In addition to the adjusting choice tasks, participants in all three experiments completed an additional task that was designed to address the issue of anchoring as related to the discounting tasks used. In each of the three adjusting tasks, one of the choice dimensions was varied systematically from choice to choice while the other choice dimensions remained unchanged. As a result of varying only one of the choice dimensions, the participant might place greater weight on the dimension that is being varied. If there were to be systematic differences between the subjective indifference points obtained from the different procedures, then those differences could be due to differential weighting of the dimension being varied. For example, in the AIA task the immediate amount is systematically adjusted until it is judged equal in value to a larger but delayed amount. Because only the amount of the immediate reward systematically changes in the AIA task, the task itself may lead participants to give more weight to the choice dimension that varies – the immediate amount. The purpose of the fully randomized version of this task was to determine if participants place greater weight on the choice dimension that is varied. If differential weighting of choice dimensions were to be found, then this would be a challenge to the underlying assumption that regardless of the approach used, valuation of delayed outcomes should be the same regardless of how the question is posed. Furthermore, any systematic differences between the task types would call into question the validity of those measures, especially if comparisons are being made between the task-types. If trying to gain a fuller understanding of the factors that may contribute to the discounting of delayed outcomes, it is important to evaluate the potential effects of task type and/or variation of the choice dimensions on choice behavior.

General Method

Participants

Approximately equal numbers (N = 31-36) of young adults (age 18-21 years) participated in each of the three experiments, resulting in a total of 100 participants. All participants were recruited via the subject pool of the Psychology Department of Washington University and received course credit as compensation for participation.

Procedure

Each of the 3 experiments involved 2 separate testing sessions. The first session served to establish a series of baseline indifference points for each participant. These baseline indifference points were then used as the starting points for the second testing session, which was completed approximately 1 week following the first session. There a total of 102 participants that completed the first session with 2 participants not returning to complete the second testing session.

In the first session, participants were asked to sign a consent form and complete a brief demographics questionnaire. Following completion of the demographics questionnaire, participants completed a computer-based discounting task. Before the start of the discounting task, each participant received verbal and written instructions as well as a set of practice trials to become familiar with the task. To minimize the likelihood of participants remembering their specific choices from session 1 to session 2, there was an interval of approximately one week between sessions. In addition to the one-week interval, participants performed several similar, but non-critical, decision-making tasks during the first testing session. These non-critical tasks were presented in a manner consistent with the critical test items, but the amounts and delays presented were different from those used in the critical tests. Although participants were not asked if they remembered their choices from the previous week, it was expected that with the one-week interval between sessions, the number of choices in the discounting task (144 total), and the additional tasks, it would be unlikely that they would remember their specific choices from session 1 to session 2.

At the beginning of the discounting tasks, participants were instructed that they would be making choices between hypothetical amounts of money presented on a computer screen. They were told that their choices would be between an amount that could be received immediately and another amount that could be received after a given delay. Participants were also instructed that there are no correct or incorrect responses and that they should select the option they prefer. For each subsequent choice, the adjusted value was either increased or decreased as a function of the current choice. For each amount x delay condition, participants made a total of 6 choices (details as to the specific amount and delay conditions will follow). This iterative method of adjustment is designed to converge rapidly on the indifference point. Total time to complete the first session was never more than 45 min.

Adjusting Immediate Amount Task. For the Adjusting Immediate Amount Task (AIA), individuals were asked to indicate their preference between a smaller, immediate reward and a larger, delayed reward where the size of the smaller immediate reward was systematically varied and the amount of and delay to the larger reward was held constant. There were 2 delayed amounts ($200 and $40,000) available at each of six delays (2 weeks, 1 month, 6 months, 1 year, 3 years, and 6 years), for a total of 12 conditions. The order of presentation of the 12 conditions was randomized for each participant.

For the AIA task, the smaller-immediate reward is varied, in an iterative manner, as a means of honing in on the individual's indifference points. That is, the program was designed to reveal the immediate amount that is subjectively equivalent in value to the larger, delayed reward. For instance, in the $200 in 6 months condition, the participant first chose between $100 now and $200 in 6 months (on the first choice, the immediate amount was always half the delayed amount). If the participant selected the $100 now, then the subsequent choice would be between $50 now and $200 in 6 months. If on that choice the immediate $50 was selected, then the next choice was between $25 now and $200 in 6 months. If the participant now chose the $200 in 6 months, then the next choice was between $37 now and $200 in 6 months. Notice that the change in size of the immediate amount was always half the prior amount in a direction towards indifference. This process was repeated for each amount x delay condition yielding a total of 12 indifference points.

Adjusting Delay Task. For the Adjusting Delay Task (AD), individuals were asked to indicate their preference between a smaller, immediate reward and a larger delayed reward in which the length of the delay to the larger amount was systematically varied while the amounts of the smaller and larger rewards were held constant. The delay to the larger reward was varied, in an iterative manner, as a means of honing in on indifference between the length of the delay to the larger reward that makes the smaller, sooner reward subjectively equivalent in value to the larger reward.

There were 2 delayed amounts ($200 and $40,000) each of which was paired with six different immediate amounts, for a total of 12 conditions. The order of presentation of the 12 conditions was randomized for each participant. When the delayed amount was $200, in different conditions the immediate amounts were $190, $155, $100, $50, $20, and $10. When the delayed amount was $40,000, in different conditions the immediate amounts were $38,000, $31,000, $20,000, $10,000, $4,000, and $2,000.

The iterative process was very similar to that experienced in the AIA task but with the length of delay to the larger outcome being varied. For example, say the participant made a choice between an immediate $100 and $200 delayed by 3 years. If the immediate alternative were selected, the next choice was between an immediate $100 and $200 delayed by 1.5 years. If the individual then chose the delayed alternative, the next choice was between an immediate $100 and $200 delayed by 2 years and 3 months. This process was repeated for each amount x delay condition yielding a total of 12 indifference points.

Adjusting Delayed Amount Task. For the Adjusting Delayed Amount Task (ADA), participants were asked to indicate their preference between a smaller, immediate and larger, delayed amount of money in which the amount of the delayed alternative was systematically varied while the immediate amount and delays were held constant. The amount of the delayed reward was varied, in an iterative manner, as a means of honing in on indifference between the smaller, immediate reward and the delayed reward, that is, an amount of a delayed reward that is subjectively equivalent to the smaller, immediate reward. There were two immediate monetary amounts ($100 and $1,000) and six delays to the larger reward (2 weeks, 1 month, 6 months, 1 year, 3 years, and 6 years), for a total of 12 conditions. The order of presentation of the 12 conditions was randomized for each participant.

As was the case in the AIA and the AD tasks, the iterative process in this task continued for a total of 6 choices and served to systematically hone in on the point where the present alternative was subjectively equivalent to the delayed alternative. In the ADA task, however, the amount of the delayed reward was varied. Again, this process was repeated for each amount x delay condition, yielding a total of 12 indifference points.

Fully Randomized Task. There were three Fully Randomized tasks: a Fully Randomized version of the AIA task, a Fully Randomized version of the AD task; and a Fully Randomized version of the ADA task. For the Fully Randomized tasks, individuals were asked to indicate their preference between a smaller, immediate reward and a larger, delayed reward. These tasks differed from each of the adjusting-type tasks, however, in that there was no immediately obvious, systematically varied, single dimension along which choice differed. The Fully Randomized tasks served as a test for potential effects of adjusting-type choice tasks where the alternative that is adjusting is readily apparent. In the aforementioned adjusting-type tasks, one of the choice dimensions was varied systematically from choice to choice in an effort to identify subjective equivalence while the two other choice dimensions remained unchanged. As a result of the systematic manipulation, a participant might place differential weight on the choice dimension that was varied.

For each of the three experiments, the critical reward amounts and delays were identical to those used in the initial task. That is to say, participants first completing the AIA task experienced the identical choice questions in the anchoring task, but the presentation of each of the choice questions was randomized. Likewise, those participants initially experiencing the ADA or AD tasks were presented with identical choice questions, respectively, but the presentation of each of the choice questions was randomized. Recall that in the AIA task, for example, the size of the immediate reward systematically changed from question to question, and the delayed amount and the length of the delay did not change as the participant worked through a specific condition. The randomization of the presentation of the questions in the anchoring task eliminated the systematic adjustment of one of the choice alternatives.

In effect, there were 12 concurrently operating conditions in the Fully Randomized tasks, and the computer program randomly selected one condition to display at a time, for one choice, and then replaced that condition and sampled the conditions again for the next choice to be presented. This random sampling of conditions continued until all 12 indifference points were established. Of note here is that the iterative process was still in place in this task and that there were a total of 6 questions per condition. For example, the participant might first have been presented with a choice between $34,000 now and $40,000 in 2 weeks, then presented with a choice between $100 now and $200 in 6 months, then presented with a choice between $1,140 now and $1,200 in 2 years, etc. The distinguishing feature with this task was that once a choice had been made, the next choice was from a randomly selected amount x delay condition. Of importance here is that when the participant returned to a specific amount x delay condition, the presented choice was based on the previous choice made in that specific amount x delay condition (i.e., the same iterative process as used in the other tasks).

Experiment 1

Participants

A total of 31 individuals participated in this experiment. There were 12 males and 19 females.

Procedure

During the first testing session, participants completed both the standard AIA task and the Fully Randomized AIA task. The 12 indifference points obtained from the standard AIA task provided the test values for the second testing session in which the participant completed the AD and ADA tasks. For example, if the participant found $145 to be subjectively equivalent to $200 in 6 months, then when returning to complete the ADA task, that same participant was asked to indicate preference between an immediate $145 and various larger amounts delayed by 6 months. Likewise, when completing the AD task, that same participant was asked to indicate preference between an immediate $145 and a delayed $200, where the length of delay was systematically varied.

In the second session, participants completed 12 conditions of the ADA task and 12 conditions of the AD task. At issue was whether the values for the delayed amount and the delay obtained from the second session would match the values from session 1. (In the previous example, this would correspond to obtaining a delayed amount of $200 in the ADA task and a delay of 6 months in the AD task). Half of the subjects completed the ADA task followed by the AD task, whereas the other half completed the tasks in the reverse order (order of tasks was randomly determined). Once a task had been selected, the order of conditions within each task was presented randomly.

Experiment 1 Results

Figure 5 shows the median discounting data for both the standard and Fully Randomized AIA tasks from each amount condition ($200 and $40,000) from session 1. Notice, for both amounts, that as the delay to receipt of the outcome increased the subjective value decreased. Compared to the smaller amount condition, the delayed reward had a much greater subjective value in the larger amount condition. This finding is consistent with the magnitude effect in which larger amounts are discounted less steeply than are smaller amounts. Regardless of the size of the delayed amount, however, visual inspection of Figure 5 reveals no obvious systematic differences between the results for the standard AIA (closed triangles) and the Fully Randomized AIA tasks (open triangles) procedures.

The curves in Figure 5 represent Equation 4 fit to the median subjective values obtained from the standard AIA and Fully Randomized AIA tasks. At the group level, discounting was well described by Equation 4 for both tasks, and this was true for both delayed amounts (all R^2s > .88). Equation 4 was also fit to individual data. Individual fits were done at each amount for both the standard AIA and Fully Randomized tasks resulting in 4 discount curves for each participant. In the standard AIA task, the means of the individual *k* values were .074 (standard error = .036) and .004 (standard error = .001) for the smaller and larger amounts, with mean R^2s of .73 and .69, respectively. For the Fully Randomized task, the corresponding means of the individual *k* values were 0.042 (standard error = 0.036) and 0.030 (standard error = 0.026) with mean R^2s of .77 and .65, respectively). A series of paired sample *t*-tests revealed no significant differences in *k* values or R^2s between the two task types at either amount (all $ps > .30$). There was a significant effect of amount; the smaller amount was discounted more steeply than the larger amount ($t(30) = 11.519$, $p < .001$).

Figure 6 shows the relationship between obtained and predicted indifference points for the three pairs of discounting tasks. In each panel, the data are collapsed across delay conditions such that each bar represents the grand mean of the ratio of the values for the task types being compared, with the standard or non-yoked version of the task in the denominator. Specifically, ratio values for the smaller and larger delayed amount conditions were calculated for each participant at each delay condition. These ratio values were then logged and then averaged to get each participant's mean log ratio. The ratios were logged for each individual because the points were highly positively skewed. Logging the values resulted in normally distributed data. The ratios presented in Figure 6 are the anti-logs of the logged means.

The top panel shows the mean ratios of the adjusted immediate amount values obtained in the Fully Randomized and standard versions of the AIA tasks for both the smaller and larger delayed amount conditions. To assess the consistency in choice behavior between the tasks, each participant's adjusted immediate amount value from the Fully Randomized version of the AIA task was divided by the amounts obtained in the corresponding delay conditions of the standard AIA task. These ratio values were then logged and then averaged. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed no significant at either the smaller (t (30) = -1.052, p = 0.301) or the larger delayed amount condition (t (30) = -1.499, p = 0.114). In the figure, a ratio of 1.0 would indicate no difference between the task types.

The middle panel of Figure 6 shows the adjusted delays obtained in the yoked AD task expressed as the ratio of their predicted values for both the smaller and larger delayed amount conditions (a ratio value of 1.0 would indicate no difference between the obtained delays from the yoked AD task and the delays experienced in the AIA task). Recall that participants first experienced the AIA task in order to generate predictions as to their behavior on the other yoked procedures. Participants first adjusted the smaller-immediate outcome until it was judged equal in value to a fixed, larger-later outcome (2 larger outcomes at each of 6 delays). At issue was whether, in the second procedure (AD), given a previously obtained value for the immediate amount, participants would adjust the length of the delay until it was equal to that experienced in the AIA task. For each participant, ratio values (delay values from the yoked AD task / delay values from the standard AIA task) for each condition were calculated. These ratio values were logged and averaged to get each participant's mean log ratio for both the smaller and larger amount conditions. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed no significant difference between the obtained and predicted delay values for the smaller amount condition (t (30) = -1.754, p = .090), but there was a significant difference for the larger amount condition (t (30) = 4.792, p < .001).

The bottom panel shows the adjusted delayed amounts obtained in the yoked ADA task expressed as a ratio of their predicted values (i.e., the delayed amounts experienced in the AIA task) for both the smaller and larger delayed amount conditions. At issue was whether, in the second procedure (ADA), participants would adjust the delayed amount until it was about the same as that experienced in the AIA task (i.e., $200 or $40,000). For each participant, ratio values (delayed amounts from the yoked ADA task / delayed amounts from the standard AIA task) for each delay condition were calculated at both the small and larger amount conditions. These ratio values were logged and averaged to get each participant's mean log ratio for both the smaller and larger amount conditions. One sample *t*-tests on the means of the logged ratios revealed no significant difference in either the smaller (t (30) = 1.672, p = .105) or the larger delayed amount condition (t (30) = -.718, p = .478).

Experiment 1 Discussion

The data from Experiment 1 suggest that similar degrees of discounting are observed on standard and fully randomized adjusting immediate amount procedures. The fully randomized task differed from the standard AIA task in that there was no immediately obvious systematically varied dimension - but the critical reward amounts and delays were identical to those used in the initial AIA task. This is important because it is possible that a discounting procedure could establish different reference points (e.g., Kahneman & Tversky, 1979) depending on which variable changes from trial to trial. That is, as a result of the systematic manipulation, the participant might place greater weight on, or anchor, the choice dimension that was varied. The data from both procedures yielded discount functions that were equally well described by a simple hyperbola, and at both the group (median) and individual levels, rates of discounting on the Fully Randomized and AIA tasks were similar.

Recall that the indifference points determined the values of the independent variables in the yoked AD and yoked ADA tasks. For the yoked AD task, participants made a series of choices between amounts that could be received immediately (which were obtained from their choices on the initial AIA task) and larger (either $200 or $40,000) delayed amounts. In this task, the length of the delay to the larger amount was systematically adjusted based on the participant’s choices in order to estimate the indifference point. It was predicted that the delays at which the subjective value of the delayed amount was equivalent to that of the immediate amount would be similar to those experienced in the initial AIA task. Although the results for the smaller delayed amount condition were consistent with this prediction, in the larger amount condition participants were willing to wait, on average, longer than would be predicted based on the delays experienced in the AIA task. In terms of discounting, this translates to less discounting with the AD task when amounts are larger.

For the yoked ADA task, participants made a series of choices between amounts that could be received immediately (which were obtained from their choices on the initial AIA task) and a larger delayed amount. In this task, the length of delay to the larger amount was the same as that experienced in the initial AIA task. Here, however, the delayed amount was systematically adjusted based on the participant's choices in order to estimate the indifference point. It was predicted that the delayed amounts whose subjective values were equivalent to that of the immediate amount would be similar to the delayed amounts experienced in the initial AIA task (either $200 or $40,000). When collapsed across the various delays, there were no significant differences between the obtained and predicted delayed amounts in either the smaller or larger delayed amount conditions.

Experiment 2

Participants

33 individuals participated in this experiment. There were 14 males and 19 females.

Procedure

During the first testing session, participants completed both the standard AD and the Fully Randomized AD tasks. The 12 indifference points obtained from the standard AD task provided the test values for the second testing session in which the participant completed the AIA and ADA tasks. For example, if the participant found an immediate $190 to be subjectively equivalent to $200 in 1.5 months, then when returning to complete the AIA task, that same participant was asked to indicate preference between $200 delayed by 1.5 months and various immediate amounts.

Likewise, when completing the ADA task, that same participant was asked to indicate preference between an immediate $190 and various delayed amounts to be received in 1.5 months.

In the second session, participants completed 12 conditions of the AIA task and 12 conditions of the ADA task. At issue was whether the values for the immediate and delayed amounts obtained from the second session would match the values from session 1. (In the previous example, this would correspond to obtaining an immediate amount of $190 in the AIA task and a delayed amount of $200 in the ADA task). Half of the subjects completed the ADA task followed by the AIA task, whereas the other half completed the tasks in the reverse order (order of tasks was randomly determined). Once a task was selected, the order of conditions within each task was presented randomly.

Experiment 2 Results

Figure 7 shows the median discounting data for both the AD and Fully Randomized tasks from both the smaller (top panel) and larger (bottom panel) delayed amount conditions. It should be noted that the x-axis is actually the dependent measure in this case. The data are plotted in this manner to allow for direct comparison to the results from the AIA task in Experiment 1 and the prior literature. For both the smaller and larger delayed amounts, subjective value decreased as delay to receipt of the outcome increased. Notice also that the lengths of delays were different across the 2 amount conditions. Compared to the smaller amount condition, the delays in the larger condition were much longer. This finding is consistent with the magnitude effect in which larger amounts are discounted less steeply than are smaller amounts. The finding that at the same delay, the subjective value of the larger delayed amount is a greater proportion of its actual value than is the subjective value of the smaller delayed amount is also consistent with the magnitude effect.

The curves in Figure 7 represent Equation 4 fit to the median subjective values obtained from the standard AD and Fully Randomized AD tasks. At the group level, discounting was well described by Equation 4 for both tasks, and this was true for both delayed amounts (all R^2s > .87). Equation 4 was also fit to individual data at each amount for both the standard AD and Fully Randomized tasks resulting in 4 discounting curves for each participant. In the AD task, the mean of the individual *k* values were 0.045 (standard error = .011) and 0.007 (standard error = .002) with mean R^2 of .76 and .71, for the smaller and larger amounts respectively. For the Fully Randomized task, the means of the individual *k* values were 0.040 (standard error = 0.01) and .003 (standard error = 0.0005) with mean R^2s of .76 and .63 for the $200 and $40,000 delayed amounts, respectively. Paired sample *t*-tests revealed a significant difference in *k* values between the two task types for the larger amount (t (31) = 2.350, p = .025) but not for the smaller amount, and no significant difference in R^2s between the two task types at either amount.

Figure 8 shows the overall relationship between obtained and predicted indifference points for the three pairs of discounting tasks. In each panel, the data are collapsed across delays such that each bar represents the grand mean of the ratio of the values for the task types being compared. As was done in Experiment 1, the ratios were logged because they were highly positively skewed. Logging the values resulted in normally distributed data. The ratios presented in Figure 8 are the anti-logs of the logged means.

The top panel shows the mean ratios of the adjusted delays obtained in the Fully Randomized and standard versions of the AD tasks for both the smaller and larger delayed amount conditions. A ratio of 1.0 would indicate no difference between the task types. To assess the consistency in choice behavior between the tasks, each participant's adjusted delay from the Fully Randomized version of the AD task was divided by the delays obtained in the corresponding delay conditions of the standard AD task. These ratio values were then logged and then averaged. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed differences between the standard and Fully Randomized AD tasks at both the smaller (t (32) = 3.745, p = .001) and larger amounts (t (32) = 5.080, $p < .001$). This difference reflects the fact that the adjusted delays from the Fully Randomized task were longer than the obtained delays from the standard AD task.

The middle panel of Figure 8 shows the adjusted immediate amounts obtained in the yoked AIA task expressed as the ratio of their predicted value (i.e., the immediate amounts experienced in the AD task) for both the smaller and larger amount conditions. Recall that participants first experienced the AD task in order to generate predictions as to their behavior on the other yoked procedures. At issue was whether, in the second procedure (AIA), participants would adjust the immediate amount until it was equal to that experienced in the AD task (a ratio value of 1.0 would indicate no difference between the obtained immediate amounts from the yoked AIA task and the immediate amounts experienced in the AD task). For each participant, ratio values (immediate amounts from the yoked AIA task / immediate amounts from the standard AD task) for each condition were calculated. These ratio values were logged and averaged to get each participant's mean log ratio for both the smaller and larger amount conditions. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed no significant difference for the small delayed amount condition (t (31) = 0.723, p = .475), but there was a difference for the large delayed amount condition (t (31) = 4.788, $p < .001$), reflecting the fact that the adjusted immediate amounts were larger than was predicted.

The bottom panel of Figure 8 shows the adjusted delayed amounts obtained in the yoked ADA task expressed as the ratio of their predicted values (i.e., the delayed amounts experienced in the AD task) for both the smaller and larger delayed amount conditions. At issue was whether, in the second procedure (ADA), participants would adjust the delayed amount until it was about the same as that experienced in the AD task (i.e., $200 or $40,000). For each participant, ratio values (delayed amounts from the yoked ADA task / delayed amounts from the standard AD task) for each condition were calculated. These ratio values were logged and averaged to get each participant's mean log ratio for both the smaller and larger amount conditions. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed a significant difference for the small delayed amount condition (t (31) = 2.948, p = .006), reflecting the fact that the adjusted delayed amounts were larger than was predicted, but no significant difference for the large amount condition (t (31) = -0.833, p = .411).

Experiment 2 Discussion

The data from Experiment 2 suggest that the Fully Randomized and standard AD tasks lead to different rates of discounting. That is, for both the smaller and larger delayed amount conditions, discounting appeared to be greater on the standard AD task. Recall that the Fully Randomized task differed from the standard task in that there was no immediately obvious systematically varied dimension, but the critical reward amounts and delays in both tasks were identical. The difference in discounting on the two tasks is a potentially important finding because it suggests that systematically varying the delay on the standard AD procedure may affect participants' reference points (e.g., Kahneman & Tversky, 1979). That is, as a result of the systematic manipulation, participants might place greater weight on, or anchor, the choice dimension that was systematically varied. In the present experiment, both AD procedures yielded discount functions that were equally well described by a simple hyperbola, but at the level of the group, the rates of discounting were different. Because discounting was greater with the standard AD task, it appears that participants became differentially sensitive to the delays (which were changing from choice to choice) on this task, suggesting that their decisions about delays were affected by preceding questions.

Recall that the standard AD task was used to establish a series of indifference points that were then used in both a yoked AIA task and a yoked ADA task. For the yoked AIA task, participants made a series of choices between amounts that could be received immediately and a larger (either $200 or $40,000) delayed amount, using delays whose durations were established in the initial AD task. In the AIA task, the immediate amount was systematically adjusted based on participants' previous choices in order to find an estimate of the indifference point. It was predicted that the participants would adjust the immediate amounts to values similar to those experienced in the initial AD task. Consistent with this prediction, there was, on average, no difference at the $200 condition. For the $40,000 condition, however, there was a difference between the yoked AIA and standard AD tasks. Here participants required a larger immediate reward on the yoked AIA task than predicted based on their choices on the standard AD task at larger amounts. In terms of discounting, this translates to less discounting on the yoked AIA task than predicted.

For the yoked ADA task, participants made a series of choices between amounts that could be received immediately and a larger delayed amount, using delays whose durations were established in the initial AD task. In the yoked ADA task, the delayed amount was systematically adjusted based on participants' previous choices in order to determine their indifference points. It was predicted that participants' would adjust the amount of the delayed reward to values similar to those experienced in the initial AD task (either $200 or $40,000). In the $200 delayed amount condition, but not the $40,000 condition, there was a significant difference between the obtained and predicted delayed amounts. In the initial AD procedure, participants indicated how long they were willing to wait for a larger amount relative to an immediate but smaller amount. When they were presented with those delays in the ADA task, the participants required a larger delayed amount than predicted. In terms of discounting, this translates to more discounting on the yoked ADA task than on the AD task.

Experiment 3

Participants

At total of 36 individuals participated in this experiment. There were 10 males and 26 females.

Procedure

During the first testing session, participants completed both the standard ADA and the Fully Randomized ADA tasks. The 12 indifference points obtained from the standard ADA task provided the test values for the second testing session in which the participant completed the AIA and AD tasks. For example, if the participant found $100 to be subjectively equivalent to $132 in 2 weeks, then when returning to complete the ADA task, that same participant would be asked to indicate preference between an immediate $100 and various larger amounts delayed by 2 weeks. Likewise, when completing the AIA task, that same participant would be asked to indicate preference between some immediate amount and $132 in 2 weeks, where the amount of the immediate reward was systematically varied.

In the second session, participants completed 12 conditions of the AD task and 12 conditions of the AIA task. At issue was whether the values for the immediate amounts and the delays obtained from the second session would match the values from session 1. (In the previous example, this would correspond to $100 in the AIA task and 2 weeks in the AD task.) Half of the subjects completed the AIA task followed by the AD task whereas the other half completed the tasks in the reverse order (order of tasks was randomly determined). Once a task had been selected, the order of conditions within each task was presented randomly.

Experiment 3 Results

Figure 9 shows the median discounting data for both the standard ADA and Fully Randomized ADA tasks from each immediate amount condition ($100 and $1,000). Notice that for both amount conditions, the delayed amount increases as a function of delay to its receipt. That is, as the delay to the larger outcome is increased, the delayed amount also increases. Although no specific mathematical form for the relationship between the delayed amount and the delay to receiving the reward has been hypothesized, the data suggest an orderly relationship of the type expected. That is, it would be expected that as the delay to receiving a reward increases, the amount of delayed reward that would be equivalent to a fixed immediate amount should increase. This increase in amount of the delayed reward would serve to offset the discounting of the value of that outcome as the delay to its receipt increased. Also notice that there are no apparent systematic differences between the standard and Fully Randomized tasks.

Figure 10 shows the overall relation between obtained and predicted indifference points for the three pairs of discounting tasks. In each panel, the data are collapsed across amounts such that each bar represents the grand mean of the ratio of the values for the task types being compared. As was done in Experiments 1 and 2, the ratios were logged because they were highly positively skewed. Logging the values resulted in normally distributed data. The ratios presented in Figure 10 are the anti-logs of the logged means.

The top panel shows the ratios of the adjusted delays obtained in the Fully Randomized and standard versions of the ADA tasks for both the smaller and larger immediate amount conditions. A ratio of 1.0 would indicate no difference between the task types. To assess the consistency in choice behavior between the tasks, each participant's adjusted delayed amount from the Fully Randomized version of the ADA task was divided by the delays obtained in the corresponding delay conditions of the standard ADA task. These ratio values were then logged and then averaged. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed no significant difference for the small immediate amount condition, (t (32) = 0.490, p = .627) but there was a significant difference in the large immediate amount condition (t (32) = -3.099, p = .004) reflecting the fact that the delayed amounts obtained from the Fully Randomized version of the ADA task were smaller than those from the standard version of the task.

The middle panel of Figure 10 shows the adjusted immediate amounts obtained in the yoked AIA task expressed as a ratio of their predicted values (i.e., the immediate amounts experienced in the ADA task) for both the smaller and larger immediate amount conditions. Recall that participants first experienced the ADA task in order to generate predictions as to their behavior on the other yoked procedures. Participants first adjusted the delayed amount until it was judged equal in value to a fixed, immediate outcome at 6 delays in each of the two ($100 and $1,000) immediate amount conditions. At issue was whether, in the second procedure (AIA), participants would adjust the immediate amount until it was equal to that experienced in the ADA task. For each participant, ratio values (immediate amounts from the yoked AIA task / immediate amounts from the standard ADA task) for each condition were calculated. These ratio values were logged and averaged to get each participant's mean log ratio for both the smaller and larger amount conditions. One sample *t*-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed a significant difference for the smaller immediate amount condition (t (30) = 3.12, p = .004), reflecting the fact that the adjusted immediate amounts in this condition were larger than predicted, but no significant differences were observed for the larger immediate amount condition (t (30) = 1.33, p = .193).

The bottom panel of Figure 10 shows the adjusted delays obtained in the yoked AD task expressed as the ratio of their predicted values (i.e., the delays experienced in the ADA task) for both the smaller and larger amount conditions. At issue was whether, in the second procedure, participants would adjust the delays until it was the same as those experienced in the ADA task. For each participant, ratio values (delay value from the yoked AD task / delay values from the standard ADA task) for each condition were calculated. These ratio values were logged and averaged to get each participant's mean log ratio for both the smaller and larger amount conditions. One sample t-tests (because the ratios were logged the critical value = 0) on the means of the logged ratios revealed no significant difference for the small amount condition (t(30) = -1.50, p= .143), but there was a difference for the large amount condition ($t(30) = 3.03$, $p = .005$), reflecting the fact that the adjusted delays were longer than predicted.

Experiment 3 Discussion

The data from Experiment 3 suggest that there is an orderly functional relation between the delayed amount equal in subjective value to a fixed immediate amount and the length of the delay; not surprisingly, as the delay increases, there is an increase in the delayed amount. This finding is important because this is the first experiment to systematically study discounting using an ADA procedure. The data are consistent with discounting in that as the delay increased the amount of delayed reward necessary to counteract the increased degree of discounting and hold subjective value constant increased. The data also appear consistent with previous findings of a magnitude effect. That is, when looking at the proportions of the delayed amounts there are systematic differences between the $100 and $1,000 conditions. In terms of proportions, the delayed amount for the $100 condition was consistently larger than that of the $1,000 condition. In terms of discounting, this translates to steeper discounting with the smaller amount, a finding that is consistent in the delay discounting literature.

The data suggest that the Fully Randomized and standard ADA tasks lead to different rates of discounting. Specifically, for the larger immediate amount condition discounting appeared to be greater with the Fully Randomized task. Recall that the Fully Randomized task differed from the standard ADA task in that there was no immediately obvious systematically varied dimension, but the immediate reward amounts and delays were identical to those used in ADA task. This difference between the standard and Fully Randomized ADA task is a potentially important finding because it is possible that systematically varying the delayed amount affects participants' reference points (e.g., Kahneman & Tversky, 1979). In this case, differences in the results between the task types appear to also be related to the size of the outcome. That is, the ADA task appears to be differentially sensitive to changes across more than one context-- decisions about delayed amounts are affected by preceding questions and the amount of the immediate reward involved.

The ADA task was used to establish a series of indifference points that provided values for yoked AIA and AD tasks. For the yoked AIA task, participants made a series of choices between amounts that could be received immediately and a larger delayed amount (the amount obtained from the initial ADA task). In the AIA task, the immediate amount was systematically adjusted based on participants' previous choices. It was predicted that the immediate amounts that participants found equal in value to the delayed amounts would be similar to those experienced in the initial ADA task. Data from the smaller immediate amount condition show that participants required, on average, larger immediate amounts as the delays to the later rewards increased. For the larger immediate amount condition, there was no overall difference between the task types. In the smaller immediate amount condition, the observed difference translates to less discounting on the AIA task than predicted from the ADA task.

For the yoked AD task, participants made a series of choices between amounts that could be received immediately (either $100 or $1,000) and a larger delayed amount obtained from the initial ADA task. In this task, the length of the delay to the larger amount was systematically adjusted based on participants' previous choices in order to determine the delay at which the immediate reward was subjectively equivalent to the delayed reward. It was predicted that participants would adjust the delays to the values experienced in the initial ADA task. This was true in the smaller immediate amount condition, but in the larger immediate amount condition, participants were willing to wait longer than predicted for the delayed reward, indicating that it was discounted less steeply than on the ADA task.

General Discussion

The present series of experiments were designed to address the question as to whether similar discounting of delayed rewards would be observed when participants make choices using different experimental procedures that have been studied in the literature. The implicit assumption in the literature is that the underlying decision-making process (discounting) is identical regardless of the procedure used to establish the indifference points. The present work tested this assumption by evaluating whether similar indifference points would be obtained from each of the procedures studied.

Three experiments were conducted in which participants experienced four different decision-making tasks: standard AIA, AD, and ADA tasks, and a Fully Randomized version of one of those tasks. Differing between the experiments was the order in which the tasks were experienced. In Experiment 1, participants first completed a standard and then Fully Randomized version of the AIA task, followed a week later by the completion of the AD and ADA tasks. In Experiment 2, participants first completed a standard and then Fully Randomized version of the AD task, followed a week later by the completion of the AIA and ADA tasks. In Experiment 3, participants first completed a standard and the Fully Randomized version of the ADA task, followed a week later by the completion of the AIA and AD tasks. The test values used for the standard and Fully Randomized tasks were identical. The only variation between these task types was the manner in which each choice trial was presented. In all three experiments, the completion of the standard task served to derive a series of indifference points which then were used as the test values for the remaining task types.

The results from each of the three experiments appear to be consistent with previous findings regarding discounting. That is, in each of the three experiments participants were affected by increases in the delay to the receipt of an outcome in a similar way: As the delay to the reward increased, the present value of that reward decreased, and the decrease in the present value of the reward was well described by a hyperbolic function. The magnitude effect, a reliable finding in the discounting literature, also was observed in all three experiments: Smaller delayed amounts were discounted more steeply than larger delayed amounts. These findings support the validity of the various tasks and confirm their generality.

The results from Experiment 1 (AIA) showed there to be no significant differences between the standard and Fully Randomized versions of the task. This is in contrast to Experiment 2 (AD) and Experiment 3 (ADA) where significant differences between the standard and Fully Randomized tasks were found with both smaller and larger amounts. This difference in results suggests that decisions about delays are affected by preceding questions, whereas, decisions about immediate amounts are not. The preceding questions under the AD task, in which delays are adjusted, led to shorter delays than were obtained on the fully randomized version of the task. That is, as the delays changed systematically from choice to choice, relatively more weight appears to be placed on the delay, which then translates into a higher degree of discounting on the standard AD task. Even though there was a higher degree of discounting on the standard AD task, the data from the Fully Randomized and standard versions of the task were both well described by the same mathematical function. If the same psychological process were to underlie decisions made in both cases, then the fact that the same mathematical function describes both equally well is a necessary but not a sufficient condition. The same process may underlie decision making (qualitatively similar), regardless of how the alternatives are presented, but there remain quantitative differences in the rate of discounting. It appears that the difference is driven by how the delayed outcomes are presented.

Within task-type comparisons (Expt. 1 AIA versus Expt. 2 AIA; and Expt. 2 AD versus Expt. 1 AD) also reveal differences between the AIA and AD task types. That is, when comparing discounting across the AIA tasks in Experiments 1 and 2 no reliable differences are observed (see Figure 11). Notice that the range of delays experienced was different for both the smaller and larger amount conditions (top and bottom panels, respectively) and that at each amount condition the range of delays differed between the standard AIA and Yoked AIA. Despite the differences in delays experienced (and that these are between subject comparisons), discounting on the AIA tasks was remarkably similar.

In contrast, when comparing discounting between the AD tasks, differences at the larger amount are apparent (see bottom panel of Figure 12). The finding of a difference at the larger amount is potentially interesting given that the differences between the AD and AIA tasks found in Experiments 1 and 2 were also found only in the larger amount conditions. Since the AIA task produced similar discounting both between the Fully Randomized and Standard tasks as well as between experiments, the difference found between the AIA and AD tasks would appear to derive from inconsistencies with the AD task. That is, the fact that participants discount larger amounts on the AIA and AD tasks differently is likely to be due to the AD task. Again, this pattern of results suggests that decisions about delays are affected by preceding questions. As was the case with the AIA tasks, there were large differences in the range of delays between the AD tasks. Unlike the AIA tasks, however, the range of delays may have affected discounting on the AD task.

The reliability in findings between the AIA task-types indicates that both the standard and the fully randomized versions are well suited for assessing the subjective value of a delayed outcome. That is, the data from the AIA tasks suggest that regardless of how the question is posed, individuals will provide consistent indifference points across a range of delays and at both smaller and larger amounts. This suggests that, although the AD task may prove informative in specific ways (discussed later), when choosing between delay discounting tasks, the AIA task may be superior to AD tasks.

The results from Experiment 3 (ADA) also point to differences between the standard and Fully Randomized versions of the ADA task. This difference is similar to that of Experiment 2 (AD) in that there appears to be context dependency on decision making with delayed outcomes. In Experiment 3, the significant difference was isolated to the larger amount condition and indicates that the Fully Randomized version of the task leads to shallower discounting than the standard version. With the standard ADA task, however, the type of context dependency is slightly different than that of the standard AD task (where it was the delay that changed from trial to trial). With the standard ADA task the amount of the delayed outcome changes from trial to trial. This suggests that context dependency is not isolated to that of the varying delays but also can involve delayed outcomes where the outcome varies from choice to choice. More generally speaking, it may be better to think of context dependency as including the entirety of the delayed outcome, not just the delay to that outcome.

Deviations between predicted and obtained values are apparent when looking at the results from the yoked AIA and AD tasks in Experiment 3. With the yoked AIA task there was a significant difference at the smaller amount condition where the adjusted immediate amounts were larger than those initially presented in the standard ADA task. This is in contrast to the findings from Experiment 1 where the adjusted delayed amounts by the participants on the yoked ADA were consistent with those experienced in the initial standard AIA task. If the degree of discounting were consistent across all AIA tasks then any deviation from predicted value would be due to the ADA task. This inconsistency between experiments is potentially problematic, however, when trying to establish some degree of internal consistency. That is, if differences are observed between the yoked AIA and standard ADA tasks in Experiment 3, it would be expected that a similar pattern of differences would be found in Experiment 1 (yoked ADA and standard AIA).

One factor that may have contributed to this apparent inconsistency is the variable that co-varied with the length of delay across conditions. In Experiment 3, participants first completed the standard ADA task followed by the yoked version of the AIA task. When participants returned to complete the yoked AIA task in Experiment 3, the delayed amounts were those that were established in the initial ADA task. That is, the size of the delayed amounts varied across delay conditions when participants completed the yoked AIA task. This is in contrast to Experiment 1 where the delayed amount was always the same ($200) but the length of the delay changed across conditions when completing the standard AIA task. Also important is that in Experiment 1, the size of the immediate amount varied across delay conditions when participants completed the yoked ADA task. This is in contrast to Experiment 3 where the immediate amount was always the same ($100) but the length of the delay changed across conditions when completing the standard ADA task. Within-task comparisons can be problematic because the specific procedure used to determine indifference points varied along more than one dimension. That is, given that there are procedural differences between the tasks in Experiments 1 and 3, it becomes difficult to isolate the determining factor as to why there are inconsistencies in the findings. If one were to assume, however, that the AIA task produces consistent results, then any differences observed between the AIA and ADA tasks is likely due to the context dependency of the ADA task. Here, however, context dependency likely depends on an interaction between a combination of factors which may include the previous choices made and the outcome amounts.

The same issue is present when comparing the results between Experiment 3 and Experiment 2 (ADA and AD). Here the ADA and AD tasks are both context dependent which makes it difficult to isolate the important factor of context. What can be said, however, is that the contextual factors appear to be related both to the previous choices made and to the overall size of the outcome, both of which may vary depending on the task type.

Given that the rate of discounting on both the AD and ADA tasks (Experiments 2 and 3) appear to be context dependent, researchers should approach using these task types with caution. If, however, contextual factors are of interest, then these task types may provide an excellent avenue of study. That is, if one were to investigate the specific effects of how previous decisions might influence current choice, then comparisons between the standard and the fully randomized version of the AD task may be particularly useful. With the AD task there is a body of literature from which to draw direct comparisons and an established body of findings with regard to the specific form of the discount function. The overall utility of the ADA task, however, is likely to be less than that of the AD task. The lack of utility is due to the inconsistent findings between the standard and fully randomized versions of the task, where significant differences were found at the larger amount condition. Furthermore, the mathematical form for the relationship between the delayed reward and the delay to receiving the reward cannot be evaluated, making empirical and theoretical connections to the discounting literature difficult.

Recall that Green et al. (2007) examined whether adjusting-amount and adjusting-delay tasks provide equivalent measures of discounting in pigeons with real food rewards. In that study, pigeons were given a choice between a smaller-sooner outcome and a larger-later outcome. In different conditions of the experiment, either the size of the smaller-sooner outcome was adjusted (analogous to the AIA task) or the length of the delay was adjusted (analogous to the AD task) based on the pigeon's previous choice. The purpose of both task types was to arrive at a point of indifference between the smaller-sooner and larger-later outcome which was then used as the test parameters for the other task. The central question was whether similar rates of discounting would be observed between the two task types. In contrast to the present study, the pigeons in the Green et al. study were consistent in their rates of discounting between the task types.

It is notable that between species consistencies in findings would be important for a general process approach to temporal discounting, but the inconsistency in the findings between the current study and the Green et al. (2007) study may be due to one or more important factors. For example, in the Green et al. study, hungry pigeons were given access to real food rewards whereas in the current study the participants experienced hypothetical monetary outcomes. However, when comparing the discounting of real and hypothetical outcomes (e.g., Lagorio & Madden, 2005) or hypothetical consumable and generalized token rewards (e.g., Estle, Green, Myerson, & Holt, 2007), delay discounting appears to be qualitatively similar in humans regardless of outcome type. Other inconsistencies between human and non-human discounting were revealed by Green, Myerson, Holt, Slevin, and

Estle (2004) where they failed to find a reliable effect of amount of reward on rate of discounting by pigeons and rats. This is in contrast to findings from Estle et al. (2007) where a significant effect of amount was found for delayed consumable outcomes. In the Estle et al. study, however, the consumable outcomes were hypothetical and the participants were not deprived, whereas the pigeons experienced the outcome (food pellets) and were food deprived. Despite these procedural differences, the inconsistency between humans and non-human animals is important to note because amount effects are a robust finding in the human discounting literature. Therefore, the inconsistencies found between the current and related animal study (Green et al., 2007) are not an isolated case.

Kahneman and Tversky (1979) revealed how shifts in reference points (e.g., a gain versus a loss) affect choices that humans make under uncertainty. That is, the choices made depend on how those choice situations are described. Loewenstein (1988) also has shown, under conditions of intertemporal choice, that reference points affect decision making. Loewenstein, in particular, found that individuals require more to delay an outcome than they are willing to pay to speed its delivery. Loewenstein attributed this asymmetrical pattern of choice behavior to differing reference points in the respective choice situations.

In the Loewenstein (1988) study, some individuals were told about an immediately available outcome and then were told that they could have the receipt of that outcome delayed for some period of time. The individuals were asked to indicate the amount of money they would need to have to offset the delay period (delay premium). In another situation, individuals were told that they will receive an outcome at some specified future time and then were asked how much they would be willing to give up to receive the outcome immediately (speed-up). Loewenstein found that individuals required much more money to compensate for delaying the receipt of the outcome than they were willing to give up to speed-up the delivery of that outcome.

The inconsistencies across tasks in the present series of experiments also may be related to “reference points” in the AD and ADA tasks. With the AD task, a participant made a series of choices between an immediately available outcome and a delayed outcome, neither of which changed in amount from choice to choice. Since both the immediate and delayed amounts remained constant across a series of choices, this may have produced a unique reference point where the length of the delay became relatively more important. Recall that with the standard AD task, participants were less willing to wait than with the fully randomized version of the AD task. Direct comparison to the choice asymmetry found by Loewenstein (1988) is not available within the current series of experiments, but the present results do suggest that a similar effect may be present in a standard AD task.

With the standard ADA task, a participant made a series of choices between an immediately available amount and an amount that was delayed, and both the immediate amount and the length of the delay were held constant from choice to choice. The reference point here may have been established by the constancy of the immediate amounts across the series of choice trials (either $100 or $1,000). With the standard ADA task, participants required a larger delayed amount than they did on the fully randomized ADA task (at least in the larger amount condition). The standard AD and ADA tasks produced steeper discounting than did their respective fully randomized version. With both the AD and ADA tasks, the immediate amount remained unchanged across a series of choices. It may be that holding the immediate amount constant across a series of choices leads to greater weighting of that amount.

The present findings reveal a systematic relation between the present value of an outcome and the delay to its receipt. That is, as the delay to a reward increases, its subjective value decreases. What has been uniquely revealed in the current series of experiments is that some discounting choice tasks have an unplanned effect on the subjective value of an outcome. That is to say, with AD and ADA tasks, subjective value is determined not just by the size of the outcome or the delay to its receipt, but to some degree by the manner in which the choices themselves are presented. Therefore, when investigating intertemporal choice, the AIA task is likely to produce the most reliable and valid estimates of indifference between immediate and delayed outcomes.

References

Ainslie, G. (1975). Specious reward: A behavioral theory if impulsiveness and impulse control. *Psychological Bulletin, 82,* 463-469.

Ainslie, G. (1985). Derivation of rational economic behavior from hyperbolic discount curves. *The American Economic Review, 81,* 334-353.

Ainslie, G., & Haendel, V. (1983). The motives of the will. In E. Gottheil, K. A. Druley, T. E. Skoloda, & H. M. Waxman (Eds.), *Etiologic aspects of alcohol and drug abuse* (pp. 119-140). Springfield, IL: Charles C. Thomas.

Ainslie, G., & Herrnstein, R. J. (1981). Preference reversal and delayed reinforcement. *Animal Learning & Behavior, 9,* 476-482.

Benzion, U., Rappoport, A., & Yagil, J. (1989). Discount rates inferred from decisions: An experimental study. *Management Science, 35,* 270-284.

Chapman, G. B. (1996). Temporal discounting and utility for health and money. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 771-791.

Christensen, J., Parker, S., Silberberg, A., & Hursh, S. (1998). Trade-offs in choice between risk and delay depend on monetary amounts. *Journal of the Experimental Analysis of Behavior, 69,* 123-139.

Du, W., Green, L., & Myerson, J. (2002). Cross-cultural comparisons of discounting delayed and probabilistic rewards. *Psychological Record, 52,* 479-492.

Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2007). Discounting of monetary and directly consumable rewards. *Psychological Science, 18,* 58-63.

Fishburn, P. C. (1988). Expected utility: An anniversary and a new era. *Journal of Risk and Uncertainty, 1,* 267-283.

Fishburn, P. C. (1989). Foundations of decision analysis: Along the way. *Management Science, 35,* 387-405.

Green, L., & Estle, S. J. (2003). Preference reversals with food and water reinforcers in rats. *Journal of the Experimental Analysis of Behavior, 79,* 233-242.

Green, L., Fisher, E. B., Jr., Perlow, S., & Sherman, L. (1981). Preference reversal and self-control: Choice as a function of reward amount and delay. *Behaviour Analysis Letters, 1,* 43-51.

Green, L., Fristoe, N., & Myerson, J. (1994). Temporal discounting and preference reversals in choice between delayed outcomes. *Psychonomic Bulletin and Review, 1,* 398-389.

Green, L., & Myerson, J. (1993). Alternative analysis for the analysis of self control. *Behavior and Philosophy, 21,* 37-47.

Green, L., Myerson, J., Holt, D. D., Slevin, J. R., & Estle, S. J. (2004). Discounting of delayed food rewards in pigeons and rats: Is there a magnitude effect? *Journal of the Experimental Analysis of Behavior, 81,* 39-50.

Green, L., Myerson, J., & McFadden, E. (1997). Rate of temporal discounting decreases with amount of reward. *Memory and Cognition, 25,* 715-723.

Green, L., Myerson, J., & Ostaszewski, P. (1999a). Amount of reward has opposite effects on the discounting of delayed and probabilistic outcomes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 418-427.

Green, L., Myerson, J., & Ostaszewski, P. (1999b). Discounting of delayed rewards across the life span: age differences in individual discounting functions. *Behavioral Processes, 46,* 89-96.

Green, L., Myerson, J., Shah, A. K., Estle, S. J., & Holt, D. D. (2007). Do adjusting-amount and adjusting-delay procedures produce equivalent estimates of subjective value in pigeons? *Journal of the Experimental Analysis of Behavior, 87,* 337- 347.

Johnson, M. W., & Bickel, W. K. (2002). Within-subject comparison of real and hypothetical money rewards in delay discounting. *Journal of the Experimental Analysis of Behavior, 77,* 129-146.

Kagel, J. H., Battalio, R. C., & Green, L. (1995). *Economic choice theory: An experimental analysis of animal behavior.* New York: Cambridge University Press.

Kahneman, D. (1991). Judgment and decision making: A personal view. *Psychological Science, 2,* 142-145.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47,* 263-291.

Kirby, K. N. (1997). Bidding on the future: Evidence against normative discounting of delayed rewards. *Journal of Experimental Psychology: General, 126,* 54-70.

Kirby, K., & Herrnstein, R. J. (1995). Preference reversals due to myopic discounting of delayed reward. *Psychological Science, 6,* 83-89.

Lagorio, C. H., & Madden, G. J. (2005). Delay discounting of real and hypothetical rewards III: Steady-state assessments, forced-choice trials, and all real rewards. *Behavioral Processes, 69,* 173-187.

Loewenstein, G. F. (1988). Frames of mind in intertemporal choice. *Management Science, 34,* 200-214.

Loewenstein, G. F., & Prelec, D. (1992). Anomalies in intertemporal choice: Evidence and interpretation. In G. Loewenstein & J. Elster (Eds.), *Choice over time* (pp. 119-145). New York: Russell Sage Foundation.

Mazur, J. E. (1984). Test of an equivalence rule for fixed and variable reinforcer delays. *Journal of the Experimental Psychology: Animal Behavior Processes, 10,* 426-436.

Mazur, J. E. (1985). Probability and delay of reinforcement as factors in discrete-trial choice. *Journal of the Experimental Analysis of Behavior, 43,* 341-351.

Mazur, J. E. (1986). Choice between single and multiple delayed reinforcers. *Journal of the Experimental Analysis of Behavior, 46,* 67-77.

Mazur, J. E. (1987). An adjusting delay procedure for studying delayed reinforcement. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analysis of behavior, 5: The effects of delay and of intervening events of reinforcement value* (pp. 55-73). Hillsdale, NJ: Erlbaum.

Mazur, J. E. (1988). Estimation of indifference points with an adjusting-delay procedure. *Journal of the Experimental Analysis of Behavior, 49,* 37-47.

Mazur, J. E., Snyderman, M., & Coe, D. (1985). Influences of delay and rate of reinforcement on discrete trial choice. *Journal of Experimental Psychology: Animal Behavior Processes, 11,* 565-575.

Mitchell, S. M. (1999). Measures of impulsivity in cigarette smokers and non-smokers. *Psychopharmacology, 146,* 455-464.

Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of the Experimental Analysis of Behavior, 64,* 263-276.

Ostaszewski, P., Green, L., & Myerson, J. (1998). Effects of inflation on the subjective value of delayed and probabilistic rewards. *Psychonomic Bulletin and Review, 5,* 324-333.

Petry, N. M., & Casarella, T. (1999). Excessive discounting of delayed rewards in substance abusers with gambling problems. *Drug and Alcohol Dependence, 56,* 25-32.

Rachlin, H. (1992). Diminishing marginal value as delay discounting. *Journal of the Experimental Analysis of Behavior, 57,* 407-415.

Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior, 17,* 15-22

Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. *Journal of the Experimental Analysis of Behavior, 55,* 233-244.

Rodriguez, M., & Logue, A. W. (1988). Adjusting delay to reinforcement: Comparing choice in pigeons and humans. *Journal of Experimental Psychology, 14,* 105-117.

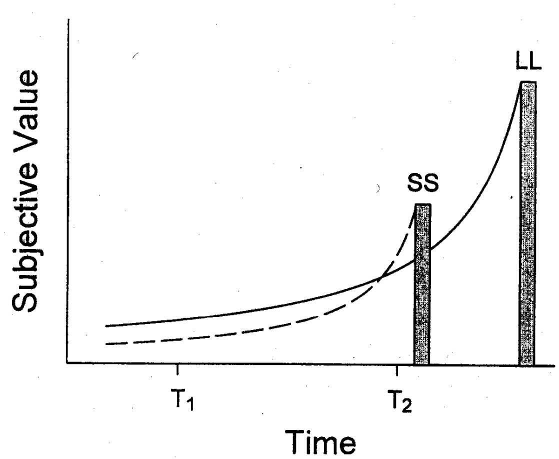
Samuelson, P. A. (1937). A note on measurement of utility. *Review of Economic Studies, 4,* 155-161.

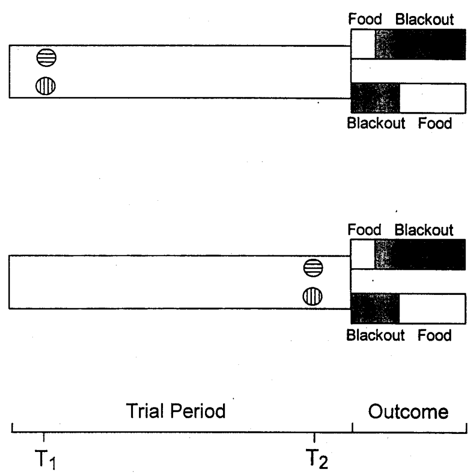
Strotz, R. H. (1956). Myopia and inconsistency in dynamic utility maximization. *Review of Economic Studies, 23,* 165-180.

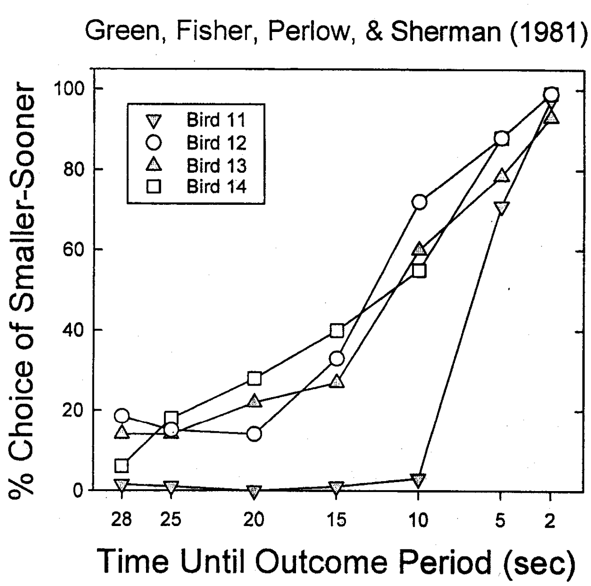
Thaler, R. H. (1981). Some empirical evidence on dynamic inconsistency. *Economic Letters, 8,* 201-207.

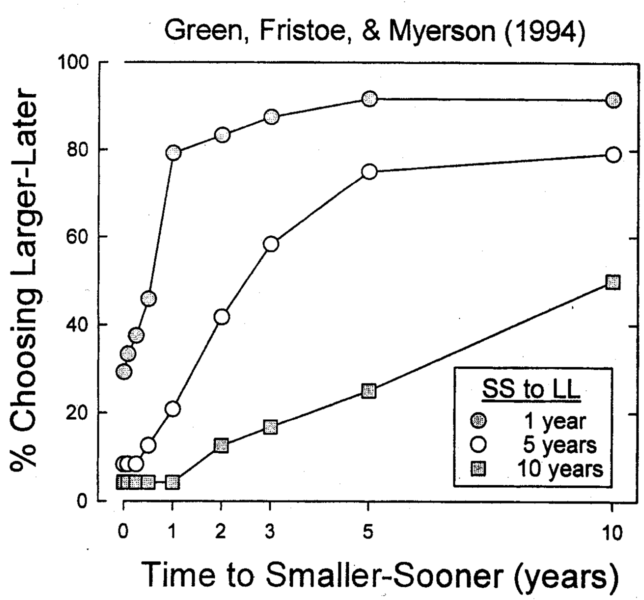
Thaler, R. H. (1991). *Quasi rational economics.* New York: Russell Sage Foundation.

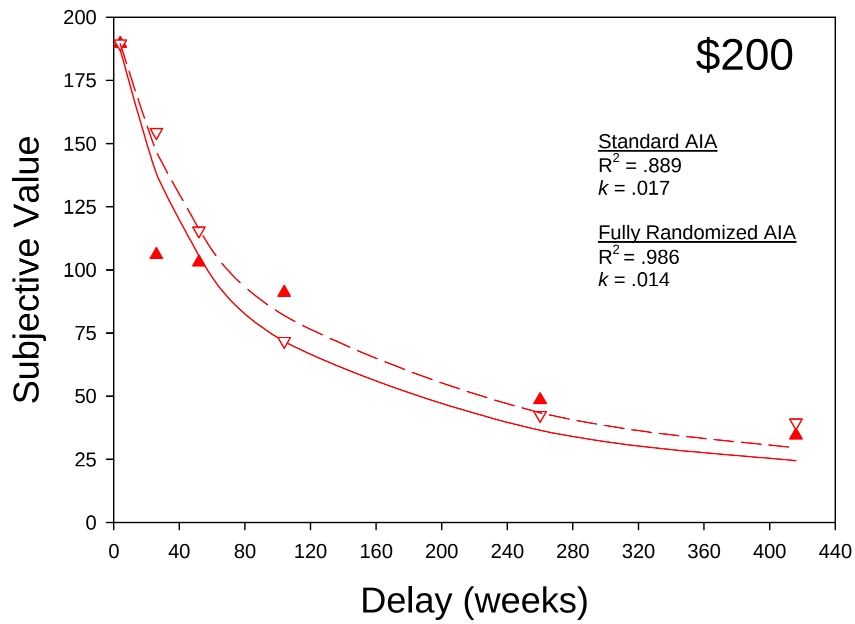
von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*, New Jersey: Princeton University Press.

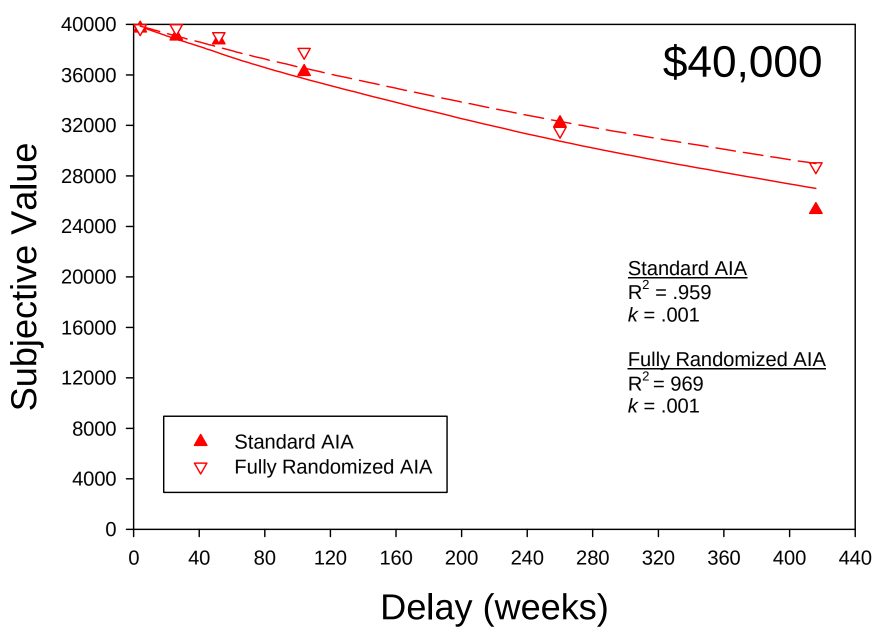

Subjective Value
LL
SS
T_1
T_2
Time

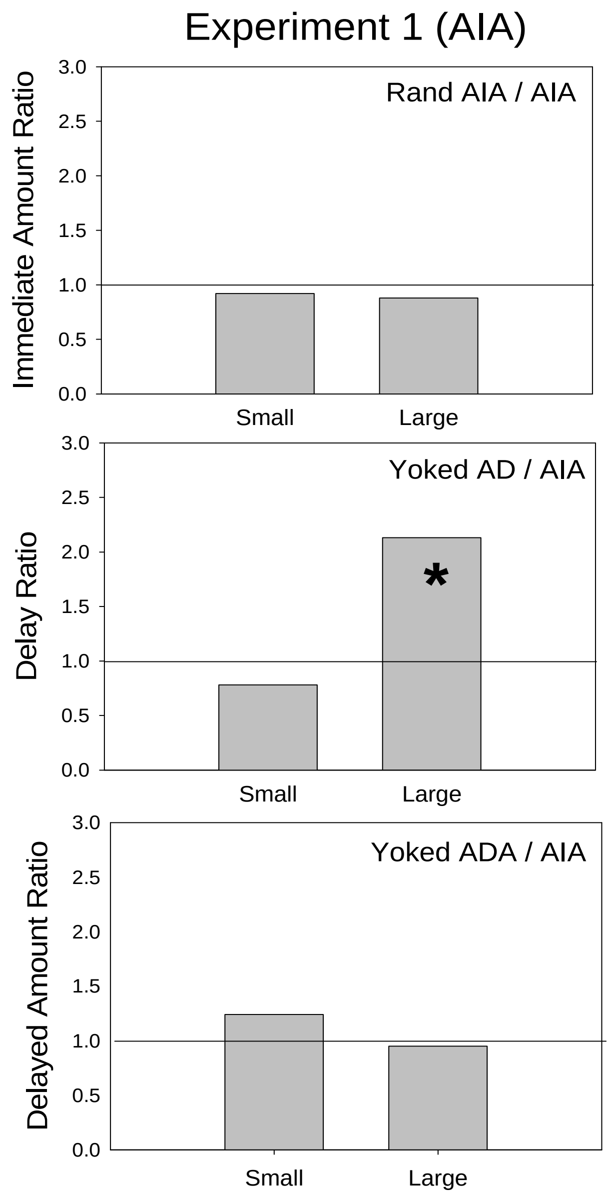

Food Blackout
Blackout Food
Food Blackout
Blackout Food
Trial Period
Outcome
T_1
T_2

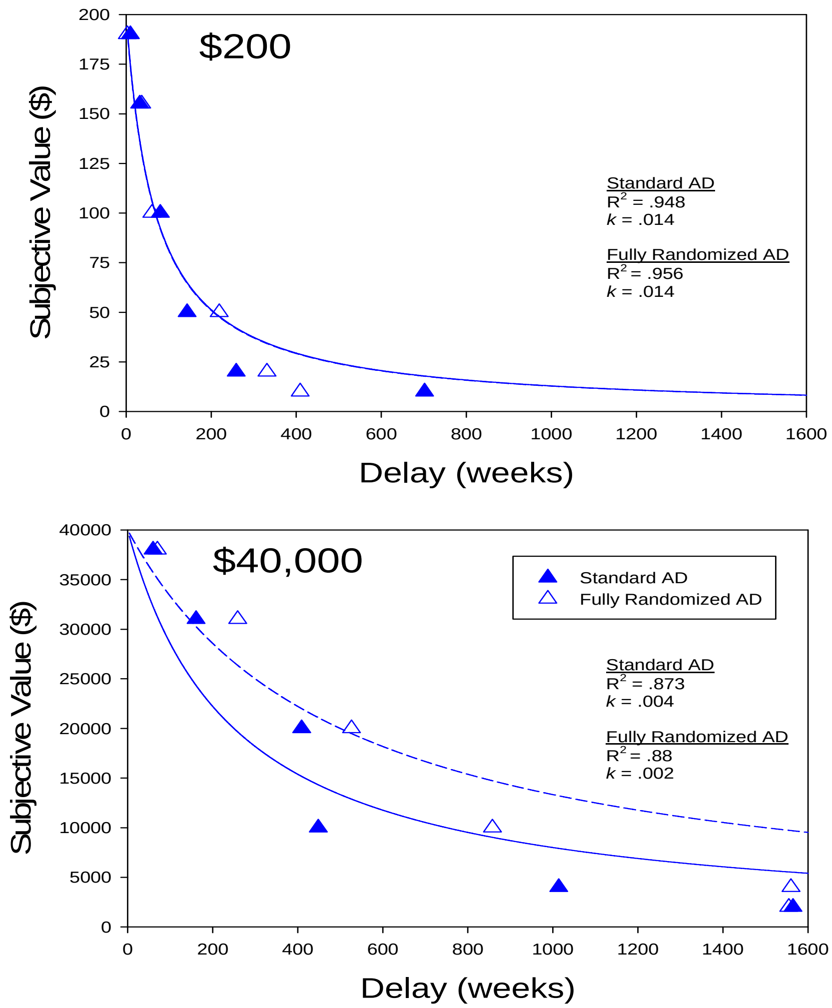

Green, Fisher, Perlow, & Sherman (1981)
% Choice of Smaller-Sooner
Time Until Outcome Period (sec)
Bird 11
Bird 12
Bird 13
Bird 14
0
20
40
60
80
100
28
25
20
15
10
5
2


Green, Fristoe, & Myerson (1994)
% Choosing Larger-Later
100
80
60
40
20
0
0
1
2
3
5
10
Time to Smaller-Sooner (years)
SS to LL
1 year
5 years
10 years

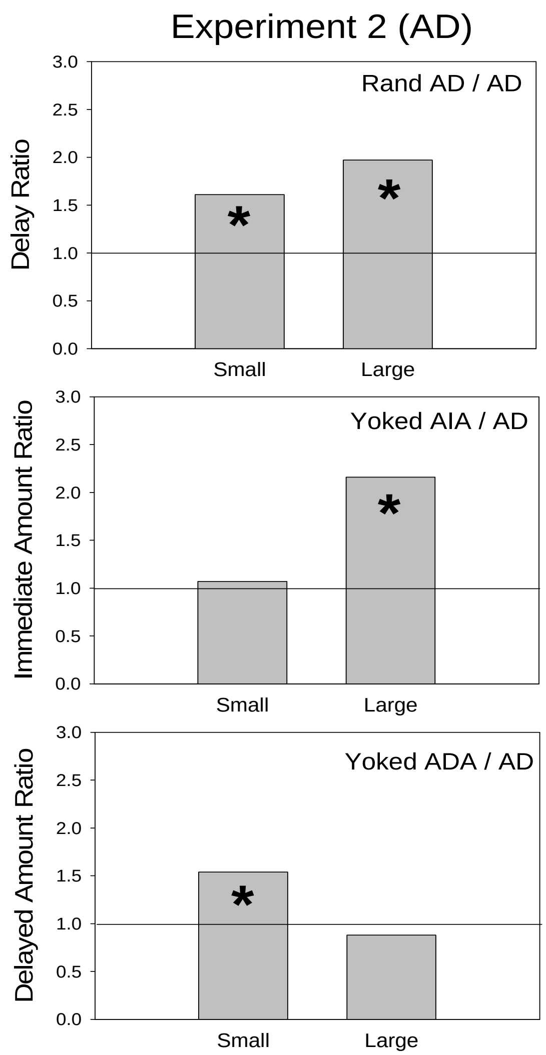

$200
Standard AIA
R2 = .889
k = .017
Fully Randomized AIA
R2 = .986
k = .014
Subjective Value
Delay (weeks)


$40,000
Standard AIA
R2 = .959
k = .001
Fully Randomized AIA
R2 = 969
k = .001
Standard AIA
Fully Randomized AIA
Subjective Value
Delay (weeks)

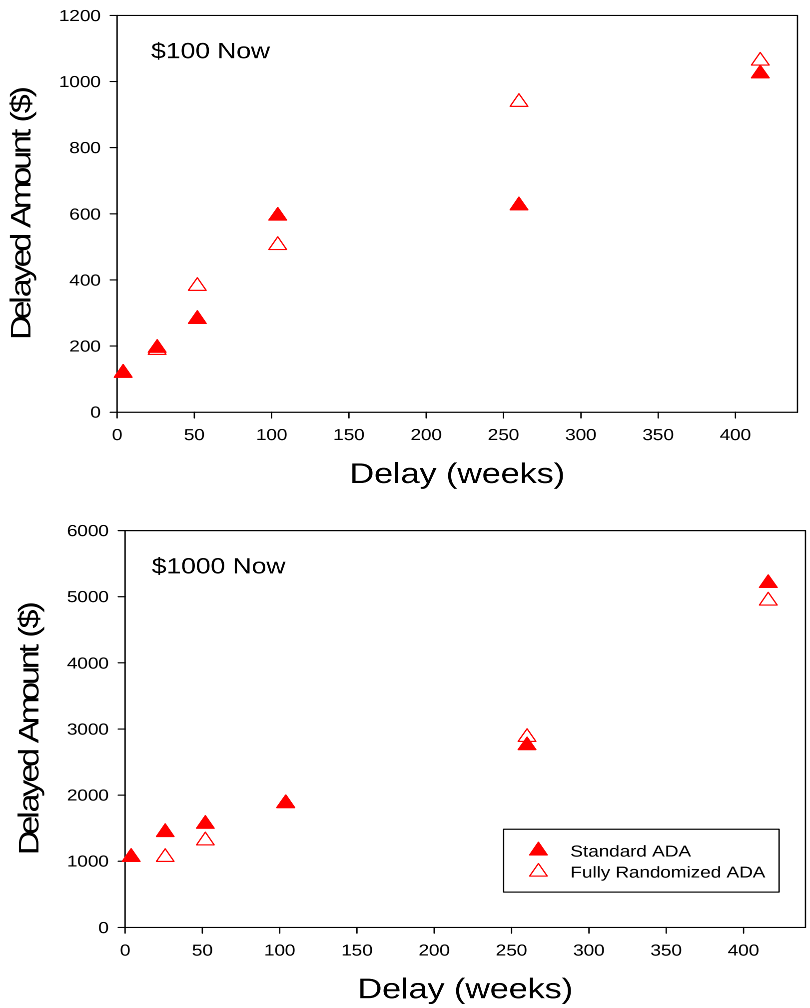

Experiment 1 (AIA)
Immediate Amount Ratio
Rand AIA / AIA
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Small
Large
Delay Ratio
Yoked AD / AIA
*
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Small
Large
Delayed Amount Ratio
Yoked ADA / AIA
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Small
Large

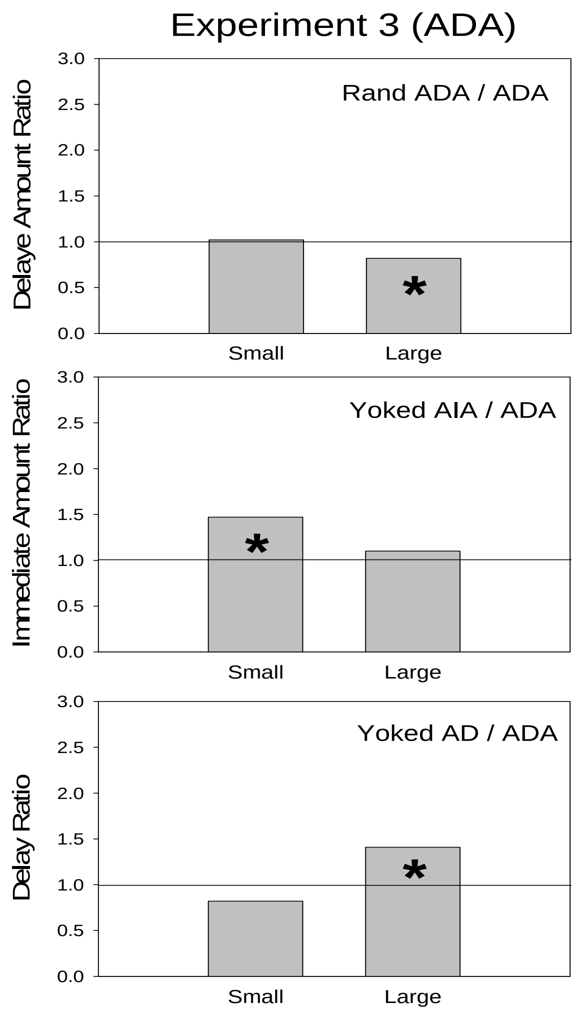


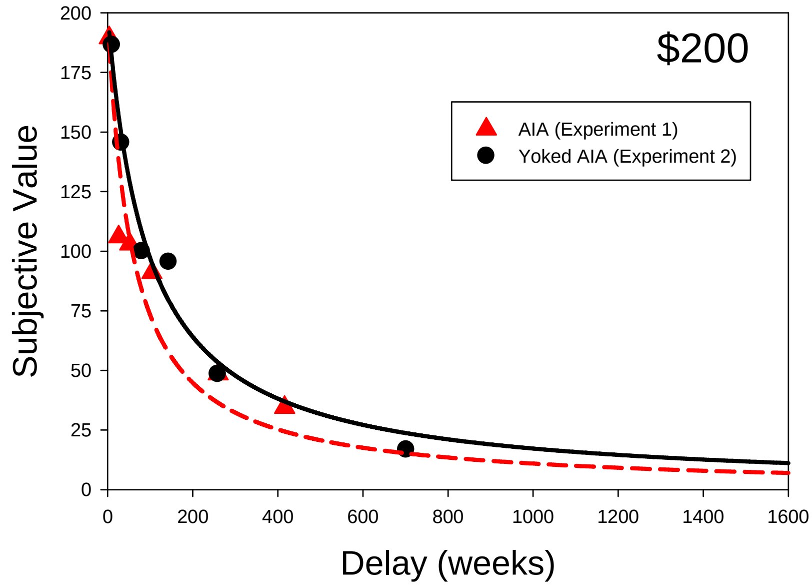
$200
Standard AD
R² = .948
k = .014
Fully Randomized AD
R² = .956
k = .014
Subjective Value ($)
Delay (weeks)
$40,000
Standard AD
Fully Randomized AD
Standard AD
R² = .873
k = .004
Fully Randomized AD
R² = .88
k = .002
Subjective Value ($)
Delay (weeks)

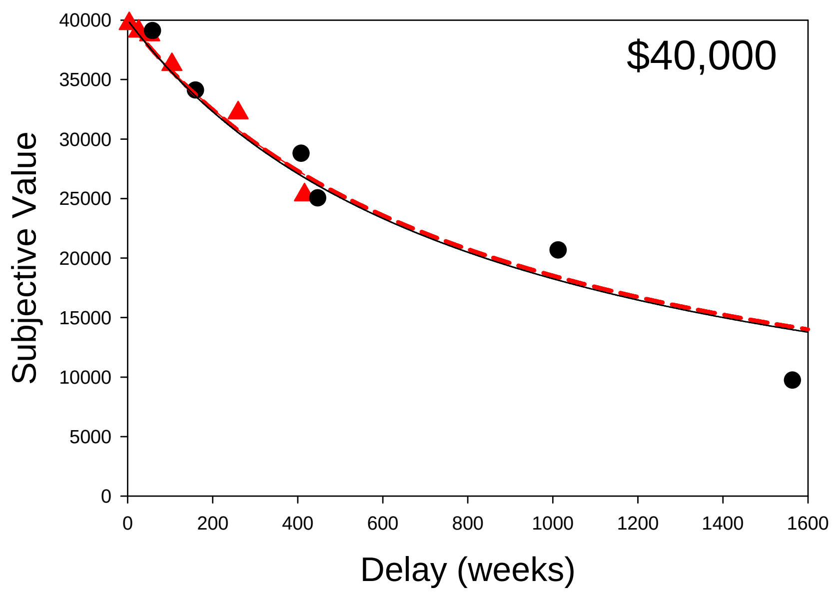


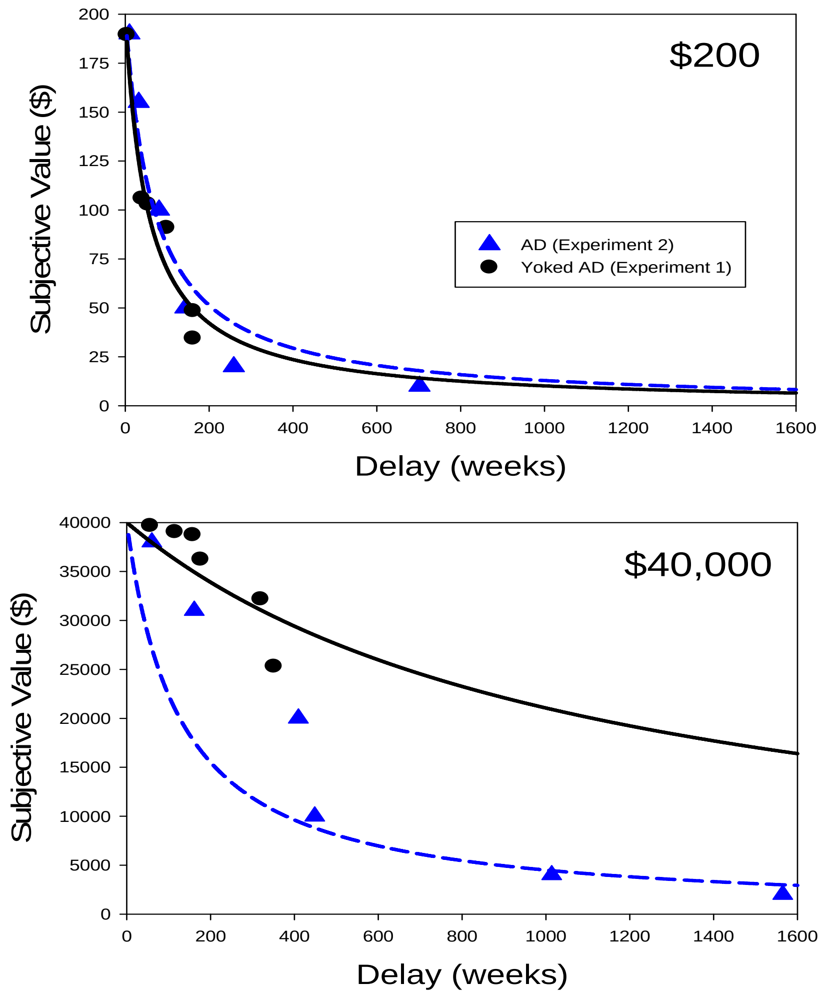
Experiment 2 (AD)
Rand AD / AD
Delay Ratio
Yoked AIA / AD
Immediate Amount Ratio
Yoked ADA / AD
Delayed Amount Ratio
Small
Large


$100 Now
Delayed Amount ($)
0
200
400
600
800
1000
1200
0
50
100
150
200
250
300
350
400
Delay (weeks)
$1000 Now
Delayed Amount ($)
0
1000
2000
3000
4000
5000
6000
Standard ADA
Fully Randomized ADA


Experiment 3 (ADA)
Delaye Amount Ratio
Rand ADA / ADA
3.0
2.5
2.0
1.5
1.0
0.5
0.0
*
Small
Large
Immediate Amount Ratio
Yoked AIA / ADA
*
Small
Large
Delay Ratio
Yoked AD / ADA
*
Small
Large


$200
AIA (Experiment 1)
Yoked AIA (Experiment 2)
Subjective Value
Delay (weeks)
0
25
50
75
100
125
150
175
200
0
200
400
600
800
1000
1200
1400
1600


$40,000
Subjective Value
Delay (weeks)
0
5000
10000
15000
20000
25000
30000
35000
40000
0
200
400
600
800
1000
1200
1400
1600



$200
AD (Experiment 2)
Yoked AD (Experiment 1)
Subjective Value ($)
Delay (weeks)
0
25
50
75
100
125
150
175
200
0
200
400
600
800
1000
1200
1400
1600
$40,000
Subjective Value ($)
Delay (weeks)
0
5000
10000
15000
20000
25000
30000
35000
40000