Published in final edited form as:
Behav Processes. 2012 July ; 90(3): 302–310. doi:10.1016/j.beproc.2012.03.003.

Estimating the Subjective Value of Future Rewards: Comparison of Adjusting-Amount and Adjusting-Delay Procedures

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Abstract

The present study examined whether equivalent discounting of delayed rewards is observed with different experimental procedures. If the underlying decision-making process is the same, then similar patterns of results should be observed regardless of procedure, and similar estimates of the subjective value of future rewards (i.e., indifference points) should be obtained. Two experiments compared discounting on three types of procedure: adjusting-delay (AD), adjusting-immediate-amount (AIA), and adjusting-delayed-amount (ADA). For the two procedures for which discounting functions can be established (i.e., AD and AIA), a hyperboloid provided good fits to the data at both the group and individual levels, and individuals' discounting on one procedure tended to be correlated with their discounting on the other. Notably, the AIA procedure produced the more consistent estimates of the degree of discounting, and in particular, discounting on the AIA procedure was unaffected by the order in which choices were presented. Regardless of which of the three procedures was used, however, similar patterns of results were obtained: Participants systematically discounted the value of delayed rewards, and robust magnitude effects were observed. Although each procedure may have its own advantages and disadvantages, use of all three types of procedure in the present study provided converging evidence for common decision-making processes underlying the discounting of delayed rewards.

Keywords

discounting; delayed rewards; adjusting-amount; adjusting-delay; humans

1. Introduction

People often make choices between two rewards, one of which may occur sooner than the other. For example, they have to decide whether to invest in a retirement plan knowing they cannot have access to the money until they retire, or spend the money on something that they would enjoy now. Choices between rewards available at different times are not only important in the context of managing one's finances, they also are involved in important health-related decisions, as is clear from research on substance abuse (Yi et al., 2010). Indeed, such choices occur in all aspects of daily life. Understanding how individuals arrive

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at a decision in such situations is of obvious theoretical importance, and a key part of this decision process involves evaluating the value of the delayed reward.

Several procedures have been developed to measure how the delay until receipt of a reward affects its present, subjective value, two of the most common being Mazur's (1987) adjusting-delay procedure and Rachlin's adjusting-amount procedure (Rachlin et al., 1991). With both procedures, the goal is to determine indifference points, that is, immediate rewards that are equivalent in value to larger, delayed rewards. The adjusting-delay procedure does this by adjusting the length of delay to a larger reward, holding the amounts of both rewards constant, until each is equally likely to be chosen (Mazur, 1987). In contrast, the adjusting-amount procedure accomplishes the same goal by adjusting the amount of the immediate reward, holding the amount of the larger reward and the delay until its receipt constant, until both the immediate and delayed rewards are equally likely to be chosen (Rachlin et al., 1991).

Both the adjusting-delay and adjusting-amount procedures can be used to determine a delay discounting function, which describes the decrease in the present, subjective value of a delayed reward as the duration of the wait until its receipt increases. One prominent form for the discounting function that has been proposed is a hyperboloid (Myerson and Green, 1995):

$$V = A/(1+kD)^s, \tag{1}$$

where V is the subjective, present value of a reward of amount A that can be received after a delay of D time units. The parameter k may be thought of as a rate parameter in the above hyperboloid function (Eq. 1), and the parameter s is believed to capture the nonlinear scaling of amount and/or time. When $s = 1.0$, Equation 1 reduces to a simple hyperbola, the form of discounting function originally proposed by Mazur (1984, 1987).

It is widely assumed that both types of procedure, adjusting-delay and adjusting-amount, assess the same behavioral processes, and in fact, both procedures have demonstrated their usefulness for studying the discounting of delayed rewards in humans and nonhuman animals (e.g., Christensen et al., 1998; Green et al., 1994; Jimura et al., 2009; Mazur, 2000; Raineri and Rachlin, 1993; Rodriguez and Logue, 1988). However, only one study, Green et al. (2007), has directly compared the two types of procedure, and it involved pigeons discounting delayed food rewards. Green et al. used a within-subject yoking technique in which the indifference point (number of food pellets delivered immediately or time until delayed food reinforcement) obtained with one procedure determined the value of the corresponding variable in the yoked condition with the other procedure. No systematic differences between the two procedures were observed in the degree of discounting, consistent with the assumption that the same process underlies the discounting of delayed rewards on both adjusting-amount and adjusting-delay procedures, at least in pigeons.

The fact that these two procedures tend to produce similar results in pigeons, while important, is no guarantee that they would produce similar results in humans, particularly when the choice is between hypothetical monetary rewards, the most frequently studied outcome in human discounting research (for a review, see Green and Myerson, 2004). Accordingly, the present study compared human choice behavior on adjusting-delay and adjusting-amount procedures, using a yoked-control strategy similar to that used in the Green et al. (2007) pigeon study. That is, indifference points obtained with one procedure were used to determine the experimental conditions studied with the other procedure. For example, if a participant was found to be equally likely to choose $50 immediately or $200 in 5 years using the adjusting-amount procedure, then the participant was tested with an immediate $50 and a delayed $200 reward using an adjusting-delay procedure in order to determine what delay would make the two rewards equal in value, and more specifically, whether that delay would be equal to 5 years.

Two experiments were conducted. In Experiment 1, participants were tested using an adjusting-amount procedure to determine the amounts of immediate reward equal in subjective value to the larger rewards ($200 and $40,000) available at different delays, and then retested with those same immediate amounts using an adjusting-delay procedure. In Experiment 2, participants were initially tested using an adjusting-delay procedure to determine the delays that made different amounts of immediate reward equal in subjective to a larger, later reward (either $200 or $40,000), and then retested with those same delays using an adjusting-amount procedure.

In both experiments, participants also were tested using an adjusting-amount procedure in which, instead of adjusting the immediate amount, the amount of the delayed reward was adjusted until participants were equally likely to choose the immediate and delayed rewards. To distinguish between these two procedures and the adjusting-delay (AD) procedure, we will refer to them as the adjusting-immediate-amount procedure (AIA) and the adjusting-delayed-amount procedure (ADA). It is to be noted that the ADA procedure, unlike the AIA and AD procedures, is not useful for establishing discounting functions but was included here as a further test of whether different procedures converge on similar indifference points.

The reason why a discounting function can be established with AIA and AD procedures, but not with an ADA procedure, is because with AIA and AD procedures, the amount of delayed reward can be held constant while determining indifference points. This is essential because the rate at which humans discount delayed rewards tends to decrease as the amount of the delayed reward increases (Green et al., 1997; Kirby, 1997), and thus discounting functions are specific to the delayed amount. With the ADA procedure, in contrast, the amount of delayed reward at an indifference point is determined by the participant's choices and thus will vary from indifference point to indifference point, thereby precluding the estimation of a single discounting function.

In addition to comparing the AIA, ADA, and AD procedures, the sequence in which choice options were presented within the AIA and AD procedures was examined. Robles and colleagues (Robles and Vargas, 2008; Robles et al., 2009) have argued that on AIA procedures, indifference points are affected by whether, for a given delay and delayed amount, the immediate reward amounts are presented in ascending or descending order, but Green et al. (1997) as well as Robles and Vargas (2007) found no difference between ascending and descending orders. Moreover, Rodzon et al. (2011) found no difference in indifference points between ordered presentation of immediate amounts and a more efficient titration procedure in which immediate amounts were adjusted up or down depending on a participant's choices (Du et al., 2002).

Although researchers using computerized AIA procedures now usually avoid ordered presentation of immediate amounts, there are other possible order effects that should be considered. We would note that in most discounting studies, the manipulation of one choice dimension is nested within manipulation of another dimension. With AIA procedures, for example, the amount of the immediate reward is changed repeatedly within a delay condition until an indifference point for that delay is determined, and then the procedure is repeated within another delay condition. Moreover, if different amounts of delayed reward are studied, delay conditions typically are nested within delayed amount conditions.

Such nested procedures raise the concern that because one choice dimension (e.g., immediate amount in AIA tasks) is varied from choice to choice while the other choice dimensions (delay and delayed amount) remain unchanged, the dimension that is being varied (immediate amount) may become more salient. Such differential salience may potentially bias participants' decisions as they choose between getting less sooner versus getting more later. In addition, nested procedures (e.g., varying immediate amounts while holding delays and delayed amounts constant on an AIA task) may affect the reference points that people establish and to which they then compare choice alternatives (Kahneman and Tversky, 1979).

The potentially biasing effects of nested manipulation of choice dimensions was assessed by comparing the usual nested manipulation on AIA tasks with a non-nested AIA procedure in which both immediate amount and delay vary from choice to choice. Similarly, the usual AD task, in which delay varies from choice to choice within amount conditions, was compared with a non-nested AD procedure in which both delay and immediate amount vary from choice to choice. These comparisons were in addition to the comparisons of indifference points obtained with the AIA, ADA, and AD procedures, which were conducted in order to address the major question of the present study: Do the AIA, ADA, and AD procedures engage a common decision-making process as revealed by equivalent discounting of delayed rewards?

2. Experiment 1

2.1 Method

2.1.1 Participants—Thirty-one undergraduate students, 12 males and 19 females, were recruited from the subject pool maintained by the Psychology Department of Washington University and received course credit as compensation for their participation.

2.1.2 Procedure—Participants were tested individually in a quiet room on computerized discounting tasks. The experiment consisted of two sessions separated by approximately one week. During the first session, participants completed both a standard AIA discounting task and a non-nested version of the AIA task in which (in addition to the immediate amount) the delay and the delayed amount changed from one choice trial to the next. During the second session, participants completed a yoked AD task and a yoked ADA discounting task. That is, the conditions studied in the second session were individually determined for each participant based on his or her indifference points established using the standard AIA procedure in the first session.

At the beginning of the first session, participants were instructed that they would be making choices between hypothetical amounts of money, an amount that could be received immediately and another amount that could be received after a given delay. Participants also were instructed that there were no correct or incorrect responses and that they should select the option that they preferred. Before each task, participants read the instructions on the computer screen and were given several practice trials and offered the opportunity to ask questions before the actual experimental task began.

2.1.2.1 Adjusting-immediate-amount Tasks: For the standard AIA task, individuals chose between a smaller, immediate reward and a larger, delayed reward displayed on the computer screen. The amount of the smaller immediate reward was systematically varied from trial to trial while 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 (1 month, 6 months, 1 year, 2 years, 5 years, and 8 years), for a total of 12 conditions. The order of presentation of the 12 conditions was randomized for each participant.

In order to determine the amount of immediate reward that a participant judged equal in value to the delayed ($200 or $40,000) reward for each delay and delayed amount, the amount of the immediate reward was varied in an iterative manner within each amount x delay condition so as to converge on the participant's indifference point (Du et al., 2002). On the first choice trial of a condition, the immediate amount was always half of the delayed amount. For each subsequent choice trial, the immediate amount was either increased or decreased depending on the previous choices, and participants made a total of 6 choices in each condition.

For example, in the $200 in 6 months condition, the participant first chose between $100 now and $200 in 6 months. If the participant selected the $100 now, then the subsequent choice would be between $50 now and $200 in 6 months. If the immediate $50 was then selected, 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 size of the previous change. This iterative method of adjustment is designed to converge rapidly on the indifference point, estimated as the immediate amount that would have been presented on a seventh choice trial. The preceding process was repeated for each amount x delay condition, yielding a total of 12 indifference points (6 for each delayed amount).

The procedure for the non-nested AIA task was the same as that for the standard version of the task except that all 12 amount x delay conditions were in effect concurrently. For each choice trial, the computer program randomly selected one condition to display at a time, beginning with an immediate amount that was one-half of the delayed amount the first time each condition was presented, and then randomly sampled the conditions again for the next choice trial to present, until all 12 indifference points were established. Of note here is that the iterative process operated the same as in the standard version of the AIA task, with a total of 6 choice trials per condition. For example, the participant might first have been presented with a choice between $100 now and $200 in 1 month, then presented with a choice between $20,000 now and $40,000 in 6 months, then presented with another choice between a $20,000 and $40,000 in 5 years. The second time the choice was between an immediate reward and $200 in 1 month, the amount of immediate reward would be either $50 or $150, depending on whether they previously chose the $100 immediate reward or the $200 delayed reward on the first choice trial.

2.1.2.2 Adjusting-delay Task: For the yoked AD task, participants again chose between a pair of smaller, immediate and larger, delayed rewards displayed on the computer screen. In each of 12 immediate x delayed amount conditions, the duration of the delay on the first choice trial of each condition was 3 years; on subsequent trials, the duration of the delay was systematically varied from trial to trial based on the participant's previous choices while the amounts of the immediate and delayed rewards were held constant. For each participant, the immediate amounts were taken from the indifference points for each of the six delay conditions that had been determined for that participant using the standard AIA task in the first session, and the delayed amounts were again $200 and $40,000. The order of presentation of the 12 conditions was randomized for each participant.

For example, if the amount of immediate reward equal in value to a $200 reward available after 6 months was determined to be $120 in the first session, then for the yoked AD task in the second session, the participant would be offered choices between $120 now and $200 later, and depending on which option was chosen, the delay until the $200 reward would be adjusted until the immediate and delayed rewards were approximately equal in value to the participant. At issue was whether in the second session, the delay would be adjusted until it converged on a value close to the delay presented in the first session (i.e., 6 months in the preceding example).

If the participant chose the immediate reward on the first choice trial in each condition, the delay would be halved to 1.5 years on the next trial, whereas if the participant chose the delayed reward, the delay would be doubled to 6 years on the next trial, and subsequent choices of the delayed reward continued to result in doubling of the delay until the immediate reward was chosen. Once the immediate reward was chosen, then (as with the AIA procedure) all subsequent increases and decreases in the delay were half the size of the preceding change. There were 6 trials per condition.

2.1.2.3 Adjusting-delayed-amount Task: For the yoked ADA task, participants again chose between a smaller, immediate reward and a larger, delayed reward. In each of 12 immediate amount x delay conditions, the amount of the delayed reward was systematically varied from trial to trial while both the amount of the immediate reward and the delay to the later reward were held constant. For each participant, the immediate amounts were taken from the indifference points for each of the delay conditions that had been determined for that participant using the standard AIA task in the first session; as in the AIA task, the delays were 1 month, 6 months, 1 year, 2 years, 5 years, and 8 years. The order of presentation of the 12 immediate amount x delay conditions was randomized for each participant, and the amount of the delayed reward on the first choice trial of each condition was either $600 or $60,000, depending on whether the immediate amount was taken from a $200 or $40,000 delayed reward condition of the standard AIA task in the first session.

For example, if the amount of immediate reward equal in value to a $200 reward available after 6 months was determined to be $120 in the first session, then for the yoked ADA task in the second session, the participant would be offered choices between $120 now and $600 in six months, and depending on which option was chosen, the amount of the delayed reward would be adjusted until the immediate and delayed rewards were approximately equal in value to the participant. The issue in the second session was whether the amount of delayed reward would be adjusted until it converged on an amount close to that presented in the first session (i.e., $200).

If on the first choice trial in each condition the participant chose the delayed reward, then the amount of delayed reward would be halved to $300 on the next trial, and subsequent choices of the delayed reward continued to result in halving of the delayed amount until the immediate reward was chosen. If the participant chose the immediate reward on the first trial, then the amount of delayed reward would be doubled to $1,200 on the next trial. Once the immediate reward was chosen, then (as with the AIA and yoked AD procedures) all subsequent increases and decreases in the amount of the delayed reward were half the size of the preceding change. There were 6 trials per condition.

2.2 Data analysis

For each delayed amount, the degree of discounting on the standard and non-nested AIA tasks as well as the yoked AD task was assessed by fitting a simple hyperbola (i.e., Equation 1 with $s = 1.0$) to the data for each task from each individual. Although having s be a free parameter typically improves the fit, for the purpose of comparing different individuals, conditions, and procedures, it is necessary to obtain a single index of the degree of discounting in each case. Previously, we have used the area-under-the-curve (AuC) measure for this purpose (Myerson et al., 2001). However, despite the fact that the use of such area measures is relatively straightforward with AIA procedures, problems arise when one wants to apply this measurement approach to discounting on AD procedures. This is because with AD procedures, the range of delays defining the discounting curve may be different for every participant in every condition. Finally, because the *k* values were extremely skewed, we took the logarithms of the estimated values of the *k* parameter before submitting these values to an analysis of variance (ANOVA).

A different measurement approach was required for assessing whether the degree of discounting on the yoked ADA task differed from that on the standard AIA task. This is because (as noted in the Introduction) discounting functions cannot be established for data from ADA tasks because in such tasks, the amount of delayed reward is not held constant. Instead, an alternative approach that did not require curve fitting was used. For each participant at each delay, the adjusted delayed amount obtained in the yoked ADA task was expressed as a proportion of the delayed amount in the corresponding condition of the AIA task. These proportions then were logged and averaged to obtain each participant's mean log proportions for both the smaller and larger amount conditions. One sample *t*-tests then were conducted to determine whether the means of the logged proportions differed significantly from zero (i.e., the logarithm of 1.0), as would be expected if the amounts of delayed reward obtained on the yoked ADA task differed systematically from those observed on the AIA task.

2.3 Results

Figure 1 shows the median discounting data from both delayed amount conditions ($200 and $40,000) of the standard and non-nested AIA tasks and the yoked AD task. As may be seen, the subjective value of the delayed reward decreased systematically as the delay to its receipt increased for all three tasks, and the smaller delayed amount (top panel) was discounted more steeply than the larger amount (bottom panel). A simple hyperbola (Eq. 1 with $s = 1.0$) provided very good fits to the group data from the standard AIA procedure (R^2s = .889 and .959, *k*s = 0.017 and 0.001, for the $200 and $40,000 delayed amounts, respectively) and from the non-nested AIA procedure (R^2s = .986 and .969, *k*s = 0.014 and 0.001, for the $200 and $40,000 delayed amounts, respectively). It also provided a very good fit to the data from the $200 delayed amount condition of the yoked AD task (R^2 = .937, $k = 0.020$), but the fit to the data from the $40,000 delayed amount condition of the yoked AD task was not as good (R^2 = .632, $k = 0.001$).

The simple hyperbola also was fit to each individual participant's data. The median R^2s for the fits to the individual data from the standard and non-nested AIA tasks were .836 and .876 for the $200 delayed reward and .778 and .825 for the $40,000 delayed reward. To compare how steeply participants discounted smaller and larger delayed rewards on the two adjusting-amount procedures, a 2 (amount) × 2 (task) repeated measures ANOVA was conducted on the logarithms of the individual *k* values. Data from the eight participants for whom the R^2 was zero at either amount on either task were excluded from this analysis, but the same pattern of results was observed when data from all participants were analyzed.[1] There was a main effect of amount (the $200 delayed reward was discounted more steeply than the $40,000 reward, $F(1,22) = 104.51$, $p < .001$), but no effect of task and no interaction, both *F*s < 1.0. Moreover, omitting those participants whose R^2s were equal to zero (and whose *k* values may be presumed to be poorly estimated), discounting on the standard and non-nested AIA tasks, as measured by the logarithm of the *k* parameter, was strongly correlated for both reward amounts (.911 and .830, respectively; both *p*s < .001).

[1]The R^2s of zero reflected nonsystematic behavior by five of the participants, little or no discounting by two of the participants, and nonsystematic behavior in one condition and little or no discounting in another condition by one participant. Out of the 124 possible cases (i.e., two amounts × 2 tasks × 31 participants), there were ten observed cases in which R^2 was zero. Six of these came from the large amount condition of the non-nested AIA task, and of these six, three showed nonsystematic behavior and three showed little or no discounting; there were no other instances of little or no discounting.

Individual data from the yoked AD task were not always as well fit by a simple hyperbola as those from the AIA tasks: The median R^2s for fits to the individual yoked AD data for the $200 and $40,000 delayed rewards were .649 and .635, respectively. To compare discounting on the standard AIA task and the yoked AD task, the logarithms of the individual *k* values on these tasks were submitted to a 2 (amount) × 2 (task) repeated measures ANOVA, again omitting data from any participant for whom the R^2 was zero at either amount on either task. [2] There was a main effect of amount (the $200 delayed reward was discounted more steeply than the $40,000 reward, $F(1,17) = 305.99$, $p < .001$), but no effect of task and no interaction, both *F*s < 1.0. A similar pattern of results was observed when data from all participants were analyzed, although the effect of task now approached significance, $F(1,30) = 4.07$, $p = .053$). Omitting those participants whose R^2s were equal to zero, discounting on the standard AIA and yoked AD tasks was significantly correlated for the $200 reward amount ($r = .497$, $p < .05$), but not for the $40,000 amount ($r = .119$).

Finally, discounting on the standard AIA task was compared to discounting on the yoked ADA task. At issue was whether participants would adjust the delayed amount on the yoked ADA task until it was about the same as that experienced in the corresponding amount condition of the standard AIA task (i.e., $200 or $40,000). For each participant at each delay, the adjusted delayed amount obtained in the yoked ADA task was expressed as a proportion of the delayed amount in the corresponding condition of the AIA task, and then these proportions were logged and averaged to get each participant's mean log proportion for both the smaller and larger amount conditions. One sample *t*-tests revealed that the means of the logged proportions did not differ significantly from zero (i.e., the logarithm of 1.0) in either the smaller delayed amount condition (mean log proportion = 0.092, $t(30) = 1.67$, $p = .105$) or the larger delayed amount condition, (mean log proportion = −0.120, $t < 1.0$, *ns*).

2.4 Discussion

The present results suggest that the same fundamental discounting process underlies decisions on adjusting-delay and adjusting-amount tasks, regardless of whether the delay to the larger reward or the amount of the immediate or the delayed reward is adjusted based on an individual's choices. Robust magnitude effects, in which smaller delayed amounts were discounted more steeply than larger amounts, were observed with all discounting tasks. The present study is the first to report magnitude effects with an adjusting-delay procedure, which rarely has been used with humans, as well as the first to report such effects with an adjusting-delayed-amount procedure, which to the best of our knowledge, has not been studied previously.

Additional results provide further evidence of the similarity of choice on AIA, ADA, and AD discounting tasks: For a given amount of delayed reward, participants (at least those whose discounting curves were described by Eq. 1) discounted the value of that reward to a similar degree, as measured by the logarithm of the *k* parameter in Equation 1, regardless of whether an AIA or a yoked AD procedure was used. Moreover, the amounts of delayed reward judged equal in subjective value to an immediate reward were, on average, approximately the same with AIA and yoked ADA procedures. In addition, participants' discounting of the $200 delayed amount on AIA and yoked AD tasks was significantly correlated although the correlation for the $40,000 amount was not significant, perhaps due

[2]There were 13 participants for whom R^2s were zero. For eleven participants this reflected nonsystematic behavior, for one it reflected little or no discounting, and one participant showed nonsystematic behavior in one condition and little or no discounting in another. Out of the 124 possible cases, there were fourteen observed cases in which R^2 was zero, of which eleven came from the yoked AD task (five from the small amount condition and six from the large amount condition). Nine of these eleven cases reflected nonsystematic behavior.

to restriction of range arising from the very shallow discounting of the larger amount (see the bottom panel of Figure 1). Finally, comparison of standard and non-nested AIA tasks revealed equivalent discounting regardless of question order.

3. Experiment 2

The results of the first experiment provide converging evidence of a fundamental discounting process underlying intertemporal decision making. The second experiment revisits this issue using an analogous design with two notable differences. First, Experiment 1 examined possible effects of question order on AIA tasks whereas the present experiment examines whether such effects are observed on AD tasks, and second, Experiment 1 compared choice on AD and ADA tasks yoked to an initial AIA task whereas the present experiment compares choice on AIA and ADA tasks yoked to an initial AD task.

3.1 Method

3.1.1 Participants—Thirty-three undergraduate students, 14 males and 19 females, were recruited from the subject pool maintained by the Psychology Department of Washington University and received course credit as compensation for their participation.

3.1.2 Procedure—The procedure for Experiment 2 was analogous to that for Experiment 1. During the first testing session, participants completed both a standard AD task and a non-nested version of the AD task in which (in addition to the delay) the immediate and delayed amounts changed from one choice trial to the next. During the second session, participants completed a yoked AIA task and a yoked ADA discounting task. That is, the conditions studied in the second session were individually determined for each participant based on his or her indifference points established using the standard AD procedure in the first session.

3.1.2.1 Adjusting-delay Tasks: For the standard AD task, the duration of the delay was systematically varied from trial to trial based on a participant's choices on previous trials while the amounts of the immediate and delayed rewards were held constant. There was a small delayed amount ($200) that was paired with six immediate amounts ($190, $155, $100, $50, $20, and $10) and a large delayed amount ($40,000) that was paired with six different immediate amounts ($38,000, $31,000, $21,000, $10,000, $4,000, and $2,000), for a total of 12 immediate x delayed amount conditions. The order of presentation of these 12 conditions was randomized for each participant, and the duration of the delay on the first choice trial of each condition was 3 years. The algorithm for adjusting the delay to obtain an indifference point was the same as that for the AD task in Experiment 1.

The procedure for the non-nested AD task was the same as that for the standard version of the task except that all 12 immediate x delayed amount conditions were in effect concurrently. As with the non-nested AIA task in Experiment 1, for each choice trial the computer program randomly selected one condition to display at a time, in this case beginning with a delay of 3 years the first time each condition was presented, and then randomly sampled the conditions again for the next choice trial until all 12 indifference points were established.

3.1.2.2 Adjusting-immediate-amount Task: For the yoked AIA task, there were12 delay x delayed amount conditions, and within each condition the amount of immediate reward was systematically varied from trial to trial while the delay and the amount of delayed reward (either $200 or $40,000) were held constant. For each participant, the delays were taken from the indifference points for each of the 12 immediate x delayed amount conditions that had been determined for that participant using the standard AD task in the first session. The order of presentation of the 12 conditions was randomized for each participant, and the amount of the immediate reward on the first choice trial of each condition was one-half of the delayed amount for that condition (i.e., either $100 or $20,000 for the small and large delayed reward conditions, respectively). At issue was whether in the second session, the amount of immediate reward would be adjusted until it converged on an amount close to that presented in the first session.

3.1.2.3 Adjusting-delayed-amount Task: For the yoked ADA task, there were 12 immediate amount x delay conditions, and within each condition the amount of the delayed reward was systematically varied from trial to trial while both the amount of the immediate reward and the delay to the later reward were held constant. For each participant, the 12 delays were taken from the indifference points for the 12 immediate x delayed amount conditions that had been determined for that participant using the standard AD task in the first session. The immediate amounts were the same as those for the AD task. The order of presentation of the 12 conditions was randomized for each participant, and the amount of the delayed reward on the first choice trial of each condition was either $600 or $60,000, depending on whether the immediate amount was taken from a $200 or $40,000 delayed reward condition of the standard AD task in the first session. The algorithm for adjusting the delayed amount to obtain an indifference point was the same as that for the ADA task in Experiment 1. At issue was whether in the second session, the amount of delayed reward would be adjusted until it converged on an amount close to that presented in the first session.

3.2 Data analysis

For each delayed amount, the degree of discounting on the standard and non-nested AD tasks as well as the yoked AIA task was assessed by fitting a simple hyperbola to the data for each task from each individual. Because the *k* values were extremely skewed, we took the logarithms of the estimated values of the *k* parameter before submitting these values to an analysis of variance (ANOVA). For the purpose of comparing the standard AD task with the yoked ADA task, the adjusted delayed amount for each participant at each delay on the yoked ADA task was expressed as a proportion of the delayed amount in the corresponding condition of the AD task. These proportions then were logged and averaged to obtain each participant's mean log proportions for both the smaller and larger amount conditions, and *t*-tests were conducted to determine whether the means of the logged proportions differed significantly from zero (i.e., the logarithm of 1.0).

3.3 Results

Figure 2 shows the median discounting data from both delayed amount conditions ($200 and $40,000) of the standard and non-nested AD tasks and the yoked AIA task. As may be seen, the subjective value of the delayed reward decreased systematically as the delay to its receipt increased for all three tasks, and a simple hyperbola provided good fits to the group median data from the standard AD procedure (R^2s = .948 and .873, *k*s = 0.014 and 0.004, for the $200 and $40,000 delayed amounts, respectively) and from the non-nested AD procedure (R^2s = .956 and .880, *k*s = 0.014 and 0.002, for the $200 and $40,000 delayed amounts, respectively). It also provided very good fit to the data from both the $200 and $40,000 delayed amount conditions of the yoked AIA task (R^2s = .975 and .938, *k*s = 0.011 and 0.001, for the $200 and $40,000 delayed amounts, respectively).

Note that in order to facilitate comparison of the results from the first sessions of Experiments 1 and 2, the dependent measure (delay) in Experiment 2 is plotted on the x-axis in Figure 2 whereas in the graphs of the results of Experiment 1, the dependent measure (immediate amount) was plotted on the y-axis (see Figure 1). As expected, the smaller delayed amount (top panel) was discounted more steeply than the larger amount (bottom panel). It may be seen that the ranges of the median delays were quite different in the two amount conditions (compare the upper and lower panels of Figure 2). This result, too, is consistent with the magnitude effect in that participants were willing to wait much longer for the delayed $40,000 reward than for the delayed $200 reward on both the standard and non-nested AD tasks.

The simple hyperbola was fit to each individual participant's data for both delayed amounts and AD tasks. The median R^2s for the fits to the individual data from the standard and non-nested AD tasks were .795 and .799 for the $200 delayed reward and .746 and .691 for the $40,000 delayed reward. To compare how steeply participants discounted delayed rewards on the two adjusting-delay procedures, a 2 (amount) × 2 (task) repeated measures ANOVA was conducted on the logarithms of the individual *k* values, omitting data from participants for whom an R^2 was zero. [3] There were main effects of both amount (the $200 delayed reward was discounted more steeply than the $40,000 reward, $F(1,30) = 128.11$, $p < .001$) and task (reflecting the fact that the standard AD task produced steeper discounting than the non-nested task, $F(1,30) = 11.99$, $p < .01$), but the interaction failed to reach significance, $F(1,30) = 2.77$, $p = .106$. A similar pattern of results was observed when data from all participants were analyzed, except that the interaction now approached significance, $F(1,32) = 3.94$, $p = .056$. Omitting those participants whose R^2s were equal to zero, discounting on the two AD tasks, as measured by the logarithm of the *k* parameter, was very strongly correlated for both the $200 and $40,000 reward amounts (.908 and .844, respectively; both *p*s < .001).

A simple hyperbola fit the individual data from the yoked AIA task at least as well as it fit those from the AD tasks: The median R^2s for fits to the individual data for the $200 and $40,000 delayed rewards were .713 and .792, respectively. To compare discounting on the standard AD task and the yoked AIA task, the logarithms of the individual *k* values on these tasks were submitted to a 2 (amount) × 2 (task) repeated measures ANOVA, again omitting data from any participant for whom an R^2 was zero.[4] There were main effects of both amount (the $200 delayed reward was discounted more steeply than the $40,000 reward, $F(1,29) = 120.46$, $p < .001$) and task ($F(1,29) = 10.22$, $p < .01$), as well as a significant amount x task interaction, $F(1,29) = 15.09$, $p = .01$. Follow-up tests revealed that the interaction reflected the fact that discounting of the smaller delayed amount did not differ between the two tasks ($t(29) = 1.40$, $p = .173$), whereas the standard AD task produced steeper discounting of the larger delayed amount than the yoked AIA task ($t(29) = 3.95$, $p < .001$). The same pattern of results was observed when data from the two participants who had R^2s of zero were included in the analysis.. Omitting these participants, discounting on the standard AD and yoked AIA tasks was significantly correlated for both the $200 and $40,000 reward amounts ($r = .875$ and .580, respectively; both *p*s< .001).

Finally, discounting on the standard AD task was compared to discounting on the yoked ADA task to determine whether or not participants would adjust the delayed amount on the yoked ADA task until it was close to the amount used in the corresponding condition of the standard AD task. For each participant at each delay, the adjusted delayed amount obtained in the yoked ADA task was expressed as a proportion of the delayed amount in the corresponding condition of the AD task; these proportions then were logged and averaged to get each participant's mean log proportion for both the smaller and larger amount conditions. One sample *t*-tests revealed that the mean of the logged proportions for the large delayed amount did not differ significantly from zero (mean log proportion = −0.054, $t < 1.0$), but a significant difference was observed for the small delayed amount (mean log

[3]There were two participants for whom R^2s were zero due to nonsystematic behavior on the standard AD task.

[4]There were two participants for whom R^2s were zero due to nonsystematic behavior on the standard AD task. In addition, one participant's data for the yoked AD task were lost.

proportion = 0.188, $t(31) = 2.95$, $p = .01$), reflecting the fact that the adjusted delayed amounts were larger than was predicted (i.e., shallower discounting was observed on the yoked ADA task).

3.4 Discussion

Although some differences between discounting tasks emerged in the present experiment, the results suggest that the same fundamental discounting process underlies decisions on adjusting-delay and adjusting-amount tasks. Robust magnitude effects again were observed with all discounting procedures, and the rates of discounting on the AD and AIA tasks were significantly correlated for both smaller and larger delayed amounts. However, an effect of question order was observed in the comparison of standard and non-nested AD tasks. In addition, the AD task tended to produce steeper discounting than the yoked AIA task, although this effect was isolated to discounting of the larger delayed amount. These results may be contrasted with those in Experiment 1 where equivalent discounting of both the smaller and larger reward amounts was observed on the AIA and yoked AD tasks. It may be noted that in the present experiment, the range of delays for the larger delayed amount was much larger than that for the smaller delayed amount and also much larger than the range of delays for both amounts in Experiment 1. Thus, the difference in results raises the possibility that a difference in discounting between adjusting-amount and adjusting-delay procedures only emerges at longer delays.

4. General Discussion

The present study was designed to address the question as to whether similar discounting of delayed rewards would be observed when participants make choices using different experimental procedures. The implicit assumption in the literature appears to be that the underlying decision-making process (discounting) is the same regardless of the procedure used, and if so, then similar patterns of results should be observed, and the indifference points obtained with one procedure should be highly similar to those obtained with other procedures.

In order to test this prediction, two experiments compared discounting on three types of discounting procedure (AIA, AD, and ADA) and also examined the effects of having to make successive choices between alternatives that varied in only one dimension within conditions. Overall, regardless of the procedure used, participants discounted the value of delayed rewards. More specifically, the subjective value of a reward decreased systematically as a function of the delay until its receipt, and for the two procedures that generate data that can be fit by a discounting function (i.e., the AIA and AD procedures), a hyperbola provided good fits at both the group and individual levels. In addition, the degree to which individuals discounted a delayed reward on one procedure tended to be correlated with the degree to which they discounted a delayed reward on the other procedure. With all three procedures, moreover, there was a robust magnitude effect, in that smaller delayed rewards were discounted more steeply than larger rewards.

Although similar patterns of results were obtained with all three types of procedure, the AIA procedure produced the most consistent measures of how steeply rewards were discounted, as may be seen in Figure 3. With the AIA procedure, there was no significant difference in discounting rate (k) between the standard and non-nested AIA tasks in either the small ($200) or large ($40,000) delayed reward condition (compare the black and gray bars from each amount condition in the top panel). Moreover, similar estimates of k were obtained with different participants on the yoked AIA task in Experiment 2 (compare each white bar with the corresponding black and gray bars in the top panel). Finally, when discounting on the yoked ADA task was compared to that on the standard AIA, participants adjusted both the smaller and larger delayed amounts so that they were approximately equal to those on the AIA task, indicating that similar degrees of discounting were observed on both tasks.

In contrast, less consistency was observed in the estimates of the *k* parameter obtained with the AD procedure (see the bottom panel of Figure 3). First, participants in Experiment 2 discounted less steeply on the non-nested AD task than on the standard AD task (compare the corresponding black and gray bars). Second, comparing these results with those for the participants who performed the yoked AD task in Experiment 1 (represented by the white bars in the bottom panel of Figure 3), the participants in Experiment 2 discounted the small ($200) delayed reward less steeply and the larger ($40,000) delayed reward more steeply. Moreover, when discounting on the yoked ADA task was compared to that on the standard AD, participants adjusted the larger delayed amounts so that they were approximately equal to those on the AD task, but when they adjusted the smaller delayed amounts, significantly shallower discounting was observed.

The degree of discounting observed with the AD procedure (Mazur, 1987) appears to be more affected by the preceding sequence of questions than those obtained with the AIA procedure (Rachlin et al., 1991), as evidenced by the fact that significant differences were observed between the non-nested and standard AD tasks in Experiment 2 whereas equivalent discounting rates were obtained with the corresponding AIA tasks in Experiment 1. In addition, discounting on AD procedures appears to have been more affected by some combination of differences between samples and the range of delays and immediate amounts examined, all of which varied between Experiments 1 and 2. Although different procedures may each have advantages when it comes to addressing specific issues, given the greater consistency observed with the AIA procedure, it may be preferred over the AD for measuring the degree of discounting. The ADA procedure, in contrast to both the AIA and AD procedures, has the distinct disadvantage that fitting discounting functions to the data generated with this procedure is, at best, not straightforward. It should be noted, however, that although each procedure may have its own advantages and disadvantages, use of all three types of procedure together provides a way of testing whether or not a specific result obtained with one procedure reflects a general finding characteristic of decision making involving delayed outcomes.

Acknowledgments

The study was supported by National Institutes of Health Grant 055308 to LG and JM. The research is based on the doctoral thesis of DH in partial fulfillment of the requirements for the doctoral degree in Psychology from Washington University. Portions of the work were presented at the 27th Annual Conference of the Society for the Quantitative Analyses of Behavior, Boston, MA, May, 2004, and the 45th Annual Meeting of the Psychonomic Society, November, 2004.

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Highlights

- Do different procedures produce equivalent discounting of delayed rewards?
- If decision-making processes are the same, similar behavior should be observed.
- The adjusting-immediate-amount procedure yielded the most consistent results.
- However, systematic discounting and magnitude effects were observed on all procedures.
- These results provide converging evidence of common decision-making processes.

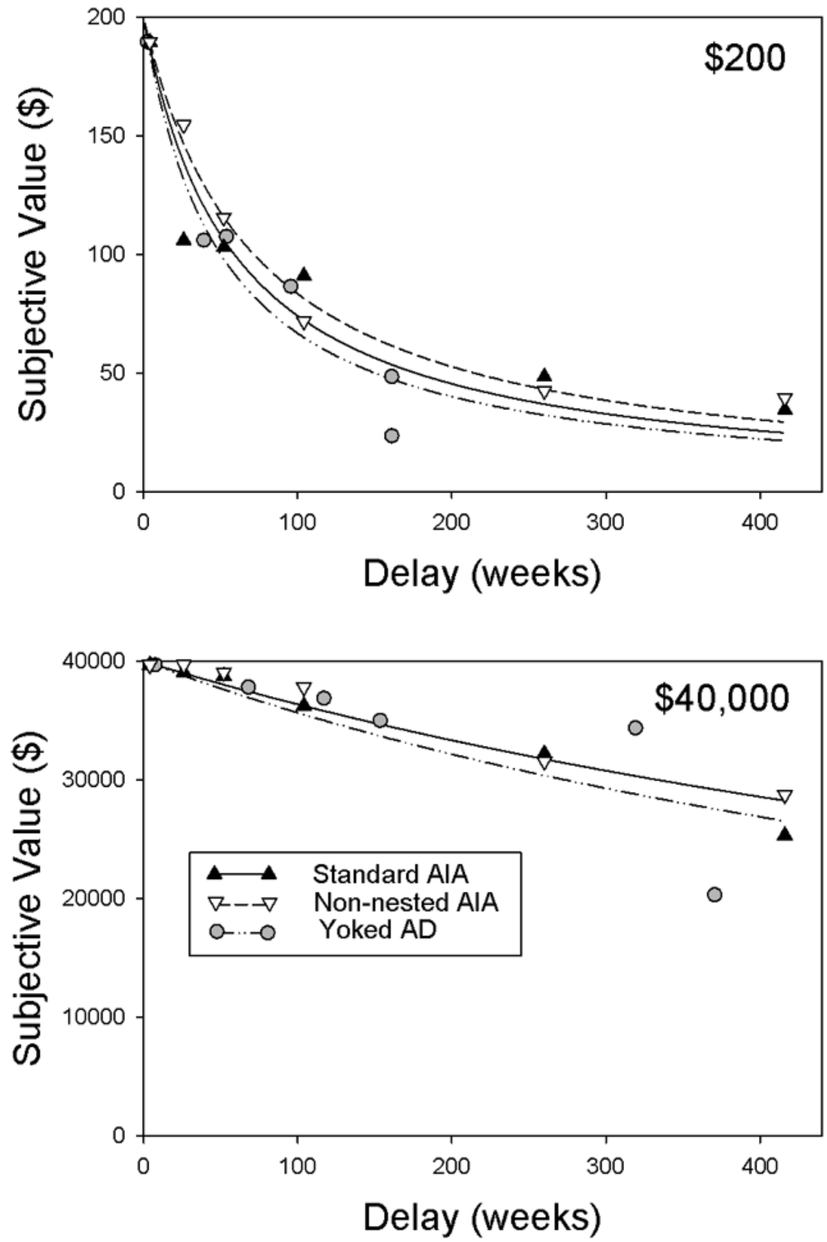

Figure 1.
Median subjective values as a function of delay for the standard and non-nested AIA tasks and the yoked AD task in Experiment 1. The top and bottom panels show the data from the $200 and $40,000 delayed amount conditions, respectively. The curves represent the best-fitting hyperbolas.

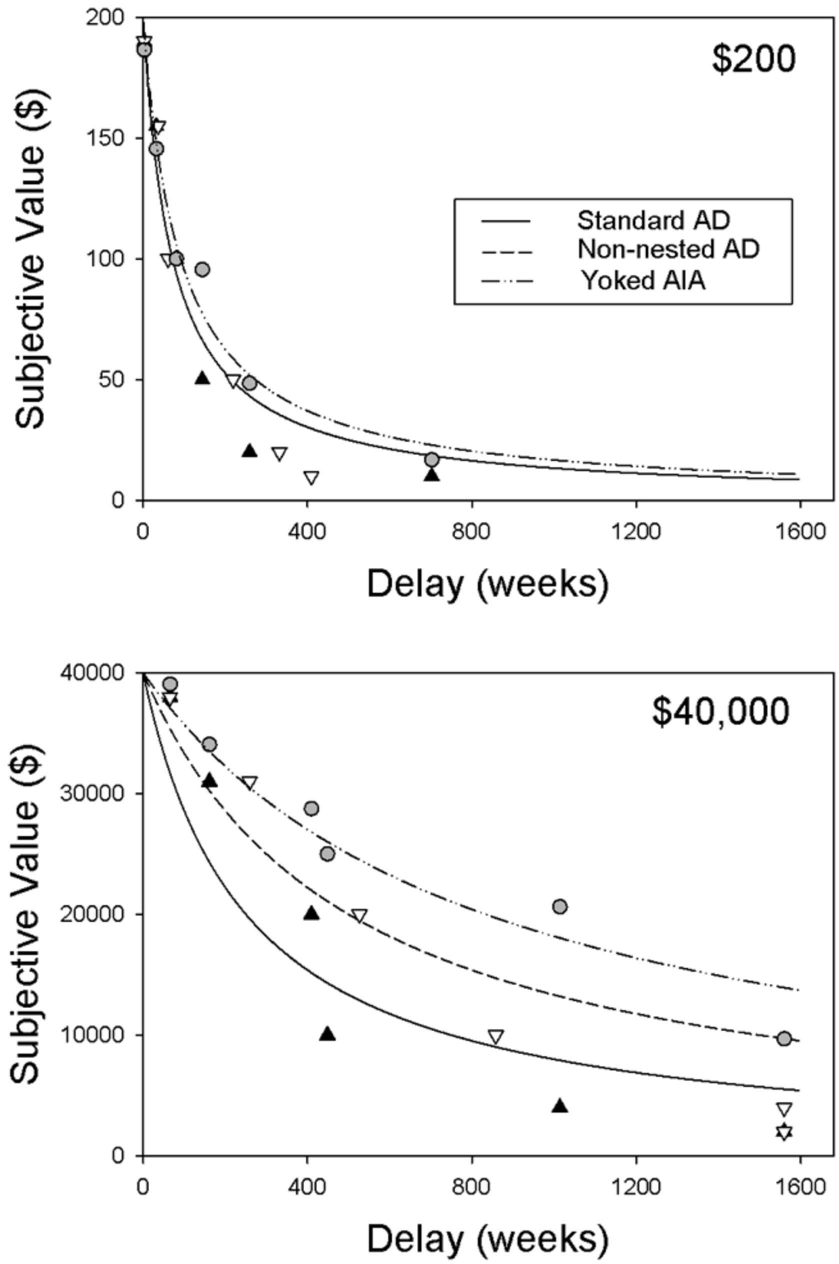

Figure 2.

Median subjective values as a function of delay for the standard and non-nested AD tasks and the yoked AIA task in Experiment 2. The top and bottom panels show the data from the $200 and $40,000 delayed amount conditions, respectively. (Note the difference in time scale from that in Figure 1.) The curves represent the best-fitting hyperbolas.

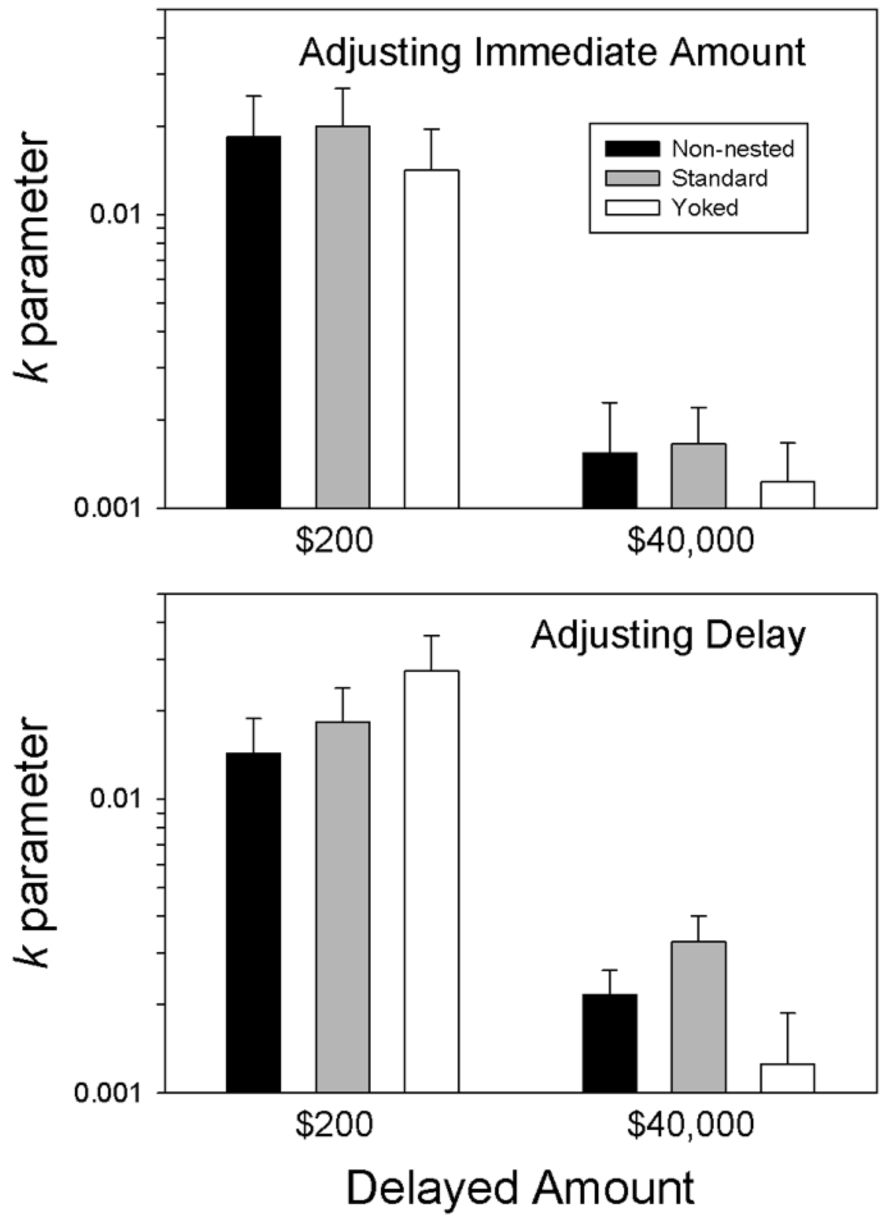

Figure 3.
Means of estimated *k* values. The top panel depicts *k* for the non-nested and standard AIA procedures in Experiment 1 and for the yoked AIA procedure in Experiment 2; the bottom panel depicts *k* for the non-nested and standard AD procedures in Experiment 2 and for the yoked AD procedure in Experiment 1. Note the logarithmic scales on the *y* axes.