Video Article

Measuring Delay Discounting in Humans Using an Adjusting Amount Task

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Abstract

Delay discounting refers to a decline in the value of a reward when it is delayed relative to when it is immediately available. Delay discounting tasks are used to identify indifference points, which reflect equal preference for two dichotomous reward alternatives differing in both delay and magnitude. Indifference points are key to assessing the shape of a delay-discounting gradient because they allow us to isolate the effect of delay on value. For example, if at a 1 week delay and a maximum of $1,000, the indifference point is at $700 we know that, for that participant, a 1-week delay corresponds to a 30% reduction in value. This video outlines an adjusting amount delay-discounting task that identifies indifference points relatively quickly and is inexpensive and easy to administer. Once data have been collected, non-linear regression techniques are typically used to generate discounting curves. The steepness of the discounting curve reflects the degree of impulsive choice of a group or individual. These techniques have been used with a wide range of commodities and have identified populations that are relatively impulsive. For example, people with substance abuse problems discount delayed rewards more steeply than control participants. Although degree of discounting varies as a function of the commodity examined, discounting of one commodity correlates with discounting of other commodities, which suggests that discounting may be a persistent pattern of behavior[1].

Video Link

The video component of this article can be found at https://www.jove.com/video/53584/

Introduction

Delay discounting is a behavioral phenomenon that affects many situations people encounter Delay discounting refers to the fact that temporally proximal rewards are more highly valued than temporally distal rewards. That is, the value of rewards decline with delays. This is an important process because many choices that people make involve a tradeoff between immediate low quality outcomes (*e.g.*, a piece of cheesecake after dinner) and delayed high quality outcomes (*e.g.*, long-term health). Delay discounting has also been observed in a variety of species in addition to humans[2,3], including monkeys[4,5], rats[6,7], and pigeons[8].

Individual differences in degree of discounting have been linked to various maladaptive behaviors[9]. The value of rewards declines as a function of delay according to a hyperbolic decay function[8]. With hyperbolic decay, value decreases extensively with relatively short delays, but decreases proportionally less so across relatively long delays. Mazur's finding that value degrades hyperbolically as a function of delay is important, because the hyperbolic function is able to predict preference reversals where other theoretical functions cannot without additional assumptions. Preference reversals are a well-documented finding[10-12] that preference for a small reward available relatively soon (SSR) over a larger reward available at a relatively distal point in the future (LLR) will reverse if a common delay is added to both alternatives. For example, if, while driving home from work, a feeling of hunger suddenly hits, a person may be inclined to stop at the first fast food restaurant in sight for a relatively unhealthy snack as opposed to waiting until they get home for a piece of fruit or some other high quality snack. If, however, the hunger hits while still at work, when the person still has to walk to their car and drive down the road before approaching the fast food restaurant, they are more likely to decide to wait until they get home for the fruit.

The steepness with which rewards decline in value as a function of delay can be considered a measure of an organism's choice impulsivity. Choice impulsivity can be defined as a preference for SSR over LLR[13,14].Higher degrees of impulsive choice are linked to use and abuse of various drugs such as alcohol[15,16], cigarettes[17,18], cocaine[19], heroin[20,21], and methamphetamine[22]. Higher degrees of impulsive choice are also linked to problematic gambling[23], obesity[24,25], and poor health and personal safety choices[26].

Various tasks can be used to assess delay discounting in humans. For instance, participants could be asked to make decisions between alternatives and experience some or all of the consequences associated with their choice (real reward task[27,28]) or they could be asked to make decisions between hypothetical alternatives, in which case they would not actually experience the consequences associated with their choice (hypothetical reward task[1-3,9,15-19,25,29]). Similar degrees of discounting are generally observed regardless of whether the reward and delays are real or hypothetical[30]. The method of administering delay-discounting tasks differs across studies. For example, various laboratories have administered the task using a fill-in-the-blank questionnaire[31], a multiple-choice questionnaire[32], an adjusting amount procedure[33], and a monetary choice questionnaire[34]. The adjusting amount task, originally developed by Du, Green, and Myerson[33], and used extensively in our laboratory, provides several benefits. Once the task is programmed data collection is automated, limiting human error throughout the process.

Due to the adjusting nature of the task, indifference points are reached with relatively few questions, which minimizes the time participants are required to be in the and laboratory and limits boredom. Importantly, the task provides detailed and reliable data. The adjusting amount task will be detailed below.

Protocol

The protocol was approved by the Institutional Review Board at Utah State University. The steps outlined below should serve as a guide for programming and conducting a delay discounting task.

1. Setting up a Delay Discounting Task

1. Choose the range of delays for which discounting will be assessed.
   NOTE: For example, a typical scenario would use delays that range from 1 week to 25 years. The selected delays should follow, by convention, an approximately exponential progression (*e.g.*, 1 week, 2 weeks, 1 month, 2 months, 6 months, 1 year, 5 years, and 25 years)
2. Choose the maximum amount of money that will be used in the task. For example, typical amounts of money used in the task are $100 or $1,000.
3. Choose the number of trials that must be completed to determine an indifference point at each delay.
   NOTE: For example, a typical number of trials for each delay should be between 6 to 8 trials to balance data resolution and participant fatigue.

2. Obtain Informed Consent and Login Participant

1. Have the participant sit in an isolated room in front of a computer. Ask the participant to turn off their cell phone and/or any other electronic devices.
2. Provide the participant with an informed consent form to review and sign if they agree to participate in the task.
3. Start the program by clicking the icon associated with the task on the computer.
4. Observe the dialogue box and enter a unique participant ID tag that will be attached to the participant's data.
   NOTE: Because the task must be programmed by experimenters, this step could be automated by having the program assign a participant tag automatically.

3. Provide Instructions and Practice Trials

1. Give the participant instructions about what he or she will experience in the task.
2. Provide practice trials that will not be included in data analysis.
   NOTE: The practice trials are designed to familiarize participants with the task design and provide participants the opportunity to ask questions if they fail to understand what is expected of them without threatening the integrity of the data collected at the beginning of the task. Practice trials should not use the adjusting procedure outlined below. Instead, practice trials should simply consist of a series of choices between immediate outcomes and delayed outcomes.
   1. For example, begin the practice trials by showing a question on the computer screen and asking the participant to choose between $10 available immediately and $100 available in 1 month. Observe the choice made on the screen.
   2. Ask the same question on the next screen but for subsequent choices increase the immediate alternative by an increment of $10 on each trial (regardless of the choices made by the participant) until the immediate and delayed alternatives are equal to $100.
3. Carry out ten practice trials to allow the participant to acclimate to the task.

4. Assess a Single Indifference Point

NOTE: Indifference points serve as the major dependent variable from delay discounting tasks and represent a point at which the present value of the delayed alternative is equal to that of the immediate alternative.

1. Display the starting amounts for the delayed and immediate alternatives to participants. For the first trial, display the maximum amount as the amount for the delayed alternative. Simultaneously display the immediate amount as ½ of the maximum amount. Set the mouse cursor to the center of the screen (equidistant from each of the choice alternatives) at the beginning of the trial.
   NOTE: The side (right or left side of the screen) on which an alternative is presented should be randomly determined on each trial.
2. Observe the participant's choice.
3. Adjust the amount of the immediate alternative by ¼ of the maximum for the second trial based on the participants choice.
   1. Decrease the amount of the immediate alternative for the second trial if the participant chose the immediate alternative on the first trial. For example, if the immediate amount was $50 and it was chosen on the first trial, then on the second trial display the immediate amount as $25.
   2. Increase the amount of the immediate alternative for the second trial if the participant chose the delayed alternative on the first trial. For example, if the immediate amount was $50, but the delayed amount was chosen on the first trial, then on the second trial display the immediate amount as $75.
4. Display the new amount of the immediate alternative and the constant delayed alternative to the participant and allow them to make their next choice.
5. Observe the participant's choice and adjust the amount of the immediate alternative by ½ of the previous adjustment.

    1. Decrease the amount of the immediate alternative for the next trial if the participant chose the immediate alternative on the current trial. For example, if the immediate amount was $25 on the second trial and it was chosen, then on the third trial display the immediate amount as $12.50.
    2. Increase the amount of the immediate alternative for the next trial if the participant chose the delayed alternative on the current trial. For example, if the immediate amount was $25 on the second trial and it was chosen, then on the third trial display the immediate amount as $37.50.

6. Repeat steps 4.4 and 4.5 until the participant has made the required number of choices
NOTE: The number of choices is up to the discretion of the experimenter; see discussion for further detail.
NOTE: The adjustment for the upcoming trial should always be equal to the maximum amount multiplied by 2^{-n}, where n is the trial number for the current adjustment (see **Figure 1**).
7. Make the final adjustment to the immediate amount based on the participant's choice. Use this new amount as the indifference point for that delay.

5. Determine Indifference Points at Each Delay

1. Fully repeat Step 4 for each of the chosen delays, resetting the amount of the immediate outcome and the amount of the adjustment for the first trial at each delay.

6. Assess Delay Discounting of Qualitatively Different Outcomes (Optional)

1. Ask the participant to provide an example of the chosen outcome. For example, if the chosen outcome is food then ask the participant "What is your favorite food?"
2. Observe the participant's response and ask the participant how much a unit of the outcome costs (*e.g.*, "What is the cost of the preferred food?").
NOTE: If experimenters are interested in assessing differences in discounting across commodities, this step will equalize commodities in terms of value so that any differences in discounting are not due to differences in the amount being discounted.
3. Display the values of the immediate and delayed starting values based on the price reported by the participant. Set the delayed amount of the outcome to be equal to the maximum value divided by the per unit price that was provided by the participant and then set the immediate alternative to ½ of that amount.
NOTE: For example, if 1 serving of ice cream costs $5 and the maximum is $100 then there are 20 servings of ice cream in $100. Use this calculated value as the delayed alternative (*e.g.*, "20 servings of ice cream in 1 week") and ½ of that amount as the immediate alternative (*e.g.*, "10 servings of ice cream now").
4. Repeat all of Steps 4 and 5 with the recalculated value of each outcome.

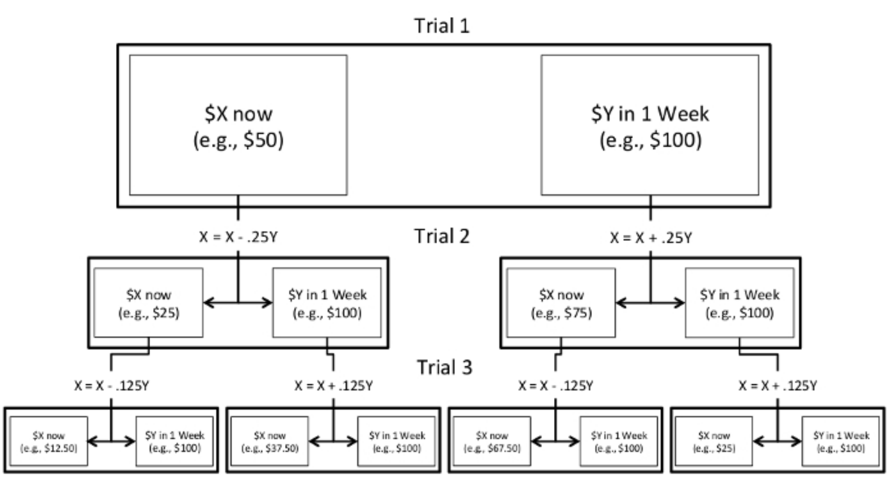

Figure 1. Trial Structure of the Adjusting Amount Task. The starting value for the delayed alternative, Y, should equal the maximum. The starting value for the immediate alternative, X, should equal .5Y. If X is chosen then the value of X should be decreased on the next trial. If Y is chosen then the value of X should be increased on the next trial. The amount of the adjustment is .25Y on Trial 1 and is .5 of the previous adjustment on each subsequent trial. Please click here to view a larger version of this figure.

7. Data Analysis

1. Import data into any preferred data analysis program. Isolate the indifference point for each delay for each participant. Calculate the median indifference point for each delay for each group.
NOTE: Calculation of median indifference points is only necessary if a group design is used.
2. Choose a curvilinear regression model (see representative results for examples). Use curvilinear regression to fit the model to the (median) indifference points. This will generate relevant parameter estimates for the selected model (see below for an explanation of the parameters).

NOTE: We have provided code to conduct curvilinear regression in Supplemental Materials for the statistical program R to aid the reader with Step 7.

Representative Results

Delay discounting results are commonly analyzed by fitting curvilinear regression models to both the median indifference points from the groups and indifference points from individual participants for each outcome. Median group indifference points are used because the indifference points for a sample are usually not normally distributed. Three non-linear regression models are commonly used: those suggested by Mazur (Equation 1)[8], Myerson and Green (Equation 2)[35], and Rachlin (Equation 3)[36].

$$(1)\ V = \frac{A}{1+kD}$$

$$(2)\ V = \frac{A}{(1+kD)^s}$$

$$(3)\ V = \frac{A}{1+kD^s}$$

In these models, V is the present (discounted) value of a delayed outcome (*i.e.*, the experimentally-determined indifference point), A is the amount of the future outcome, D is the delay to the outcome, and k is a free parameter that quantifies the steepness with which the delayed outcome loses value as a function of delay. In Equations 2 and 3, s is a scaling parameter that is also free to vary. Traditional statistical analyses may be conducted on the natural log (ln) of k from Equation 1. Statistical analyses are less appropriate for $\ln(k)$ from Equation 2 and Equation 3 because k is not an independent measure of discounting due to its interaction with the s parameter.

In our laboratory, we have shown that the specific outcome that is being investigated (*e.g.*, food vs. money) affects discounting (*e.g.*, food is discounted more steeply than money[1]). Despite this fact, individual participants' degree of discounting is correlated across different outcomes. We have interpreted this finding as evidence that delay discounting is a trait-like process. However, while delay discounting seems to be a trait-like process, it is also affected by state variables[37,38].

The following results, previously published in the journal *Psychopharmacology*[1] demonstrate typical delay discounting curves obtained through non-linear regression. For group analysis, median group indifference points are obtained for each delay. These points are fit to the non-linear regression model (see provided R code). **Figure 2** displays the model fits of Equation 2 for four outcomes: money, alcohol, entertainment, and food. Results have been separated into two groups: cigarette smokers and non-smokers.

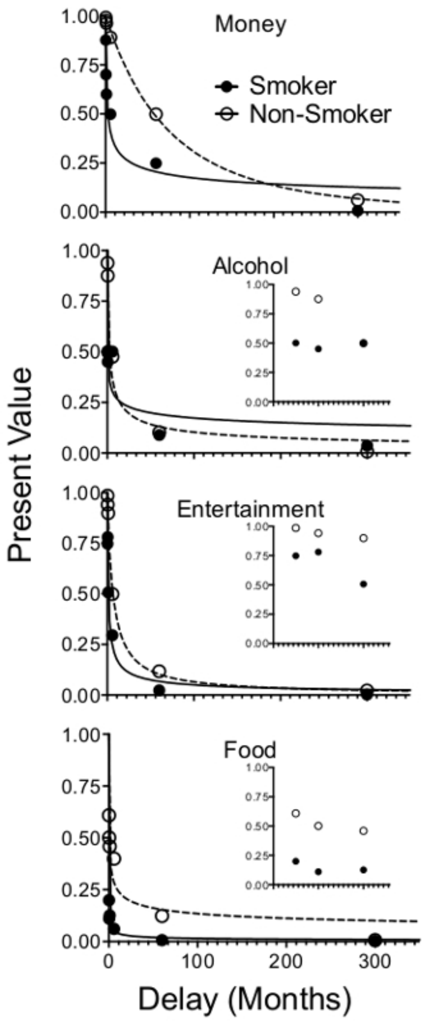

Figure 2. Delay Discounting of Different Commodities. Discounting functions for smokers and non-smokers for the commodities of money, alcohol food, and entertainment. In all four panels, the points show median indifference points and lines show the best fitting hyperbola-like discounting function[35]. Insets for the commodities of alcohol, entertainment, and food are the same data with the x-axis scaled to show indifference points at the shortest delays. In some cases, data points may overlap. This figure was originally published in *Psychopharmacology*[1] (under CC-BY license). Please click here to view a larger version of this figure.

The quality of the fits can be evaluated using two measures: R^2 and Akaike Information Criteria (AIC). R^2 is calculated as 1 - (Residual Sum of Squares/Total Sum of Squares). R^2 scores for non-linear regression should be interpreted with caution (and possibly avoided) because the model sum of squares and error sum of squares do not equal 1. Nonetheless, we typically include R^2 scores due to convention and so that the values from our studies can be compared to previous studies. AIC is calculated as 2k + n Log(RSS/n) where k is the number of free parameters (1 for Equation 1, and 2 for Equations 2 and 3), and n is the number of indifference points (see **Table 1**). Individual data are analyzed in a similar method. Median R^2 and AIC values are reported to demonstrate the quality of the individual fits (**Table 2**). It is important to note that Equation 1 is a special case of Equation 2 and Equation 3 (when s = 1) and will never produce a larger R^2 value than these other equations. Thus, AIC can be used to evaluate if the gain in R^2 for the more complex models justifies the extra parameter (the increased complexity) in these equations. An alternative method of evaluating whether the more complex model is justified would be to determine whether s differed significantly from 1[39].

Alternatively, a non-theoretical measure, area under the curve (AUC), can be obtained from the participant's indifference points[40]. AUC is the sum of the trapezoidal area between each set of adjacent indifference points. AUC is calculated as $(x_2 - x_1)[(y_1 + y_2)/2]$, where x_1 and x_2 are the successive delays and y_1 and y_2 are the indifference points for those delays (see provided R code). AUC ranges between 0 and 1 and lower values indicate steeper discounting. Parametric statistics can be used to analyze AUC if the specific sample meets the requirements of normality.

	Outcome	AIC		Median R^2	
		Mazur (1987)	*Myerson and Green (1995)*	*Mazur (1987)*	*Myerson and Green (1995)*
Non-smoker	Money	9.11	**7.57**	.96	**.98**
	Alcohol	**14.92**	15.97	.52	**.75**
	Ent.	**5.69**	7.68	.87	**.95**
	Food	15.90	**13.68**	.63	**.80**
Smoker	Money	15.74	**14.32**	.74	**.82**
	Alcohol	17.63	**16.43**	.12	**.54**
	Ent.	**12.08**	12.99	.70	**.85**
	Food	8.31	**6.94**	.38	**.61**

Table 1:Model Fit Comparisons. Model fit comparisons for the Mazur[8] hyperbola and Myerson and Green[35] hyperboloid. Bolded values indicate the better fit. For median indifference points, the Akaike Information Criterion (AIC) results indicate that the hyperboloid provided a better fit five out of eight times. Comparisons of R^2 values obtained from fitting both models to individual participant data indicate that the hyperboloid fit better in all cases than the hyperbola.

	Outcome	*k*	*s*	R^2
Non-smoker	Money	0.004	3.61	0.99
	Alcohol	1.30	0.47	0.92
	Entertainment	0.16	0.97	0.99
	Food	19.91	0.26	0.91
Smoker	Money	3.28	0.30	0.94
	Alcohol	66.18	0.20	0.71
	Entertainment	1.71	0.58	0.97
	Food	206.30	0.42	0.94

Table 2: Parameter Estimates. The *k* and *s* parameters as well as R^2 for hyperboloid fits to median indifference points for each outcome for each group.

Supplemental File 1. Monetary Discounting Eprime Instructions.txt Please click here to download this file.

Supplemental File 2. Monetary Gain Delay Discounting Only.ebs2 Please click here to download this file.

Supplemental File 3. Monetary Gain Delay Discounting Only.es2 Please click here to download this file.

Supplemental File 4. JOVE Pseudocode.pdf Please click here to download this file.

Supplemental File 5. Delay Discounting.R Please click here to download this file.

Supplemental File 6. Data.txt Please click here to download this file.

Discussion

This video describes the steps that should be taken to conduct a delay discounting experiment using the adjusting amount task. The adjusting amount task is relatively quick to conduct (10 - 15 min per participant) and produces reliable data. The adjusting nature of the task provides a fine-tuned analysis of an individual participant's degree of discounting. Since the task is computer-based data collection is automated, which limits human-error and influence during the data collection process. Typically the task is used to assess discounting of hypothetical outcomes, but it has also been used to assess discounting of real outcomes[28]. One limitation to the adjusting amount task is that the task is not robust against participant error. Due to the titrating nature of the task an error made in the first trial of a delay block (*e.g.*, clicking $50 now instead of $100 in a week when the participant meant to choose $100 in a week) will drastically affect the indifference point for this delay as the immediate option will never again reach $50 in this block due to the decreasing adjustment across trials. An error made in a later trial within a block will not affect the indifference point as much. Based on observation in our laboratory, we find that such errors are relatively rare. The experimenter could program the task to verify with the participant that the indifference point is accurate and repeat the process for that delay if it is not.

Three critical parameters within a delay discounting experiment using the adjusting amount task are up to experimenter discretion, but should align with the experimental question: 1) The amount of the outcomes being used should make sense for the experimental questions (*e.g.*, $100,000 worth of food is nonsensical). 2) The delays used in the experiment should make sense with the outcome and amounts being used (*e.g.*, due to steep discounting $10 may not be enough to provide meaningful data if one uses a delay progression that ranges from 1 week to 25 years). 3) The number of adjustments within each delay block should balance resolution and time (more resolution with more trials, but greater time required from participants). Here we outlined one way in which a delay discounting assessment can be carried out, but delay discounting tasks are robust to variation and slight modifications of the procedure outlined above are not likely to make a significant difference in the findings.

Analyzing data from delay discounting experiments consists of curvilinear regression techniques that are relatively easy to implement and produce good fits to the data. We have included several documents in Supplementary Materials that will aid in programming a delay discounting experiment and analyzing the data that are collected through a delay discounting task: pseudo-code to assist in programming a delay discounting task in any language, a delay discounting task programmed in E-Prime, and script for running non-linear regression in the statistical program R (with comments).

Delay discounting experiments, using the adjusting-amount task, provide a robust way to identify between-group and within-subject differences in impulsive choice. Experiments have identified differences in the degree of delay discounting between people with maladaptive behavior patterns and control participants[41]. Experiments using delay-discounting tasks can also be used to identify variables that impact delay-discounting within-subject and assess the relative permanence of those manipulations.

While previous research has focused on examining differences in delay discounting among different populations, more research is needed to understand how delay discounting can be impacted through therapeutic intervention. Delay discounting experiments have been extremely successful in identifying differences between control populations and populations of people with maladaptive behavior patterns and provide researchers with a rationale for why individuals gamble, use drugs, overeat, or have little regard for health-related behavior. Because the negative outcomes associated with these behaviors are delayed, those outcomes have little impact on the behavior of people with steep discounting functions.

Little research has yet focused on the mechanisms underlying delay discounting. What gives rise to high degrees of discounting, which may lead to these maladaptive behavior patterns? Although there is evidence to suggest that delay discounting is at least somewhat heritable[42], delay discounting may still be malleable. It is important to identify the psychological and neurobiological mechanisms underlying delay discounting and variables that can impact those mechanisms. It is possible that the degree of delay discounting may be reduced by therapeutic intervention[43], but more research is needed to understand the generality of these findings and the impact that decreases in delay discounting may have on the propensity to engage in the maladaptive behavior patterns associated with steep delay discounting gradients.

Disclosures

The authors have nothing to disclose.

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