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Effects of delay and probability combinations on discounting in humans

David J. Cox*, Jesse Dallery

University of Florida, Department of Psychology, 945 Center Drive, Gainesville, FL, 32611-2250, United States

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ABSTRACT

To determine discount rates, researchers typically adjust the amount of an immediate or certain option relative to a delayed or uncertain option. Because this adjusting amount method can be relatively time consuming, researchers have developed more efficient procedures. One such procedure is a 5-trial adjusting delay procedure, which measures the delay at which an amount of money loses half of its value (e.g., $1000 is valued at $500 with a 10-year delay to its receipt). Experiment 1 (n = 212) used 5-trial adjusting delay or probability tasks to measure delay discounting of losses, probabilistic gains, and probabilistic losses. Experiment 2 (n = 98) assessed combined probabilistic and delayed alternatives. In both experiments, we compared results from 5-trial adjusting delay or probability tasks to traditional adjusting amount procedures. Results suggest both procedures produced similar rates of probability and delay discounting in six out of seven comparisons. A magnitude effect consistent with previous research was observed for probabilistic gains and losses, but not for delayed losses. Results also suggest that delay and probability interact to determine the value of money. Five-trial methods may allow researchers to assess discounting more efficiently as well as study more complex choice scenarios.

1. Introduction

Humans often choose between outcomes that differ in delay, probability, and amount. For example, smoking cigarettes may result in immediate relief from withdrawal and delayed, yet uncertain, adverse health outcomes. Abstaining from smoking may result in immediate discomfort and delayed and uncertain positive health outcomes. Similar differences in delay, probability, and amount of adverse or beneficial outcomes may occur for a number of health-related behaviors such as physical exercise, balanced nutrition, substance use, and risky sexual behavior.

Researchers have been primarily interested in the effects of manipulating one or two of these dimensions on choice (e.g., Ritschel et al., 2015; McKerchar et al., 2009; Bruce et al., 2015; McKerchar and Renda, 2012). For example, researchers have studied how delay to receiving a commodity affects its current value (see Odum, 2011; for review). The tendency for the current value of a commodity to decrease as a function of delay to receipt is termed delay discounting. The rate at which a commodity loses value can be described mathematically by a hyperbolic equation (Mazur, 1987):

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

In this equation, V is the current value of a delayed commodity, A is the undiscounted value of the commodity, D is the delay to receipt of that commodity, and k is a parameter representing rate of delay discounting. Other researchers have assessed how the probability of obtaining a commodity affects its current value (see McKerchar and Renda, 2012; for review). A reduction in the current value as a function of the odds against receiving the commodity is termed probability discounting. The same hyperbolic equation used to describe delay discounting can be extended to probability discounting:

$$V = \frac{A}{(1 + h\theta)}. \quad (2)$$

Odds against (Θ) is substituted for delay and is calculated as (1-p)/p, where p is the probability of receiving the commodity. V and A are the same as Eq. (1) and h is a parameter representing rate of probability discounting (i.e., how the value of a commodity reduces as a function of increasing uncertainty).

Researchers have observed several patterns when studying delay and probability discounting. When the outcomes are gains,

* Corresponding author. Correspnding author.:University of Florida Department of Psychology, 945 Center Drive, Gainesville, FL, 32611-2250, United States.
E-mail addresses: david.j.cox@ufl.edu (D.J. Cox), dallery@ufl.edu (J. Dallery).

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the magnitude of the outcome alters the rate of discounting (i.e., a magnitude effect). Delay discounting decreases as magnitude increases (e.g., Green et al., 1997). In contrast, probability discounting increases as magnitude increases (e.g., Green et al., 1999; Yi and Bickel, 2005). Unlike outcomes involving gains, however, researchers have not found a magnitude effect in delay or probability discounting when the outcomes are described as losses (Estle et al., 2006; Green et al., 2014). Although an integrated, theoretical account of these patterns has not been widely accepted, they nevertheless provide benchmarks to evaluate the validity of new methods to measure discounting.

A challenge in assessing the influence of multiple outcomes on choice is that traditional methods involve relatively lengthy procedures when choice alternatives become more complex. For example, Du et al. (2002) assessed delay discounting using a common adjusting amount procedure at seven delays. A series of six choices were presented at each of seven delays resulting in 42 total response trials for each participant. Using a similar adjusting amount method, the total number of responses increases to 125 when five choices are presented for alternatives that are both delayed and probabilistic (five delays x five probabilities x five response trials per combination of delay and probability; e.g., Vanderveldt et al., 2015). If one is interested in studying the effects of two outcomes, where both alternatives are delayed and probabilistic, the total number of responses by each participant expands to 3125 (125 trials for delayed and probabilistic first outcome x five delays of the second outcome x five probabilities of the second outcome). The duration of task administration for more complex discounting scenarios may limit practicality for researchers and result in participant fatigue, which may influence the quality of responses. Therefore, a more efficient method is needed to measure the effects of multiple outcomes on choice behavior.

Koffarnus and Bickel (2014) described a procedure to determine a delay at which a commodity loses half of its value (i.e., effective delay of 50% or ED_{50}). In this procedure, the immediate alternative is fixed at half the delayed alternative (e.g., $500 if the delayed alternative is $1000). The delay to the larger amount adjusts over five trials based on participant responses. The final delay (i.e., ED_{50}) following these adjustments provides the discounting parameter for that participant (Yoon and Higgins, 2008). Koffarnus and Bickel (2014) demonstrated that this 5-trial adjusting delay task provides similar *k*s compared to traditional adjusting amount tasks. In addition, their results replicated several other effects from the discounting literature (Green et al., 1997; Bickel et al., 2008; Yi et al., 2006; Estle et al., 2007; Jimura et al., 2009; Magen et al., 2008; Radu et al., 2011), including the magnitude effect, which suggests that this method is valid for delayed gains (see Koffarnus and Bickel, 2014 for full explanation).

Experiment 1 sought to extend 5-trial adjusting delay and probability tasks to delayed losses, probabilistic gains, and probabilistic losses. Experiment 2 extended 5-trial tasks to examine the combined effects of delayed and probabilistic gains, and delayed and probabilistic losses. We compared discounting rates obtained from 5-trial tasks to traditional adjusting amount method. In addition, we assessed whether 5-trial adjusting delay and probability tasks would result in magnitude effects similar to traditional measures of discounting.

2. Experiment 1

Koffarnus and Bickel (2014) demonstrated that traditional adjusting amount and 5-trial adjusting tasks produced similar rates of discounting for delayed gains. The authors also found evidence for the magnitude effect. Experiment 1 sought to extend the 5-trial adjusting delay procedure to probabilistic gains, probabilistic losses, and delayed losses. Specifically, we compared 5-trial adjusting delay and probability procedures to traditional adjusting amount procedures. In addition, we manipulated amount using the 5-trial adjusting tasks to evaluate the magnitude effect.

2.1. Method

2.1.1. Participants

Two hundred and twelve participants were recruited from the Psychology participant pool from a large public university in the southeast United States. The average age of participants was 19.09 (range 18–22) and 68% were female. Participants were randomly assigned to receive hypothetical monetary outcomes that involved delayed loss, probabilistic loss, or probabilistic gain.

2.1.2. Delayed loss

Each participant assigned to the delayed loss condition completed three discounting tasks. This included a traditional adjusting amount task with the larger-later value of $1000, a 5-trial adjusting delay task with a larger-later amount of $1000, and a 5-trial adjusting delay task with a larger-later amount of $10. Individual trials were presented by asking the participant, "Would you prefer losing $(*amount*) immediately or $1000 in (*delay*)?"

The traditional adjusting amount procedure was completed for seven different delays. Delays assessed were 1-week, 1-month, 4-months, 8-months, 12-months, 5-years, and 10-years. The first trial always presented the immediate amount at half the value of the delayed amount. The amount of the delayed option stayed the same for all trials (i.e., $1000). The amount of the immediate alternative adjusted following each choice made by a participant and was rounded to the nearest dollar for ease of presentation. Specifically, the immediate amount increased if the immediate option was chosen or decreased if the delayed option was chosen. The amount of the immediate alternative adjusted by 25% of the larger amount following the first trial, by 12.5% of the larger amount following the second trial, and by 6.25%, and 3.125% of the larger amount following the third and fourth trials. The amount of the immediate option adjusted by 1.5625% of the larger amount following the fifth trial and the resulting value was selected as the indifference point for the participant at that particular delay.

An identical version of the 5-trial adjusting delay task from Koffarnus and Bickel (2014) was used for participants assigned to the delay loss condition in Experiment 1. Table 1 contains the 31 potential delays (i.e., Indices 1–31) and the potential trial number that each delay could be presented to a participant. The immediate amount remained fixed at half of the larger delayed amount for all trials (i.e., $500 vs. $1000, or $5 vs. $10). The participant was first presented with a choice between a smaller immediate amount and a larger amount at a 3-week delay (i.e., index 16, trial number 1). If the participant selected the immediate alternative, the delay to the larger amount increased by 8 indices (i.e., to a delay of 2-years at index 24, trial number 2). If the participant selected the delayed alternative, the delay to the larger amount decreased by 8 indices (i.e., to 1-day, index 8, trial number 2). Following the choice made on the second, third, and fourth trial, the delay to the larger alternative increased if the immediate alternative was chosen and decreased if the delayed alternative was chosen. Delays adjusted by 4, 2, and 1 indices, following the second, third, and fourth trials respectively. Fig. 1 shows an example of how choice alternatives would change based on the pattern of responses made by a hypothetical participant. The left side displays hypothetical participant responding for the 5-trial adjusting delay task.

The choice alternative selected for the fifth trial was used to determine *k* as outlined in Table 1. For immediate choices at fifth trial indices, *k* was calculated by dividing 1 by the geometric mean of the delay for the fifth trial and the delay at the index immediately