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Within-subject differences in degree of delay discounting as a function of order of presentation of hypothetical cash rewards

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ABSTRACT

Procedural variants in estimating delay discounting (DD) have been shown to yield significant differences in estimated degree of DD as well as variations in individual patterns of choice. For example, a recent study found significantly different degrees of DD between groups assessed using either an ascending or descending order of presentation of the immediately available rewards. The purpose of this study was to test for within-subject effects of order of presentation of the immediate rewards in a DD task. In a single session, college students ($N = 29$) were asked to complete two DD tasks, one with the immediate rewards presented in ascending order and one in descending order. Consistent with previous results, significantly larger mean area under the discounting curve (AUC) was observed when the descending sequence was used compared to the ascending order of presentation; and the correlation between both measurements was moderate. These results suggest that some DD assessment tasks may be sensitive to contextual variables such as order and range of the reward and delay values.

1. Introduction

Delay discounting refers to the observed reduction in subjective value of a reward as a function of delay between the time when the choice is made and the time when the reward becomes available. The decay in subjective value over time is best described by a hyperbolic model first proposed by Mazur (1987).

$$v_d = \frac{V}{1 + kd} \tag{1}$$

where v_d is the current subjective value of a delayed reward (the indifference point), V is the value of the delayed consequence, d is the delay duration, and k is an empirically derived constant proportional to the degree of delay discounting.

Delay discounting is consistently observed in humans and other animals over a wide range of conditions (Bickel et al., 1999; Green et al., 1994; Mazur, 1987, 2007; Rachlin et al., 1991; Richards et al., 1997; Reynolds, 2007; Rodriguez and Logue, 1988; Stevens et al., 2005; Woolverton et al., 2007). Research in DD has experienced vigorous growth over the past 20 years, and among the possible factors stimulating its growth are the theoretical value of DD as a behavioral process occurring across species, as well as the promise of DD to aid our understanding of clinically important human behavior such as addiction to gambling and drugs.

Recently, two studies (Robles and Vargas, 2007, 2008) comparing computerized algorithms to estimate DD in college students found that the order of presentation of the immediate rewards significantly influenced the degree of DD obtained. The first study, presenting a series of 240 trials in random order yielded higher DD values, longer assessment sessions, and characteristically different distributions of response times than presenting the same 240 trials in strict ascending or descending order. The second study (Robles and Vargas, 2008) revealed significantly lower delay-discounting values in subjects that were assessed using a descending order of presentation of the immediately available rewards compared to subjects exposed to an ascending order, across algorithms involving either a fixed or a variable number of trials. That study also ruled out the possibility that the observed differences in degree of delay discounting associated with the order of presentation of the immediate rewards were due to differences in the number of trials, when the number of trials was controlled by the subject. It is not yet clear why such differences in estimated degree of delay discounting occur. To further explore the role of the effects of the context on choice, the purpose of this study was to evaluate, within-subjects and in a single session, the effect of order of presentation of the immediate rewards in a delay-discounting task.

2. Materials and methods

2.1. Subjects

Participants were 29 college undergraduates; 60% female. Students were recruited from the Department's subject pool, and

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received extra course credit for participating in research. All participants signed a consent form approved by the local Institutional Review Board.

2.2. Procedure

All participants were asked to complete two DD tasks in a single session lasting approximately 30 min. The computerized tasks presented choices between 30 amounts of immediately available hypothetical cash (US $1000, $999, $995, $990, $960, $940, $920, $850, $800, $750, $700, $650, $600, $550, $500, $450, $400, $350, $300, $250, $200, $150, $100, $80, $60, $40, $20, $10, $5, $1) and $1000 available after 8 delays (6 h, 1 day, 2 weeks, 2 months, 6 months, 1 year, 5 years, and 25 years). In one assessment (*Ascending*), for each delay value, the immediately available rewards were presented in ascending order. Once a subject showed indifference between the immediate and delayed rewards for a given delay value, trials showing larger immediate rewards for that delay value were omitted. The other assessment was identical except that the immediate reward values were presented in descending order (*Descending*). Participants were randomly assigned to receive the ascending or descending sequence first. This method to estimate indifference points corresponds to the *Abbreviated* method in Robles and Vargas (2008). A large number of variants on the questionnaire method developed by Rachlin et al. (1991) have been used to estimate degree of delay discounting (see Robles and Vargas, 2007). However, two characteristics were important in choosing the abbreviated method for use in this experiment: (1) the immediate reward values are presented in strict order (ascending or descending), which permits the study of sequential effects, and (2) this is a faster way to estimate DD than the full-length method, and yields DD values are comparable to those obtained when the full series of 240 trials is presented (Robles and Vargas, 2008).

Immediately after completing each DD task, all participants were presented with two visual analog scales (VAS) and asked to report how easy–difficult and how boring–interesting they thought the DD task was.

2.2.1. Assessment of delay discounting

After participants entered their identification data, the computer program presented a screen with the following instructions:

> "This program will show you a series of screens where you will be asked to choose between an amount of money available now and $1,000 available after some delay. The money in this program is hypothetical, "pretend money", but please make your selections as if you were really going to get the amounts you choose. We don't expect you to choose one in particular, so please don't select what you think we might want you to choose, but click on the alternative you really would prefer. After each choice the program will go on to the next screen, and it will tell you when you are done. Now click on the START button when you are ready to begin."

Participants chose between the two options by clicking the left button of the computer mouse over a command button associated with that option. The location on the screen of the virtual button associated with the delayed and immediate rewards was switched randomly from trial to trial. There was no limit to the amount of time that the subjects could take to choose between the two options; and they were not instructed as to how quickly they should respond. Once a choice was made a 2-s intertrial interval started during which responses had no effect. After completion of the first DD task and visual analog scale assessments, a computer screen instructed participants to relax in their place, and displayed a 120-s count-down timer. At the end of the 2-min break, participants were required to click on a button to initiate the second assessment task. All data collection and management software was written in Microsoft Visual Basic 6.0.

2.2.2. Visual analog scales (VAS)

Immediately after completing each DD task subjects were asked to rate the task in terms of how difficult ("Very Easy" to "Very Difficult") and how interesting ("Boring" to "Interesting") they thought the task was. Participants were presented with a computer screen showing two VAS and the following instructions: "On the sliders below, move the marker to the point that best represents how you feel about the task you just completed." The first VAS was anchored at "Very Easy" and "Very Difficult"; the second VAS was anchored at "Boring" and "Interesting". The scales were implemented as slider controls that allowed the subjects to drag an indicator between the two extremes of each scale. No additional feedback was provided to the participants. Values between 0% and 100% of the slider's width were recorded for later analysis.

3. Results

Median indifference points obtained with the ascending and descending order of presentation of the immediate rewards were well described by Mazur's (1987) hyperbolic model, resulting in R^2 of .94 (k = .002) and .91 (k = .0006), respectively.

Area under the discounting curve (AUC) was calculated for each subject and order of presentation using the method described by Myerson et al. (2001; see Fig. 1). After testing for normality ($p < .05$), a two-way (order of exposure [first vs. second] × order of presentation of the immediate rewards [ascending vs. descending]) repeated measures ANOVA was used to compare AUC. The test revealed no differences due to order of exposure to the ascending and descending procedures ($p = .80$) or to the interaction between the variables ($p = .70$). However, significantly larger mean AUC was estimated when subjects were assessed using the descending order of presentation of immediate rewards (.48), compared to the ascending order (.36; $F(1,27) = 4.42$, $p < .05$). For comparison, the effect of order of presentation was also assessed in terms of individual k values. The distributions of k values obtained with the ascending and descending order of presentation were skewed ($p > .05$), and were thus compared with a Wilcoxon Signed Rank test. Consistent with AUC results, the test revealed a significantly smaller median k (.0006 vs.

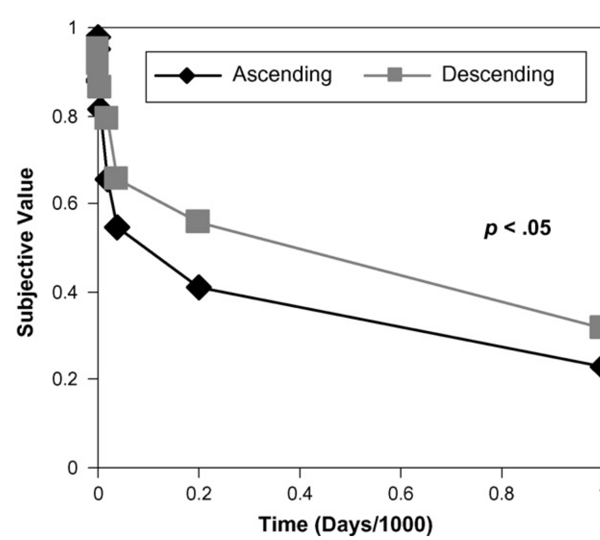

Fig. 1. Subjective value of $1000 as area under the discounting curve (AUC) obtained when the immediately available rewards were presented in ascending (squares) or descending (diamonds) order.

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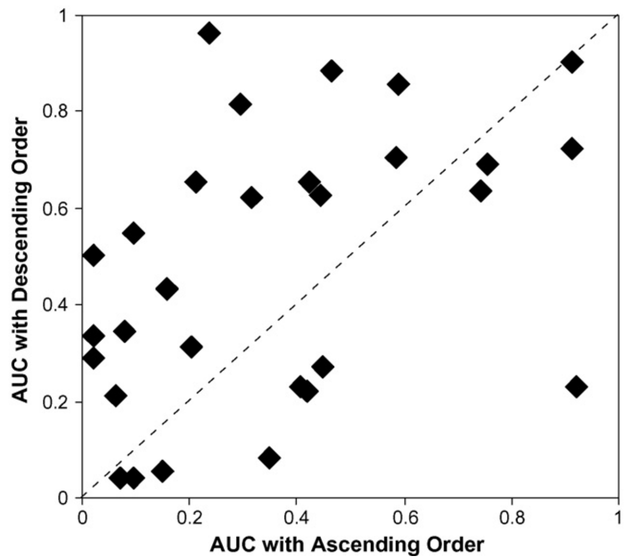

Fig. 2. The correlation between each individual's scores obtained with the ascending and descending sequence was moderate ($\rho = .44$, $p < .05$).

.002) when the descending order of presentation was used ($W = 191$, $T+ = 313$, $T- = -122$, $p < .05$).

As shown in Fig. 2, the correlation between AUC values obtained with both methods was moderate ($\rho = .44$, $p < .05$), accounting for 19% of the total variance.

Regarding the subjects' evaluation of the two procedures, comparing the VAS scores with *t*-tests for paired data revealed no differences in the subjects' assessment of the ascending and descending procedures on either the easy–difficult (13.5 vs. 15.2) or the interesting–boring scale (39.3 vs. 46.5; both $p > .05$).

4. Discussion

Significantly greater delay discounting, as measured by lower AUC values, was obtained when the ascending sequence of immediate rewards was used, compared to the descending sequence. These results confirm, within-subjects, the results of our earlier study (2008) where different algorithms (abbreviated vs. full) and orders of presentation of the immediate rewards were tested in a between-groups design. That study also ruled out the possibility that subjects responded to reduce or minimize the number of trials, and as a consequence finished the assessment sooner. Since the number of trials needed to estimate degree of DD with the abbreviated method used in this study varies depending on the particular choices a subject makes, it is possible for subjects to respond in such a way as to reduce or minimize the number of trials and finish the assessment sooner, instead of choosing according to their preference between the immediate and delayed rewards regardless of the time and effort involved. The 2008 experiment ruled out this confound by showing that the descending order of presentation yields lower degree of DD regardless of the number of trials in the task.

It is not clear how the order of presentation of immediate rewards in a series of trials might have affected a subject's subjective value of hypothetical money. However, the demonstration of this effect within-subjects, in a single session, strongly suggests that contextual variables may be involved. Evidence from psychophysical research indicates that in judging brightness of a light, for example, subjects not only base their responses on the concurrently available stimulus and context (e.g., intensity of the stimulus and background), but also on comparisons between the present stimulus and previous events (Lockhead, 2004). It is possible, then, that during DD tasks subjects not only respond to the values presented in a given trial, but also compare current reward and delay values to those seen in previous trials. Specifically, it is possible that choices between the two hypothetical amounts of cash might be affected by the context of the (ascending or descending) sequence being used. For example, the descending sequence begins with the best possible outcome (the maximum amount of money available immediately) where participants choose between $1000 now and $1000 after some delay; so, we expect most subjects to choose the immediate outcome. Then, subsequent choices in the delay series offer successively poorer outcomes for choosing the immediate reward. On the other hand, the ascending sequence begins with the worst outcome for choosing the immediate reward (the minimum amount of money) where participants choose between $1 now and $1000 after some delay; so, most subjects choose the delayed outcome. Then, subsequent choices in the delay series offer increasingly better outcomes for choosing the immediate reward. Although identical choices are available to the subject in both procedures, the *perceived* worsening of the outcomes in one case (a decreasing immediate amount) may lead to early switching and the *perceived* improvement of the outcomes in the other (an increasing immediate amount) may lead to switching later in the series. In both cases, however, the hyperbolic model of DD describes the indifference points equally well.

Another contextual variable potentially responsible for the differences in DD observed in this study is the magnitude of the immediate and delayed rewards to which subjects are exposed. It has been reliably demonstrated that humans discount smaller hypothetical delayed rewards at higher rates than larger delayed rewards, which is known as the *magnitude effect* (see Grace and McLean, 2005; Green et al., 1997). In this study, although the delayed reward was always $1000, subjects were exposed to either large immediate rewards (descending sequence) or small immediate rewards (ascending sequence) first. Since the series ended when subjects showed indifference, during most delay series subjects were exposed only to either the larger or the smaller immediate rewards, depending on the order of presentation. The magnitude effect would predict that discounting rates should be greater in the ascending sequence, which is consistent with our data. Further research is needed to assess whether the observed differences in DD are related to the magnitude effect or some other factor.

In this study, we chose the *abbreviated* delay-discounting task because it allowed us to observe order-of-presentation effects. However, most studies in DD are based on tasks that either average indifference points obtained with preset ascending and descending series, or minimize sequential effects by adjusting the reward values based on each subject's specific choices. One advantage of such procedures is that the resulting data are generally less variable. However, although it is not clear how contextual variables such as recent history of choice might affect temporal choice in real life, it seems safe to assume that the context is similarly important in non-laboratory situations. While there are good reasons to eliminate unnecessary variability from our studies, we must keep in mind that averaging indifference points or experimentally controlling for sequential effects essentially hides a potentially important phenomenon.

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