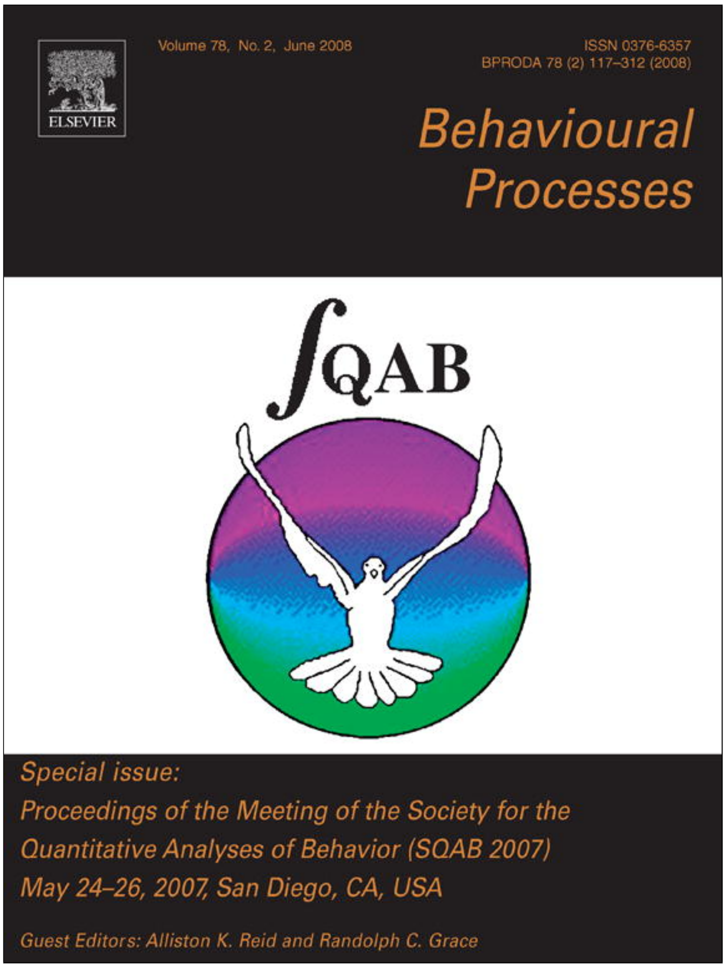
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Short communication

Parameters of delay discounting assessment: Number of trials, effort, and sequential effects

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Abstract

Procedural variants in estimating delay discounting (DD) have been shown to yield significant within-subject differences in estimated degree of delay discounting as well as variations in the patterns of choice. The purpose of this study was to evaluate the effect of subject control over the number of trials in a delay discounting task, on degree of delay discounting. Participants were assessed with two computerized DD assessments: the full-length method presented participants with a fixed set of 240 trials, and the abbreviated task, where once participants had shown indifference between the immediate and delayed rewards, the remaining trials for that delay value were omitted. While the full-length and abbreviated methods did not differentially affect patterns of choice or estimated delay discounting, the order of presentation (ascending or descending) of immediate rewards produced differences in each measure: rate of delay discounting was significantly lower when estimated with the descending sequence; a larger proportion of area under the discounting curve was concentrated around the indifference point trial with the descending sequence; and a lower correlation was observed between estimates obtained across methods with the descending sequence.

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Keywords: Delay discounting; Discounting functions; Impulsiveness; Research methods

1. Introduction

Delay discounting (DD) refers to the observed reduction in subjective value of a reinforcer as a function of time to its delivery. This is a robust phenomenon consistently observed in laboratory animals as well as humans (Bickel et al., 1999; Green et al., 1994; Mazur, 1987; Rachlin et al., 1991; Richards et al., 1997; Reynolds, 2007; Rodriguez and Logue, 1988; Woolverton et al., 2007). Choosing smaller immediate rewards over larger but delayed rewards is said to indicate impulsiveness (Ainslie, 1975). With human subjects, this interpretation has been supported by studies showing correlations between DD and personality measures of impulsiveness (Alessi and Petry, 2003; Madden et al., 1997; Reynolds et al., 2006; Richards et al., 1999), as well as by significant associations between DD and clinically important behavior such as substance abuse and pathological gambling (see Reynolds, 2007). In general, a higher rate of DD has been observed in subjects with more severe smoking (e.g., Bickel et al., 1999; Dallery and Raiff, 2007; Johnson et al., 2007; Krishnan-Sarin et al., 2007; Reynolds et al., 2004, 2006; Yoon et al., 2007), drinking (e.g., Field et al., 2007; Petry, 2001a; Vuchinich and Simpson, 1998), illicit drug use (e.g., Kirby et al., 1999; Madden et al., 1997, 1999; Petry and Casarella, 1999), and gambling problems (e.g., Alessi and Petry, 2003; Dixon et al., 2003; Petry, 2001b; Petry and Casarella, 1999).

In human studies DD rate is sometimes estimated by giving subjects direct exposure to contingencies of reinforcement where the magnitude of reinforcement and delay are systematically varied in choice situations (Reynolds, 2006; Lane et al., 2003). However, most human studies on DD have used variations of the questionnaire method developed by Rachlin et al. (1991). In these studies, degree of DD is estimated by presenting a subject with a series of hypothetical choices between varying amounts of a reinforcer (e.g., cash, drugs) to be had immediately, and a larger reinforcer available after a fixed delay, and identifying the point of self-reported indifference in preference between the reinforcers. Thus, a point of indifference in preference represents the subjective value of the delayed reinforcer. In turn, an individual's DD function is sampled by identifying a reinforcer's subjective value at selected points in the delay continuum.

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While preserving essential components of the questionnaire method developed by Rachlin et al. (1991), a large number of studies report using this method with variations in the number of trials, the order of presentation of the reinforcer and delay values, the modality (manual or computerized), and other parameters (for a detailed list see Robles and Vargas, 2007). Importantly, despite the wide range of procedural variations in the method used to estimate it, the reduction in subjective value of a reinforcer as a function of delay has been observed in every study. On the other hand, within-subject differences in an individual's rate of DD have been reported in studies that directly compared methods used to estimate it. For example, Epstein et al. (2003) found different magnitudes of discounting depending on whether a computerized procedure or a paper-and-pencil questionnaire was used. The study showed significantly higher rates of delay discounting estimated by the computerized assessment, particularly for small rewards. In another study, Kowal et al. (2007) compared two computerized algorithms to estimate DD; the decreasing adjustment method (Du et al., 2002), and the double limit method (Richards et al., 1999). Using a within-subjects design, Kowal et al. found that the decreasing adjustment method yields higher rates of DD than the double limit method. Then, a study by Robles and Vargas (2007) compared two computerized algorithms to estimate DD that differed in the order of presentation of the immediate rewards (ascending or descending vs. randomized). In that study, presenting the same 240 trials in random order yielded higher DD rates, longer assessment sessions, and characteristically different distributions of response times. One conclusion common to the three reports is that despite high correlations in the rate of DD estimated by the methods compared, variations in the algorithms used to estimate DD may lead to significant differences in an individual's observed amount of DD, and thus it may not be possible to directly compare values obtained by different methods. To date, it is not clear how the procedural variations compared in those studies led to differences in the estimated rate of delay discounting.

One possible factor leading to within-subjects differences is the relative effort involved in choosing associated with each algorithm. Analysis of response time distributions during assessments of DD show that subjects take longer to choose when the magnitudes of reward and delay in a given trial approximate the point of indifference (Robles and Vargas, 2007). A similar effect was reported earlier by McClure (2004), who observed longer response times during trials presenting subjects with difficult choices; those in which the difference between the early and delayed reward was 5–25%. Also, while responding on a DD task that presents the immediate reward values in a fixed ascending or descending sequence, subjects take longer to choose before the point of indifference than after it, when it is no longer necessary to ponder the values of delay and reward in order to choose consistently (Robles and Vargas, 2007). Finally, some tasks used to assess delay discounting rate require more trials than others and, in adjusting tasks, the total number of trials depends on the subject's choices (Du et al., 2002; Rachlin et al., 1991; Richards et al., 1999). These results suggest that the amount of effort involved in making choices during estimation of DD is not constant, and may influence the likelihood of some choices. The present study is an initial attempt at understanding the effects that effort during the assessment task might have on the resulting degree of delay discounting.

2. Method

2.1. Participants

Sixty-five college students participated in the study in exchange for class credit. Data for 10 participants were not included in the analyses because they did not report indifference between the immediate and delayed rewards at one or more of the delay values tested. Participants assigned to the ascending sequence group ($n = 25$) were 56% female, 64% Caucasian, 20% Hispanic, 16% other race/ethnicity, and had a median age of 19 years. Participants assigned to the descending sequence group ($n = 30$) were 50% female, 50% Caucasian, 20% Hispanic, 16% Black, 14% other race/ethnicity, and had a median age of 19 years.

2.2. Procedure

Participants were randomly assigned to one of two groups (ascending or descending sequence) and asked to complete 2 computerized delay discounting tasks, where the delayed reward was a hypothetical $1000. One of the tasks presented a series of 8 delay magnitudes (6 h, 1 day, 1 week, 2 months, 6 months, 1 year, 5 years, 25 years), and within each delay magnitude, 30 hypothetical cash rewards (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) to be had immediately. This assessment task always consisted of 240 choice trials, irrespective of the subject's choices (full-length method). Participants were also asked to complete a DD task that potentially presented the same 240 choices in the same (ascending or descending) order as above, except that the series of trials for a given delay value was terminated once the subject showed indifference at each of the 8 delay values (abbreviated method). An important difference between the full and abbreviated methods is that while the total number of trials in the task is fixed in the full-length method, it is variable in the abbreviated form and depends on the subject's particular choices. Specifically, the sooner the participant switches between the immediate and delayed rewards, the smaller the number of trials in the task. Furthermore, switching early between the immediate and delayed rewards during the abbreviated *ascending* task results in higher estimated degree of DD compared to switching later in the task. On the other hand, switching early during the abbreviated *descending* task results in lower estimated DD compared to switching later in the task. Half of the subjects were randomly assigned to complete the abbreviated task first.

2.2.1. Assessments

2.2.1.1. 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 command button associated with the delayed and immediate rewards was exchanged 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, the computer stored the time it took the participant to choose (reaction time, RT) along with the rest of the trial's information, and showed a full size computer screen for the 2-s intertrial interval, during which responses had no effect. Variations in the duration of the delay discounting task, therefore, depended on the subject's behavior. After completion of the first assessment task, 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.

2.2.1.2. 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

3.1. Degree of delay discounting

Fig. 1 shows median indifference points for both groups. Area under the delay discounting curve (AUC) was calculated for each subject and task as proposed by Myerson et al. (2001). The effect of the method used (full vs. abbreviated) was assessed within-subjects with a Wilcoxon Signed Rank test ($W = 268$, $T = 823$,

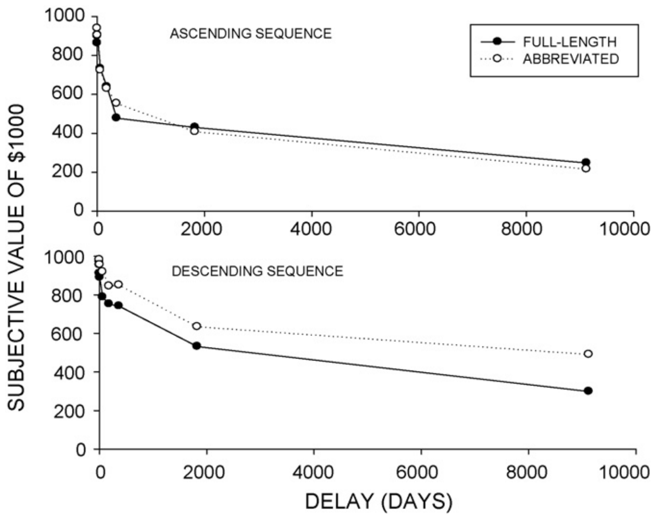

Fig. 1. Mean indifference points by order of presentation of the immediate rewards. Significantly greater mean AUC (.552 vs. .334) was observed in the group that received the descending order of presentation compared to the group that received the ascending order of presentation regardless of whether the full-length or the abbreviated method was used.

$T- = -555$, $p = .224$) that revealed no significant differences (median = .452 vs. .512). On the other hand, between-groups, the effect of the order of presentation of the immediate rewards (ascending vs. descending) was assessed with a Mann–Whitney Rank Sum test ($T = 2107$, n(small) = 50, n(big) = 60, $p < .001$) that revealed a significantly larger AUC (median = .541 vs. .227) in the group that received the descending order of presentation compared to the group that received the ascending order of presentation.

Using non-linear regression, the goodness of fit of the hyperbolic model proposed by Mazur (1987), was determined for the median indifference points obtained with each method and order of presentation. For the ascending order, $k = .002$ for both the full-length and abbreviated methods; $R^2 = .90$ and $R^2 = .88$, respectively. For the descending order, $k = .0006$ for the full-length method, and $k = .0002$ for the abbreviated method; $R^2 = .96$ and $R^2 = .88$, respectively.

3.1.1. Relationship between estimates

The degree of association between values of AUC obtained with the full-length and abbreviated tasks was assessed by Pearson's Product-Moment correlation. Within-subjects, AUC correlate highly between ascending tasks ($R^2 = .84$, $N = 25$, $p < .0001$), but correlate moderately between descending tasks ($R^2 = .27$, $N = 30$, $p < .01$).

3.2. Reaction time (RT)

The time between presentation of the choice stimuli and the subject's response (RT) was recorded for every trial. Congruent with previous reports, visual inspection of individual RT showed bimodal distributions with a peak at the first trial of every delay series and another peak at or near the indifference point trial. Because the number of trials between the first trial and

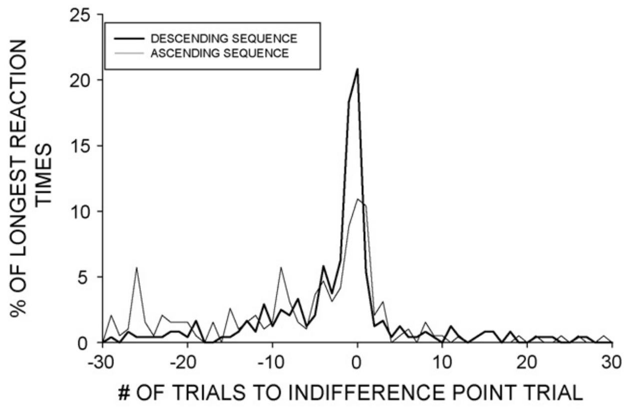

Fig. 2. Distribution of the longest RT in each delay series occurring during successive trials in relation to the trial showing indifference (position zero) obtained with the full-length method for both orders of presentation.

the trial corresponding to the indifference point varies between delay series and individuals, averaging RT by trial was not possible. Thus, in order to show the effect around the indifference point, the first RT in each series was removed, then the relative frequency of the longest RT in each position relative to the indifference point trial was obtained as described in Robles and Vargas (2007). Note that the resulting distributions do not depict RT duration; instead, they are relative frequency distributions of only the longest RT from each series for all subjects. Consistent with previous results, the longest RT in all distributions tended to fall around the indifference point. In all four distributions, the mode fell on the indifference point trial (see Figs. 2 and 3). For both, the full-length and the abbreviated methods, the descending sequence produced more compact distributions with a larger AUC at or near the indifference point. Since in the abbreviated method the series of trials for each delay value was terminated when the subject showed indifference between the rewards, the corresponding distributions end at the indifference point trial (see Fig. 3).

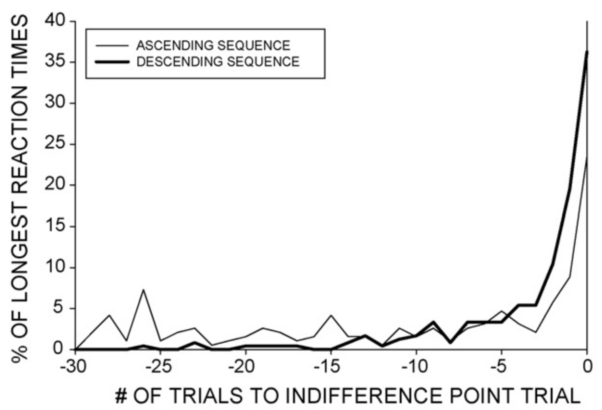

Fig. 3. Distribution of the longest RT in each delay series occurring during successive trials in relation to the trial showing indifference (position zero) obtained with the abbreviated method for both orders of presentation. In the abbreviated method the series of trials for each delay value was terminated when the subject showed indifference between the rewards.

3.3. *Number of trials & session duration*

The abbreviated method led to 66% fewer trials (138 vs. 240) per subject on average. The average duration in minutes of the full-ascending task was 11.78 ± 1.95; full-descending = 11.44 ± 1.74; abbreviated-ascending = 7.56 ± 2.37; abbreviated-descending = 3.70 ± 1.66.

3.4. *Self-report*

Within-subjects, VAS scores as a function of method (full-length vs. abbreviated) were compared using Wilcoxon Signed Rank tests. Scores on the "Boring–Interesting" scale were significantly higher (less boring/more interesting) for the abbreviated method ($W = 443.00$, $T+ = 694.50$, $T- = -251.50$, $p = .007$). On the other hand, no differences were observed on the "Very Easy–Very Difficult" VAS ($W = -8.00$, $T+ = 163.00$, $T- = -243.00$, $p = .365$). Between-group comparisons of VAS scores as a function of order of presentation of the immediate rewards (ascending vs. descending) were performed using Mann–Whitney Rank Sum tests. No differences in VAS scores were observed on either the "Boring–Interesting" scale ($T = 2425$, $n(\text{small}) = 46$, $n(\text{big}) = 60$, $p = .821$) or the "Very Easy–Very Difficult" scale ($T = 2564$, $n(\text{small}) = 46$, $n(\text{big}) = 60$, $p = .511$) as a function of order of presentation.

4. Discussion

This study explored whether choosing during a delay discounting task was affected by a reduction in the number of trials when the reduction in the number of trials was contingent on switching. We hypothesized that if the effort associated with making choices was reduced by switching early, subjects would tend to switch early during both the ascending and descending abbreviated tasks. Switching early during the *ascending* sequence of immediate rewards, however, would result in higher estimated rate of DD, while switching early during the *descending* sequence would result in lower estimated rate of DD. As expected, the resulting number of trials and duration of the assessments were much smaller with the abbreviated method, representing a reduction in the absolute amount of effort to complete the tasks. Nevertheless, a within-subject comparison of the area under the discounting curve observed when the full or abbreviated methods were used revealed no significant differences. On the other hand, the between-group comparison of AUC for order of presentation revealed significantly larger AUC (*lower* estimated DD rate) for the descending sequence group regardless of the method used to estimate it. Importantly, the hyperbolic model proposed by Mazur (1987) fit the data well, accounting for 88–90% of the variance.

Consistent with previous results, reaction times tended to be longer near the indifference point, presumably indicating the amount of effort involved in choosing as the subjective value of the two options become increasingly similar. Within-subjects comparison of reaction times distributions by method was not possible due to the truncation of the trials after the indifference point in the abbreviated method. On the other hand, between-groups, the sequence of presentation of the immediately available rewards was associated with a distinctive relative frequency distribution for each method. Compared to the ascending sequence, the descending sequence produced reaction time distributions with a larger area under the curve concentrated around the indifference points. It seems as if choosing near the point of indifference required more effort when the immediate reward values are presented in a descending order.

The self-reported level of difficulty associated with each method was assessed by a visual analog scale. No differences were observed on the "Very Easy–Very Difficult" scale regardless of the method or sequence of presentation experienced. In turn, no differences were observed on the "Boring–Interesting" scale as a function of sequence. However, the abbreviated method was experienced as less boring/more interesting than the full-length method.

Taken together, these results provide no evidence that the amount of effort involved in the full-length assessment task compared to the abbreviated task might be responsible for the differences in amount of delay discounting observed within-subjects. In this study, the reduction in number of trials in the task occurred by eliminating trials following the indifference point, which tend to be associated with the least effort. Therefore, although the absolute effort involved in completing the task was reduced in the abbreviated method by reducing the number of trials, the most effort-demanding trials, those that tend to occur just prior to the indifference point trial and are characterized by longer reaction times, were not affected by the abbreviated method. Consistently, the smaller number of trials did not affect the subjects' assessment of the level of difficulty of abbreviated tasks; shorter tasks were merely judged as less boring/more interesting. It is possible, therefore, that a different kind of delay discounting task, one that significantly alters the number of trials presenting choices with values close to the indifference points, might be better suited to reveal differences in responding due to the amount of effort required.

While the full-length and abbreviated methods did not differentially affect patterns of choice or estimated delay discounting, the order of presentation (ascending or descending) of immediate rewards produced differences in three measures: degree of delay discounting was significantly lower when estimated with the descending sequence; a larger proportion of AUC was concentrated around the indifference point with the descending sequence; and a lower correlation was observed between estimates obtained across methods with the descending sequence.

In this study, subjects tended to switch early when the amount of the immediately available reward decreased with every trial, and to switch later when the amount of the immediately available reward increased from trial to trial. It is possible, therefore, that the observed differences may reflect *framing* effects (Levin, 1998; Tversky and Kahneman, 1981, 1991). It has been shown, for example, that in judgment and decision making situations, subjects tend to choose more conservatively when the options in a trial are presented in terms of losses than when they are presented in terms of gains, even though both alternatives may be objectively equivalent descriptions of the same situation. This phenomenon, known as *loss aversion*, has been consistently documented in judgment and decision making studies including research on medical decisions, social dilemmas, and consumer preference, among others (for a review, see Levin, 1998). While it is not clear to what extent the differences observed in this study might be effects of framing, they are consistent with those expected from a reference-dependent model (Tversky and Kahneman, 1991), and suggest the need for further evaluation. As they stand, however, these results suggest that presenting the immediate rewards during DD assessment tasks in a random order may control for framing effects, and yield more consistent estimates of delay discounting.

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