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Within-Subject Comparison of Degree of Delay Discounting Using Titrating and Fixed Sequence Procedures

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Abstract

Different procedures are often used across experiments to estimate the degree of delay discounting, a common measure of impulsivity. In all procedures, participants indicate their choice between a reward available immediately and one available after a delay. The present experiment determined whether there are differences in the degree of discounting for a hypothetical $100 produced by a procedure that titrates the immediate amount (titrating sequence procedure) versus a procedure that presents a fixed sequence of immediate amounts (fixed sequence procedure) using a within-subject design. The adult human participants showed no significant differences in degree of discounting between procedures as assessed by a hyperboloid model and the Area Under the Curve. Furthermore, the Area Under the Curve values from the two procedures showed a strong positive correlation. These findings suggest there may be no systematic difference between the degree of delay discounting as estimated by the titrating sequence and fixed sequence procedures. Given the apparent similarities in the results, it appears researchers may be justified in basing their choice of which procedure to use on convenience.

Keywords

Delay discounting; money; human; impulsivity; titrating sequence procedure; fixed sequence procedure

1. Introduction

Impulsive decision making encompasses a number of aspects of behavior, including delay discounting (Logue, 1988). Delay discounting is the reduction in the present value of a reward as a function of delay to its receipt (Mazur, 1987). The preference for a smaller immediate reward is defined as impulsive while preference for a larger delayed reward is defined as self-controlled (Rachlin and Green, 1972). Impulsive decision making is implicated in a variety of human health problems (see e.g., Reynolds, 2006). For example, in drug addiction, people often choose a smaller immediate reward (e.g., a drug high now) over a larger delayed reward (e.g., good family relations in the future).

The present value of a reward is negatively related to the time until its receipt. An immediate reward is inherently more valuable than the same reward delivered later (e.g., $100 now vs. $100 in a 1 year), but a person may choose to take a smaller amount now over a larger amount later (e.g., $85 now vs. $100 in a year). As the difference between the amount of the immediate and delayed rewards increases (e.g., $50 now versus $100 in a year) the present value of the delayed reward ultimately may outweigh the value of the immediate reward,

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resulting in a switch to more self-controlled preference. The indifference point is the amount at which the immediate and delayed rewards are of equal subjective value (where preference switches from the immediate to the delay reward). Similar to reward difference, the delay until receipt also influences the indifference point with larger delays (e.g., 25 years) resulting in smaller indifference points or more impulsive decisions than shorter delays (e.g., 1 month).

The decrease in indifference points over time is well described using the following hyperboloid function (Rachlin, 2006; Rodriguez and Logue, 1988):

$$V = A/(1 + kD^s) \quad (1)$$

where V is the value at the indifference point, A is the amount of the delayed reward, D is the delay to receipt of the reward, *k* is the degree to which the value of the reward is degraded by delay, and *s* is the sensitivity of present value to delay. If *s* = 1.0, then Eq. 1 is identical to a simple hyperbola (Mazur, 1987).

$$V = A/(1 + kd) \quad (2)$$

The delay discounting procedure is widely used to study impulsivity across a range of populations and reward types. Pigeons and rats (e.g., Mazur and Biondi, 2009), humans (e.g., Jones and Rachlin, 2009), and non-human primates (e.g., Freeman et al., 2009) all show hyperbolic discounting. In addition, various commodities are discounted hyperbolically including money (e.g., Rachlin et al., 1991), food and water (e.g., Odum and Rainaud, 2003; Richards et al., 1997), and drugs of abuse (e.g., Bickel et al., 1999; Madden et al., 1997). Furthermore, the hyperbolic model provides a good description of discounting of both hypothetical and actual monetary rewards (e.g., Johnson and Bickel, 2002; Madden et al., 2003, 2004).

1.1. Titrating Sequence versus Fixed Sequence Procedures

Among a number of techniques previously used to measure delay discounting, the present experiment focused on two commonly used procedures: a titrating sequence (e.g., Du et al., 2002; Odum and Baumann, 2007) and fixed sequence (e.g., Rachlin et al., 2001; Odum et al., 2006) of immediate rewards. In both, participants make a series of choices between a smaller more immediate reward and a larger more delayed reward at a number of different delays. Both titrating and fixed sequence procedures measure the decrease in present value with increases in delay to the larger reward, but there are differences in the presentation of the immediate reward. In the titrating procedure of interest in the present paper (Du et al., 2002), the immediate amount is modified based on the participant's previous choice. An increase in the immediate reward occurs after choice of the delayed reward, and a decrease in the immediate reward occurs after choice of the immediate reward. The size of the change decreases by half with each choice. This adjustment takes place over 10 trials for each delay with the final immediate amount being the indifference point for each delay. A fixed sequence procedure (e.g., Madden et al., 1997; Rachlin et al., 1991) presents a fixed set of immediate amounts (often 25 for each delay) that do not change based on the participant's previous response. The indifference point for each delay is defined as the last immediate reward chosen. Across the literature, titrating and fixed sequence procedures are used interchangeably to measure delay discounting, but whether they produce similar results has not been directly examined.

Two differences between the titrating sequence and fixed sequence techniques could plausibly affect the degree of discounting obtained using these procedures. First, the order of

question presentation has been shown to have an effect on discounting. Using a fixed list of immediate rewards (fixed sequence), Robles and Vargas (2007) found that random question order produced steeper discounting than sequential order. The titrating sequence procedure could plausibly produce steeper discounting than the sequential, fixed sequence procedure due to the non-sequential amount presentation order in the titrating sequence task.

Second, the starting point of the immediate outcome in fixed presentation orders has been shown to affect the degree of discounting. Ascending immediate amounts produce significantly higher levels of discounting than descending amounts (Robles and Vargas, 2008; Robles, Vargas, and Bejarano, 2009). The titrating sequence procedure used by Du and colleagues (2002), with an initial immediate amount equal to half of the delayed amount, could potentially produce a different degree of discounting than fixed sequence procedures. For example, the titrating sequence procedure could produce a higher degree of discounting than a descending fixed sequence because the initial immediate amount is lower than the delayed amount, similar to an ascending sequence.

Thus, there are plausible reasons to suppose that a delay discounting procedure that adjusts the immediate amount could produce a different degree of discounting than a procedure that uses a fixed sequence of immediate amounts. Delay discounting as measured by the two procedures has not been directly compared, however, despite the fact that both are commonly used. Therefore, we used a within-subject design to evaluate the effect of procedure (titrating or fixed sequence) on the degree of delay discounting.

2. Materials and methods

2.1. Participants

Twenty-four undergraduate students (14 Female, 10 Male) were recruited from an undergraduate introductory psychology course for participation in the current experiment. Participants received laboratory credit for participation and provided their informed consent. All experimental procedures were approved by the Utah State University Institutional Review Board.

2.2. Setting and Apparatus

The experimental room was equipped with a single desk and chair, a 2000 Dell personal computer, a monitor, a mouse, and a keyboard. The room measured 2.95 m by 2.87 m. Experimental manipulations and data recording were programmed using E-Prime 2.0®.

2.3. Procedure

The participant was seated in front of the computer monitor and read directions provided on the screen similar to those delivered verbally byOdum et al. (2006). Participants pressed the spacebar to progress through instructional screens and then pressed ‘d’ or ‘ k’ for choice questions. All choice screens were presented to the participant with the wording “Would you rather have [amount] now or [amount] in [delay]?” Participants selected either ‘k’ for delayed amounts or ‘d’ for immediate amounts (all other keys were inoperative). Which side was the immediate amount and which side was the delayed amount varied randomly across trials. Following 10 practice trials, all participants experienced both a fixed amount (fixed sequence) discounting procedure (cf. Odum et al., 2006) and a titrating amount (titrating sequence) discounting procedure (cf. Du et al., 2002), with the order of presentation of tasks randomized across participants. The delays tested in both titrating and fixed sequence procedures were one week, two weeks, one month, six months, five years and 25 years, in that order. Upon each transition point in the experiment, a text screen indicated the change prior to presentation of choice trials. For example, between the two different procedures, the

words “The next part of the study will begin now” were presented. Within procedures, a similar screen noted the change to a different delay duration.

Within the fixed sequence procedure, immediate amounts were presented in a fixed descending order ($100.00, 99.00, 97.50, 95.0, 92.50, 90.00, 80.00, 70.00, 60.00, 50.00, 40.00, 30.00, 20.00, 10.00, 7.50, 5.00, 2.50, and 1.00). The delayed amount was constant at $100. All aforementioned values were presented at each delay. The indifference point in the fixed sequence procedure was defined as the last immediate amount chosen at each delay.

The titrating sequence procedure began with the choice of $50 dollars now or $100 dollars after a delay, and the immediate amount increased or decreased based on the participants’ response. If the immediate outcome was selected, the amount of the next immediate outcome decreased, and if the delayed outcome was selected, the amount of the next immediate outcome increased. The adjustment on the first trial was half of the difference between the immediate and delayed outcomes (i.e., $25); for each subsequent trial the magnitude of the adjustment was half of the previous adjustment. There were a total of 10 trials at each delay duration. The indifference point for the titrating sequence procedure was the last value of the immediate outcome for each delay.

3. Results and Discussion

There were no significant differences between the degree of discounting obtained with the titrating sequence and fixed sequence procedures. Fig. 1 shows the median indifference points decreased as delay increased for both procedures. Equation 1 provided a good fit to the median indifference points for both the titrating sequence (R^2 = .98; k = 0.122) and fixed sequence (R^2 = .99; k = 0.081) procedures. Equation 1 was also fit to indifference points from individual participants. The median k values for the titrating and fixed sequence procedures were 0.079 and 0.139, respectively. A Wilcoxon signed rank paired t test (used for skewed distributions like that of k; Rachlin et al., 1991) revealed no significant difference between k values for the titrating sequence and fixed sequence procedures (t_{23} = 0.62, p = .399).

In addition to the k values obtained by using Eq. 1 for the titrating and fixed sequence procedure, the same analyses were applied to the current data set using discounting models proposed by Green and Myerson (1995), Mazur (1987), and Takahashi (2007). The conclusions regarding the k values were the same as presented here. Eq. 1, with the additional s parameter, was chosen for presentation because it provided the best fit to the data overall as assessed by the Akaike information criterion (data not shown).

We also evaluated the degree of discounting between the two procedures using the Area Under the Curve (AUC; Myerson et al., 2001), which offers a theoretically neutral characterization of delay discounting. A Wilcoxon signed rank paired t test found no significant difference between the AUC for the titrating sequence and fixed sequence procedure (t_{23} = 0.19, p = .484). The mean and standard error of the AUC values for the titrating and fixed sequence procedures was .421 (.062) and .418 (.056), respectively.

There was substantial within-subject consistency in the degree of discounting across the two procedures as well. Fig. 2 presents a Pearson correlation analysis for AUC of the titrating and fixed sequence procedures for each participant. AUC values for the titrating sequence procedure were positively and significantly correlated with AUC values for the fixed sequence procedure (r = .8134, p < .0001).

Prior research has shown that the order of presentation of immediate amounts (random vs. sequential; ascending vs. descending) can affect the degree of discounting by delay (Robles

and Vargas, 2007; 2008 Robles et al., 2009). These results suggested that the titrating and fixed sequence procedures could produce different estimates of the degree of discounting due to: (a) the varied versus sequential presentation of the immediate reward and (b) differences in the initial amount of rewards between procedures. The titrating and fixed sequence procedures investigated here are both commonly used in the delay discounting literature, prompting the current within-subject study designed to detect any differences in the degree of discounting generated by the two procedures.

The titrating (Du et al., 2002) and the fixed sequence procedure (Rachlin et al., 1991) both produced orderly discounting and similar estimates of the degree of discounting by delay as assessed by the hyperboloid model and the theoretically neutral AUC. Furthermore, there was strong within-subject correspondence between the estimates of discounting obtained with the two procedures. Overall, these findings suggest there may be no systematic or substantial effect of which of these two methods is used to estimate the degree of discounting by delay.

These findings may seem surprising, given the differences due to the order of presentation of immediate amounts documented in prior studies. First, random sequences produce steeper discounting than fixed sequences (Robles and Vargas, 2007). While it therefore seemed possible a titrating sequence could produce a different degree of discounting from a fixed sequence, both the sequences investigated in the present study differ from a random sequence in that they are predictable and clearly ordered. Thus, the difference in discounting between random and fixed sequences found previously could be due to orderly versus non-orderly presentation, rather than sequential versus non-sequential presentation.

Second, prior studies have indicated that the starting point of a fixed sequence of immediate amounts has an effect on the degree of discounting: strictly ascending sequences produce steeper discounting than strictly descending sequences (e.g., Robles and Vargas, 2008). In the present experiment, the first immediate amount in the titrating procedure was half the amount of the delayed outcome. This amount was therefore lower than the amount used in the fixed descending sequence, which started with the greatest immediate amount. The titrating procedure adjusted the amount of the immediate outcome up and down after the initial choice, however, unlike a strictly ascending sequence as used in prior research in which the next choice always involved a larger immediate amount than the last choice. Based on these procedural differences, it may be that a continuously improving sequence (ascending immediate amounts) produces greater delay discounting than a continuously worsening sequence (descending immediate amounts) or a sequence in which the immediate amount increases and decreases (titrates).

An alternative explanation for the lack of difference between the degree of delay discounting with the two procedures, however, could be due to the within-subject procedure used. As one possibility, participants may have recalled their answers from the first task presented and for the sake of consistency replicated those answers on the second task presented. This explanation does not seem likely, however. Examination of the questions posed for each task shows that the two procedures had only one question in common (i.e., $50 now versus $100 later). Furthermore, previous research has demonstrated significant differences in degree of discounting for different commodities and/or delayed amounts using within-subject designs with a similar number of participants (e.g., Green et al., 1997; Johnson & Bickel, 2002; Odum & Rainaud, 2003). The possibility remains, however, that another experimental design could produce a different result.

The similar estimates of the degree of discounting obtained with the titrating and fixed sequence procedures provide support for the interchangeable use of these methods. The

titrating procedure requires fewer trials, and thus requires less time, and so may be preferable on those grounds. The titrating sequence procedure is more complex to implement, however, and so the fixed sequence procedure may be preferable nonetheless in some situations (e.g., where a computer is not available to conduct the task).

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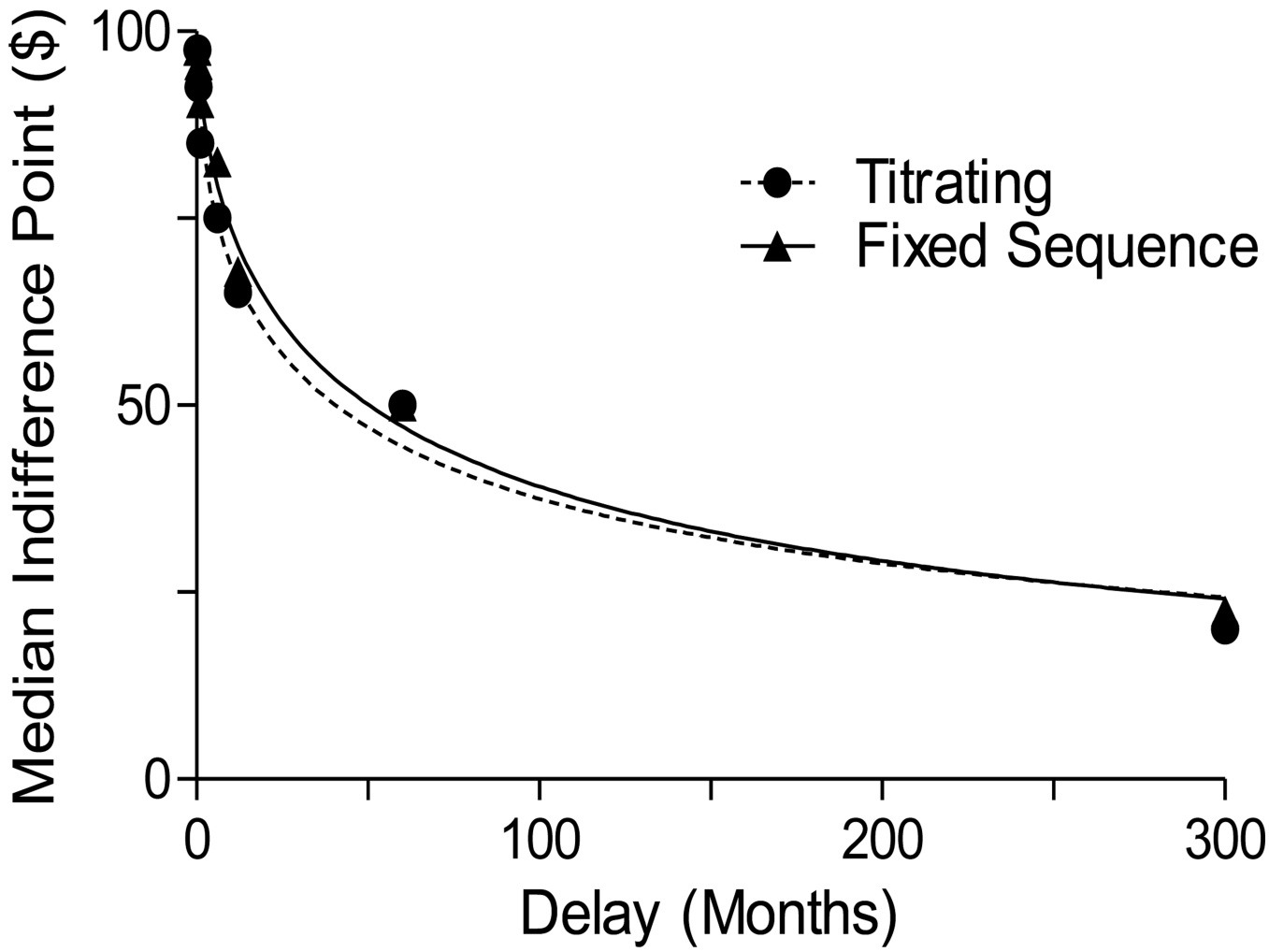

Fig. 1.
The median indifference points as a function of delay (months) for both the titrating sequence and fixed sequence procedure. Triangles and circles represent the indifference points of the fixed and titrating sequence procedures, respectively. Lines show the best fit of Eq. 1 to the indifference points.

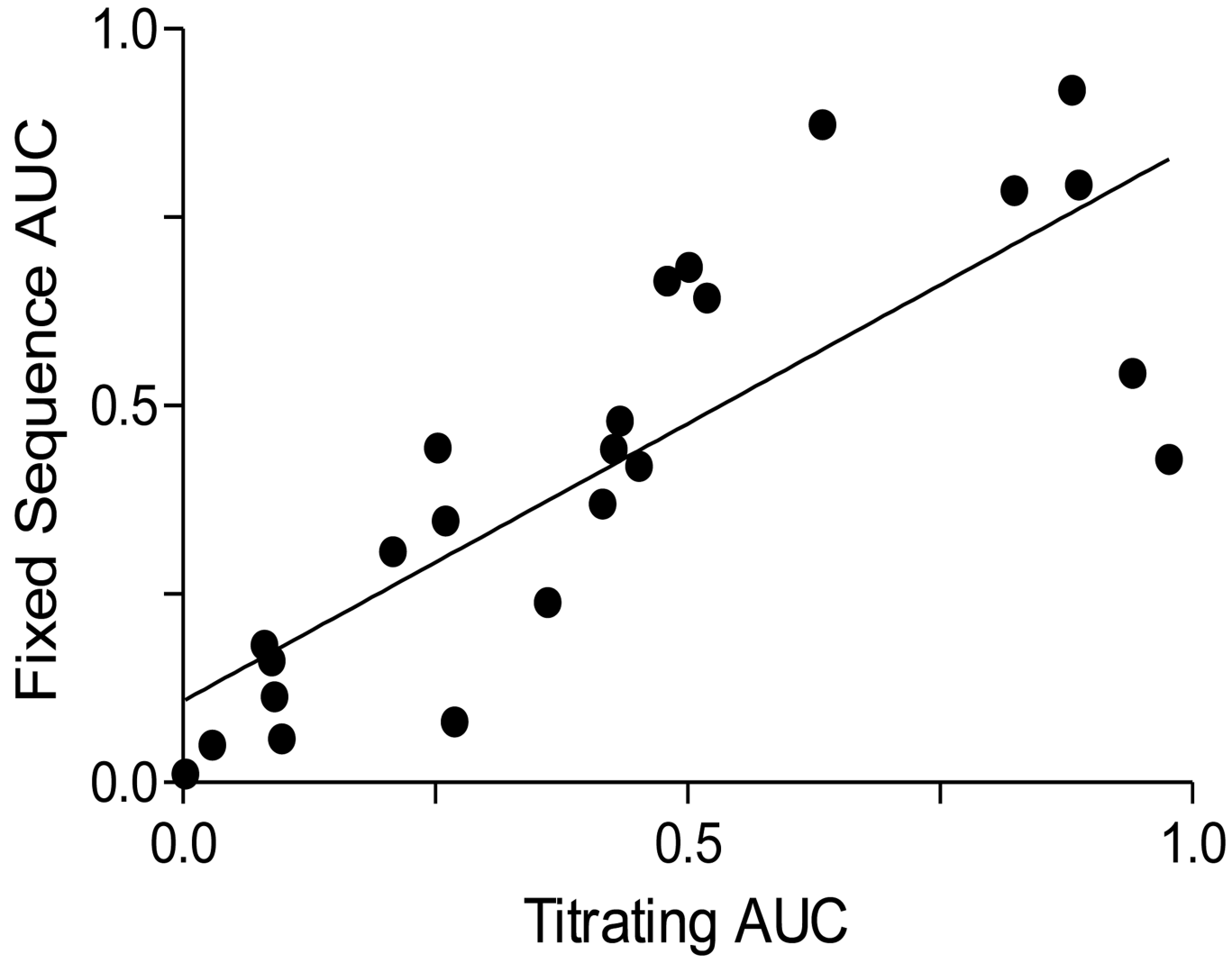

Fig. 2.
The Pearson Product moment correlation for AUC of the titrating and fixed sequence procedure for each participant. Each circle represents data from one participant. The line represents the best fit to the data.