An adaptive delay discounting procedure for the E-Prime programming environment

Keywords: Delay discounting, E-Prime, Excel, hyperbolic

Abstract

Background and objective: Delayed rewards are commonly perceived as less valuable than immediate rewards, a phenomenon referred to as either delay discounting or temporal discounting. Here, an adaptive discounting procedure developed for the E-Prime programming environment and an associated analysis script implemented in Excel are described.

Methods: The experimental procedure was developed in E-Prime 2.0.10.242 and an associated analysis workbook in Excel 2013. Area under the curve (AUC) and hyperbolic discounting were used to measure delay discounting.

Results: Example data from a sample (n= 19, mean age 21, 14 females) are presented. There was good agreement between AUC and log k values (hyperbolic) (AUC 100 and log$K$ 100 was $r(19) = -.889$, $p < .001$, AUC 1000 and log$K$ 1000, $r(19) = -.906$, $p < .001$ and AUC 10000 and log$K$ 10000, $r(19) = -.872$, $p < .001$. At the individual level, the fit of the hyperbolic discounting function to the data was generally good (R^2 values ranged between .88 and .97)

Conclusions: An adaptive delay discounting procedure within the E-Prime programming environment and an associated analysis script (executed in Excel) are described. This implementation, freely available to the scientific community, may be suited to laboratories with limited programming resources or experience that intend to use this software suite for developing and implementing experimental paradigms.

Introduction

Decisional impulsivity can be objectively measured in human participants using temporal discounting (1). Typically, participants are presented with a series of binary choices in which they indicate their preference for a (generally hypothetical) smaller immediate reward or a larger delayed reward. Through several series of trials the immediate reward is increased until the participant selects the immediate reward over the delayed reward. This change in choice (from larger/delayed to smaller/immediate) is referred to as the indifference point and reflects the point at which the immediate reward and delayed reward are equivalent in terms of subjective value.

To assess temporal discounting a participant's indifference points, determined at different delays, are estimated and a curve of subjective values for each participant can be generated and a discounting rate estimated. One simple, atheoretical, approach to express delay discounting is to use the area under the curve (AUC; see Methods). Alternatively, indifference points can be fitted to a theoretical model using nonlinear regression. One widely used approach assumes hyperbolic discounting (2). Here, indifference points are fit to the following equation:

$$V=A/(1+kD) \quad [1]$$

where V is the indifference point, A is the amount of reward, D the delay to reward and k a free scaling parameter estimated by the fit of the data to the model. The numeral 1 appears in the denominator to prevent $V \rightarrow$ infinity as $D \rightarrow 0$. Larger values for k indicate a preference for smaller immediate rewards.

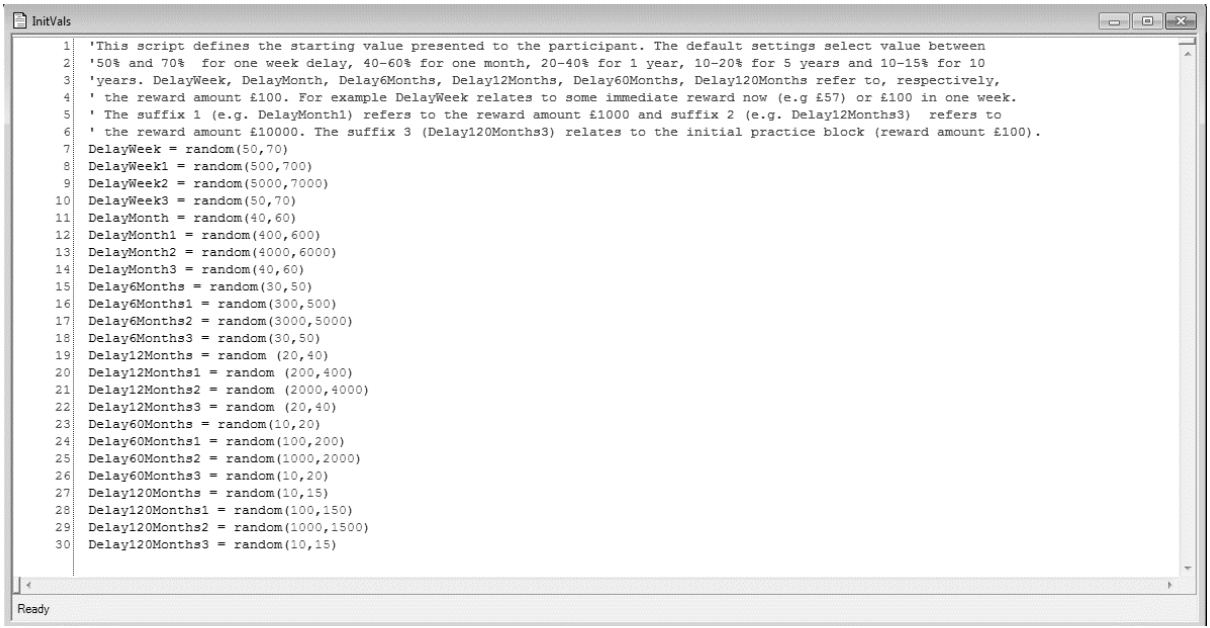
Questionnaire-based versions of temporal discounting (3) are available. However, scoring relies on assigning individuals to specific ranges for k which limits the resolution with which discounting can be estimated (4). By contrast, computer-based tasks allow programmed adjustment procedures to optimise the task to the individual thereby improving the reliability of indifference estimates. Here, a delay discounting routine developed for use in the E-Prime environment (Psychology Software Tools Inc., Pittsburgh, PA) and an accompanying Microsoft Excel (2013) analysis workbook are described for potential use in laboratories with limited programming resources and/or experience of using E-Prime.

Methods

The experimental procedure was developed in E-Prime 2.0.10.242. At each trial participants are asked to indicate their preference for receiving a larger amount (e.g. £100) after some delay or a smaller amount (e.g. £45) to be received immediately (e.g. "Would you prefer £45 now, or £100 in 1 month"). If the participant rejected the immediate reward its value was increased (see schedule below) until the participant accepted or the maximum value (£100, £1000 and £10000) was reached. This process was then repeated and the indifference point computed as the average of the two accepted values. The protocol included a practice run to allow participants to familiarise themselves to the task and three experiment blocks at each of the three amounts (£100, £1000 and £10000), each presented with the following delays (1 week, 1 month, 12 months, 5 years and 10 years). Participants completed all three conditions of the experiment (£100, £1000 and £10000) which were presented in random order.

Initial value

The inline script object InitVals contains a list of initial values presented to the participant at the start of each trial (please see Figure 1). The default settings randomly select a value of between 50% and 70% of the maximum for a one week delay, 40-60% for one month, 20-40% for 1 year, 10-20% for 5 years and 10-15% for 10years. These values are user-defined and can be easily edited without any need for a detailed knowledge of E-Prime or programming.

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'This script defines the starting value presented to the participant. The default settings select value between
'50% and 70%  for one week delay, 40-60% for one month, 20-40% for 1 year, 10-20% for 5 years and 10-15% for 10
'years. DelayWeek, DelayMonth, Delay6Months, Delay12Months, Delay60Months, Delay120Months refer to, respectively,
' the reward amount £100. For example DelayWeek relates to some immediate reward now (e.g £57) or £100 in one week.
' The suffix 1 (e.g. DelayMonth1) refers to the reward amount £1000 and suffix 2 (e.g. Delay12Months3)  refers to
' the reward amount £10000. The suffix 3 (Delay120Months3) relates to the initial practice block (reward amount £100).
DelayWeek = random(50,70)
DelayWeek1 = random(500,700)
DelayWeek2 = random(5000,7000)
DelayWeek3 = random(50,70)
DelayMonth = random(40,60)
DelayMonth1 = random(400,600)
DelayMonth2 = random(4000,6000)
DelayMonth3 = random(40,60)
Delay6Months = random(30,50)
Delay6Months1 = random(300,500)
Delay6Months2 = random(3000,5000)
Delay6Months3 = random(30,50)
Delay12Months = random (20,40)
Delay12Months1 = random (200,400)
Delay12Months2 = random (2000,4000)
Delay12Months3 = random (20,40)
Delay60Months = random(10,20)
Delay60Months1 = random(100,200)
Delay60Months2 = random(1000,2000)
Delay60Months3 = random(10,20)
Delay120Months = random(10,15)
Delay120Months1 = random(100,150)
Delay120Months2 = random(1000,1500)
Delay120Months3 = random(10,15)
```

Figure 1. Screenshot of the editable inline script 'IinitVals'. Starting values can be easily set by the user by changing the values within this script.

Indifference points

At the start of each trial the participant is presented with the option to accept the smaller immediate reward or wait for the larger delayed reward (please see Figure 2). If the

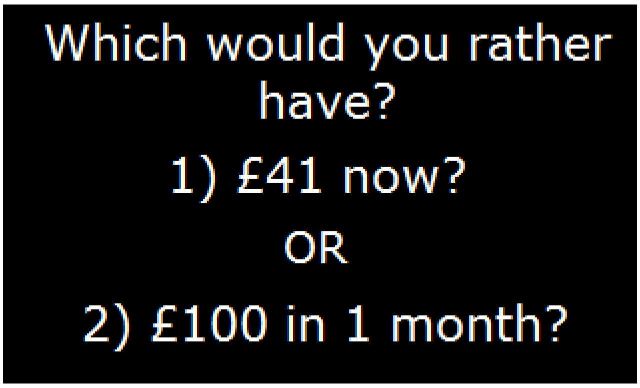

Figure 2. Screenshot of an example trial. At each screen the participant is reminded of the maximum amount (here £100) and the delay to getting that amount (one month).

immediate smaller reward is rejected the initial value is updated according to the following schedule:

```
'If immediate reward is immediately selected then ACC = 1 and reward amount is reduced by a third otherwise reward amount increased incrementally as detailed below

If SlideDelayMonth3.ACC = 1 Then
        DelayMonth3 = DelayMonth3 * 0.666
Else
        If DelayMonth3 * 1.04 >= 100 Then
        DelayMonth3 = 100

                ElseIf DelayMonth3 * 1.08 >= 100 Then
                DelayMonth3 = DelayMonth3 * 1.04

                        ElseIf DelayMonth3 * 1.167 >= 100 Then
                        DelayMonth3 = DelayMonth3 * 1.08

                ElseIf
                DelayMonth3 * 1.334 >=100 Then
                DelayMonth3 = DelayMonth3 * 1.167

        Else
        DelayMonth3 = DelayMonth3 * 1.334

End If
```

As can be seen the immediate reward increases incrementally until either the computed value is equal to or greater than the delayed reward or the participant accepts the smaller immediate reward. The process is then repeated with an initial value of 66% of previously accepted immediate reward. The indifference point is then computed as the average of the two accepted values.

Two methods are provided to summarise indifference. The first estimates the free parameter *k* in equation [1] using non-linear regression implemented using SOLVER. Second, the AUC is estimated following Myerson et al., (2001). Delays and indifference points are first normalised (expressed, respectively, as a proportion of the maximum delay and maximum reward amount). These normalised values provide the *x* and *y* coordinates to construct a graph subdivided into a series of trapezoids. The area of each trapezoid is estimated as: $(x_2 - x_1)[(y_1 - y_2)/2]$, where x_1 and x_2 are successive delays and y_1, y_2 are the indifference points associated with these delays. The area under the empirical discounting function is equal to the sum of the areas of these trapezoids. As *x* and *y* are normalised values, the AUC can vary between 0 (steepest possible discounting) and 1 (no discounting). As the AUC is calculated using the actual data points rather than from a curve fit to the data the AUC measure is free of any theoretical assumptions. (5)

Running the experiment

The E-Prime script, sample output, task instructions and accompanying Excel analysis workbook is provided as a zip file in supplemental materials. By default it will extract to a folder “DD”, remove this from the end of the expansion so that an unnecessary ’DD’ folder is not created. In the extracted folder there should be six files: DD_Template.xlsm; DD.es2, DD.ebs2, the sample output DD_V1-1-1.edat2, sample task instructions DD_instructions.pdf and analysis instructions DD_analysis.pdf.

At the start of the experiment the researcher is prompted for a participant number and researcher initials, participant and session number (e.g. RN001-1). During the initial practice block, and in subsequent experimental blocks, the participant is presented with the reward amount (e.g. £100) in red text followed by each delay period presented in yellow text (1 week, 1 month, 12 months, 5 years and 10 years). The indifference point at that delay is then estimated before moving on to the next delay. The three experimental blocks are presented in random order. At successful completion of each experiment the participant's results will be written to the DD directory (e.g. C:\Users\username\Desktop\DD\RN001-1.edat2). Step-by-step instructions of how to combine this file with the analysis workbook (DD_Template.xlsm) are provided in supplemental data (DD_analysis.pdf)

Example results

Example data are a sample (*n*= 19, mean age 21, 14 females) taken from a previous experiment (6). Table 1 shows mean (SEM) indifference points at each delay (1 week, one month etc.) for each reward amount (£100, £1000 & £10000). Also shown are the corresponding values for *k* (estimated using Equation 1) and the AUC. Figure 3 shows individual indifference points as a function of delay (reward amount £100) for three individuals.

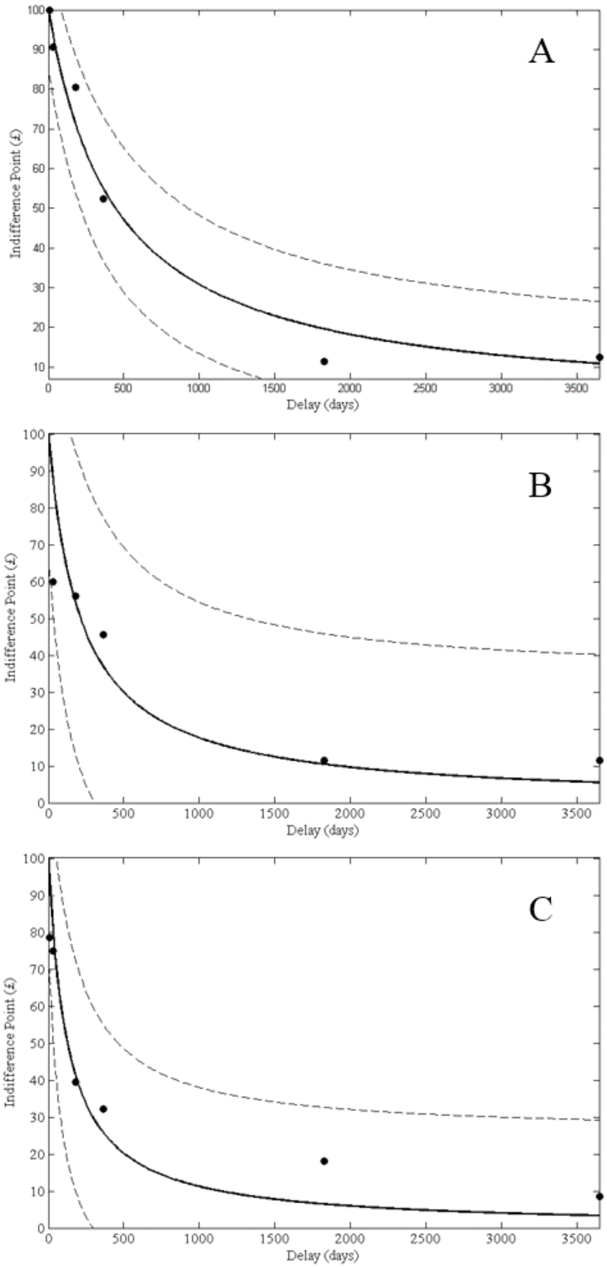

Figure 3. Individual indifference points as a function of delay (reward amount £100) for three example participants. Markers show indifference points, solid black line shows fit of Equation 1 to the data using Matlab R2014 (The Mathworks Natick, Massachusetts) and dashed lines 95% prediction bounds.

	Delay							
Amount	OneWeek	OneMonth	SixMonths	OneYear	FiveYear	TenYears	*k*	AUC
100	86.13 (3.79)	71.92 (4.49)	55.24 (5.13)	37.06 (3.11)	26.97 (5.55)	26.34 (7.01)	0.009 (0.003)	0.318 (0.046)
1000	930.32 (23.47)	656.32 (83.5)	602.63 (35.63)	565.63 (74.77)	241.74 (35.04)	401.95 (80.26)	0.006 (0.002)	0.385 (0.04)
10000	9277.32 (277.86)	5279.84 (971.77)	4717.42 (914.31)	6108.21 (816.71)	4293 (853.4)	4777.89 (834.75)	0.014 (0.006)	0.489 (0.061)

Table 1. Displayed are mean (SEM) indifference points for each delay and each amount. Also shown are the mean (SEM) values for *k* and the AUC.

The fit of Equation 1 to the data are generally good (see Table 2 for goodness of fit (R^2) values). There was also good agreement between AUC and log *k* values (Figure 4).

Participant	R^2	*k*
A	0.97	0.0022
B	0.84	0.0047
C	0.88	0.0079

Table 2. Goodness of fit (R^2) for Equation 1 and corresponding *k value* for the data shown in Figure 3.

The correlation between AUC 100 and log*K* 100 was $r(19) = -.889$, $p < .001$, AUC 1000 and log*K* 1000, $r(19) = -.906$, $p < .001$ and AUC 10000 and log*K* 10000, $r(19) = -.872$, $p < .001$ (please see Figure 4).

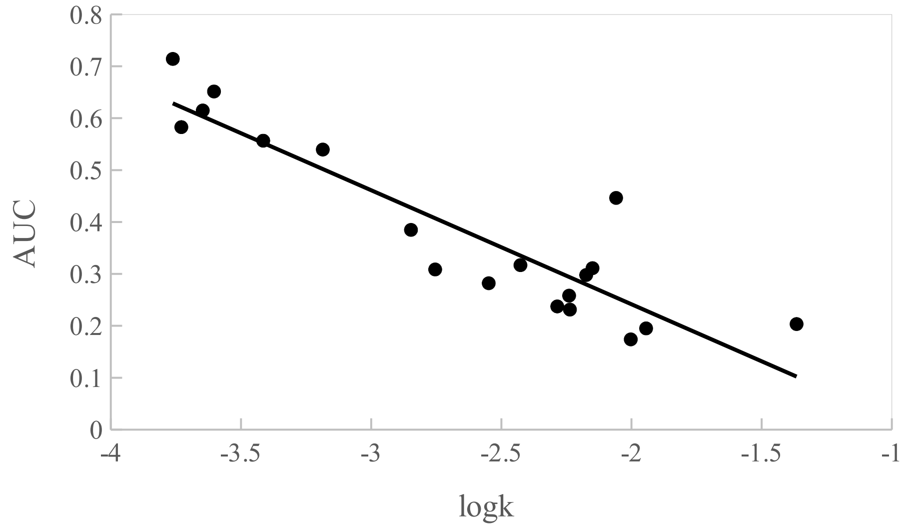

Figure 4. Scatterplot of AUC 1000 scores and log *k* 1000 values.

Discussion

The aim of this tutorial was to provide a software routine for performing an adaptive delay discounting procedure within the E-Prime programming environment and an associated analysis script (executed in Excel). The delay discounting E-Prime script, associated analysis workbook, example data and user guides are available as supplemental material that interested parties can download and implement easily with little or no programming experience.

The ability to respond quickly in a flexible and changing environment is advantageous in many settings. However, if such impulsive behaviours are chronically expressed they become maladaptive and salient to a number of brain disorders including attention-deficit hyperactivity disorder and drug addiction, and damaging behaviours such as smoking and binge eating (1).

One widely used objective measure of decisional impulsivity is delay discounting – which can be thought of as the cognitive processes by which an individual is able to compare values between the immediate and delayed consumption of a determined commodity. It is supposed that when making a decision individuals consider future consequences and that the effect of these consequences weakens with delay. If a future event is severely discounted its impact on current behaviour will be diminished and impulsive choice selected.

Questionnaire-based versions of temporal discounting (3) are available. However, scoring relies on assigning individuals to specific ranges for k which limits the resolution with which discounting can be estimated (4). It would be of utility, therefore, to provide an easy-to-use computer-based task that allows programmed adjustment procedures to optimise the task to the individual thereby improving the reliability of indifference estimates. Here, a delay discounting routine is implemented, made freely available to the scientific community, and may be suited to laboratories with limited programming resources or experience that intend to use this software suite for developing and implementing experimental paradigms. The procedure is easily customisable and can be adjusted to the needs of the user (e.g. delay periods or rewards can be changed as required).

References

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Conflict of interest statement

The author has no conflict of interest to report.

Author contributions

RN was responsible for the conception and design of the study, E-Prime programming, the analysis code, data analysis, manuscript preparation and subsequent manuscript revisions.

Ethical statement

No new data were collected as part of this report. The example data presented here were part of a previous experiment (6) for which approval from the local ethics committee at the University of Roehampton was obtained.