Individual differences in temporal and probabilistic discounting of costs.

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I confirm that the work presented here is my own, the research was carried out by myself under the supervision of Professor Mike Oaksford and the report was written by myself. All sources used in writing the report have been acknowledged and are listed in the references section.

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Abstract. The effects of delay, probability and monetary amount on individuals' subjective evaluation of costs were measured experimentally, using a web-based procedure, and potential relationships with personality and demographic characteristics evaluated. Larger delayed and uncertain amounts were discounted more steeply than corresponding smaller amounts, and highly significant correlations between individual rates of discounting of delayed and uncertain costs were found. These findings are consistent with a theoretical model where a single process is implicated in both probabilistic and temporal discounting of costs and contrast with those observed elsewhere for discounting of rewards, which do not support such a model. Highly significant and consistent correlations were also found between individual discounting of delayed and uncertain costs and scores on the agreeableness personality scale, gender and income. Variance in predictability of discounting behaviour was found to be greater than in similar previous work. Although this may be due to methodological differences, an alternative hypothesis is that individuals differ in the extent to which they utilise relative references to proximal exemplars, rather than absolute psychophysical scales of time and chance, when making subjective assessments of costs.

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Introduction

Human beings intuitively appreciate the implications of delay and/or risk when choosing between two alternative monetary rewards, and behave accordingly. Thus an immediate reward is preferable to a delayed one of the same value and a certain reward is preferred to an uncertain one of the same value. These simple examples are not controversial and most humans will make the same, easily predictable choice in these situations. However, matters become more complex when the choices differ not just in one dimension (time or probability) but also simultaneously in the actual value of the reward involved.

In this situation we can envisage that the choice now contains two factors, which must simultaneously be subjectively evaluated and resolved (not necessarily consciously) by the individual, in order to make a choice between the two possible alternatives. In choosing, the person is tacitly making a trade-off between, for example, time and size of reward that may not necessarily reflect rational behaviour in macroeconomic terms. Despite this, human beings thrive in their environment and this must reflect an ability to make at least tolerably good choices under conditions of incomplete information and time constraints. This gap between the predictions of classic theories of normative behaviour and actual behaviour, which can be assumed to be adaptive, represents a paradox requiring closer study of the cognitive processes involved in this commonplace situation.

Discounting of rewards

Temporal and probabilistic discounting of rewards has been extensively studied in order to understand better the cognitive processes that underlie this behaviour (for a review, see Green & Myerson, 2004). Key to this is a description of the equation, or discounting function, that best models the decrease in subjective value of a delayed or risky reward as delay or risk increase. There is strong evidence (Green, Fry & Myerson, 1994; Kirby, 1997; Mazur, 1987) that a hyperbolic rather than exponential function (as would be predicted by standard microeconomic theory for temporal discounting) is a better model and Myerson and Green (1995) have made a strong case for a hyperbola-like curve with two parameters, reflecting their theory that choice between two temporally displaced alternatives involves subjective evaluation of two distinct components, time and amount. Although there is abundant empirical support for this as a basic general model for discounting behaviour, there is much less

agreement concerning a number of peripheral questions relating to specific aspects of discounting.

Are probabilistic and temporal discounting the same process?

One of these ancillary questions is whether or not temporal and probabilistic discounting functions are similar, and perhaps are implemented by a single, common cognitive process. There is evidence that both behaviours may be described accurately by equations of the same form (Green & Myerson, 1996; Rachlin, Logue, Gibbon & Frankel,1986; Stevenson, 1986), with different discounting parameters, which is consistent with the possibility that there may be a single, common discounting process.

This begs the question of which form of discounting (temporal or probabilistic) might be fundamental. Rachlin, Raineri and Cross (1991) suggest that temporal discounting is fundamental and probabilistic situations are conceived as series of repeated gambles where resultant probability equates to the number of repetitions needed before a reward is expected. Myerson and Green (1995) advance the opposite viewpoint that probabilistic discounting is more fundamental, and that temporal discounting is due to increased risk to the expected reward because of the longer period of time until the reward is received.

Prelec and Loewenstein (1991) also propose an overall model for discounting of rewards and other similar phenomena that emphasises similarities between probabilistic and temporal factors. This reflects a similar basic cognitive model to that employed by prospect theory (Kahneman & Tversky, 1979), in which the process of evaluation of alternatives comprises two components, one dealing with amount and the other with the other attribute (time or probability). It is suggested that each of these components is independently modified through the application of an associated subjective weighting function and that the overall utility of the alternative being evaluated is determined by the product of these factors.

The weighting function for amount is assumed to be common to both probabilistic and temporal discounting situations. The weighting functions for the delay and risk are assumed to follow similar hyperbola-like forms because they are both subject to two key influences which Prelec and Loewenstein term *decreasing absolute sensitivity* and *increasing proportional sensitivity.*

Decreasing absolute sensitivity refers to the effect whereby, when a constant is added to the values of an attribute for both alternatives (e.g. delay), the weight given to that attribute will decrease. For example, increasing delay for both alternatives by a constant amount will result in greater emphasis being placed on the amount component rather than the delay component. This is consistent with observed preference reversals, first identified in humans by Green, Fristoe and Myerson (1994). For example a person might prefer $500 now rather than $550 in one month's time, but if the delays are changed by a constant amount, say six months, so that the choice is between $500 in six months or $550 in seven months, the preference may be found to reverse.

Increasing proportional sensitivity describes the effect of *multiplying* values of an attribute by a constant amount and is proposed to have the same effect of increasing the relative significance of the amount component in a choice. For example an individual might be indifferent to a choice between $10 now or $20 in a year's time, but would prefer $100 now to $200 in a year's time.

The model proposed by Prelec and Loewenstein and its consequent predictions for comparison judgements are consistent with a general hyperbola form of the discounting equation rather than an exponential form. This is supported by empirical observations as discussed above, but their proposed cognitive model for discounting may be further tested by comparison of behaviour under probabilistic versus temporal conditions. Thus, the question of whether probabilistic and temporal discounting are implemented as a single cognitive process, or by separate, dual processes, becomes a central question in evaluating theorised models.

Effect of amount of reward on discounting behaviour

There is considerable empirical evidence from a number of studies (e.g. Benzion, Rapoport & Yagil, 1989; Thaler, 1981; Johnson & Bickel, 2002) of a robust effect of amount of reward on discounting behaviour in both probabilistic and temporal contexts. This so called *magnitude effect* contradicts standard economic theory which assumes that rate of discounting will be independent of amount.

This effect presents difficulties for the cognitive models of discounting proposed by Green and Myerson and Prelec and Loewenstein, discussed above. In each of these models the discounting function is made up of two separate weighting components

for amount of reward and for the temporal or probabilistic attribute. Localising the observed magnitude effect in the weighting component for amount of reward would lead to the prediction that changes in magnitude of reward should have similar effects in both probabilistic and temporal discounting contexts.

However, in fact, the effect is observed to operate in opposite directions for temporal versus probabilistic discounting. Specifically, larger delayed rewards are discounted less steeply than smaller rewards (Green, Myerson & McFadden, 1997; Raineri & Rachlin, 1993), whereas larger risky rewards are discounted more steeply than smaller rewards (Green, Myerson & Ostaszewski, 1999; Myerson *et al*, 2003). Prelec and Loewenstein point out that the latter effect seems to be intuitively implausible because risk aversion in a probabilistic discounting case might be expected to increase with magnitude of reward.

The alternative explanation of the magnitude effect that reconciles these theoretical models with the empirical data is that amount of reward affects temporal and probabilistic discounting in different ways. This implies that the magnitude effect must be localised in the weighting component of the models that deals with the probabilistic or temporal attribute, rather than the weighting attribute that reflects value. This is inconsistent with a single-process theory of discounting, whereby probabilistic and temporal discounting behaviour are both proposed to reflect a single underlying cognitive process.

This latter account of the magnitude effect has been developed by Green and Myerson (2004) who offer a speculative approach (which they acknowledge as *post hoc*) to explaining the difference between probabilistic and temporal discounting behaviour. They suggest that this is due to differential effects on the two parameters of the hyperbola-like general discounting function which they advocate.

Despite this, differing magnitude effects observed in probabilistic and temporal discounting of rewards present significant difficulties for single process models.

Hypothetical compared to real rewards

One obvious general criticism that can be levelled at these studies relates to the use of hypothetical rather than actual rewards, and the authenticity of participants' behaviour under these conditions has been challenged on grounds of poor ecological

validity. This concern has been addressed by work which has used real rewards (e.g. Baker, Johnson & Bickel, 2002; Kirby & Marakovic, 1995; Kirby, 1997), albeit with smaller amounts for obvious reasons. These have shown the same type of general discounting behaviour, but have not directly compared discounting behaviour for real versus hypothetical rewards in a within-subjects experimental design.

However, this comparison was made by Johnson and Bickel (2002), using a larger range of rewards ($10 to $250), but with a small sample of six participants. They found that for five of the six participants there was no significant effect of real versus hypothetical rewards. Madden *et al* (2003) repeated this comparison using a larger sample of 20 participants and, again, found no significant effect due to the reality or otherwise of the reward. These studies, which specifically consider the use of hypothetical rewards in discounting studies, are further endorsed by a broader review undertaken by Camerer and Hogarth (1999) which deals with the validity of hypothetical financial incentives in experimental economics generally.

Discounting of costs rather than rewards

The preceding discussion has focused exclusively on discounting of *rewards*. However, rewards are probably less common in everyday life than costs. In fact, numerous social devices have been specifically constructed to allow individuals to deliberately manipulate delayed and risky costs, in the form of financial credit and insurance respectively.

In contrast, rewards are encountered less frequently and often do not involve an element of choice of the same form. We are encouraged 'not to look a gift horse in the mouth' and be grateful for our good fortune when an unsolicited reward comes along, rather than to question whether or not it represents an optimal course of action. Moreover, prospect theory (Kahneman & Tversky, 1979) is predicated on different treatment of gains compared to losses, so perhaps it should not be assumed that discounting behaviour in both contexts will be similar.

Discounting behaviour for costs rather than for rewards may therefore represent a more realistic ecological setting for research on subjective evaluation of temporal and probabilistic discounting. Furthermore, resulting theory may have greater scope for practical application (e.g. as described by Stewart, Chater & Brown, 2006) because costs are more frequent and ubiquitous in human society than are rewards.

Prelec and Loewenstein's model of discounting behaviour referenced above predicts an effect due to the sign of the amounts concerned i.e. whether they represent rewards or costs. This is proposed to arise because of asymmetrical value functions for rewards and costs, following prospect theory, which they labelled *loss amplification*, leading to lower discounting for future costs than future rewards. According to Prelec and Loewenstein, this arises because changing sign increases the relative weight of the amount component and, as discussed above, increase in amount leads to accordingly lower discounting.

This prediction was confirmed by Murphy, Vuchinich and Simpson (2001) comparing delayed discounting costs and rewards and also by Estle *et al* (2006) comparing costs and rewards in both temporal and probabilistic discounting situations. Both of these studies reported significant observations of steeper discounting for rewards than for costs.

Murphy *et al* evaluated an exponential curve against a simple hyperbolic curve for the discounting function and found that the latter provided a better description of the observed data. Estle *et al* found that their data was best described by a hyperbola-like function of the form

$$V = A/(1 + aX)^b$$

where, V represents the subjective value, X the delay or risk, A the amount and a and b discounting parameters. This is the same form of function as that originally proposed by Green and Myerson (2004) to describe discounting of rewards and Estle *et al* found that this form of equation provided a good description of their data in all four configurations of the reward/cost and temporal/probabilistic conditions.

Despite this similarity in *form* of the discounting function, Estle e*t al* found gain-loss asymmetry in the effect of amount on discounting rate. Specifically, delayed rewards were discounted more steeply than delayed costs but only at smaller amounts, whereas probabilistic rewards were discounted more steeply than probabilistic costs but only at *larger* amounts. They conclude from this that different processes are likely to be implicated in discounting of rewards and costs.

It is worth noting also, that in both studies the goodness of fit of the proposed curve (simple hyperbola or hyperbola-like respectively) was worse for costs than for rewards. Murphy *et al* quote mean R^2 values of 0.359 and 0.596 for costs and

rewards respectively and Estle *et al* median R^2 values of 0.84 and 0.95 respectively, for temporal discounting. A similar difference, albeit not of the same magnitude was reported by Estle *et al* for probabilistic discounting.

The magnitude effect that has been found to be so robust in studies of discounting of rewards was replicated by Estle *et al*, but they found no corresponding effect for discounting of costs. This presents further evidence for their hypothesis that discounting of rewards and costs involve different cognitive processes.

Both of these studies used relatively small (28 and 20 participants respectively) and homogeneous (undergraduates with mean age between 19.2 and 20.7 years) samples and may therefore have generalisation constraints.

In summary, studies of discounting have concentrated on rewards rather than costs and insufficient work on the latter has been undertaken so far to reach a consensus regarding which equation best models behaviour, or the precise nature of the effect of other relevant variables such as magnitude.

Effects of individual differences on discounting behaviour

Little research attention also has been generally directed towards individual differences in discounting behaviour, in the form of demographic characteristics, personality and mood. The work that has been undertaken has focused on rewards (e.g. Green, Myerson & Ostaszewski, 1999; Green *et al*, 1996) rather than costs and has mainly sought to use discounting behaviour as a predictor for extreme problem behaviour in special groups such as drug or alcohol abuse and smoking, rather than the general population (e.g. Madden *et al* 1997; Mitchell 1999; Reynolds *et al* 2004). An understanding of discounting is also potentially relevant to fundamental psychological and clinical issues such as will-power, self-control and attitude towards risk identified by Ainslie (1975, 1992 & 2001).

Working with discounting of rewards, Myerson *et al* (2003) reported weak to moderate correlation between probabilistic and temporal discounting in individuals. Although their experimental design did not include any measurement of personality traits *per se*, they express this finding as a counter-intuitive association between tendencies to prefer immediate rewards and avoid risk. These represent opposite extremes of the conventional definition of the impulsivity personality trait (Eysenck &

Eysenck, 1977; Richards *et al*, 1999). As with the magnitude effect, this provides support for dual process theories of discounting, namely that probabilistic and temporal discounting of rewards are mediated through separate cognitive processes.

Further evidence against a single process model for discounting was obtained by Du, Green and Myerson (2002) who found different effects of culture on probabilistic and temporal discounting, but that all groups' discounting behaviour fitted well to the same general hyperbolic equation. This study characterises effects due to demographic factors such as culture as modifications to a consistent underlying general model of discounting behaviour.

Income is an obvious demographic characteristic that might be expected to affect discounting behaviour. Again, working with rewards, Green *et al* (1996) reported that low-income individuals discount a given amount more steeply than high-income individual in temporal trials. This is counter-intuitive since it would be expected that the relative value of a given sum would be greater to low-income individuals and this increase in perceived value would lead to less-steep discounting.

In the same study Green *et al* found no significant effect of age on discounting behaviour, comparing groups with median ages of 33 years and 71 years.

Internet-based experimental procedures

A key methodological aspect of the present study was the use of an online experimental procedure made available to participants using the internet. Although this experimental approach has become more commonplace over the last five years, there is still some debate regarding its validity. The advantages are clear to see, including automated data collection, anonymity, cost, speed, absence of experimenter effects, availability, increased reach and enhanced external validity. Potential disadvantages include selection bias, scope for malicious or frivolous participation, control of experimental conditions and high drop-out rates.

One objective of the present study was to repeat previous work but with larger and more heterogeneous samples, and this could be achieved through the extended reach and efficiency of an internet study. The web makes an experiment available to any internet user worldwide and they can undertake an experiment with no involvement of the researcher, giving unlimited scalability in execution terms. There

is evidence (Musch & Reips, 2000) that web experiments achieve more diverse participants than corresponding typical laboratory studies and previous objections of selection bias caused by demographic patterns of internet access have now reduced. Previous internet-based psychological studies have reported wide variance in proportion of female participants ranging from 8% (Swoboda et al, 1997) to 71% (Pasveer & Ellard, 1998), but this was not anticipated as an issue for the present study.

Although an internet-based study seems to offer benefits for sample size and heterogeneity, it is important to consider potential disadvantages compared to traditional methods that might confound the overall objectives of the current study. Most studies that have directly compared pencil and paper with computer based surveys have found no difference in results (e.g. Stanton, 1998; O'Neill & Penrod, 2001; Joinson, 2001; Buchanan & Smith, 1999). There is also evidence that participants find computer surveys more interesting and perceive them to be shorter than equivalent conventional paper based equivalents (Rosenfeld et al, 1993).

A major factor in internet-based studies is the rate of participant dropout, which can be relatively high. Musch & Reips (2000) found that an average of 55% of participants completed online surveys without reward and Frick, Bächtiger and Reips (2001) found that completion rates could be improved by requesting some personal data (e.g. email address) at the beginning of the experiment. Dropout may be considered to have certain advantages since unmotivated participants will tend to self-exclude themselves from analysis, rather than to complete a lab-based test under sufferance with potential implications for resultant data quality.

Guidance for mitigation of this and other issues such as multiple submissions and frivolous data entry (e.g. sex? "yes please") provided by Reips (2002), were incorporated into the experimental design. It is worth noting also that this type of study, particularly the iterative process involved in the discounting trials, is very well-suited to computer delivery *per se*, so that delivery via the internet does not impose any incremental restrictions on the basic design.

Research questions and expected findings of present study

Against this background of previous research into discounting behaviour, the present study was designed with a number of objectives in mind. Firstly, it was intended to

partially replicate previous studies of Estle *et al* and Murphy *et al* by measuring both probabilistic and temporal discounting of costs, but with a larger and more heterogeneous sample.

This included consideration of the effect of amount, but no direct comparison of discounting behaviour between costs and rewards was undertaken. This reflects the conclusion of Estle *et al*, that different cognitive processes are implicated in discounting rewards and costs. This was expected to inform theories of the general shape of the discounting function specifically for costs and whether or not temporal and probabilistic discounting of costs reflect a single or multiple cognitive process(es).

The second objective was to extend these studies to examine individual rather than general probabilistic and temporal discounting behaviour for costs. This included the question of whether individual differences in discounting behaviour for costs are related to demographic characteristics, personality or mood of the participant. Given the lack of previous work on effects of individual differences on general discounting behaviour and on discounting of costs, it was felt that it would be premature to offer a specific hypothesis in this respect.

Finally, it was intended to explore whether or not the correlation between individual probabilistic and temporal discounting of rewards reported by Myerson *et al* (2003) would be replicated with discounting of costs. As above, this was expected to inform single or dual process theories of discounting and also to identify possible effects of other developmental and contextual factors on discounting behaviour.

Method

An online experiment was developed, using a combination of HTML, JavaScript and PHP programming environments. This was accessed by participants via the internet and therefore undertaken anonymously without any extra instruction from the researcher. The online introduction to the experiment explained that its objective was to explore the ways in which people subjectively assess future and uncertain costs and confirmed that the test would not download files onto the user's computer or change its configuration in any way.

The test may be accessed at http://www.decide.org.uk.

Materials.

An 50-item personality questionnaire was used, from the public domain International Personality Item Pool (IPIP) organisation, designed to measure personality traits against the well-known 'big-five' scales as follow:

Extraversion – tendency to engage with the external world, to enjoy being with people and often experience positive emotions. In groups, extroverts like to talk, draw attention to themselves and are generally assertive.

Agreeableness – tendency to cooperate and to promote social harmony and get along with others. Agreeable people are typically generous, friendly and willing to accommodate others through compromise of their own interests.

Conscientiousness – tendency to achieve by purposeful planning and persistence and to regulate and control impulses and to avoid spontaneity. Conscientious people are generally regarded by others as intelligent and reliable.

Emotional Stability – a tendency to resist negative emotions such as anxiety, anger and depression. These individuals are generally calm and emotionally stable without persistent negative feelings although not necessarily experiencing a high level of positive emotions (which is instead a component of the extraversion scale).

Openness to Experience – a tendency to be imaginative, creative and to show curiosity and sensitivity. Open such people appreciate art, are aware of their own feelings, are open to change and may hold personal and unconventional beliefs.

Each of the five dimensions was scored from ten behaviour statements to which the participant compared themselves, using a five point scale. This gave a total score for each dimension which was then normalised by conversion to a *z*-score in order to allow comparison across the five scales.

Participants.

The test was attempted by a total of 213 participants. Of these, 153 participants (72%) went on to successfully complete the test. Participants were recruited from several different sources: personal contacts, the Birkbeck College psychology department participant database and inclusion on the APA-sponsored online experiment web-site portal at http://psych.hanover.edu/research/exponnet.html.

Prospective participants were asked if they would be willing to undertake an online experiment which would take approximately 30 minutes, where all data would be held confidential, and not used for other purposes. No demographic or other selection criteria were applied and no reward was offered for participation. Participants were also invited to ask their friends and colleagues to participate. Because the experiment was made available over the web, the participants exhibited a wide range of demographic characteristics, summarised in the table below.

Gender	Male	73
	Female	80
Age Range	Under 20	5
	20 - 30	44
	30 - 40	43
	40 - 50	39
	50 - 60	15
	Above 60	7
Income	Under $20K	42
	$20K - $40K	44
	$40K - $100K	40
	$100K - $200K	19
	Above $200K	8
Educational level	High School	75
	University	45
	Postgraduate	33
Country	UK	102
	USA	36
	Other (12 countries)	15

Figure 1: Summary of demographic characteristics of sample

Design.

A within-subjects design was employed. Demographic and personality data was collected by online questionnaire and the experimental phase of the study manipulated three independent variables as follows:

- The nature of the discounting factor at two levels - temporal and probabilistic
- The amount of the cost at three levels - £200, £2,500 & £15,000
- The discounting scenario at five levels, described below in more detail

The dependent variable was an estimate of the participant's subjective evaluation of a delayed or uncertain cost, compared to an alternative immediate or certain cost.

Procedure.

The online procedure comprised three separate phases. In the first phase, basic demographic information about gender, age, nationality, income and education was collected. Participants were also asked to enter an email address in order to improve data quality (Reips 2000 & 2002) and to discourage multiple submissions although it was not possible actually to validate email addresses. Each element of demographic data was selected by the participant from a list which had a neutral pre-selection value, so that the creation of false data by the participant failing to make an explicit choice was avoided (Reips 2000 & 2002). In this phase a unique identifier was created for the participant in order to identify them in the future phases. This was done by checking the system time and writing this to the participant's browser as a cookie which was then accessed in each of the following phases. This unique identifier was also used to further guard against multiple submissions.

In the second phase, participants were asked to complete a 50-item psychometric inventory questionnaire from the public domain International personality Item Pool (IPIP). Participants were asked to rate themselves against each statement of behaviour using a five point Likert scale ranging from 'very inaccurate' to 'very accurate', with a neutral mid-point. The questions are listed in Appendix A. The online script validated that participants had completed all questions before allowing them to move to the next phase. Participants were then asked to complete five questions to assess their current mood, using a 9-point Likert scale. The five scale extreme pairs were 'refreshed/tired', 'calm/anxious', 'alert/unaware', 'positive/negative' and 'amused/sober'.

In the third phase of the procedure, the participant undertook a number of trials designed to measure their individual temporal and probabilistic discounting of costs. This trial was split into two blocks – dealing with temporal and probabilistic in turn, presented in randomised order for each participant. Each block contained 15

individual tasks in which the participant was asked to choose between two alternative costs by mouse clicking on the preferred options for a series of choices. These 15 tasks were presented in random sequence in both blocks.

In each task, the participant undertook an iterative process similar to that used in previous studies of discounting (e.g. Rachlin *et al* 1991, Holt, Green, & Myerson, 2003; Myerson *et al*., 2003), designed to converge on a point of subjective indifference by iteratively varying one of the choices in the light of the previous preference.

For temporal discounting, the choice was between an immediate cost and a delayed, greater, cost. Five levels were used for the delay independent variable – 3 months, 1 year, 2 years, 4 years & 7 years. This part of the trial started with the following instructions presented to the participant in their web browser.

> *In this part of the test you will be offered two options to pay for something and asked to choose which you prefer. You can either pay one amount RIGHT NOW or a different amount LATER. Please click on whichever option you would prefer if you were offered this choice for real. You have enough money to be able to choose whichever option you prefer and you have already received whatever it is you are paying for. The RIGHT NOW amount of money will change after each of your decisions. The LATER amount of money will stay the same for a group of choices. Please keep choosing until the test stops.*

The first choice at each delay was between a delayed cost and an immediate cost equal to half the delayed amount. Three levels for the amount independent variable were used - £200, £2,500 & £15,000. For each of the subsequent choices at a given delay and value, the amount of the immediate cost was adjusted according to the participant's prior choice. If the participant preferred the immediate cost, then its amount was increased on the following trial; alternatively if the participant preferred the delayed, greater cost, then the amount of the immediate cost was decreased on the following trial. The magnitude of the first adjustment was half the smaller cost amount in the initial condition and the magnitude of each subsequent adjustment was half that of the previous one. Each trial consisted of six iterations of this adjustment process. The table below shows an example, with the shading showing the participant's choices.

Iteration	NOW	In 1 Year	Adjustment
0	£100	£200	£50
1	£50	£200	£25
2	£75	£200	£12.50
3	£88	£200	£6.25
4	£81	£200	£3,13
5	£84	£200	n/a

The final subjective point of indifference was calculated as the mean of the largest immediate cost that was preferred to the delayed cost and the smallest immediate cost for which the corresponding delayed amount was preferred. In the example above, these two values would be respectively £81 and £84, giving a mean value of £83.

There were two special cases where a different rule was used to calculate the final subjective value – when a participant chose either the immediate or the delayed option in all iterations. In these cases the subjective value was deemed to be the mean of the last presented immediate cost and the minimum or maximum cost respectively. For example, with an initial delayed cost value of £200, if the participant always preferred the delayed cost, the subjective value would be the mean of £197 and £200.

For probabilistic discounting, the choice was between a certain cost and greater cost with a less than certain probability that the cost would be incurred. Five levels were used for the probability independent variable - 10%, 30%, 50%, 70% & 90% and this part of the test started with the following instructions presented to the participant in their internet browser.

> *In this part of the test you will be offered two options to pay for something you want to buy and you will be asked to choose which you prefer. .The first option is to pay a fixed amount of money for certain. The second option is to take a chance and POSSIBLY pay a sum of money, or (if you are lucky) pay nothing. For this option you will be told the POSSIBLE amount of money you may have to pay (if you are unlucky) and the probability that you will have to pay it. Please click on the option you would prefer if you were offered this choice for real. You have enough money to be able to choose whichever option you prefer. The CERTAIN*

amount of money will change after each of your decisions. The POSSIBLE amount of money will stay the same for a group of choices. Please keep choosing until the test stops.

The first choice at each delay was between an uncertain cost and a certain cost equal to half the delayed amount. As in the temporal discounting trial, three levels for the value independent variable were used - £200, £2,500 & £15,000. The iterative procedure to converge on an estimate of the participant's subjective evaluation of the cost concerned was similar to that employed for the temporal discounting trial.

In both temporal and probabilistic discounting trials, the first scenario was included for familiarisation and its result was discarded in each case. This was not revealed to the participant.

The time at which the experiment was completed was recorded in order to measure the total elapsed time taken by each participant and to safeguard against cases where the participant had made random, rapid choices without reading the questions fully.

Ethics.

One characteristic of an internet experiment is the lack of contact between researcher and participant. This eliminates the opportunity for the former to monitor the state of the latter and to take appropriate action in the case of distress or other unexpected consequences of the experiment. Given the nature of the study being conducted it was considered that this was extremely unlikely and did not therefore represent an ethical issue.

Participants were asked to provide an email address during the study in order to minimise likelihood of dropout and to guard against multiple submissions (Reips 2002). As such, this information did not form part of the data, so was discarded before analysis was undertaken in order to safeguard against possible confidentiality issues. This study was assessed according to the Birkbeck College School of Psychology ethics standards procedure and was deemed to be routine and the relevant documentation was placed on file. A copy of this is included in Appendix B.

Results and Discussion

Data quality

The mean elapsed time to complete the test was 20.1 minutes, with a standard deviation of 13.7 minutes and a positively skewed distribution that may have resulted from some participants taking breaks during the test. The minimum possible time required to complete the test with random selections was measured to be approximately 4 minutes. The 24 participants whose elapsed time was less than 12 minutes were subjected to closer scrutiny to establish if they had exhibited an overly-regular pattern of responses across multiple phases of the test that would indicate indiscriminate selection of options.

Eight participants were excluded on this criterion, leaving a total sample of 145 participants taken forward for further analysis. This met the objective of the present study to partially replicate Estle *et al's* previous work, but with a larger sample. A further objective was also achieved, through greater sample heterogeneity in every measured dimension including age, income level, nationality etc.

Dropout levels experienced in the present study (28%) were better than the average of 55% for online surveys with no financial incentive, reported by Musch & Reips (2000). This generally endorses the design of the internet experiment which reflects advice offered by Reips (2002) regarding measures that can be taken to minimize dropout. As discussed in detail below, the present study found more erratic individual discounting behaviour than other similar studies and this could be due to frivolous or malicious input from participants. This could potentially be reduced in future studies by providing an option at the end of the test for the participant to elect not to submit their results. Apart from this the design of the online experiment appeared to be effective.

Which curve best describes average discounting behaviour?

Discounting behaviour was analysed by first determining which equation provided the best fit to general discounting behaviour of the group overall. In order to allow comparison between participant's responses at different levels of cost amount, scores were normalised to a percentage of the initial future or uncertain cost. For

example a score of £185 for a trial with a starting future or uncertain cost of £200 was transformed to a normalised score of 0.925 and a score of £12,000 for a trial with a starting future or uncertain cost of £15,000 to one of 0.8000.

Median scores for each of the conditions are summarised below.

Probabilistic Discounting					
Chance of cost	**90%**	**70%**	**50%**	**30%**	**10%**
£200 Absolute	180	158	133	118	99
£200 Relative	0.900	0.790	0.665	0.590	0.495
£2,500 Absolute	2,247	2,012	1,895	1,817	1,270
£2,500 Relative	0.899	0.805	0.758	0.727	0.508
£15,000 Absolute	13,711	12,539	11,367	10,196	9,258
£15,000 Relative	0.914	0.836	0.758	0.680	0.617

Temporal Discounting					
Delay of (mths)	**3**	**12**	**24**	**48**	**84**
£200 Absolute	196	193	190	158	143
£200 Relative	0.980	0.965	0.950	0.790	0.715
£2500 Absolute	2,480	2,403	2,286	2,208	1,895
£2,500 Relative	0.992	0.961	0.914	0.883	0.758
£15,000 Absolute	14,883	14,180	13,711	12,539	12,071
£15,000 Relative	0.992	0.945	0.914	0.836	0.805

Figure 2: Median discounting scores summary

The median scores for each value were fitted to both a simple hyperbola and a hyperbola-like curve proposed by Estle *et al*, using the non-linear regression function of GraphPad Prism version 5.00 for Windows, GraphPad Software, San Diego California, USA, www.graphpad.com. The specific functions are as follows

Simple hyperbola $V = A/(1+aX)$

Hyperbola-like function $V = A/(1+aX)^b$

Where,

V = Subjective value,
X = Probability of cost being incurred or delay in cost being incurred,
A = Amount of cost

Plots of each function fitted to the median scores for each experimental condition are shown in the tables below.

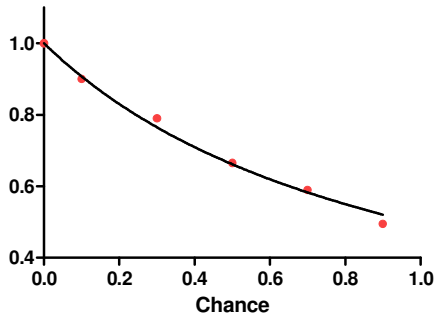
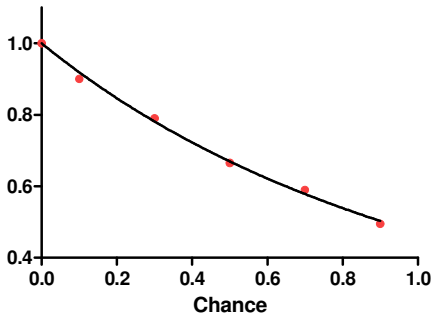
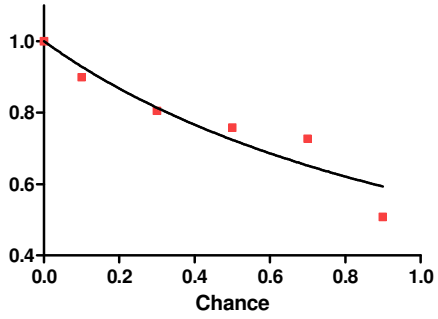
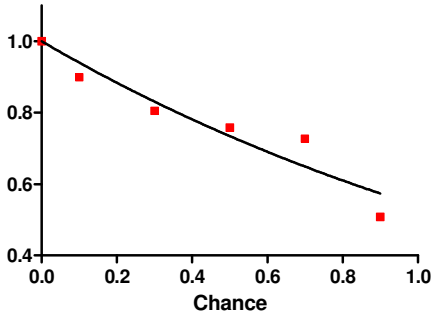
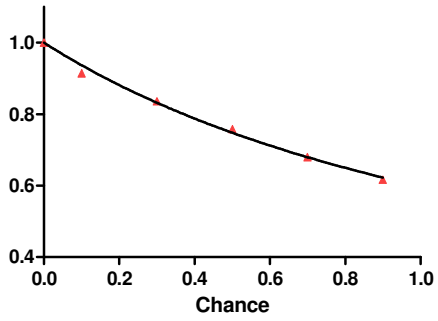
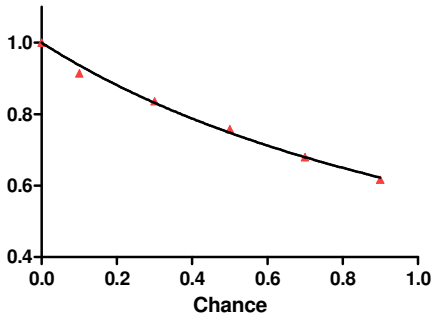
Simple Hyperbola	Hyperbola-like
	
£200 Cost	£200 Cost
	
£2,500 Cost	£2,500 Cost
	
£15,000 Cost	£15,000 Cost

Figure 3: Plots for probabilistic condition - x axis measures the chance of *not* incurring uncertain cost alternative and y axis the median normalised subjective point of indifference.

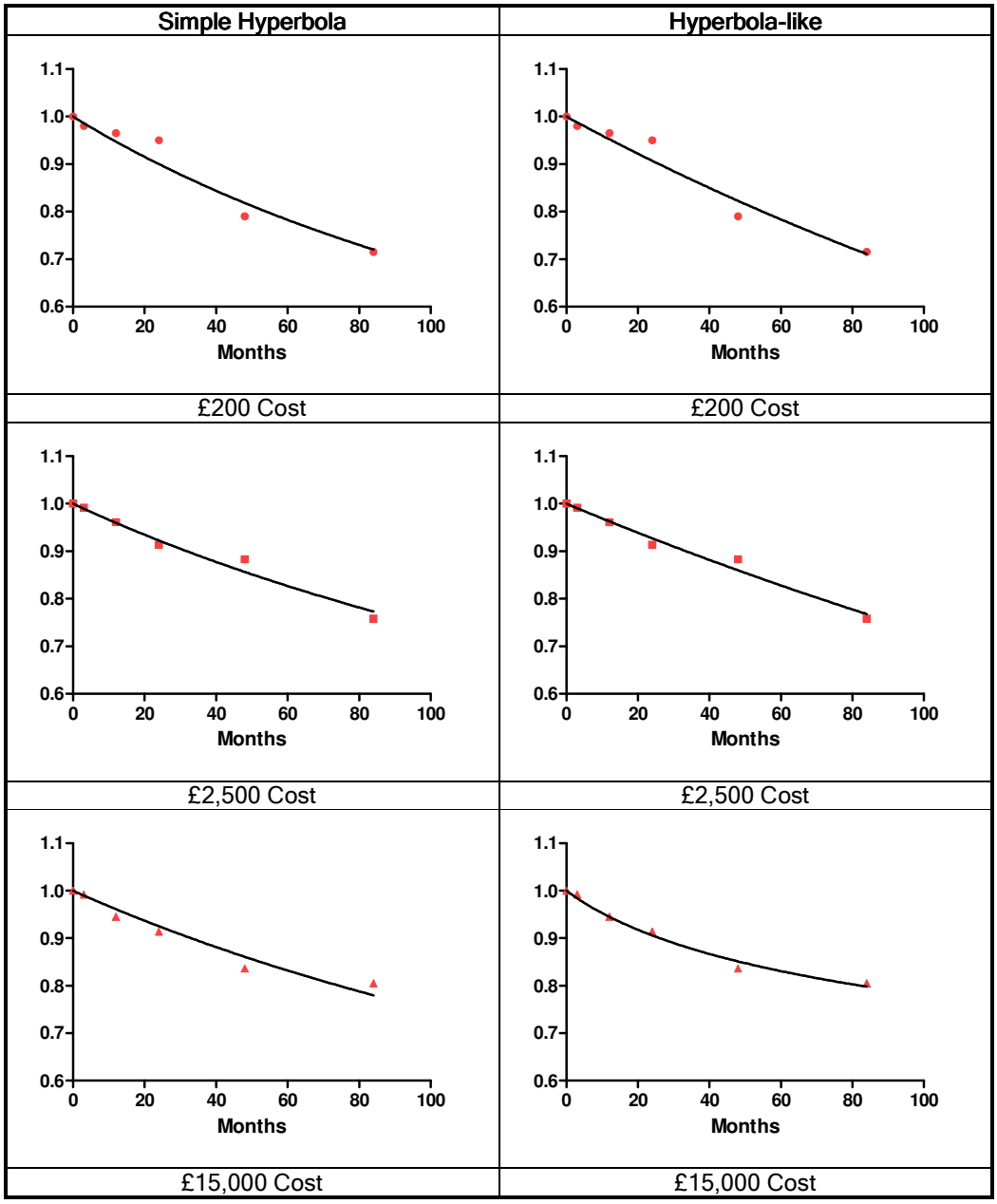


Figure 4: Plots for temporal condition - x axis measures the length of delay for the delayed cost alternative and y axis the median normalised subjective point of indifference.

The goodness of fit to the group median data of the two equations being considered was evaluated systematically by first calculating coefficient of determination (R^2) values for each. The coefficient of determination gives an estimate of the proportion of the data which can be accounted for by the equation being evaluated. A high value means that a high proportion of the data can be explained by the equation in question, and there is a good fit between the theoretical model and the empirical

data. R^2 values for the two equations being compared are shown in the figure below, for each of the experimental conditions.

	Probabilistic Discounting (R^2)		Temporal Discounting (R^2)	
Amount of Cost	**Hyperbola**	**Hyperbola-like**	**Hyperbola**	**Hyperbola-like**
£200	0.9924	0.9964	0.9472	0.9545
£2,500	0.8932	0.9052	0.9751	0.9801
£15,000	0.9935	0.9935	0.9488	0.9875

Figure 5: Calculated goodness-of-fit (R^2) for median scores summary

Although the hyperbola-like function gave higher coefficients of determination and therefore lower sum-of-squares values, it is a more complicated function than the simple hyperbola with two parameters rather than one. Generally speaking a complicated function will fit a given data set better than a simple function because it can have more inflection points, so a more balanced means of comparing the two equations was employed.

Firstly, because the two equations are related, with the simple hyperbola being a simpler case of the hyperbola-like function, a series of ANOVAs was carried out on the difference between the sum-of-squares of the two models. This computes an F ratio (change in sum-of-squares compared to reduction in degrees of freedom) and an associated *p* value, to determine whether or not to reject the null hypothesis corresponding to the simpler model. These values were calculated using the GraphPad Prism software package and in all cases except for one (temporal discounting at amount = £15,000, $p = 0.025$) the *p* value was found not to be significant, so the null hypothesis to use the simpler model was accepted.

A further comparison of the two models was carried out using Akaike's Information Criterion (AIC) which is based on information theory rather than on hypothesis testing (Akaike, 1974). AIC scores were calculated for the two models using GraphPad Prism, which reports a corrected value for AIC to compensate for the small number of data points (six in this case) compared to the number of parameters. In all cases the corrected AIC scores favour the simple hyperbola over the hyperbola-like model. The corrected AIC scores are shown in the table below, with lower AIC scores representing better fit.

	Probabilistic Discounting (AIC)		Temporal Discounting (AIC)	
Amount of Cost	**Hyperbola**	**Hyperbola-like**	**Hyperbola**	**Hyperbola-like**
£200	-42.217	-36.739	-36.396	-27.299
£2,500	-27.949	-18.666	-44.090	-35.433
£15,000	-46.592	-36.592	-41.160	-39.598

Figure 6: Calculated AIC scores for median scores summary

Which curve best describes individual discounting behaviour?

The same analysis was then carried out at an individual level, by fitting each participant's data to both the simple hyperbola and hyperbola-like functions and computing individual R^2 and AIC values and performing the ANOVA in each case. A summary of the comparisons is shown in the tables below. Note that the results in rows five to seven show the proportion of participants for whom that equation gave the better fit. For example, when comparing individual AIC scores for each participant in turn, it was found that for 98% of participants at the £200 condition the hyperbola gave a better fit.

		£200		£2,500		£15,000	
		Hyperbola	**Hyperbola-like**	**Hyperbola**	**Hyperbola-like**	**Hyperbola**	**Hyperbola-like**
1	Mean of individualR^2	0.492	0.741	0.467	0.716	0.444	0.703
2	SD of individual R^2	0.527	0.258	0.524	0.253	0.531	0.245
3	Mean of individual AIC	-17.612	-11.116	-18.788	-11.833	-18.899	-11.320
4	SD of individual AIC	9.136	7.796	9.773	9.019	10.793	8.938
5	Individual AIC comparison	98%	2%	95%	5%	98%	2%
6	Individual F test comparison	99%	1%	95%	5%	97%	3%
7	Individual R^2 comparison	12%	88%	12%	88%	11%	89%

Figure 7: Summary of comparisons of individual curve fitting for probabilistic condition

		£200		£2,500		£15,000	
		Hyperbola	**Hyperbola-like**	**Hyperbola**	**Hyperbola-like**	**Hyperbola**	**Hyperbola-like**
1	Mean of individualR^2	0.589	0.796	0.514	0.713	0.542	0.788
2	SD of individual R^2	0.439	0.220	0.540	0.339	0.544	0.215
3	Mean of individual AIC	-29.525	-17.561	-31.715	-18.031	-33.473	-21.240
4	SD of individual AIC	15.708	13.173	16.463	12.680	15.731	14.304
5	Individual AIC comparison	93%	7%	94%	6%	94%	6%
6	Individual F test comparison	89%	11%	93%	7%	89%	11%
7	Individual R^2 comparison	23%	77%	28%	72%	31%	69%

Figure 8: Summary of comparisons of individual curve fitting for temporal condition

In summary, it was found that the hyperbola-like function consistently gave a higher mean value for R^2 overall, as well a higher values for R^2 in a majority of individual cases. However, the simple hyperbola gave a better mean AIC score and better individual AIC scores in a majority of cases. Also the ANOVA F-test favoured the simple hyperbola in a majority of individual cases.

On the basis of these findings, it was decided to use a simple hyperbola for further analysis of discounting behaviour. An additional consideration was the merit of a one parameter model of discounting behaviour compared to a two-parameter model for use in subsequent planned correlation analysis. It was noticed that using the hyperbola-like function would often give a high goodness-of-fit, but a relatively wide 95% confidence interval for the best fit value of its two parameters. This reflects the greater intrinsic flexibility of the multi-parameter model to fit specific data, discussed above, but does not provide a reliable single coefficient that may be used to describe individual discounting behaviour.

Accuracy of description of individual cost discounting behaviour

The more significant finding of the current study in this regard is the generally far worse average individual fit observed, particularly compared to results obtained by Estle *et al* and Murphy *et al*. For example, Estle *et al* report median R^2 value for discounting of a $200 cost of 0.910, compared to an equivalent result in the current study for discounting of £200 cost of 0.864 (using the hyperbola-like equation for analysis). R^2 is not represented as a ratio scale, so this deficit is greater than might be immediately apparent.

The capability of a proposed model to describe data at the individual as well as the group level is of central interest because this would support a hypothesis that individual differences are quantitative rather than qualitative in nature, and that the underlying process is consistent across individuals.

The deficit in accuracy of model fit in the present study compared to previous work was found also at the individual level. Reanalysis of Estle *et al*'*s* data using the method employed in the present study revealed that only three participants out of the total sample of 20 (15%) showed discounting behaviour that could not adequately be described by a hyperbola. Similarly, Murphy *et al* excluded 10 out of 28 participants

(36%) who had non-significant *t* ratios in one or both amount conditions in their temporal discounting case

In comparison, the present study excluded 75 out of 145 participants (52%) who had non-significant *t* ratios in at least one of three amount conditions. This is not directly comparable to the exclusion rates observed by Estle *et al* and Murphy *et al*, because of the need to satisfy three criteria for inclusion (one for each level of amount) rather than one and two respectively in their studies. However, given that the events are unlikely to be independent (assuming an individual's behaviour across different amounts of cost is at least somewhat consistent) the difference is noteworthy.

It is proposed that this difference may be due to a key methodological difference relating to the sequence of presentation of discounting trials. Estle *et al* (in common with previous work) presented different levels of the temporal and probabilistic independent variables in increasing order, for example delay sequences of 1 month, 6 months, 1 year....etc. Murphy *et al* do not explicitly specify the sequence used in their study, but imply similar sequential presentation. This sequential presentation of trials could enable a participant to retain a reference point from the previous trial in working memory that might influence their discounting in the next trial.

For example, if a participant's subjective equivalent of a £200 cost in one year's time was an immediate cost of £175 in one trial, and the next trial presented a £200 cost in two years' time, the previous outcome would probably still be accessible and would act as a ceiling value.

In the present study, the temporal and probabilistic phases were presented as separate blocks, but the sequence of trials comprising different levels of amount and delay/chance within each block was also randomised. Thus, for example, a participant could be asked to consider a £200 cost delayed by 3 months, followed by a £15,000 cost delayed by 7 years. Therefore it would be unlikely that any reference point from the previous trial, accessed from working memory, would be relevant to the conditions of the next trial.

The actual experimental orders of conditions for each participant were analysed *post hoc* in order to generate an estimate of deviation from sequential presentation in each case and this was compared to the corresponding *t*-ratio, but no significant correlation was found. This would be consistent with the absence of a simple direct

link between predictability of individual discounting behaviour and differences in individual experimental conditions, although this has not been systematically tested and must therefore be treated as speculative. Systematic variation of the sequence of trials could provide the basis for subsequent investigation in an appropriately-designed experiment.

A *post hoc* explanation of this methodological difference is that the observed greater tendency towards erratic discounting when a sequential reference point is absent results because some individuals make subjective assessments of delay/chance and/or time in a relativistic rather than absolute manner. The subjective evaluation of a given delay or chance appears not to be calibrated according to an absolute internal reference scale, but by comparison to other available exemplars. This accords with the *decision by sampling* theory advanced by Stewart, Chater and Brown (2006) which proposes that there are no underlying psychoeconomic scales *per se*, but that subjective values of an attribute are derived from a series of binary ordinal comparisons to a sample drawn from memory.

The difference might also be at least partly explained by an anchoring effect (Tversky & Kahneman, 1974), where the outcome of the previous trial influences the next. In a sequential presentation of increases in the delay and chance variables, any anchoring effect would be fairly consistent, but random presentation of trials would tend to cause random patterns of the effect.

The greater inconsistency in discounting behaviour observed in the present study compared to previous studies is considered to be extremely significant. Although the deficit may potentially be explained by methodological differences, the implications for accurate description and modelling of discounting behaviour are potentially far-reaching. At question is the extent to which individuals are able to utilise absolute psychophysical scales of time and risk, in order to make an assessment of subjective value, independent of proximal reference points.

Current models of discounting behaviour (e.g. Green & Myerson) assume that this is the case and do not include a factor that represents the influence of other contextual variables. It is important to recognise that the present study did not make or test any hypotheses in this regard, but it does perhaps suggest a need for to evaluate this assumption more closely.

Predictable versus erratic individual discounting behaviour

These possible explanations for erratic discounting behaviour compared to previous similar studies cannot, however, account for the fact that significant numbers of participants (50% for probabilistic discounting and 52% for temporal discounting) showed discounting behaviour under the same conditions that *was* judged to be adequately predictable. The *t*-ratios that were used as criteria for predictability of discounting behaviour, shown below, appear to be approximately normally distributed with a positive skew, with no evidence of a bimodal distribution that would suggest two different populations.

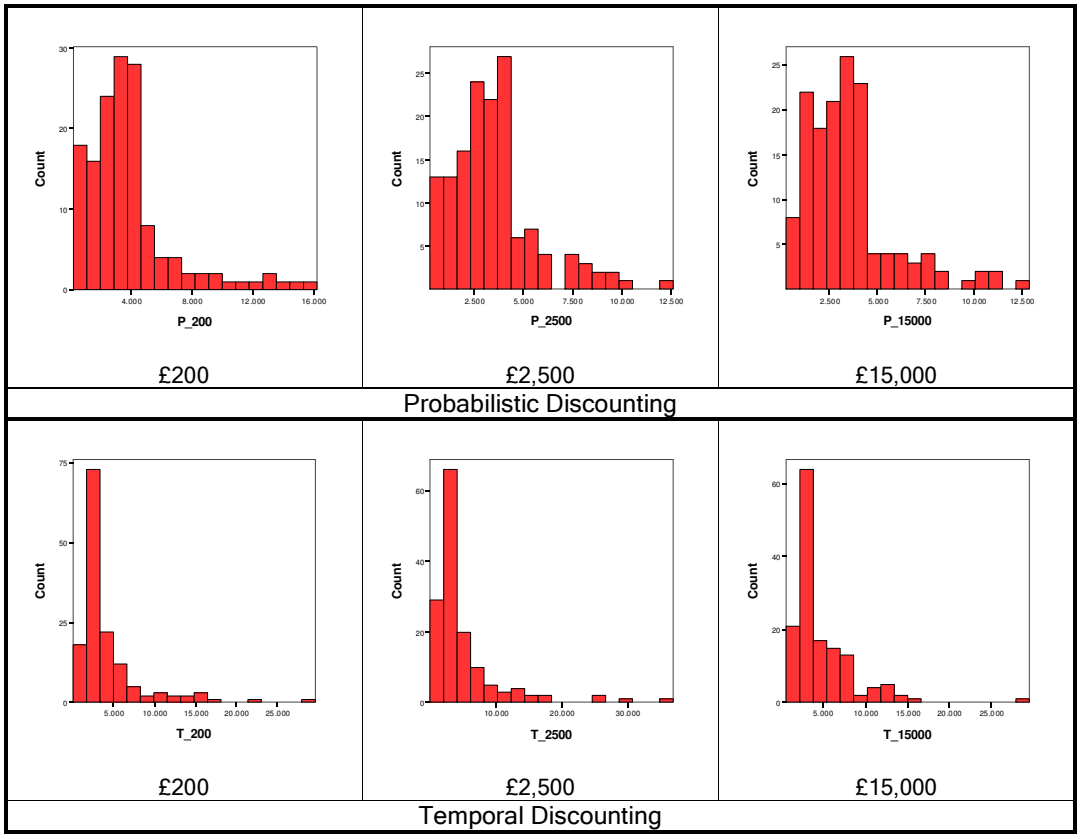


Figure 9: Frequency histograms for individual t-ratios for discounting behaviour.

It should be remembered that the formation of two categories, predictable and erratic discounting behaviour, is arbitrarily determined by the selected critical value for the *t*-ratio, rather than necessarily representative of a true dichotomous difference. Furthermore, the relatively small number of data points in each trial and the nature of the automated curve estimation algorithm mean that erratic discounting behaviour tends to be emphasised. Visual inspection of the data for participants classified as erratic indicated that this was often as a result of a single data point only.

Potential relationships between whether or not a participant showed discounting behaviour that could be adequately described by a simple hyperbola (discounting category) and other measured variables were examined. Type of discounting behaviour was represented as a dichotomous categorical variable (predictable or erratic) and compared to other variables. This was done using a series of Chi-square tests for variable such as gender, age, income and education, which were also categorical (either by nature or because of the present experimental design). Relationship with interval scale variables (personality dimension scores and mood score) was evaluated using Spearman's correlation, as above.

Probabilistic discounting

There was a highly significant association between whether or not the participant showed discounting behaviour that could be adequately described by a simple hyperbola and gender $X^2(1) = 11.335$, $p = 0.001$. This translates to a tendency for a tendency for females to exhibit predictable discounting behaviour and for males to show erratic behaviour.

Possible associations between adequacy of fit to simple hyperbola and age group and income could not be undertaken because some of the expected frequencies were less than 5. Association of adequacy of fit to simple hyperbola and education level was examined and found not to be significant.

There was also a significant point-biserial correlation between whether or not the participant showed discounting behaviour that could be adequately described by a simple hyperbola and the emotional stability personality dimension score, $r_{pb} = 0.217$, $p = 0.009$. This suggests that people who may be characterised as emotionally stable and calm show more predictable probabilistic discounting behaviour

Temporal discounting

As with probabilistic discounting, Chi-square analysis to test the association between discounting category and age and income could not be undertaken because of expected frequencies of less than 5. Analyses of the association between discounting category and gender and education were undertaken and found to give non-significant results.

Also, no significant correlations were found between discounting category and personality dimensions and mood scores.

Summary of predictable versus erratic discounting behaviour considerations

The present study has observed individual discounting behaviour that is more erratic than comparable previous work. This may be due simply to a methodological difference, but *post hoc* analysis suggests a more complex situation where individuals differ in their tendency to exhibit predictable discounting. This could be indicative of differences in the balance between use of absolute and relative cognitive psychophysical scales.

Relationship between discounting behaviour and individual differences

Using the simple hyperbola, individual discounting behaviour was modelled and values for the discounting parameter, *a*, computed for each participant and condition using the non-linear regression function of GraphPad Prism.

The goodness-of-fit in each case was judged using the ratio of the value of the estimate of the hyperbolic parameter *a*, to its standard error, as described by Gallant (1987). This is distributed as a *t* ratio with degrees of freedom equal to the number of data points (six in this case) minus the number of parameters in the equation (one in this case). A ratio less than the critical value of *t* (for $p < 0.05$), was taken to indicate that the estimated value was not a sufficiently accurate fit for the data.

73 participants had significant *t* ratios in all three levels of the amount condition of the probabilistic trials and 75 participants had significant *t* ratios in all three levels of the temporal trials. Descriptive statistics for the hyperbolic discounting parameter *a* including R^2 values in the different conditions are summarised in the table below. The absolute magnitude of the discounting parameter is sensitive to the units of measure employed (months for temporal discounting and percent chance for probabilistic discounting) and no comparison across the two conditions should be drawn.

Statistic	Probabilistic (N = 73)			Temporal (N = 75)		
	£200	£2,500	£15,000	£200	£2,500	£15,000
Mean	1.558	1.281	1.159	0.014	0.009	0.007
Standard Deviation	1.158	1.082	0.968	0.047	0.031	0.025
Skewness *z*-score	4.185	2.932	2.740	23.260	21.538	27.480
Mean R^2	0.704	0.658	0.654	0.765	0.797	0.776
R^2 SD	0.387	0.385	0.400	0.294	0.243	0.258
Median R^2	0.849	0.798	0.796	0.862	0.892	0.885

Figure 10: Summary of descriptive statistics for discounting parameter *a*

The interpretation of the value of *a* may be characterised as:-

- A high value indicates a tendency to prefer delayed and risky costs
- A low value indicates a tendency to prefer immediate and certain costs.

The distributions of the discounting parameter *a* are shown in the histograms below.

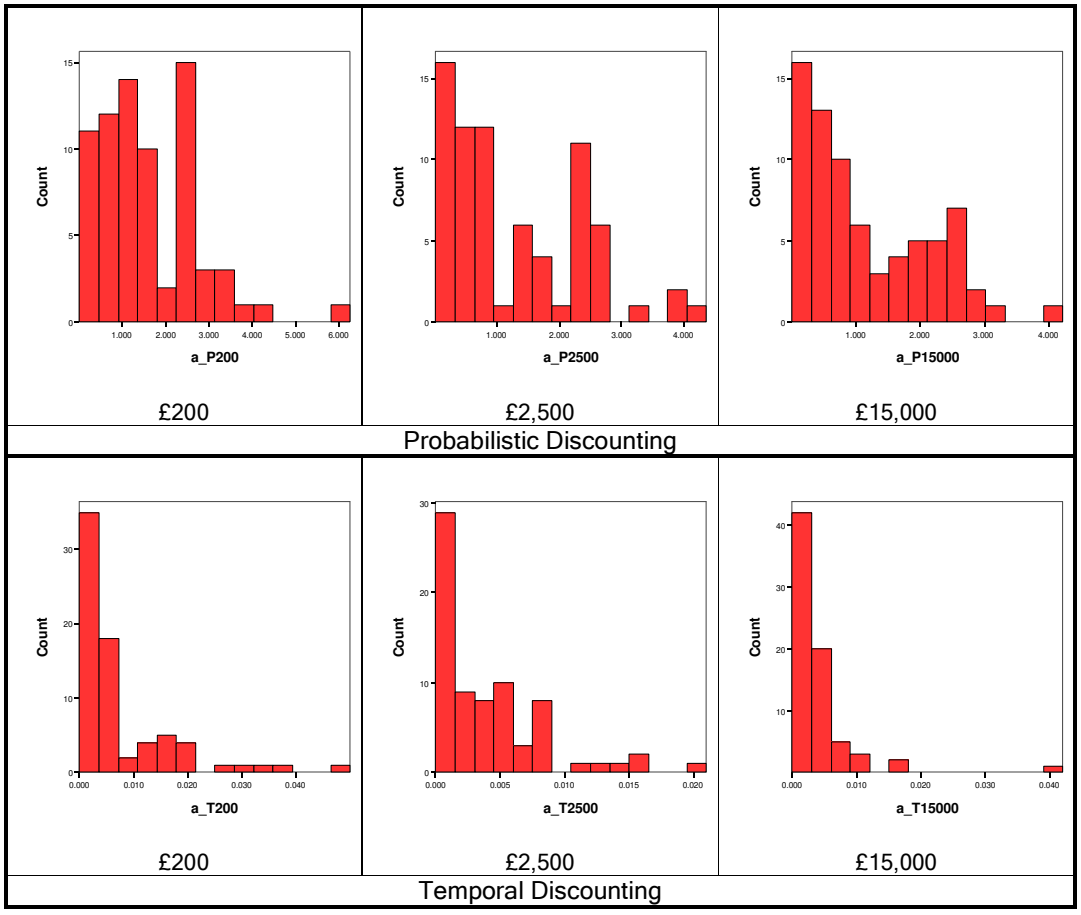


Figure 11: Frequency Histograms for calculated values of discounting parameter *a*

The *a* values for these groups of participants were then correlated against corresponding scores for the personality tests and demographic information. This was done using Spearman's test because the *a* values were judged not to be normally distributed, and also because some of the demographic data variables were not measured on an interval scale. This was done separately for probabilistic and temporal discounting conditions.

Probabilistic discounting

Highly significant correlations (shown in yellow in the figure below) were found between the values of *a* at the three different levels of amount of cost in the probabilistic condition.

Significant correlations (shown in green in the figure below) were also found between the discounting parameter *a* and the *agreeableness* (PII) and *openness to experience* (PV) personality dimension scores at each of the three levels of amount of cost.

Further significant correlations (shown in pink in the figure below) were found between gender and income level and the value of the discounting parameter *a*, at each of the three levels of amount of cost.

Correlations

			a_P200	a_P2500	a_P15000	PII	PV	Gender	Income
Spearman's rho	a_P200	Correlation Coefficient	1.000	.899**	.905**	-.312**	.289*	-.459**	.295*
		Sig. (2-tailed)	.	.000	.000	.007	.013	.000	.011
		N	73	73	73	73	73	73	73
	a_P2500	Correlation Coefficient	.899**	1.000	.895**	-.283*	.273*	-.482**	.296*
		Sig. (2-tailed)	.000	.	.000	.015	.019	.000	.011
		N	73	73	73	73	73	73	73
	a_P15000	Correlation Coefficient	.905**	.895**	1.000	-.294*	.343**	-.478**	.291*
		Sig. (2-tailed)	.000	.000	.	.012	.003	.000	.012
		N	73	73	73	73	73	73	73
	PII	Correlation Coefficient	-.312**	-.283*	-.294*	1.000	.083	.488**	-.379**
		Sig. (2-tailed)	.007	.015	.012	.	.486	.000	.001
		N	73	73	73	73	73	73	73
	PV	Correlation Coefficient	.289*	.273*	.343**	.083	1.000	-.122	.084
		Sig. (2-tailed)	.013	.019	.003	.486	.	.303	.481
		N	73	73	73	73	73	73	73
	Gender	Correlation Coefficient	-.459**	-.482**	-.478**	.488**	-.122	1.000	-.469**
		Sig. (2-tailed)	.000	.000	.000	.000	.303	.	.000
		N	73	73	73	73	73	73	73
	Income	Correlation Coefficient	.295*	.296*	.291*	-.379**	.084	-.469**	1.000
		Sig. (2-tailed)	.011	.011	.012	.001	.481	.000	.
		N	73	73	73	73	73	73	73

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 12. Spearman's Rho for correlation of probabilistic discounting parameter *a*, scores on personality scales II & V, gender & income.

Temporal discounting

As with probabilistic discounting, highly significant correlations (shown in yellow in the figure below) were found between the value of *a* at the three different levels of amount of cost for individual temporal discounting.

Significant correlations (shown in green in the figure below) were also found between the discounting parameter *a* and the *agreeableness* (PII) personality dimension score at each of the three levels of amount of cost.

Further significant correlations (shown in pink in the figure below) were found between gender and income level and the value of the discounting parameter *a*, at each of the three levels of amount of cost.

Correlations

			a_T200	a_T2500	a_T15000	PII	Gender	Income
Spearman's rho	a_T200	Correlation Coefficient	1.000	.915**	.843**	-.277*	-.284*	.281*
		Sig. (2-tailed)	.	.000	.000	.016	.014	.015
		N	75	75	75	75	75	75
	a_T2500	Correlation Coefficient	.915**	1.000	.919**	-.347**	-.366**	.405**
		Sig. (2-tailed)	.000	.	.000	.002	.001	.000
		N	75	75	75	75	75	75
	a_T15000	Correlation Coefficient	.843**	.919**	1.000	-.320**	-.350**	.395**
		Sig. (2-tailed)	.000	.000	.	.005	.002	.000
		N	75	75	75	75	75	75
	PII	Correlation Coefficient	-.277*	-.347**	-.320**	1.000	.537**	-.313**
		Sig. (2-tailed)	.016	.002	.005	.	.000	.006
		N	75	75	75	75	75	75
	Gender	Correlation Coefficient	-.284*	-.366**	-.350**	.537**	1.000	-.456**
		Sig. (2-tailed)	.014	.001	.002	.000	.	.000
		N	75	75	75	75	75	75
	Income	Correlation Coefficient	.281*	.405**	.395**	-.313**	-.456**	1.000
		Sig. (2-tailed)	.015	.000	.000	.006	.000	.
		N	75	75	75	75	75	75

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 13: Spearman's Rho for correlation of temporal discounting parameter *a*, scores on personality scale II, gender & income.

Summary of relationship between discounting behaviour and individual differences

The pattern of correlations described above is highly consistent and several general characterisations may be advanced.

Firstly, rate of discounting of future and uncertain costs appears to be inversely related to score on the agreeableness personality trait dimension. This may be portrayed as a tendency for more agreeable individuals to show a relative preference for immediate and certain costs over future and risky ones.

Secondly, rate of discounting appears to be related to gender, with males showing significantly higher rates of discounting and therefore a preference for immediate and certain costs over future and risky ones.

Finally, rate of discounting was found to be positively related to income level, suggesting that wealthier individuals have a tendency to a relative preference towards future and risky costs rather than immediate and certain ones. This might be intuitively expected because there is abundant empirical evidence that larger amounts are discounted less steeply than smaller amounts and that a wealthier person will give a smaller subjective value to a particular amount of money than would a poorer person. Combining these two factors would predict steeper discounting (of rewards and costs) by wealthier individuals, as observed in the present study. However, this is the opposite finding to that reported by Green *et al* (1996) who studied the effect on income level on discounting of rewards. This provides evidence for the hypothesis that discounting of costs and rewards involve different cognitive processes.

Various other correlations were also noted, but these did not exhibit the same level of consistency across amount of cost and discounting domain, and are not therefore considered to be noteworthy. Significant correlations were also noted between several of the independent variables (agreeableness, gender and income level) which are indicative of the complex nature of the interaction between these factors and the discounting parameter.

Effect of amount of cost on discounting behaviour

For the group of participants whose discounting behaviour gave an adequate fit to a simple hyperbola, the effect of amount of cost on value of the estimated discounting parameter, *a*, was investigated for each of the temporal and probabilistic discounting conditions, using Friedman's ANOVA. This test was used because the discounting parameter, *a*, was found not to be normally distributed, as discussed above.

In both probabilistic and temporal discounting conditions a highly significant negative effect of value on the discounting parameter, *a*, was found as shown in the figures below. This contrasts with the observations of Estle *et al*, who reported no significant effect of amount in the cost condition.

Test Statistics[a]

N			73
Chi-Square			40.021
df			2
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000
	99% Confidence Interval	Lower Bound	.000
		Upper Bound	.000

a. Friedman Test

Figure 14: Output from Friedman's ANOVA, testing effect of amount independent variable on probabilistic discounting parameter *a*.

Test Statistics[a]

N			75
Chi-Square			13.924
df			2
Asymp. Sig.			.001
Monte Carlo Sig.	Sig.		.001
	99% Confidence Interval	Lower Bound	.000
		Upper Bound	.002

a. Friedman Test

Figure 15: Output from Friedman's ANOVA, testing effect of amount independent variable on temporal discounting parameter *a*.

Post hoc procedures using paired Wilcoxon signed-rank tests with a critical value for significance of 0.0167 (Bonferroni correction of 0.05 divided by 3 comparisons) were carried out. In both the probabilistic and temporal discounting conditions, highly significant effects were confirmed for the £200/£2,500 and £200/£15,000 pairs. The Wilcoxon *z* values are shown below.

Test Statistics[b,c]

			a_P2500 - a_P200	a_P15000 - a_P200	a_P15000 - a_P2500
Z			-3.796[a]	-5.720[a]	-1.537[a]
Asymp. Sig. (2-tailed)			.000	.000	.124
Monte Carlo Sig. (2-tailed)	Sig.		.000	.000	.131
	99% Confidence Interval	Lower Bound	.000	.000	.122
		Upper Bound	.001	.000	.139
Monte Carlo Sig. (1-tailed)	Sig.		.000	.000	.063
	99% Confidence Interval	Lower Bound	.000	.000	.057
		Upper Bound	.001	.000	.069

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

c. Based on 10000 sampled tables with starting seed 624387341.

Figure 16: Output from Wilcoxon signed rank paired tests of effect of level of amount on probabilistic discounting parameter *a*.

Test Statistics[b,c]

			a_T2500 - a_T200	a_T15000 - a_T200	a_T15000 - a_T2500
Z			-4.098[a]	-3.617[a]	-1.342[a]
Asymp. Sig. (2-tailed)			.000	.000	.179
Monte Carlo Sig. (2-tailed)	Sig.		.000	.000	.177
	99% Confidence Interval	Lower Bound	.000	.000	.167
		Upper Bound	.000	.000	.187
Monte Carlo Sig. (1-tailed)	Sig.		.000	.000	.090
	99% Confidence Interval	Lower Bound	.000	.000	.083
		Upper Bound	.000	.000	.098

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

c. Based on 10000 sampled tables with starting seed 743671174.

Figure 17: Output from Wilcoxon signed rank paired tests of effect of level of amount on temporal discounting parameter *a*.

Thus, participants' preference for certain and immediate costs tended to increase with the amount of the cost. This may be evaluated against theoretical cognitive models for discounting of rewards (e.g. Prelec & Loewenstein), which propose that the difference between costs and rewards is simply a matter of sign of the weighting component for amount.

In contrast to discounting of rewards, the direction of the observed magnitude effect on discounting of costs is consistent in both probabilistic and temporal cases. This gives support for a single process model of discounting of costs, where both delay and chance are represented by a single factor in the subjective overall estimation of value.

On the other hand, this contrast suggests that the difference between discounting of rewards and costs cannot simply be one of sign as suggested above. This is consistent with the findings of Estle *et al* that, although discounting behaviour can be described well by the same general *form* of equation in all tested situations, there is evidence that different processes were implicated in discounting of positive and negative outcomes.

Correlation between probabilistic and temporal discounting of costs

For those participants whose discounting behaviour could adequately be described by a simple hyperbola in *both* probabilistic and temporal trials (N = 50), potential correlation between their respective discounting parameters was analysed using Spearman's method. At each level of cost amount, highly significant correlations

(with $p < 0.0005$ in each case) were found between calculated values of participants' probabilistic and temporal discounting parameters *a*. The values for Spearman's coefficient of correlation in each case are shown in the table below.

Correlations

			a_200P	a_200T	a_2500P	a_2500T	a_15000P	a_15000T
Spearman's rho	a_200P	Correlation Coefficient	1.000	.601**	.915**	.620**	.905**	.622**
		Sig. (2-tailed)	.	.000	.000	.000	.000	.000
		N	50	50	50	50	50	50
	a_200T	Correlation Coefficient	.601**	1.000	.513**	.921**	.516**	.862**
		Sig. (2-tailed)	.000	.	.000	.000	.000	.000
		N	50	50	50	50	50	50
	a_2500P	Correlation Coefficient	.915**	.513**	1.000	.486**	.908**	.544**
		Sig. (2-tailed)	.000	.000	.	.000	.000	.000
		N	50	50	50	50	50	50
	a_2500T	Correlation Coefficient	.620**	.921**	.486**	1.000	.504**	.895**
		Sig. (2-tailed)	.000	.000	.000	.	.000	.000
		N	50	50	50	50	50	50
	a_15000P	Correlation Coefficient	.905**	.516**	.908**	.504**	1.000	.590**
		Sig. (2-tailed)	.000	.000	.000	.000	.	.000
		N	50	50	50	50	50	50
	a_15000T	Correlation Coefficient	.622**	.862**	.544**	.895**	.590**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.
		N	50	50	50	50	50	50

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 18: Values of Spearman's Rho for correlation of individual probabilistic discounting and temporal discounting parameters.

This suggests that individuals with a tendency to prefer immediate costs also prefer certain costs and individuals who prefer delayed costs also prefer risky costs. This is consistent with the Prelec and Loewenstein model of discounting discussed above and extends the weak correlations reported by Myerson *et al* (2003) dealing with the corresponding situation for individual discounting of rewards.

Taken with the consistent effect of amount of cost on probabilistic and temporal discounting discussed above, this provides evidence at an individual level that a single process is implicated in both conditions. This contrasts with findings for discounting of rewards, where the effect of amount is in opposite directions for probabilistic and temporal discounting and only weak correlation has been reported at an individual level.

Consideration was also given to whether or not individual participant's *type* of discounting behaviour (erratic or predictable by a simple hyperbola) was consistent across probabilistic and temporal conditions. In other words, if a participant showed erratic discounting behaviour for one condition would they also be erratic in the other?

This potential association was analysed with a Chi-square test between participants' discounting category (able to be adequately fitted by a simple hyperbola or not) in each condition and found to approach significance only, with $X^2(1) = 3.659$, $p = 0.056$.

Significance of findings

The present study highlights several aspects of discounting of costs that are considered to be of significance.

Individual differences in discounting behaviour.

Three strong correlations of discounting behaviour with individual differences were found. Perhaps more importantly, they were highly consistent across levels of amount of cost and probabilistic and temporal conditions. This contrasts to previous findings for discounting of rewards (e.g. Du, Green & Myerson), where reported observations have often been inconsistent across the two domains. This is believed to be the first study to investigate effects of individual differences on discounting of costs rather than rewards, and the consistent observed pattern of correlations is encouraging and indicates that this domain may represent a more productive context for further work.

General form of discounting of costs

As discussed earlier, there is strong advocacy for a hyperbola-like equation to describe discounting of rewards (e.g. Green, Fry & Myerson, 1994; Myerson & Green, 1995). Estle *et al* have proposed the same model for discounting of costs, but this has not been extensively tested elsewhere.

The current study did not replicate this finding for discounting of costs, but found instead that a simple hyperbola provided a better description of the data. This was largely due to differences in the chosen method of analysis, using a comparison based on information theory rather than simple goodness of fit which is sensitive to the number of parameters in the equation being tested. It is acknowledged therefore that this is open to question regarding how best to compare competing models. Despite their strong advocacy of a hyperbola-like function, Green and Myerson (2004) recognise the relative merit of a simpler model, suggesting that 'reliance on the simpler model would be more justified if the accuracy of the empirical descriptions provided by the two models did not differ substantially.'

Relative influence of proximal reference points versus absolute internal scales.

The greater prevalence of erratic discounting observed in this study compared to previous work may be linked to random rather than sequential presentation of trials. Experimental confirmation of this would provide support for subjective comparison to proximal reference points in discounting, rather than exclusive dependence on absolute internal scales of time and chance.

Does a single process underlie both probabilistic and temporal discounting of costs?

In common with previous studies, a significant effect of amount of cost on rate of discounting was observed. However, in contrast to discounting of rewards, the effect was in the same direction for probabilistic and temporal discounting. This is consistent with a single-process theory of cost discounting in which both probabilistic and temporal discounting reflect the same cognitive process.

The observed strong correlation at the individual level between discounting rate in probabilistic and temporal contexts provides further support for this single-process theory. Furthermore, this is strengthened by the observed consistent pattern of correlation of discounting behaviour to certain individual differences across probabilistic and temporal conditions.

Differences between discounting of costs and rewards

The present study did not compare discounting of costs and rewards, but findings are consistent with Estle *et al's* hypothesis that these involve different cognitive processes. Specifically, the observed magnitude effect and direction of correlation of discounting to income level are qualitatively different to those previously reported for rewards.

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Appendices

Appendix A – Psychometric evaluation procedure

Instructions to participants

In this test, there are phrases describing people's behaviours. Please use the rating scale below to describe how accurately each statement describes ***you***. Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Please read each statement carefully, and then fill in the bubble that corresponds to the number on the scale.

Please answer every item. Note that the answer circles appear directly to the right of each question. Please make sure that the circle you are choosing corresponds to the question you are considering. If you make a mistake or change your mind, simply click the circle you wish to choose. After you have answered all of the questions, please press the send button at the bottom of the page. You will the move to the next task.

Response Options

1: Very Inaccurate;
2: Moderately Inaccurate;
3: Neither Inaccurate nor Accurate;
4: Moderately Accurate;
5: Very Accurate

Evaluation statements

No.	Statement	Key
1	Am the life of the party.	1+
2	Feel little concern for others.	2-
3	Am always prepared.	3+
4	Get stressed out easily.	4-
5	Have a rich vocabulary.	5+
6	Don't talk a lot.	1-
7	Am interested in people.	2+
8	Leave my belongings around.	3-
9	Am relaxed most of the time.	4+
10	Have difficulty understanding abstract ideas.	5-
11	Feel comfortable around people.	1+
12	Insult people.	2-
13	Pay attention to details.	3+
14	Worry about things.	4-
15	Have a vivid imagination.	5+
16	Keep in the background.	1-
17	Sympathize with others' feelings.	2+
18	Make a mess of things.	3-
19	Seldom feel blue.	4+
20	Am not interested in abstract ideas.	5-
21	Start conversations.	1+
22	Am not interested in other people's problems.	2-
23	Get chores done right away.	3+

24	Am easily disturbed.	4-
25	Have excellent ideas.	5+
26	Have little to say.	1-
27	Have a soft heart.	2+
28	Often forget to put things back in their proper place.	3-
29	Get upset easily.	4-
30	Do not have a good imagination.	5-
31	Talk to a lot of different people at parties.	1+
32	Am not really interested in others.	2-
33	Like order.	3+
34	Change my mood a lot.	4-
35	Am quick to understand things.	5+
36	Don't like to draw attention to myself.	1-
37	Take time out for others.	2+
38	Shirk my duties.	3-
39	Have frequent mood swings.	4-
40	Use difficult words.	5+
41	Don't mind being the center of attention.	1+
42	Feel others' emotions.	2+
43	Follow a schedule.	3+
44	Get irritated easily.	4-
45	Spend time reflecting on things.	5+
46	Am quiet around strangers.	1-
47	Make people feel at ease.	2+
48	Am exacting in my work.	3+
49	Often feel blue.	4-
50	Am full of ideas.	5+

Scales

Factor I - Extraversion
Factor II - Agreeableness
Factor III - Conscientiousness
Factor IV - Emotional Stability
Factor V - Openness to Experience

Appendix B - Ethics form