

The Impact of Experiencing Outcomes on Delay and Probability Discounting

by

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Abstract

Temporal and probability discounting refer to the decrease in subjective value of rewards that are either delayed or uncertain. Comparatively high degrees of discounting have been linked to other indices of impulsivity in both animals and humans, but the study of human discounting has primarily relied on participant reports of preferences between hypothetical outcomes. A number of studies to date have illustrated not only how sensitive these preferences are to manipulations within such hypothetical procedures, but also that tasks where each consequence is actually experienced are able to capture changes in behaviour that hypothetical tasks may not.

The current thesis examined temporal and probability discounting using a novel experiential discounting task in the form of a computer game-based discounting task in which the delays or probabilities of the preferred outcomes were experienced following each choice. The game had participants collect points by skiing over jumps, and discounting choices between either immediate and delayed or certain and uncertain point outcomes provided additional opportunities for point gain.

Discounting was examined across four samples primarily composed of university students. Experiment 1, a test of the newly created task in two parts, assessed the most appropriate descriptive model of both temporal and probability discounting, as well as examined the relation between the two, hypothetical discounting and self-report measures of impulsivity and risk taking. Experiment 2 examined the effect of magnitude manipulations on both temporal and probability discounting. Experiment 3 examined the effect on degree of temporal discounting of manipulations to post-reward delays and access to alternative reinforcement during this period. Lastly, Experiment 4 attempted to manipulate the association between delay and risk and examined the impact of this on discounting of delayed outcomes.

Participants across all studies showed systematic decreases in subjective value of both delayed and uncertain point outcomes. However, the shape of this decrease in value differed across the two types of outcomes, as did the effect of the magnitude manipulations. Furthermore, neither post-reinforcement duration, access to alternative reinforcement, nor experience with risk influenced degree of temporal discounting. The results are discussed in terms of single process accounts of discounting, the implications for individual trait interpretations of discounting and the relevance of experiential and hypothetical discounting to the construct of impulsivity.

Chapter 1 : Rationality, Impulsivity, Subjective value and Discounting

A basic tenant of the concept Homo economicus, used by economists in proposing models of human behaviour, holds that humans are rational beings whose behaviours are motivated by maximizing gain. However, in many situations when we are presented with two alternatives, in other words are given a choice, we fall short of this rational ideal and prefer the objectively lesser valued of the two options despite 'knowing' that this is the case. Humans take unnecessary risks and often engage in behaviours that, relative to alternative behaviours, do not lead to the greatest overall reward. People gamble and play the lottery despite the infinitesimally small chance that their investments will be returned with profit, and often prefer behaviours that lead to small short term gain rather than large long term benefits. Furthermore, we often make these choices in the full knowledge that we end up with less than if we had preferred the alternative outcome. Preference for either a small immediate over a larger delayed outcome, or for a large risky outcome over a smaller certain outcome has been defined as impulsive (Green & Myerson, 2004), and may appear irrational. However, as investigated by behavioural psychologists, these seemingly irrational choices fall within the bounds of rational behaviour by defining the value of an outcome not by its absolute objective value, but by its subjective value to the individual. More specifically, the types of choices described above, between certain and uncertain outcomes on the one hand or between immediate and delayed outcomes on the other, are investigated under the rubrics of probabilistic and temporal discounting, respectively. The research into temporal and probability discounting has boomed in the past decades and the interest does not appear to be dissipating. However, the literature on discounting has relied on a relatively narrow range of procedures since the early 1990s and the data produced with these procedures have formed the foundations for our understanding of how value decreases as a function of either delay or uncertainty. Efforts to establish the best equation for describing value loss, investigations into manipulating degree of discounting, as well as comparisons of degree of discounting across different groups have predominantly used the same methods. Consequently, the equations we use to describe value loss, and a number of replicable discounting effects may be heavily influenced by the use of these methods. Furthermore, these standard procedures break from common behavioural practice by relying on subjects' reported preferences between hypothetical outcomes, delays and probabilities. This issue has been noted previously, and there is already evidence that the experience of outcomes exerts an influence on discounting (Navarick, 2004). A

number of experimenters in recent years have used alternative procedures with results that put into question the suitability of standard discounting procedures. One of the chief differences across the established and novel tasks is the extent to which choices result in hypothetical or real outcomes. Comparisons between the more commonly used procedures and these novel approaches show that different procedures produce different data, and imply that current conceptions of discounting processes have been heavily influenced by the particular methods used. For the current thesis, a novel discounting procedure was developed with the aim of re-examining discounting and the generalizability of findings from traditional discounting research.

The following literature review describes the mathematical descriptions of value loss as a function of both delay and uncertainty, the theoretical implications of these models, and the investigations into how discounting varies both across and within individuals. It gives an indication of the research conducted on both temporal and probability discounting, before addressing the specifics of the procedures used in that body of work. The review is structured into three parts. In Part 1 and 2, respectively, the research on temporal and probability discounting is reviewed. First in each of these sections, the mathematical descriptions of discounting are detailed, along with their theoretical implications. Second within each section, discounting is considered within the context of impulsivity and risk-taking by reviewing evidence relating it to sub-optimal behaviour and self-report measures of impulsiveness. Lastly, the malleability of discounting is demonstrated through research that has examined the effects of various temporary manipulations on how fast outcomes lose their value. Part 3 of the review covers the methodological details of discounting research by first reviewing and critiquing the dominant hypothetical procedures, and then examining alternative, experiential, procedures.

Temporal discounting

The subjective value of a reward is influenced by both its absolute size and the delay until its receipt. Subjective value *increases* as a function of reward size, such that given a choice between two rewards at equal delays (either delayed or immediate) but differing sizes, it is natural to assume that the larger of the two will be preferred. Receipt of one hundred dollars today should be preferred over receipt of ten dollars today, and likewise one hundred dollars in a month should be preferred over ten dollars in a month. Subjective value also *decreases* as a function of

delay, such that given a choice between two rewards of equal size but differing delays, the more immediate reward will be preferred. Receipt of one hundred dollars today should be preferred over receipt of one hundred dollars in a month. Neither of these sets of choices should be difficult to make.

In a large proportion of real life choices, however, delay and size co-vary such that the larger of the options is also the more delayed, for example if the ten dollars was to be received today but the one hundred was received in a month. Understanding choice in such complex situations necessitates knowledge of how the increase in subjective value as a function of reward size is offset by the value reducing influence of delay. The research on temporal discounting deals specifically with the decrease in the subjective value of a reward as a function of delay (Madden & Bickel, 2010).

The effect of delay on subjective value has proven a useful framework by which to investigate impulsivity and self-control. When preference for large and delayed rewards is heavily influenced by increases in the delay (i.e. its subjective value decreases relatively sharply as a function of delay), behaviour is said to be impulsive. When, however, delay has a minimal effect on the subjective value of a delayed reward, behaviour is said to be relatively self-controlled. Compared to someone who shows self-controlled behaviour, an impulsive individual will show a stronger preference for the lesser of the two rewards at smaller amounts of the immediate reward relative to the delayed reward (Green & Myerson, 2004).

The claim that value decreases as a function of delay is hardly controversial. It is a well-established finding in the behavioural literature that delayed rewards are less effective in controlling behaviour than immediate outcomes (Renner, 1964). There is however, a degree more debate regarding the way in which the value decreases. Whereas the economic perspective, from which discounting research originated, has assumed a constant rate of discounting, the majority of data produced from within psychology (and indeed even economics) has supported a non-constant rate of discounting, in which the discounting rate decreases as delay increases. A discussion of the three most commonly cited models of temporal discounting, the exponential, hyperbolic and hyperboloid models, and of their ability to describe intertemporal choice followsⁱ.

Exponential discounting

Redish and Kurth-Nelson (2010) noted that discounting is necessary given the loss of investments of a present alternative as well as the uncertainty inherent in waiting for future outcomes. The often cited ‘economic perspective’ has described discounting as constant decrease in value according to an exponential function (Samuelson, 1937),

$$V = Ae^{-kD} \quad \text{[Equation 1; Myerson & Green, 1995]}$$

in which the (present) discounted value of a delayed reward (V) is determined by its undiscounted amount (A), the delay to its receipt (D), and the free parameter (k) that describes the rate at which delayed rewards are discounted. Redish and Kurth-Nelson (2010) noted that, although other functions describing a constant decrease would work, the exponential function is a logical choice to describe discounting given “the assumptions of compound interest with no uncertainty” (p. 4). Benzion, Rapoport and Yagil (1989) describe a classical approach in which discounting should show no individual differences because it is equal to market riskless discount rate. However, the function also accounts for discounting in the presence of risk, given the assumption that the probability of prevented delivery is constant over time (Green & Myerson, 1996). Unlike the classical approach, this latter risk-inclusive perspective also allows for variation in discount rates beyond market discount rate, while maintaining a constant discount rate across time.

Hyperbolic discounting

In contrast to this economic view, the psychological literature has advocated the use of a hyperbolic function, using the same parameters as Equation 1, (Equation 2; Mazur, 1987).

$$V = A/(1-kD) \quad \text{[Equation 2]}$$

This function describes a successively smaller decrease in rate of discounting per unit of delay as the delay increases. For example, it describes a larger decrease in subjective value between the delays of two and three months than between thirteen and fourteen months, even though the difference in both cases is one month. Compared to the constant exponential function

the hyperbolic model describes an initially steeper decrease in value at short delays and a shallower decrease at long delays (Myerson & Green, 1995).

The non-constant shape of hyperbolic discounting has been described both in terms of rate and in terms of risk (Rachlin, Logue, Gibbon & Frankel, 1986; Green & Myerson, 1996). For example, Green and Myerson elaborated on a risk interpretation of delay discounting in which risk is not constant (as assumed with exponential discounting), but hyperbolic itself. According to this interpretation, each additional unit of delay adds progressively less chance of prevented delivery and results in a hyperbolic decrease in subjective value over delay.

As summarised in Table 1.1, the superior ability of the hyperbolic discounting function to describe actual discounting behaviour of both animals and humans has been supported by the frequent observation that this model provides a better fit to actual data than the exponential. This applies to both monetary and non-monetary outcomes, such as cigarettes (Bickel, Odum & Madden, 1999). The exponential model tends to systematically overestimate subjective value at short delays and underestimate the value at longer delays. By describing a successively smaller decrease in rate per unit as the delay increases, the hyperbolic function decreases the extent of these systematic errors and describes behaviour more accurately (Green, Myerson & McFadden, 1997).

The hyperbolic function also more readily accounts for inconsistencies in preferences when the delays to both rewards change. Research in both animals and humans has shown that when equal delays are added to both rewards, preferences shift from the smaller to the larger reward (Green, Fristoe & Myerson, 1994). These changes in preference are referred to as *preference reversals* and are inconsistent with a rational view of behaviour in which preference should not change across time (Madden & Bickel, 2010). As an illustrative example, although the smaller alternative may be preferred in a choice between \$100 today and \$120 in three months, the larger alternative is more likely to be preferred if the choice is between \$100 in 12 months and \$120 in fifteen months. In one study of undergraduate participants, Green et al. (1994) examined whether preferences reversed when delays were added to both the smaller (originally immediate) and the larger (and more delayed) outcomes. They showed that the percentage of participants choosing the larger delayed outcome increased as the delay to the smaller outcome increased and that this increase was greater when the time between the two outcomes was small (1 week to 3 years) than when it was large (5 years or more).

Table 1.1

A selection of articles comparing temporal discounting across magnitudes and reporting R^2 fits for both Equation 1 and Equation 2.

Article	Magnitude	R^2 value		
		Equation 1	Equation 2	
Myerson and Green (1995)	\$1 000 \$10 000	.923 .810	.992 .938	
Madden, Bickel and Jacobs (1999) **	\$1000	.60 ⁽¹⁾ .78 ⁽²⁾	.79 ⁽¹⁾ .94 ⁽²⁾	⁽¹⁾ monetary and ⁽²⁾ heroin rewards
Green, Myerson, and McFadden (1997)		.658 .973 .978 .968	.857 .992 .983 .995	
Madden, Begotka, Raiff and Kastern (2003)	\$ 10	.54 ⁽¹⁾ .85 ⁽²⁾ .67 ⁽³⁾ .70 ⁽⁴⁾	.65 ⁽¹⁾ .73 ⁽²⁾ .81 ⁽³⁾ 0.63 ⁽⁴⁾	¹⁾ Group median hypothetical reward. ²⁾ Group real reward ³⁾ Individual hypothetical reward ⁴⁾ Individual real reward
Kirby & Marakovic (1995)	\$14.75 - \$28.50	.975	.980	Mean R^2 for range of rewards sizes of potentially real rewards in a sealed-bid auction task
Kirby (1997) Experiment 1	\$10(*) \$20(*)	.947 .973	.961 .979	
Kirby (1997) Experiment 2	\$10(*) \$20(*)	.979 .990	.985 .992	
Kirby (1997) Experiment 3	\$10(*) \$20(*)	.957 .976	.967 .982	

Bickel, Odum and	\$1000(*)	.74 ⁽¹⁾	.89 ⁽¹⁾	⁽¹⁾ Current smokers
Madden (1999)**		.81 ⁽²⁾	.88 ⁽²⁾	monetary reward
		.83 ⁽³⁾	.85 ⁽³⁾	⁽²⁾ Never-smokers
		.87 ⁽⁴⁾	.89 ⁽⁴⁾	monetary reward
				⁽³⁾ Ex-smokers monetary reward
				⁽⁴⁾ Current smokers, cigarette rewards

(* indicates significant effect)(**When non-monetary rewards were used, and when not otherwise stated, the non-monetary reward was deemed equivalent to the monetary reward quoted.)

As shown in the top panel of Figure 1.1 (from Green & Myerson, 1996, p. 499), preference reversals are consistent with the decreasing effect of delay described by the hyperbolic function. At t_1 , when the delay to the small, more immediate, reward is short, the subjective value of this reward is greater than the subjective value of the larger delayed reward. At t_2 however, when both rewards are delayed, the smaller reward, which has also been discounted, has a subjective value lower than that of the larger one. The point at which the lines of the subjective values cross is the point at which preference reversal occurs. Because the hyperbolic function predicts an initially steep decrease in value followed by a progressively slower decrease, this function predicts that subjective values will 'cross' and preferences will change as the delay to both outcomes decrease.

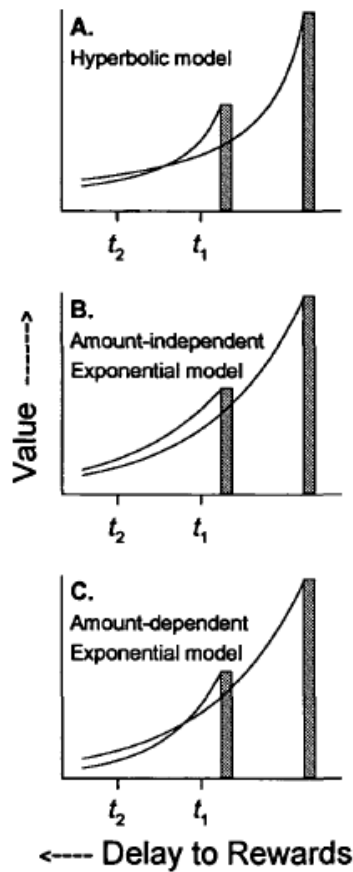


Figure 1.1. Subjective value as a function of delay (Green & Myerson, 1996, p. 499). The bars depict the objective value of two rewards and the sloping lines depict their subjective values. The top panel depicts preference reversal of the hyperbolic model, the middle panel an amount independent exponential model (in which preferences do not cross) and the bottom panel shows the preference reversals produced by an amount dependent exponential model.

In contrast, the exponential function does not inherently predict preference reversals. The constant decrease in subjective value predicted by the exponential function is inconsistent with a change in preference from one reward to the other, as indicated from the middle panel of Figure 1.1. The lines of subjective value do not cross and the smaller sooner alternative always has a larger subjective value than the larger later, even when the delay to both outcomes is long. However, the exponential discounting function can account for preference reversals if rate of discounting is steeper for smaller than for larger rewards. This does indeed appear to be the case

(Green et al., 1997). Given this condition, the exponential function can also account for preference reversals. As indicated in the bottom panel of Figure 1.1, if the discounting rate of the smaller outcome is allowed to be steeper than that of the larger, preferences do reverse even when discounting rate is described by an exponential function.

Hyperboloid discounting

The third commonly used function includes an additional free parameter (Myerson & Green, 1995) and is referred to as the hyperboloid modelⁱⁱ.

$$V = A/(1-kD)^s \quad \text{[Equation 3; Myerson & Green, 1995]}$$

This model includes the same parameters as the exponential and hyperbolic, but raises the denominator to a power, s . This additional parameter has been proposed to represent individual differences in scaling of amount and time or probability, with the assumption that amount and time are nonlinearly scaled (Stevens, 1957, cited in Myerson & Green). When s equals 1, the hyperboloid model is a simple hyperbola, but when it is less than 1 the model allows for steeper decreases in value at short delays and shallower decreases at long delays compared to a simple hyperbola, making the decrease in value even more dissimilar in shape to the exponential model. As k approaches 0, however, the hyperboloid function becomes an exponential function (Prelec, 1989, as cited in Raineri & Rachlin, 1993).

The hyperboloid model does describe additional variance over both the exponential and hyperbolic models (Myerson & Green, 1995), also for non-monetary outcomes (Odum, Baumann & Rimington, 2006), but comparisons using variance accounted for across models that vary in number of free parameters have been criticised because a two-parameter model would by default account for data better than a single parameter model of a similar form (Schull, 1991). In light of the differences in complexity across the single parameter models on the one hand and the hyperboloid on the other, the latter has also been evaluated based on other criteria. Odum et al. calculated Akaike's Information Criterion (AIC) for the hyperbolic and hyperboloid models and found that the latter performed better overall than the former. It has also been advocated that s should be allowed to vary from 1 (a simple hyperbola) because when it is, s tends to be significantly different from 1 (Myerson & Green, 1995). Green, Myerson & Ostaszewski (1999)

found that s was less than 1 for delayed monetary rewards and Odum et al. showed the same for delayed food rewards.

Research with the hyperboloid model has also stimulated novel interpretations of the discounting rate parameter (k) as an individual difference variable describing impulsivity. When fit to delayed outcomes varying in magnitude, the hyperboloid model produces better fits when the s variable rather than k variable is kept constant across magnitudes (Myerson & Green, 1995), leading to suggestions that the exponent rather than the discounting rate parameter accounts for such individual differences.

Irrespective of which of the above models best describes the shape of value loss, the importance of the discounting framework as a whole relies on its relevance to choices in everyday life that result from an overemphasis of immediacy. If the degree to which people de-value delayed rewards is not related to the choices they make in their day to day lives, it has little value outside the experimental setting, regardless of which of the functions works best. A further issue is whether or not discounting (be it either the k or the s parameter) is a stable personality trait, an individual difference variable. To address these questions, a large number of discounting studies have sought to establish connections between discounting rates and behaviours categorised as ‘impulsive’ (Reynolds, 2006a), as well as attempting to determine whether or not parameter estimates remain stable across experimental manipulations. In various ways, these studies have been able to show that the decrease in subjective value of delayed rewards is indeed relevant to everyday impulsive choices; that such behaviour may be a product of an over-valuing of immediacy. However, there is also growing evidence that discounting rates are not stable within-subjects.

As reviewed in the following sections, discounting rates do differ across individuals, but they also vary within-subjects as a function of a number of factors. Although the former finding implies that the discounting framework is a good tool to investigate impulsivity, the latter puts into question the assumption that discounting rate is a stable trait capturing impulsivity.

Delay discounting, group differences and behavioural correlates

Many impulsive behaviours such as substance abuse and dependence (be it to nicotine, alcohol or illicit substances), and other health related behaviours with long term consequences (E.g. obesity) can be simplified into basic delay discounting choices between behaviours with

either small immediate or large delayed consequences. It is therefore natural that many studies have used such behaviours to demonstrate that discounting rates are a valid way to conceptualise impulsivity.

A number of studies have used the approach of categorically differentiating between so called ‘impulsive’ and ‘self-controlled’ individuals, such as smokers and non-smokers, and comparing these groups on the extent of their discounting. In general, these studies use group level analyses and many have shown that participants belonging to ‘impulsive’ groups do indeed show steeper discounting rates than controls, or ‘self-controlled’ individuals. A strong focus of this literature has been on smokers, alcoholics and other drug abusers. But, by the same reasoning, discounting rates have also been investigated in reference to clinical diagnoses relevant to impulsivity or impulse-control, such as attention deficit/hyperactivity disorder (ADHD) and borderline personality disorder. This growing body of research is important in establishing the usefulness of temporal discounting as a measure of impulsive behaviour, but is not strictly relevant to the purpose of the current thesis. Therefore, the following review of the literature is far from exhaustive and, for the sake of brevity, focused on the literature on substance abuse, ADHD and gambling. Many more studies have been conducted on other clinical diagnoses relevant to impulsivity and impulse control (for example Borderline Personality Disorder; Lawrence, Allen & Chanen, 2010) as well as other impulsive/self-controlled behaviours, such as saving for retirement and health behaviours (Weller, Cook III, Avsar & Cox, 2008).

Smoking

Smoking can easily be understood as an inter-temporal choice such as that investigated in delay discounting. The reinforcement maintaining the behaviour can be framed in terms of the immediate satisfaction of smoking a cigarette and the delayed benefit of good health. Self-reported impulsivity and consideration of future consequences has been found to relate to cigarette smoking (Mitchell, 1999; Reynolds, 2007; Strathman, Gleicher, Boninger & Edwards, 1994), and a number of links have been revealed between smoking and discounting rates, examining not only group differences in discounting rates, but also the effects of deprivation on discounting and its relation to successful quitting.

One study failed to find a significant difference in discounting rates between adolescents who currently smoked, had recently first tried smoking, and did not smoke (Reynolds, Karraker, Horn & Richards, 2003), and another study found that the relationship may differ across women and men (Jones, Landes, Yi & Bickel, 2009). However, the results of these two studies are the exceptions rather than the rule; smokers *do* seem to discount delayed rewards more than non-smokers. There is evidence that the age of first smoking is negatively correlated with discounting rates (Kollins, 2003) and that discounting rates increase with both daily dose of nicotine intake and number of cigarettes smoked per day (Epstein, Richards, Saad, Paluch, Roemmich & Lerman, 2003; Ohmura, Takahashi & Kitamura, 2005; Reynolds, 2006b). Furthermore, a number of studies with heavier smokers (more than 15 cigarettes per day) have shown steeper discounting of monetary outcomes in comparison to ex-smokers and non-smokers (Bickel, Odum & Madden, 1999; Mitchell, 1999; Baker, Johnson & Bickel, 2003, Reynolds, Richards, Horn Karraker, 2004; Reynolds, 2006b; Johnson, Bickel & Baker, 2007). Even lighter smokers have been shown to discount future monetary rewards more than non-smokers (Johnson et al., 2007; Reynolds, Patak & Shroff, 2007; Reynolds, Patak, Shroff, Penfold, Melanko & Duhig, 2007). The lack of an effect for smoking status found by Reynolds et al. (2003) was likely the result of using an adolescent sample whose self-reported consumption of cigarettes averaged 46 cigarettes a week, approximately half that of the light smoker group in Johnson et al. (2007).

A related line of investigation has focused specifically on the discounting rates of smokers (as opposed to comparisons between smokers and non-smokers). For example, Field, Santarcangelo, Sumnall, Goudie and Cole (2006) showed that nicotine deprivation was associated with increases in delay discounting, and Baker et al. (2003) found significant magnitude effects in the discounting of cigarettes whereby smokers discounted small cigarette outcomes more than large cigarette outcomes. Lastly a number of studies have shown that cigarettes are discounted more steeply than money (Bickel et al., 1999; Baker et al., 2003; Johnson et al., 2007).

One study comparing smokers, ex-smokers and non-smokers indicated that smokers discounted more steeply than both ex-smokers and non-smokers but that ex-smokers did not differ from non-smokers (Bickel et al., 1999). This study could not, however, identify whether ex-smokers happened to be smokers with shallower discounting functions, or if current smoking status led to steep discounting. Unlike group comparisons such as this, which do not do not allow

conclusions to be drawn as to whether or not smoking leads to increased discounting or if steep discounting of future outcomes leads to smoking, studies that investigate how discounting rates are related to smoking abstinence and successful cessation have revealed more about the direction of the relationship between discounting rates and smoking. They suggest that rate of discounting in current smokers is predictive of later successful smoking abstinence and cessation. Dallery & Raif (2007) used a group of smokers who reported no intention of quitting to investigate whether discounting rates would differentiate between those who later abstained and those who smoked in a testing session when abstinence was reinforced. They found that participants who smoked during the session had steeper discounting rates than participants who did not smoke.

The participants in Dallery and Raif (2007) were not trying to quit smoking, but simply had to abstain during the testing session, but two studies have investigated discounting rates and smoking cessation. In a sample of women who spontaneously quit smoking upon finding out that they were pregnant, continued abstinence 24 weeks postpartum was predicted by delay discounting rates elicited during pregnancy; women who relapsed before 24 weeks had previously shown steeper discounting than those who did not relapse (Yoon, Higgins, Heil, Sugarbaker, Thomas, & Badger, 2007). Similarly, the success of adolescent smokers who participated in a smoking cessation program within their high school was also predicted by discounting rates taken at the start of the program such that those who continued smoking discounted delayed rewards more than those who did not (Krishnan-Sarin et al., 2007). Another study, however, showed that smokers exposed to a weeklong contingency management program to reduce smoking produced significantly shallower discounting post-training than pre-training, while the discounting rates of a control group did not differ pre- to post-training (Yi, Johnson, Giordano, Landes, Badger & Bickel, 2008). Unlike the conclusion that smokers who initially had shallower discounting rates were the ones who successfully become ex-smokers, this study suggested that smokers and ex-smokers may initially have shown the same levels of discounting.

One contributing factor to continued smoking despite the long term health consequences of such behaviour could be that smokers discount future health to a greater extent than non-smokers. This has been tested and while one study did find that smokers appeared to discount health outcomes as well as monetary outcomes faster than non-smokers (Odum, Madden &

Bickel, 2002), two others have failed to show a significant difference (Baker et al, 2003; Johnson et al., 2007).

Overall, the data on smoking status and extent of temporal discounting does support the notion that smokers, as individuals who prefer the small immediate reward of a cigarette over long term health benefits, do discount delayed monetary rewards more steeply than controls.

Alcohol

Similar patterns have emerged in the alcohol consumption literature, which has examined group differences in discounting rates, age when drinking first occurred, the influence of family history of alcoholism, as well as the acute effects of alcohol consumption on discounting rates.

A number of studies have shown that problematic alcohol consumption is associated with steeper discounting of delayed rewards. Vuchinich and Simpson (1998) showed that problem drinkers discounted significantly more than light drinkers; Petry (2001) found that discounting rates of hypothetical monetary rewards decreased across active alcoholics, currently abstinent alcoholics and control subjects, in that order, and likewise, Petry (2001b) also showed that discounting rates of hypothetical alcoholic beverages became progressively steeper for controls, currently abstinent alcoholics and active alcoholics, respectively. Furthermore, in two comparisons between abstinent alcoholics and controls, the former group discounted more than the latter (Bjork, Hommer, Grant & Danube, 2004; Mitchell, Fields, D'Esposito & Boettiger, 2005).

Two studies have indicated that the age at which drinking began is important. In a sample of college students, the age of first drinking and when first passing out from drinking were both negatively correlated with discounting rates (Kollins, 2003) and in another discounting rates differentiated between groups of alcoholics based on the age at which alcohol abuse began (Dom, D'haene, Hulstijn & Sabbe, 2006). Early onset alcoholics, those whose alcohol abuse started before the age of 25, discounted more than late onset alcoholics and non-abusers.

Although alcoholics differ from controls, the investigations into differences in discounting rates across different groups of drinkers have not produced a consistent picture. Hazardous drinkers, classified as those who scored 6 or more on the Alcohol Use Disorders Identification Test, did not discount more than social drinkers who scored between 1 and 5 on the same test (MacKillop, Mattson, Anderson MacKillop, Castelda & Donovic, 2007). Similarly, heavy social

drinkers who were not problem drinkers discounted only marginally more than light drinkers in Vuchinich and Simpson's (1998) sample of college students, and currently abstinent alcoholics with and without cluster B personality disorders (with borderline, antisocial, histrionic or narcissistic diagnoses) did not differ significantly in delay discounting (Dom, de Wilde, Hulstijn, van den Brink & Sabbe, 2006).

The acute effects of alcohol consumption on discounting rates have also been investigated. Richards, Zhang, Mitchell and de Wit (1999) compared discounting rates of hypothetical monetary outcomes within subjects after consuming no alcohol, a placebo or a moderate amount of alcohol; Ortner, Macdonald and Olmstead (2003) conducted the same comparison in a between-subject design; and Reynolds, Richards, and de Wit (2006) compared placebo with consumption of moderate alcohol doses. None of these studies found a significant effect of dose on discounting rates. However, all of the above comparisons used tasks in which only one outcome of multiple choices was actually received by the participant. Reynolds et al. suggested that the lack of an acute effect of alcohol could be due to the nature of the tasks, and also tested a task in which all delays and outcomes were experienced during the experimental session. When using this task, participants did discount more steeply after a moderate dose of alcohol than after ingesting a placebo.

Two studies have investigated the role of familial history of alcoholism on discounting rates. Petry, Kirby and Kranzler (2002) showed that women without a paternal history of alcohol abuse discounted delayed monetary rewards less than women with paternal history of alcohol abuse and men with and without such a history. Men with and without paternal history did not differ in discounting rates. Similarly, in an exclusively male sample, Crean, Richards and de Wit (2002) did not find an effect of familial history of alcohol on discounting rates. These studies suggest that there are gender differences in how familial history of alcohol influences discounting of delayed rewards.

When it comes to distinguishing the direction of causality between alcoholism and discounting rates, the cross-sectional approach used in the studies described above (e.g. Petry, 2001; Petry, 2001b; Bjork et al., 2004; Mitchell et al., 2005) have the same limitation as those investigating smokers. Given that current alcoholics discount more than currently abstinent alcoholics, who in turn discount more than non-alcoholics, it is possible that the abuse of alcohol itself produces steeper discounting and that this effect slowly wears off following abstinence.

However, it could also be that steep discounting rates pre-date alcohol use and make some individuals more vulnerable to abuse. In this view, currently abstinent alcoholics are a specific sub-type of alcoholics with less steep discounting functions, who are subsequently able to quit.

Although no traditional delay discounting study to my knowledge has examined rates of abusers, abstainers and non-alcoholics over time, Tucker, Vuchinich and Rippens (2002) examined the proportion of discretionary monetary expenditures allocated across alcohol and savings outcomes in problem drinking individuals who had indicated a desire to either abstain or moderate their drinking. Unlike the majority of the discounting studies discussed above, these participants were not inpatients, and their drinking habits were examined over a period of three years. Those participants who at the end of the three years were successfully abstaining or moderating their drinking had allocated proportionally more of their discretionary income on savings than on alcohol three years prior than those participants who had relapsed. This result is more in line with the latter interpretation of discounting and alcoholism; problem drinkers with shallower discounting rates may be less likely to relapse, and therefore become ‘abstaining alcoholics’, than those problem drinkers who have very steep discounting rates. However, longitudinal research of actual discounting rates across different groups of problem drinkers still needs to be conducted to further elaborate on the relationship between discounting rates and vulnerability to problematic drinking and successful drinking resolution.

Use of illicit substances

Several studies have shown that opioid dependent individuals in treatment for their dependence discount delayed monetary rewards more than matched controls (Madden, Petry, Badger, & Bickel, 1997; Kirby, Petry & Bickel, 1999), and similarly, that cocaine dependent participants discount more than matched controls (Coffey, Gudleski, Saladin & Brady, 2003).

There are also studies that point to additive effects between discounting rates and impulsive behaviour. Odum, Madden, Badger and Bickel (2000) found that discounting rates were steeper for heroin addicts who agreed to share needles than addicts who did not, indicating that such additional risk taking behaviour even within substance abuse groups is associated with greater impulsivity in discounting. Similarly, Petry and Casarella (1999) investigated discounting and co-morbidity between substance abuse and problem gambling. They found that substance

abusers (cocaine, heroin and alcohol abuse) with gambling problems discounted delayed monetary rewards more than both controls and only substance abusing counterparts, as well as showing that substance abusers without gambling problems discounted more than controls. Petry (2001c) showed the same pattern of an additive effect of gambling and substance abuse when using the Bechara card task (see Bechara, Damasio, Damasio & Anderson, 1994) in which choices are made between decks of cards that vary in number and probability of rewards and punishers. Petry found that pathological gamblers with substance abuse problems and substance abusers without gambling problems made more disadvantageous plays than controls, and that the former group played more impulsively than the latter. Petry (2002) showed that the same additive influence occurs when comparing controls, substance abusers and substance abusers with antisocial personality disorder (ASP), such that discounting rates increase with comorbid ASP. Petry also found modest correlations between k values and number of ASP and conduct disorder symptoms.

The participants in two of the above studies (Petry, 2001; Petry 2001c) abused a variety of substances, including alcohol, cocaine and heroin, and early studies of substance abuse and discounting compared only abusers with non-abusers. Two later studies have made comparisons across substance abuse types. Kirby and Petry (2004) found that alcohol abusers discounted less than cocaine and heroin users but that the cocaine and heroin groups did not differ. Bornolova, Daughters, Hernandez, Richards and Lejuez (2005) in contrast, compared two groups of inpatient substance abusers, either primary crack cocaine or primary heroin users, and showed that crack cocaine users discounted delayed rewards more than primary heroin users, and that this effect remained significant when age and gender differences were entered as covariates.

The smoking literature suggests that short term smoking abstinence increases discounting, whereas long term abstinence is associated with shallower discounting (Field et al., 2006; Bickel et al., 1999). With regards to the illicit substance literature, substance abusing participants in Kirby et al. (1999) and Madden et al. (1997) were enrolled in substance abuse treatment programs and were receiving buprenorphine at the time of the study. Both of these studies found that substance abusers discounted more than controls. In three studies however, currently active and currently abstinent substance abusers were compared. Bretteville-Jensen (1999) found that active heroin and amphetamine users discounted more than former users who in turn discounted more than non-users. Kirby and Petry (2004) compared currently active, abstinent and non-

substance abusers of alcohol, cocaine or heroin and found differences across substances. Whereas abstinent and active alcoholics and cocaine abusers did not differ in discounting rates, abstinent heroin addicts discounted less than active addicts, consistent with Brettevill-Jensen. However, in this study abstinent heroin addicts had only marginally higher rates than non-abusing controls (Kirby & Petry, 2004). The participants were classified as abstinent users if they reported no alcohol or substance use within two weeks of initial telephone screening, which took place no more than one week prior to the testing session. Heil, Johnson, Higgins and Bickel (2006) suggested that longer periods of abstinence may be necessary to have an effect on discounting rates in cocaine dependent individuals. They compared out-patients, currently active or abstinent for at least 30 days, and controls, and found no differences between the three groups. When the substance users were combined into one group however, their discounting rates were significantly steeper than the controls, consistent with other literature. Collectively, these studies suggest that different substances of abuse also differ in the effect they have on discounting rates following periods of abstinence.

The literature on substance abusers, be it users of illicit substance, cigarettes or alcohol, has produced a relatively consistent pattern that discounting rates of these individuals (as a group) tend to be steeper than those of control subjects, in line with the idea that discounting rates describe a tendency towards impulsive behaviour. But substance abusers are not the only groups of 'impulsive' individuals who have been investigated. The discounting framework has also been used to investigate attention deficit/hyperactivity disorder and pathological gambling.

Attention deficit/hyperactivity disorder (ADHD)

Sonuga-Barke and colleagues have hypothesised that delay aversion is a significant contributor to ADHD, and their research using the Choice Delay Task (CDT), in which repeated choices are made between one point in 2 seconds or two points after 30 seconds, have indeed suggested that individuals with ADHD show less tolerance for delays (e.g. Solanto et al., 2001). However, the experiments investigating ADHD symptoms and delay discounting have yet to produce a consistent picture. One study comparing ADHD participants to controls using hypothetical outcomes found a significant effect for a \$100 outcome but not a \$1000 outcome (Barkley, Edwards, Laneri, Fletcher & Metevia, 2001), another failed to find a relationship between ADHD symptoms and discounting using hypothetical outcomes but found an effect

when delays and outcomes were experienced (Scheres, Lee & Sumiya, 2008), and yet a third showed that ADHD and control participants differed when using hypothetical outcomes but not real ones (Paloyelis, Asherson, Mehta, Faraone & Kuntsi, 2010). Despite this inconsistency, other experiments have illustrated the relevance of the delay discounting framework to ADHD research. For example, Scheres et al. (2008) tested ADHD symptoms of hyperactivity and impulsivity separately from symptoms of inattention and found that the former, but not the latter, was correlated with delay discounting, and Shiels et al. (2009) found a significant effect of methylphenidate on discounting rates.

Although many details are yet to be clarified, relating to for example, the directionality between steep discounting and substance abuse, the research reviewed above clearly illustrates the delay discounting differentiates between people who by behavioural definitions are impulsive and those who, by the same behavioural criterion, are not. The group level analyses reviewed above go a long way to show that the rate parameter does measure impulsiveness, and given some of the research discounting rate may possibly even describe a relatively stable inheritable tendency on the impulsiveness-self-controlled continuum. However, many of the studies described above also include more traditional Likert-scale personality measures of impulsivity in addition to discounting tasks, and this research has produced a much less consistent picture of discounting as a framework for investigating impulsivity.

Correlation with self-reported impulsivity

There are numerous self-report measures of impulsivity, but two of the most commonly used measures in the temporal discounting literature are the Barratt Impulsiveness Scale (Version 11; Patton, Stanford & Barratt, 1995) and the impulsiveness subscale of the Eysenck personality questionnaire (e.g. I7; Eysenck, Pearson, Easting & Allsopp, 1985). Self-report measures generally measure broader definitions of impulsivity, including the tendency to act without much consideration of the consequences of one's behaviour and the inability to control one's impulses (for a review see Evenden, 1999). Research combining discounting and self-report measures of impulsivity has investigated whether or not steep discounting rates are correlated with high self-reported impulsiveness, as would be expected of two measures of similar constructs.

Many of the studies noted above comparing discounting rates of substance abusers with those of control groups also found that self-report indices of impulsivity were higher for substance

abusers than controls. Opioid dependent individuals (Madden et al., 1997; Kirby et al., 1999), adolescent and adult smokers (Reynolds et al., 2007; Mitchell, 1999), early onset alcoholics (Dom et al., 2006) as well high risk psychiatric outpatients (Crean, de Wit & Richards, 2000) have all produced higher self-reported impulsivity than their control, late onset or low risk counterparts. Furthermore, university students self-reporting high self-reported impulsivity (upper third scores on the EPQ-R) discounted delayed rewards more than students whose self-reported impulsivity fell in the lower third of scores on the EPQ-R (Ostaszewski, 1997). Such consistency in group differences suggest that discounting of delayed rewards and self-reported impulsivity might be related.

Despite the consistency in categorically differentiating between groups, there is limited and inconclusive evidence that the two approaches capture the same 'impulsiveness'. Madden et al (1997) found a significant correlation between self-reported impulsivity and discounting rates only for the control group discounting money. The correlations between self-reported impulsivity and discounting rates in opioid participants did not reach the usual significance level of .05 for either discounting of money or heroin. Across two samples of light, heavy and problem drinkers, Vuchinich and Simpson (1998) found significant correlations between discounting rates and only the liveliness subscale of the I5 and the disinhibition and thrill and adventure seeking subscales of the Sensation Seeking Scale (SSS), a measure of risk taking. Similarly, Mitchell (1999) found only eight out of 84 correlations to be significant at the 0.05 level, noting that this was the number expected when using that significance level. The significant correlations included the attentional impulsiveness factor of the BIS and the disinhibition subscale of the SSS. Dom et al. (2006), who tested early and late onset alcoholics, found no significant correlations between temporal discount rates and self-reported impulsivity (BIS-II) or sensation seeking (SSS). Neither Reynolds et al (2006), Krishnan-Sarin et al. (2007) nor Dai, Grace and Kemp (2009) found any significant correlations between discounting rates and self-reported impulsivity on the BIS-II or the I-7. Finally, Crean de Wit and Richards (2000) assigned psychiatric outpatients into either low or high risk of impulsiveness according to their DSM-diagnoses. High risk diagnoses included substance dependence and abuse, borderline personality disorder and bipolar disorder, whereas the low risk diagnoses included mood (without manic episodes) and anxiety disorders. Despite significant group differences in both self-reported and behavioural impulsivity, the two were not significantly correlated.

Some have been more successful in finding correlations. Kirby et al. (1999) found that self-reported impulsivity and venturesomeness on the I-5 and the subscales of non-planning and cognitive impulsiveness of the BIS-10 were significantly correlated with k values. In this study, only motor impulsiveness was not significantly correlated with discount rates. Similarly, Petry (2001b) and Petry (2002) showed that Eysenck Impulsivity scores were correlated with k values, and de Wit, Flory, Acheson, McCloskey and Manuck (2007) found a correlation between k values and BIS nonplanning scores.

Overall, the research on self-reported impulsivity and discounting suggest that although they both measure impulsiveness, they each capture different facets of the construct. Indeed, discounting and personality measures such as the BIS are only two ways out of many to investigate a very multifaceted construct (Evenden, 1999).

Is k -value an individual difference variable?

The discounting rate parameter, k , (alternatively the s parameter of the hyperboloid model) has been conceptualised as an individual difference variable, describing how subjective values are affected by delay, and in support of this several studies have reported that discounting rates appear stable over time, despite great inter-individual variability. Simpson and Vuchinich (2000) as well as Baker, Johnson and Bickel (2003) tested stability over one week, Ohmura, Takahashi Kitamura and Wehr (2006) over three months, and Kirby (2009) over one year, and all concluded that discounting rates were stable across time. Furthermore, the established group differences across ‘impulsive’ and ‘non-impulsive’ individuals described above has also supported the claim that some people may be more affected by delay than others. This, in turn, has contributed to the idea that discounting rates describe a stable impulsiveness trait. There are in fact a number of reasons why a trait interpretation is problematic. Discounting rates vary as a function of the magnitude of the outcomes and across different outcome types, appear to change with age, and as a result of manipulations to both the environment, the individual, and the specific procedure chosen to elicit discounting.

Interestingly, despite the apparent relevance to the question of whether or not discounting rates reflect an underlying trait, comparatively few studies reporting within-subject changes in discounting have also reported correlational analyses between discounting rates across experimental conditions (Kirby, 1997; Du, Green & Myerson, 2002; Green, et al. 1999;

Ostaszewski, Green and Myerson, 1998; Field, et al., 2006; Giordano et al 2002, Reynolds, Richards & De Wit, 2006; Odum, Baumann & Rimington, 2006; Odum & Rainaud, 2003; Baker et al., 2003; Petry, 2001; Reynolds & Schiffbauer, 2004; Bickel et al., 1999; Estle, Green, Myerson & Holt, 2007; Coffey, et al., 2003). Fortunately, others have.

Yi, de la Piedad & Bickel (2006) showed that temporal discounting of large and small rewards were significantly correlated. Similarly, Madden et al. (1997) found a significant positive correlation between discounting of money and heroin outcomes, even though heroin was discounted to a greater extent than money. Charlton and Fantino (2008) found that discounting rates of food, CDs, DVDs, books and money were all positively correlated. Lastly, Tsukayama and Duckworth (2010) showed that candy, chips, beer and money were all significantly correlated. Some studies manipulating procedural variables have also found significant correlations across conditions (Kowal, Yi, Erisman & Bickel, 2007; Robles & Vargas, 2007; Robles, Vargas & Bejarano, 2009).

The magnitude effect

One of the most robust findings in the discounting literature is that within-subject discounting rates are affected by the size of the delayed outcome. Numerous experiments have shown that large delayed rewards are discounted less steeply than small delayed rewards (e.g. Kirby & Marakovic, 1996; Green et al., 1997; Green et al., 1999; Du et al., 2002; Baker et al., 2003). The amount dependent decrease in temporal discounting rates has been found using a variety of outcomes, including delayed hypothetical and potentially real monetary outcomes (Johnson & Bickel, 2002), and non-monetary outcomes such as hypothetical health (Chapman & Elstein, 1995; Chapman, 1996), vacation (Raineri & Rachlin, 1993), cigarette (Baker et al., 2003) and heroin (Giordano et al., 2002) outcomes. However, it is not consistently found in consumable rewards. Experiments examining varying magnitudes of candy, soda and beer (Estle et al., 2007) and units of alcohol (Petry, 2001) have failed to find a significant difference between large and small outcomes. Notably, Jimura et al. (2009) did find that participants were more impulsive with smaller amounts of liquid rewards than with large amounts of liquid rewards using a procedure in which outcomes were actually consumed.

Although robust, the magnitude effect is not always strong enough to be seen above and beyond individual variation of discount rates. Whereas Raineri and Rachlin (1993) showed the

magnitude effect between subjects using hypothetical monetary rewards, Odum et al. (2006) failed to find a significant amount effect for either hypothetical food or money. However, these two studies differed in the reward magnitudes they tested, and illustrate the importance of using magnitude differences large enough to compare across subjects given the high inter-individual variability. Raineri and Rachlin tested \$100, \$10,000 and \$1 million hypothetical monetary rewards, whereas Odum et al. compared discounting of \$10 and \$100. The magnitude effect, given how often it has been tested and its robustness, is the most striking example of how within-subject discounting rates change. A second widely examined example is the so called commodity effect.

The Commodity effect

The majority of discounting research uses monetary rewards (either hypothetical or real), but a number of studies using alternative outcomes have shown within-subject changes in discounting rates across different types of outcomes. This has become known as the commodity or domain effect.

Comparisons across commodities have shown that substance abusers discount drugs of abuse more than money (Madden, Bickel & Jacobs, 1999; Baker et al., 2003; Coffey et al., 2003; Yi et al., 2008), that alcoholics, currently abstinent alcoholics and non-alcoholics discount alcohol outcomes more than money (Petry, 2001), that food and drinks are discounted more than money (Odum & Rainaud, 2003; Odum, Baumann & Rimington, 2006; Estle, Green, Myerson & Holt, 2007), and that the commodity effect across food, alcohol and monetary outcomes is consistent across large and small magnitudes (Petry, 2001, Odum et al., 2006). Charlton and Fantino (2008) showed that the commodity effect applied also to non-consumable outcomes such as food, candy and substances. They found that discounting of food was steeper than discounting of books, cds, dvds and money, and that books and cds (but not dvds) were discounted significantly more than money.

Indeed, not even all monetary outcomes are discounted the same. Ostaszewski et al. (1998) found that delay discounting of two currencies of monetary outcomes, American dollars and Polish Zloty, differed within-subjects. At the time of the first experiment, the Polish Zloty had had a few years of high levels of inflation and as a result American dollars were also commonly used as a more stable alternative. Participants who were used to both currencies discounted the

Zloty significantly more than the dollar. When the second experiment was conducted, a new and more stable Zloty had been introduced. Unlike the experiment two year previously, discounting rates did not differ between the new Zloty and American dollars. Interpreted as a domain effect, this study implies that within-subject differences in discounting rates can even occur when the same outcome, money, is compared across currencies.

The commodity effect has been attributed to various factors, including negative withdrawal symptoms of drugs of abuse, the perishability of consumable outcomes, the distinction between consumable and non-consumable outcomes as well as the difference between primary and conditioned reinforcers. Madden et al. (1997) and Bickel et al (1999) suggested that steeper discounting of drugs could be due to avoidance of negative withdrawal symptoms. Though this avoidance of negative experience likely plays a part in the steeper discounting of drugs of abuse, it does not account for steeper discounting in individuals who do not experience withdrawal symptoms (such as the abstinent and non-alcoholics in Petry, 2001) or differences in rates across outcomes that are not associated with withdrawal effects, such as food, books and money (Charlton & Fantino, 2008). An alternative explanation is that non-monetary outcomes are simply not worth as much as monetary outcomes, and that the domain effect is essentially the result of a magnitude effect, whereby the ‘smaller’ consumable outcome is discounted more than the ‘larger’ monetary outcome (Petry, 2001; Charlton & Fantino, 2008). However, some studies have equated the commodities for magnitude within subjects to avoid this interpretation. For example, Odum and Rainaud, (2003) had each participant provide the name and price per unit of their favourite food and beverage and used the number of units equivalent to the monetary outcome (in this case \$100) in the discounting procedure. Participants still showed steeper discounting of food and money, implying that magnitude was not the determining difference. Furthermore, Odum et al. (2006) used the same procedure for a smaller amount of money (\$10) to ensure that the amount of food and beverage could feasibly be consumed in one sitting. Again, the same effect was found. Odum and Rainaud, (2003) suggested instead that a distinction should be made between food and drinks as primary and consumable outcomes and money as a conditioned and non-consumable outcome. Other suggestions have held the perishability of an outcome (Odum et al., 2006), the potential of satiation, or the immediacy of consumption (Raineri & Rachlin, 1993) as possible mechanisms.

Charlton and Fantino (2008) proposed that metabolic processing, immediate consumption and functionality of outcomes combined to determine differences in discounting rates and made a novel comparison between discounting of food, entertainment media and money,. They suggested that discounting of food was steepest because it is metabolically processed, that entertainment media was less steeply discounted than food because it was not metabolically processed, but that it in turn was discounted more than money because it can be immediately consumed and/or has a direct function, unlike money which holds its value by being exchanged for another commodity.

Tsukayama and Duckworth (2010) introduced yet another variable to take into consideration when investigating the commodity effect. In addition to the standard domain effect of food vs. money, they examined if an individual's temptation for a reward influenced discounting rates. They had participants indicate how tempting they found consumption of three different types of outcomes; beer, candy and chips, and then had them complete discounting measures of each of the outcomes. Not only did discounting of beer and chips increase with temptation ratings across individuals, such that an individual who found beer or chips more tempting relative to another individual also discounted that outcome relatively more, but discounting rates were also influenced by temptation across outcomes. An individual who showed strong temptation for candy but low temptation for beer discounted the former more than the latter, and an individual who showed the opposite pattern of temptation also showed the opposite pattern in rates of discounting. The effect of temptation on discounting is consistent with studies on deprivation and discounting. As described above, substance abuse literature has shown steeper discounting following nicotine (Field et al., 2006) and opioid (Giordano et al., 2002) deprivation. Interestingly, both studies found that participants discounted not only the drug of abuse, but also monetary outcomes more steeply, suggesting that deprivation made participants more impulsive overall and not specific to the deprived substance (although, see Mitchell, 2004). Deprivation of other sorts also affects discounting. Kirk and Logue (1997) found that food and water deprivation produced steeper discounting of food outcomes, and Reynolds and Schiffbauer (2004) found increased discounting following sleep-deprivation.

The research on magnitude and commodity effects show us that outcomes lose their subjective value differently to the same person depending on how large the outcomes are, what they are, and as a function of very state-dependent manipulations. Even though an individual

may discount relatively more on all of those outcomes than another individual, the applied value of the rate parameter as an indicator of impulsiveness decreases with each factor that is found to affect its degree within-subjects. Complicating the issue further is the fact that both the situation in which tests are conducted, and the procedures used to elicit indifference points impact how fast outcomes lose their value.

Situational and procedural manipulations

Discounting rates differ within subjects as a function of the context in which discounting rates are elicited, and as a function of relatively minor procedural changes using hypothetical choice tasks. Two studies have shown how context can affect discounting (Dixon, Jacobs & Sanders, 2006; Wilson & Daly, 2004). Dixon et al. (2006) tested delay discounting in gamblers in both an off-track betting facility and a neutral (café) environment. When discounting questions were asked in the gambling context rates were steeper than when they were asked in the neutral context. In another experimental manipulation, Wilson and Daly (2004) elicited discounting rates of potentially real monetary outcomes in males and females before and after rating images of either attractive or unattractive pictures of the opposite sex. They found both a significant increase in discounting rates from pre to post rating in men who viewed pictures of attractive women, and a significant difference in post rating discounting rates between men who had viewed photos of attractive women and those who had viewed photos of unattractive women. For women, no significant differences were found, either in pre- to post rating rates or across groups who had viewed either attractive or unattractive men. Wilson and Daly suggested that the results were consistent with the idea that in men viewing images of attractive women activated ‘neural mechanisms associated with cues of sexual opportunity’ (p. 179), and they argued that such increases were an adaptive response to the context. Finally, although not strictly described as a manipulation of context by the authors, Liu and Aaker (2007) found that impulsive choices were lower in participants for whom the salience of long term life outcomes had been increased.

Specific comparisons of different discounting tasks have also illustrated the sensitivity of discounting rates to procedural changes. Robles and Vargas (2007) compared two computer based hypothetical choice tasks that differed in how the small immediate outcome changed across trials. They showed that random presentation of the immediate alternative produced steeper discounting than orderly increases or decreases. A further two studies showed that an

ascending order of presentation produced steeper discounting than a descending order, one between subjects (Robles & Vargas, 2008) and one within-subjects (Robles et al., 2009). Discounting rates also differed significantly within-subjects across a questionnaire and a computer based discounting task (Epstein et al., 2003). These two tasks determined indifference points using different methods, the questionnaire task estimated discounting rates based on answers to 27 binary choice questions and the computer based task used an algorithm by which the adjusting delay varied depending on participant responses. Although discounting rates on the two tasks were significantly correlated, the questionnaire produced greater discounting than the computer task overall (Epstein et al., 2003). Similarly, the specific algorithm used in computer based tasks can also affect degree of discounting (Kowal et al., 2007). The double limit algorithm (Richards et al., 1999) produced shallower discounting rates than the decreasing adjustment algorithm (Du et al., 2001).

Both Kowal et al. (2007) and Epstein et al. (2003) were within-subjects comparisons of discounting rates, but other between-subjects designs have also evidenced differences in discounting rates across groups as a function of procedural changes. Traditional discounting questions, whether they be computer or pen and paper based, usually frame the scenario in terms of a choice between a small amount of money now or a large amount of money at a delay. Magen, Dweck and Gross (2008) compared this way of phrasing choices (implicit zero) to a so called 'explicit zero' condition. In the explicit zero condition, the alternatives were phrased in terms of a small amount now and \$0 at a given delay' or \$0 today and a large amount at a certain delay. Participants who completed the explicit zero condition were less impulsive than participants in the implicit zero condition. Although the mechanism accounting for this difference may be debated, the fact that behaviour changed as a result of different phrasing of the discounting questions again shows how sensitive discounting rates are to procedural manipulations.

Temporal discounting conclusion

The research devoted to investigating all facets of temporal discounting has practically exploded in recent years, and there is little doubt that the field is useful in the study of impulsivity. However, it is problematic that at the same time as discounting rates differ predictively between groups across dimensions of impulsivity, discounting rates also vary

significantly *within* subjects across a (possibly growing) number of factors, and as a consequence suffer from a lack of predictive power. Turning away briefly from this conundrum, in the following section I will review the research on probability discounting, before returning to a possible explanation for the problem of within subject variation of discounting rates.

Probabilistic discounting

Decrease in value of an uncertain reward

Just as the delay until receipt changes the subjective value of a reward, the uncertainty of delivery also affects subjective value. The greater the uncertainty of a reward the lower its subjective value. In a choice situation, just as an immediate reward will be preferred over a delayed one of equal size, it is natural to assume that a certain reward will be preferred over an uncertain one of equal size and delay. The decrease in the subjective value of a reward as a function of probability, or odds-against, is referred to as probability or probabilistic discounting (Rachlin, Raineri & Cross, 1991). Discounting of uncertain outcomes is also relevant to the construct of impulsivity, as broad definitions of the trait often also involve an aspect of risk taking (Evenden, 1999).

Rachlin et al. (1986) showed that the loss of subjective value of uncertain outcomes could be described by the same hyperbolic discounting function as the loss in value of delayed outcomes.

$$V = A / (1 + h\theta) \quad \text{[Equation 4; Rachlin et al., 1986]}$$

Where θ represents the odds against receiving the reward ($\theta = (1/p) - 1$), h the rate at which the uncertain reward loses subjective value, and A the undiscounted amount of the reward. They suggested that with repeated gambles the delay until a successful gamble was determined by the probability of the outcome. A low probability reward would, on average, require more gambles and entail a longer delay before a successful outcome, than would a higher probability reward. Rachlin, et al. (1986) therefore held that discounting of uncertain outcomes was fundamentally due to the delays associated with the probability.

Following the success of the hyperboloid model in describing discounting of delayed outcomes, Ostaszewski, Green and Myerson (1998) tested an equivalent hyperboloid model on probabilistic outcomes,

$$V = A/(1+h\theta)^s$$

[Equation 5; Ostaszewski et al., 1998]

where the parameters are the same as in the hyperbolic model but with the addition of the exponent s . They found that the hyperboloid model provided a good description of discounting of probabilistic outcomes, and that estimates of s were significantly less than 1, consistent with a scaling interpretation. Subsequent studies have confirmed that the hyperboloid model also describes probabilistic data well and that s tends to be less than 1 (Green et al., 1999; Holt, Green & Myerson, 2003; Myerson, Green, Hanson, Holt & Estle, 2003).

As noted, Rachlin and colleagues proposed that delay discounting was fundamental even to discounting of uncertain outcomes; the greater the uncertainty, the longer the delay to success. An alternative description of discounting, described by Myerson and Green (1995) and Green and Myerson (1996) assumes that delayed outcomes lose their value because the delay is associated with a risk that something will prevent the outcome from being delivered. This approach is based on the calculation of the expected value of a reward (derived by multiplying the amount of a reward by its probability) and argues that the probability is described by a function of the delay and a constant (k)ⁱⁱⁱ. According to this perspective, the s parameter represents individual scaling of amount, time and/or probability.

Much like temporal discounting, the non-constant decrease in value of uncertain outcomes predicts that preferences reverse as the probabilities associated with both rewards increase by a constant probability. Rachlin, Castrogiovanni, and Cross (1987) showed that this is indeed the case.

Reflective of the early discounting articles by Rachlin and colleagues (e.g. Rachlin et al., 1986; Rachlin et al., 1991), a substantial amount of the work on human probability discounting has examined it in terms of similarities and differences to delay discounting. Established phenomena in temporal discounting, such as the magnitude and domain effects, have been examined also in terms of choice between probabilistic outcomes. Results of such studies have had a substantial impact on the understanding of how probability and delay discounting are related, specifically with regards to single process views that propose that either risk or rate/delay is the fundamental process by which outcomes lose value. These studies have examined correlations between delay and probability discounting rates, magnitude and domain

effects, correlations between probability discounting and impulsive or risky behaviours, and lastly with self-report measures of impulsivity

Correlations between discounting types

Initial evidence in favour of single process accounts was promising in that similar hyperbolic equations described both types of discounting (Rachlin et al., 1991) and that correlations between the two were positive (e.g. Richards et al., 1999; Crean et al., 2000). However, further study has complicated the picture. Some studies have found them to be uncorrelated (e.g. Holt et al., 2003; Ohmura et al., 2006; Olson, Hooper, Collins & Luciana, 2007) and it has been argued that procedural characteristics of the studies that found significant relationships inflated their relationship (Reynolds et al., 2003).

Magnitude effect

To reiterate, discounting rates of delayed outcomes decrease with increasing reward magnitude (e.g. Baker et al., 2003). In the first study to examine the magnitude effect in probabilistic outcomes, Ostaszewski et al. (1996) had a sample of Polish university students give their subjective values of US\$100 and US\$1000 probabilistic rewards. They fitted the hyperboloid function to responses and found that discounting rates did not differ significantly, but tended to be shallower with the small amount than the large amount. Green et al. (1999) replicated the procedure using differently sized outcomes. When the small reward was \$500 and the large \$10,000, discounting was significantly steeper for the latter than former. In a second experiment they compared discounting of \$200, \$5000 and \$100,000, and found that discounting rates continued to steepen as the reward sizes increased. This ‘reverse magnitude effect’ has been replicated in a number of studies using hypothetical monetary rewards (Rachlin, Brown & Cross, 2000; Du et al., 2002; Estle, Green, Myerson & Holt, 2006; Myerson et al., 2003).

The second experiment of Green et al. (1999) illustrated another difference in the effect of amount on delayed and uncertain outcomes. Whereas no significant difference was found between delayed rewards of \$5000 and \$100 000, the two amounts did differ in probabilistic discounting rate, indicating that the magnitude effect levels off at large amounts in temporal but not in probabilistic discounting, at least within this range of reward amounts.

Use of Equation 5 has also indicated that uncertain and delayed outcomes have different effects on the rate and exponent parameters of the function. Whereas the exponent s remains

constant and the k parameter varies within-subjects across magnitudes in delay discounting, the opposite occurs in probability discounting. Myerson et al. (2003) tested discounting in two samples using \$200 and \$40,000 hypothetical rewards in one sample, and \$200 and \$25,000 in the other. Both samples showed the standard magnitude effect for delayed outcomes and the reverse magnitude effect for probabilistic outcomes. Furthermore, when examining the best fitting functions for the two amounts, estimates of s for the large amount were larger than estimates for the small amount, but only in probability discounting. Estimates of s for the delayed outcomes did not vary across magnitude.

The implications of these differences are twofold. Firstly, opposite effects of magnitude of discounting rates imply that delay and probability discounting are not governed by the same underlying process, be it either rate, as proposed by Rachlin and colleagues, or risk, as proposed by Myerson, Green and colleagues. Both single process views predict that the same manipulation would have the same effect on discounting rates. It should be noted that opposing amount effects in delayed and probabilistic outcomes are consistent with a trait interpretation of discounting. Both delay and probability discounting have been characterised as measures of impulsivity; delay discounting measures sensitivity to delays, and probability discounting measures sensitivity to risk. The inverse effect of amount on temporal discounting and the positive effect of amount on probability discounting both imply decreased impulsivity to larger magnitudes (Green et al., 1999). However, positive correlations between probability and delay discounting rates are inconsistent with this trait approach (Myerson, et al., 2003). The single view models are also inconsistent with the opposing effects of magnitude on the s parameter. Secondly, changes in the s parameter across magnitudes are inconsistent with the scaling interpretation of the exponent (Myerson et al., 2003), which implies that the exponent should remain constant across magnitudes because it describes a rule about “the way that changes in some objective quantity affect the perceived quantity” (McKerchar, Green & Myerson, 2010. p. 3). This rule should not change as a function of magnitude. McKerchar et al. noted that the scaling interpretation of the s parameter in probability discounting needs to be re-evaluated, and they suggested an alternate interpretation that the exponent governs decision weights rather than scaling.

Domain effects, impulsive behaviours and self-reported impulsivity

In addition to different effects of magnitude on discounting rates, there is also evidence that probabilistic discounting is not affected in the same way as temporal discounting rates by other factors such as domains, inflation, culture, age and IQ (Ostaszewski et al., 1998; Du et al., 2002; Olson et al, 2007). Such differential effects are also inconsistent with a single process account of discounting.

Only a few studies have examined domain effects in probability discounting, but some of these have illustrated the differences between discounting of delayed and uncertain outcomes. For example, unlike discounting of delayed candy, beer and soda, which differed significantly from delayed money, Estle et al. (2007) found no differences in the probability discounting rates of the different commodities.

Other comparisons across groups have also produced noteworthy distinctions between probability and temporal discounting. Du et al. (2002) compared American, Chinese and Japanese university students on delay and probability discounting. They found that while the groups did not differ in the fit of the function nor in amount effects, they did discount the two types of rewards to different extents. The Japanese students discounted the value of delayed reward less than the Chinese and American students, but the Chinese students discounted the value of uncertain rewards significantly less than the Japanese and the American students. This result showed that culture can influence the degree to which delayed or uncertain outcomes lose their value, but also that the interaction with culture does not have to apply to both delayed and uncertain outcomes equally. In another study, the effect of inflation on delay and probability discounting was compared, and while inflation had a significant impact on delay discounting rates, they did not on probability discounting (Ostaszewski et al., 1998).

Like magnitude and domain effects, these findings are inconsistent with single process models that would predict the same pattern of responding to both delayed and uncertain outcomes.

Probability discounting has been considered a facet of impulsivity related to risk-taking. Self-report measures of impulsivity sometime include items about risky behaviour or disregard for risky consequences of behaviour, and risk taking is often a component of impulsive behaviours such as substance abuse. For example, opioid dependent out-patients who risk HIV and other infections by sharing needles are more impulsive according to delay discounting rates than

opioid dependent out-patients who do not share needles (Odum et al., 2000). However, a number of studies have shown that probabilistic discounting does not relate to self-reported impulsivity. Ostaszewski (1997) found that high and low impulsive and extroverted participants did not differ in probability discounting even though they did differ in the expected direction for delay discounting. Mitchell (1999) showed that smokers did not differ from non-smokers in discounting rates even though smokers were significantly more impulsive than non-smokers and Crean et al. (2000) failed to find a difference in probability discounting rates between two groups of psychiatric out-patients who differed significantly in self-reported impulsivity scores. Finally, Scheres, dijkstra, Ainslie, et al. (2006) found no difference in probability discounting between ADHD children and controls, although high impulsivity is implicated in ADHD diagnosis.

Another approach has been to investigate probability discounting directly with measures of risk taking. High-sensation seekers in Ostaszewski (1997) discounted large probabilistic outcomes less than low sensation seekers, showing that the latter group was more risk prone than the former. However, despite finding that smokers and non-smokers differed on three of four subscales of the sensation seeking scale, Mitchell (1999) did not find that discounting rates differed between groups. Neither did any of the subscales of sensation seeking correlate significantly with probability discounting rates. The results of Richards et al. (1999) also suggested that the association between probability discounting and sensation seeking is weak. They found that three out of four sensation seeking subscale were not significantly correlated with probability discounting. These studies suggest that although there is conceptual overlap between probability discounting, impulsivity and risk taking, probabilistic discounting rates appear to measure different constructs than self-report measures of impulsivity and risk taking. This at least, is consistent with research on temporal discounting and self-reported impulsivity and sensation seeking.

Smokers vs. non-smokers

As reviewed above, several researchers have shown that smoking status has a significant effect on discounting of delayed outcomes, whereby smokers discount delayed monetary rewards more steeply than non-smokers (E.g. Mitchell, 1999; Baker et al., 2003). In contrast, the evidence that smoking status relates to probability discounting is less convincing. Two studies found that uncertain outcomes lose value faster for smokers than for non-smokers (Reynolds et

al., 2004; Reynolds, 2006b) and another that adolescents who had tried smoking but were not current smokers discounted more than both non-smokers and current smokers (Reynolds et al., 2003). Others, on the other hand, have shown no effect for smoking status on probability discounting (Mitchell, 1999; Ohmura et al., 2005; Reynolds et al., 2007). Although it has been suggested that the differences across studies is an artefact of using light, moderate or heavy smokers, non-significant results were found in the same studies that found significant effects in temporal discounting. This shows that even when taking into account smoking levels, the association between smoking status and temporal discounting is stronger than that with probability discounting. An analysis by Yi, Whitney and Baker (2007) suggested one possible explanation for the inconsistency across studies. In their study, discounting rates of heavy smokers and non-smokers did not differ overall, but when the hyperbolic function was fit to the most likely probabilities only (95%, 75%, and 50%) discounting rates did differ as a function of smoking status. They suggested that the inconsistency across smoking studies is partly due to differences in the probabilities used, and that the difference between smokers and non-smokers lies in how steeply they discount more likely outcomes, but not less likely outcomes.

Self-report measures of impulsivity show that smokers are more impulsive than non-smokers (Reynolds et al., 2007; Mitchell, 1999) and that they discount delayed rewards more steeply. Given the assumption that both temporal and probability discounting reflect impulsivity and that risk taking is a facet of this, it is noteworthy that Reynolds et al. (2004) and Reynolds (2006b) showed smokers discounted probabilistic outcomes MORE than non-smokers because this suggests that they were actually LESS impulsive. Unlike temporal discounting, where steep discounting is conceptualised as impulsive and shallow discounting as self-control, shallow probabilistic discounting is consistent with risk proneness and steep discounting with risk aversion. If studies investigating self-reported impulsivity, delay and probability discounting predict that smokers are more impulsive than non-smokers, this should correspond to greater self-reported impulsivity, steeper temporal discounting, and *shallower* probabilistic discounting. A study comparing gambling and non-gambling college students illustrates this point. Gamblers are more impulsive than non-gamblers according to delay discounting rates (Petry, 2001b) and Holt et al. (2003) found that gamblers discounted uncertain outcomes significantly less than non-gamblers, also consistent with them being more 'impulsive'. How then is it that; according to

Reynolds et al. (2004) and Reynolds (2006b), smokers discount more, i.e. are less impulsive, than non-smokers?

Interim summary

The above sections of the review have touched on a number of important themes in the existing discounting literature. It addressed the question of which mathematical function best describes the way in which value decreases as a function of delay and probability; the similarities and differences between probability and temporal discounting; and lastly the relationship between discounting of either type and trait measures of impulsivity and every-day impulsive behaviours.

The third and final part of the review describes the procedures commonly used in discounting research, and is directly relevant to a major purpose of the current thesis; namely the re-evaluation of our current understanding of discounting processes using novel experimental procedures.

General procedure

Standard discounting studies rely on psychophysical choice procedures in which participants indicate their preferences between two reward outcomes, one of which is large but delayed (or uncertain) and the other small but more immediate (or more certain). Points of indifference are identified by varying either the size of the smaller or the delay to the larger outcome over successive trials (Green et al., 1994). Indifference points refer to the point, for each delay, at which the participant is indifferent between the larger and smaller outcomes. For example, a participant may indicate a preference for 50 dollars immediately over 100 dollars in one month, but prefer the delayed 100 over 40 dollars now. In such a case the mean of the two points may be taken as the indifference point, meaning that an individual is indifferent between 45 dollars now and 100 dollars in one month.

Procedures differ in how they vary the smaller magnitude. In some studies (e.g. Rachlin et al., 1991) the smaller amount is increased or decreased sequentially through all options for each delay irrespective of participants' choices, others only provide choices until the participant's preference changes (Ostaszewski et al., 1996), and yet others present the amounts in random order (Robles et al., 2007). More recent studies have adopted algorithms by which the amount titrates based on participants' choices (e.g. Du et al., 2002), progressively narrowing in on that

particular participant's indifference point. A number of studies have investigated the effects of these specific procedural variations. Degree of discounting does not differ between tasks using a titrating and a fixed descending adjusting procedure (Rodzon, Berry & Odum, 2011), and neither do they differ as a function of the number of trials (and hence task duration) in a fixed sequence task (Robles & Vargas, 2008). In contrast, discounting rates are steeper when the amount varies randomly than when it changes in either a descending or ascending order (Robles & Vargas, 2007) and a descending order of presentations produces shallower discounting than an ascending order (Robles & Vargas, 2008; Robles, Vargas Bejarano, 2009). In addition, different algorithms by which the small amount changes also produce differences in degree of discounting (Kowal et al., 2007). Regardless of the titration method, indifference points are used to fit the mathematical function describing discounting, or to calculate the area under the curve (AUC; Myerson et al., 2001).

Some studies have moved away from the binary choice procedure described above. Participants may also be asked to indicate their own indifference points through fill-in-the-blank questionnaires, or to bisect a line at their point of indifference (Rachlin et al., 2000). Comparisons of these procedures have shown that the binary choice pairs procedure produces steeper discounting rates than fill-in-the-blank procedures. However, degree of discounting using one procedure is significantly correlated with degree of discounting on another and discounting is well described by hyperbolic discounting models (Smith & Hantula, 2008).

Hypothetical, real reward and real time measures of discounting

Different discounting tasks can also be classified according to the nature of the participants' experience of the outcomes and the delays. Reynolds identified three levels of experience; hypothetical, real reward, and real time measures (Reynolds, 2006a). The majority of studies use hypothetical rewards and delays based on the procedure developed by Rachlin et al. (1991). In this type of task participants are typically instructed that although none of the choices will actually be awarded, choices should be made as if each outcome would be received at the specified delay. For example, the participant might be asked whether he or she prefers a hypothetical \$100 now or a hypothetical \$500 in one year. As noted above, indifference points are established by varying either the delay to the large reward or the amount of the small reward over trials. Following a series of choices the participant may or may not be paid for participation, but no amount is contingent on the choices he or she made.

This hypothetical approach has enabled the use of outcome magnitudes and delays not experimentally feasible if using real rewards. In the first discounting study to use hypothetical rewards, Rachlin et al. (1991) used delays of up to fifty years, and in subsequent research, reward magnitudes of \$1000 or more have not been uncommon (Green et al., 1997). Though these delays and reward magnitudes may seem unnecessarily large, they reflect the notion that humans show a greater degree of self-control than animals. In tasks with comparable delays animals exhibit impulsive behaviours where humans are far more self-controlled (Logue, Pena-Correal, Rodriquez & Kabela, 1986). Rachlin et al. argued that humans' ability to imagine the reward outcomes, based on past experience of similar situations, makes this a realistic procedure.

Nonetheless, concern has been expressed about the validity of these hypothetical reward measures (Madden, Begotka, Raiff & Kastern, 2003), and particular criticism can be directed at the use of reward magnitudes with which many participants will have had little personal experience. It should be noted though, that many studies do use 'reasonably' sized reward magnitudes, such as \$10 or \$100, with which even tertiary student populations will be familiar (e.g. Mitchel, 1999). The criticisms of hypothetical choice tasks will be discussed further below.

Other procedures with real rewards have been used to investigate impulsivity and self-control, but many of these do not produce data that can be fit to discount functions (e.g. Logue, et al. 1986). The question is whether the choices made between hypothetical rewards are equivalent to choices made if the rewards are really delivered.

An alternative approach to the purely hypothetical reward procedure has been to provide actual rewards for a subset of choices. These procedures belong to the real reward category described by Reynolds (2006a). Using a lottery structure, the participants are instructed that they will be given their preferred outcome for one or more trials randomly selected from the experimental session (Mitchell, 1999). Because all rewards have the same likelihood of being delivered but not all choices have real outcomes these tasks are referred to as potentially real reward tasks throughout this thesis. The rationale of potentially real tasks is that each choice will be made as if all the outcomes are real because the participant cannot predict which reward will be delivered.

The third type of task, referred to by Reynolds (2006a) as real time procedures, have participants experience both the outcomes and delays of their choices. In such tasks each choice is followed by the delay and outcome specified for that trial, prior to presentation of the next

choice trial. A number of real time discounting tasks have been created. Those that have been used in number of experiments, such as the Experiential Discounting Task and the aeroplane task, are reviewed below.

Real time (experiential) tasks

Reynolds and Schiffbauer (2004) developed the Experiential Discounting Task (EDT); a computer task in which participants make repeated choices between immediate and certain outcomes and larger delayed and uncertain outcomes that are displayed on the computer screen in US dollars. The size of the small reward varies across trials based on the participants' choices but the large alternative (the standard outcome) is always US\$0.30. The delay to the latter outcome varies between blocks (at either 0, 15, 30 or 60 seconds) but its probability is constant throughout the task (at 35%). Following each choice and reward delivery, the participant confirms receipt of the reward by assigning it to the 'total amount' bank, and this total is delivered to the participant once all choices have been made. In the EDT, the size of the small certain reward titrates depending on participants choices such that it decreases following a preference for this alternative, but increases following preference for the standard outcome. Furthermore, each individual's discounting function is adjusted to account for the effect of making the standard delayed outcome probabilistic.

The EDT has been used in a number of studies, primarily examining temporary state effects on discounting rates. In the first study to use the task, Reynolds and Schiffbauer (2004) investigated the effect of sleep deprivation on degree of discounting. Participants completed the EDT both when rested and following 21 hour sleep-deprivation, and discounted significantly more in the latter condition. In another study, within-subject acute effects of alcohol consumption were shown; discounting rates in the EDT were steeper following consumption of a moderate dose of alcohol (0.8% g/kg) than a placebo (Reynolds et al., 2006). Notably, participants in this study also completed a hypothetical choice task, but no acute effects of alcohol were identified using this method. According to the authors, this difference between the EDT and hypothetical task suggests that real time tasks such as the EDT are better suited at capturing temporary state changes in discounting. Furthermore, a similar dissociation in acute effects on discounting was shown in a within-subject manipulation of methylphenidate medication in children with ADHD (Shiels et al., 2009). Both low and high doses of the psychostimulant produced significantly shallower discounting than placebo in the EDT, but no

significant differences were identified in the hypothetical choice task, consistent with Reynolds et al.

Reynolds (2006b) showed that the EDT is also capable of capturing the same group differences that have been identified with hypothetical choice tasks. Smoking status had a significant effect on EDT discounting, confirming that smokers discount delayed rewards significantly more than non-smokers also when all the delays are experienced. Similarly, individuals currently using and at risk of substance abuse discounted EDT rewards more than controls (Meda, Stevens, Potenza, Pittman, Gueorguieva, Andrews, et al., 2009). Two other EDT studies of smokers have shown that group differences in IQ, income and psychopathy levels also impact EDT discounting. When controlling for group differences in IQ and median income levels the differences in smoking status disappeared in Fields, Collins, Leraas and Reynolds (2009) and were reduced but remained significant in Melanko, Leraas, Collins, Fields and Reynolds (2009). Melanko et al. also compared high and low psychopathy smokers to controls and found that low psychopathy smokers discounted more than high psychopathy smokers and controls on the EDT.

In a study of adolescent smokers, EDT discounting rates that were elicited at the start of a smoking cessation program were predictive of abstinence four weeks later (Krishnan-Sarin, et al., 2007). Consistent with the literature comparing smokers and ex-smokers, those participants who were abstinent at the conclusion of the program had significantly shallower discounting rates than those who were not abstinent.

Not all EDT studies have produced significant state effects or shown significant group differences on discounting rates. A relatively high dose of Diazepam, a benzodiazepine drug often prescribed to treat anxiety and insomnia, failed to have an effect on either EDT or hypothetical discounting rates in comparison to placebo, despite producing significant subjective effects on stimulation and sedation (Acheson, Reynolds, Richards & de Wit, 2006). However, diazepam has variously been found to increase, decrease or not change impulsivity in other studies. In another study, the UK version of the EDT did not differentiate between ADHD participants and controls even when a hypothetical task did (Paloyelis et al., 2010).

Another real-time task has been used in a few studies examining temporal discounting in children, adolescents and adults diagnosed with ADHD (Scheres, Dijkstra, Ainslie, Balkan, Reynolds, Sonuga-Barke, E., et al., 2006). Like the EDT, this is also a computer based task in

which the small reward varies in size and the large remains the same, but unlike the EDT neither alternative is probabilistic. The large reward is always worth 10 cents and delayed up to 30 seconds. Participants make choices between outcomes that are visually represented as aeroplanes filled with different quantities of money. Selection of either outcome results in the chosen plane dropping its cargo and the height of the planes off the ground represents the delays until receipt. The amount of money collected throughout the task is also presented on the screen, and like the EDT, this amount is given to the participant upon completion of the task. Rather than titrating the small reward depending on participant choices, the aeroplane task presents each small reward twice with each delay of the large reward in a fixed pseudo-random order and indifference points are then determined by independent raters.

Scheres, et al. (2006) used two versions of the task, one in which each trial was separated by an inter-trial delay equivalent to the pre-reward delay until the standard outcome, and another version in which trials followed directly after each other without delay. In the latter version overall trial duration (as well as task duration) decreased as a function of immediate reward preferences, whereas trial and task durations remained the same, irrespective of preference in the former. Subsequent tests using this task have used the non-adjusting rather than the adjusting version (e.g. Scheres, Sumiya & Thoeny, 2010).

The aeroplane task was developed to test whether ADHD participants would show steeper discounting of delayed rewards than controls, consistent with the idea that ADHD is associated with strong delay aversion. In the first published use of the task, Scheres et al. (2006) failed to find a significant difference between controls and ADHD participants, but did show that younger children (6-11 years old) discounted significantly more than older children (12-17 years old), irrespective of ADHD diagnosis. Similar age effects have also been shown with potentially real choice tasks (Olson et al., 2007). Further examinations by Scheres et al. (2008) and Scheres, Tontsch, Thoeny and Kaczurkin (2010) suggested that specific ADHD symptoms differentially predicted discounting rates in the aeroplane task, namely that symptoms of impulsivity, but not inattention, are predictive of discounting rates. Higher levels of impulsivity were associated with steeper discounting, but only in the real-time task (Scheres et al., 2008) and hyperactive/impulsive type but not inattentive type ADHD participants discounted delayed rewards more than controls. Similar to Reynolds et al. (2006) and Shiels et al. (2009), the

aeroplane real-time task captured group differences in discounting rates that the traditional hypothetical choice task failed to distinguish (Scheres et al., 2008).

In one of few experiential studies to investigate human discounting of non-monetary rewards, participants made repeated choices between small and large amounts of delayed liquid outcomes (Jimura et al., 2009). Across experiments the large delayed reward was either 16ml or 8 ml of liquid. The delays until the large reward were up to 60 seconds in length and the small reward titrated as a function of the participants' choices. If a participant preferred the delayed reward, the small reward increased by half its size for the next trial and if the immediate reward had been preferred it decreased by half its size. Once a choice had been made, and the delay had been experienced if the delayed reward was selected, the reward was delivered to the participant through a plastic tube.

Across three experiments, Jimura et al. (2009) showed that real liquid rewards were discounted as a function of relatively short delays; that this discounting was well described by the two parameter hyperboloid model; and that discounting was affected by magnitude in a manner consistent with hypothetical tasks (discounting rates were steeper for small amounts of the delayed liquids than large amounts). A significant magnitude effect for food outcomes is of note because Odum et al. (2006) were unable to show the same using a hypothetical choice procedure.

Jimura et al. (2009) fit the hyperboloid model to their data, Lane, Cherek, Pietras and Tcheremissine (2003) used the single parameter hyperbolic model, and data produced with the EDT has been shown to fit the hyperbolic model better than the exponential (Reynolds & Schiffbauer, 2004). Scheres and colleagues in contrast, calculated the 'area under the curve' (AUC) rather than fit data points to any function. Other experiential choice tasks have used the proportion of self-control choices as a measure of impulsiveness. Pietras, Cherek, Lane, Tcheremissine and Steinberg (2003) created a task in which rather than vary the amount of the small outcome, the delay until the large alternative (15 cents) decreased following preference for the small alternative (5 cents), and increased following preference for the larger. Like the EDT and aeroplane procedures, reward amounts accumulated in a computer counter and the total was only delivered to the participants at the end of the day. Unlike the other tasks, however, the small alternative was also slightly delayed, at 5 seconds. This experiment manipulated methylphenidate dose within-subjects in a sample of adult males and used both the number of

choices for the delayed outcome and the average delay per session as dependent measures. Methylphenidate tended to increase self-controlled responding, but there was both large inter-individual variability and variability in the dose (0.15, 0.30 or 0.60 mg/kg) that had the strongest effect in comparison to placebo.

Hinvest and Anderson (2010) also used an adjusting delay procedure with delays to the smaller amount (10 pence) ranging between 0 and 10 seconds and the larger (20 pence) either the same or longer (up to 30 seconds). Each participant completed the task twice, once with real rewards that were delivered upon completed participation, and once with hypothetical outcomes (using the same procedure and reward structure). Comparisons of AUCs and indifference points across real and hypothetical outcomes showed that participants were less impulsive with real outcomes than hypothetical outcomes, but that discounting rates across the two types were positively correlated.

Probability discounting procedures

Similar to temporal discounting, probability discounting has been examined with tasks that vary in whether outcomes are real or hypothetical. Rachlin et al. (1986) had participants make repeated choices between two spinners that varied in likelihood of success. One spinner had a 17/18 chance of success (the safe gamble), and the likelihood on the other (risky gamble) varied as a function of participants' choices. If the participant opted for the risky gamble it was made less attractive in the following trial by decreasing its likelihood, and if the participant opted for the safe gamble, the risky spinner was made more likely. Each choice was followed by a spin of the preferred option and the participant was told whether they 'won' or 'lost', but no money was actually delivered following successful gambles, i.e. gambles were experienced, but outcomes were hypothetical.

Hypothetical and potentially real task are structured the same as their temporal versions. Participants make repeated choices between a fixed uncertain outcome and a smaller titrating certain outcome and indifference points are established at various levels of certainty for the uncertain outcome. In purely hypothetical probability tasks participants simply indicate which of two outcomes would be preferred (e.g. Green et al., 1999). In potentially real procedures, one or more trials are randomly selected and if the uncertain outcome is chosen on these trials, it is delivered according to the probability specified for that trial. For example, Mitchell (1999)

placed tokens in a paper bag. ‘Yes’ and ‘No’ tokens represented wins or losses respectively, and the proportion of each reflected the probability specified in the trial. The participants were allowed to pull one token from the bag and if a ‘yes’ token was retrieved, they received the outcome. If a ‘no’ token was retrieved, they received nothing.

Some probability tasks that mirror ‘real-time’ temporal procedures have also been created, though less research has been conducted on experiential probability discounting than experiential delay discounting. Experiential probability tasks deliver outcomes contingent on every choice in a session. In addition to the aeroplane temporal task, Scheres et al. (2006) developed an experiential probability task. In this computer task a trial consists of breaking the shell of one of two piggy banks presented on the screen. One piggy bank is more difficult to break but contains more money than the other. Using this task, Scheres et al. found that probability discounting remained stable across age and ADHD diagnostic groups in children and adolescents, and that it correlated with temporal discounting using the aeroplane task.

Hinvest and Anderson (2010) also investigated the effect on probability discounting of type of outcome. This task was equivalent to the delay task except that each block contained more trials. Participants made choices between 10 pence and 20 pence (that were either hypothetical or real). The probabilities of both outcomes varied, but the large outcome was always either equally or less likely than the small. Like the Rachlin et al. (1991) task, outcomes were presented on two wheels that composed of red (loss) and green (win) segments. Following choice, an arrow spun for 2 seconds on the chosen outcome and ‘landed’ on either win or loss.

In conclusion, a number of different experiential choice tasks have been developed and evidence shows that that experiential tasks correlate with hypothetical choice procedures (Reynolds, 2006b), are sensitive to state changes (Reynolds et al., 2006; Reynolds & Schiffbauer, 2004) drug effects (Pietras et al., 2003), and that they differentiate between groups similarly to hypothetical choice tasks (Reynolds, 2006b; Krishnan-Sarin, et al., 2007).

Does experience make a difference?

The research reviewed in sections 1 and 2 shows that hypothetical choice tasks have been used successfully to elicit decreases in subjective value that are systematic and able to differentiate across behavioural correlates of impulsivity as expected. Given this success, and the comparable ease of using hypothetical rather than real outcomes, many researchers continue to

use the method with a cursory nod to the few studies that have investigated the effect of type of outcome on discounting, saying that hypothetical procedures produce discounting consistent with real reward procedures. Most studies utilising hypothetical outcomes in recent years refer to Johnson and Bickel (2002), Madden et al. (2003), Madden, Raiff, Lagorio, Begotka, Mueller, Hehli and Wegener (2004), Lagorio and Madden (2005) as evidence that discounting is unaffected by the nature of the outcomes (e.g. Weller, Cook III, Avsar & Cox, 2008; Steinberg, Graham, O'Brien, Woolard, Cauffman & Banich, 2009; Callan, Shead, & Olson 2011).

Johnson and Bickel (2002), Madden et al. (2003) and Madden et al. (2004) all compared hypothetical and potentially real discounting procedures. Johnson and Bickel used a within-subjects design in which participants completed one session with both hypothetical and potentially real outcomes. Two participants completed the real reward condition first followed by the hypothetical and the remaining four participants did the opposite order. The experiment included outcomes of varying sizes; both conditions included outcomes of \$10, \$25, \$100 and \$250, and delays of up to 6 months. In addition, the hypothetical condition included \$1000 and \$2500 outcomes and delays up to 25 years. Examinations of individual indifference points at the delays common to both conditions showed no systematic differences across the conditions and individual discounting rates were correlated across conditions. Furthermore, both real and hypothetical conditions produced the standard magnitude effect.

Johnson and Bickel (2002) concluded that hypothetical outcomes produce equivalent discounting as real outcomes. In a similar study, Madden et al. (2003) compared within-subjects discounting of a hypothetical and a potentially real \$10 reward, and reached the same conclusion. Madden et al. adjusted two aspects of Johnson and Bickel. First of all, Johnson and Bickel included only six participants. Secondly, participants completed both conditions within one session with only a couple of five minute breaks. Although outcomes were blocked rather than intermixed, Madden et al. argued that participants may have remembered performance in one block and acted accordingly in the second. Madden et al. addressed both issues by increasing the sample size and separating the conditions with a 20 minute filler task. Because carry over from one condition to the other was still possible in this task, Madden et al. (2004) made the same comparison in a between-subjects design and also increased the proportion of real rewards delivered, with the same results. These three studies collectively suggest that discounting is

similar across the two outcome types both when participants can and cannot remember performance in a previous task.

Common to all three comparisons, Johnson and Bickel (2002), Madden et al. (2003) and Madden et al. (2004) investigated discounting of hypothetical outcomes and *potentially* real outcomes. Although these two types of outcomes are the most frequently used in discounting work, and comparisons between them are important in their own right, one might argue that these studies do not adequately address the question of whether hypothetical outcomes are equivalent to real outcomes. Indeed, these findings imply that hypothetical outcomes can be used as a good proxy for potentially real rewards in studies using human participants. However, it may be over-stating the results to say that hypothetical discounting is a good proxy for discounting of real rewards because it assumes that potentially real rewards are discounted equivalently to all real rewards. There are several reasons to be cautious of this assumption because potentially real reward procedures differ from real time procedures with all real rewards in a number of important ways.

Potentially real reward procedures confound probability and delay in a way that can be avoided with all real rewards or real time tasks^{iv}. First of all, a potentially real outcome is a probabilistic outcome because only one or a few of the total choices will be delivered. As the task is being completed, each choice *may* lead to an outcome. Although studies do differ in the proportion of real outcomes to total trial numbers, in many the odds are not high. Madden et al. (2004) reported that participants in Johnson and Bickel (2002) made approximately 90 choices for each reward, and in Madden et al (2003) 432 choices were made for each outcome delivered. Even the greater of these proportions is quite small.

Secondly, in the procedure of Johnson and Bickel (2002) and Madden et al. (2003), each of the chosen outcomes is probabilistic in that the delivery of the delayed outcome (which was posted as a check or could be picked up) is uncertain. If, as proposed by Green and Myerson (1996), delayed outcomes lose value as a function of risk, the implied uncertainty associated with delayed rewards in potentially real studies should therefore be greater than in for example real time tasks where delivery occurs within the experimental session. One possible consequence of this is that there is a greater difference between immediate and delayed rewards in potentially real procedures than in most real time procedures, because one is associated with lesser uncertainty than the other. Such confounding of delay and uncertainty, as will be discussed

further below, has important implications for investigations of the single process accounts of discounting.

The reliance on potentially real reward procedures in behavioural research is interesting because of the timing of the rewards relative to the behaviour. Hypothetical tasks work on the assumption that the individual can draw on previous experience with delayed rewards to make accurate decisions, without the need for any outcomes to be experienced within the session. Potentially real outcomes assume the same, but the delivery of a subset of outcomes is intended to ensure that participants are more motivated to make each choice as if it is actually real. Both of these situations rely on participant experiences outside of the controlled laboratory environment. In real time procedures in contrast, outcomes are experienced within the session and participants' experiences can be controlled to a greater extent. In this sense, hypothetical and potentially real procedures are more like self-report measures because they rely on participants following instructions and reporting how they 'think' they would act, similarly to how they may be asked to think about and report on 'who they are' when completing a personality measure such as the BIS. In experiential procedures participants experience delays across trials, and reach an indifference point that should, at least in theory, be contingency shaped. Participants do not simply report what they think they would do, but they do it, and, more importantly perhaps, they do it repeatedly. As the task progresses, each participant is given the opportunity to experience both the aversive and reinforcing aspects of each delay and outcome.

Real time tasks become, in this sense, more dynamic than potentially real reward tasks because they allow the participants' experiences of the delays and rewards to influence current behaviour. This quality of the task, as suggested by Reynolds and Schiffbauer (2004) may make it more sensitive to state changes than a hypothetical choice task.

Lastly, both hypothetical and potentially real discounting experiments have a number of specific procedural differences to animal studies of discounting. This particular aspect is of importance when drawing parallels and discovering contrasts between human and non-human discounting, a specific example of which is the presence of the magnitude effect in humans but not in animals (Ong & White, 2004). As noted by Lagorio and Madden (2005) these procedural differences include forced choice trials, exposure to the consequences of each choice during the experimental session and the use of stability criteria. Lagorio and Madden investigated discounting of hypothetical and all real rewards in six participants who made choices between

amounts of money that had to be used as soon as they were received to purchase goods in the ‘experiment shop’. These goods included chips, candy and liquids. In the real reward condition participants also completed two forced choice sessions for each delay. Lagorio and Madden concluded that discounting remained stable across sessions and that discounting did not differ across outcome types.

The real reward condition of Lagorio and Madden (2005) shares more similarities with animal discounting procedures and human experiential discounting tasks than the real reward conditions in Johnson and Bickel, Madden et al. (2003) and Madden et al. (2004), but reached the same conclusion as to the effect of reward type. However, the constraints of the real reward condition (having to purchase the goods in the experiment store) has been criticized (Hinvest & Anderson, 2010) and at least two other comparisons of procedures with all real contingent rewards have concluded that experience does indeed influence discounting. As a matter of interest, Lagorio and Madden (2005) conducted the hypothetical condition followed by the real condition with the reasoning that the real condition may affect hypothetical discounting, but not vice versa. This in itself speaks volumes of the importance of experience, and is at least an acknowledgement that the two types of rewards do differ as to the effect they have on subsequent behaviour.

Like Lagorio and Madden (2005), Lane et al., (2003) pointed out that potentially real reward procedures fail to make rewards contingent on every choice and therefore superimpose a probability across choices at all the delays. As noted above, the interactive effects of combining probability and delay in such a manner are unknown. Lane et al. therefore compared a standard hypothetical choice procedure with a compressed hypothetical procedure in which delays and rewards were smaller as well as a real time procedure in which each choice was associated with small monetary outcomes. The delayed amount varied in size in all three conditions, as did the delays associated with them. In the standard, compressed and contingent condition respectively, the longest delays were 25 years, 90 days and 90 seconds, and the large delayed amounts were \$1000, \$150 and \$0.15. Like the previous comparisons, Lane et al. found that discounting on all tasks was well described by the hyperbolic model, but the contingent procedure produced some notable results. Firstly the contingent procedure produced lower group median fits than the other procedures. Secondly, several participants (4/16) showed no discounting in this task, but all

participants discounted in the other two tasks. Thirdly, AUCs from the contingent and hypothetical procedures were uncorrelated.

This study has been criticized on a number of points. The fact that the three conditions utilised outcomes of such differing sizes introduces the possibility that differences in discounting were accounted for by magnitude effects, as noted by Madden et al. (2004). The contingent procedure in particular is problematic for two reasons. First, it did not include an adjusting delay between trials, meaning that impulsive preferences increased rate relative to self-controlled preferences. Without an adjusting delay, impulsive preferences may have resulted from either preference for immediacy or from preference for higher rates, the latter of which is not technically impulsive. Secondly, although money was delivered contingent on choice in the form of increases in a counter presented on the computer screen, money was only delivered to the participant at the end of the experimental day. Hyten, Madden and Field (1994) showed that the delay to delivery of the actual monetary outcome has a stronger influence on participant responding than so called ‘point delays’, the delays between choice and for example additions to a counter. Lagorio and Madden (2005) also reported that when monetary outcomes are used in such tasks, participants report that they prefer to wait for the larger later reward in order to save up a larger amount of money to be spent following the experiment.

Although the contingent procedure used by Lane et al. (2003) has flaws as identified above, the results suggest that when outcomes are experienced following each choice, as opposed to delivered for a subset of choices following task or session completion (as in Johnson & Baker, 2003; Madden et al., 2003; Madden et al., 2004), discounting behaviour differs from when outcomes are hypothetical, and imply that experiential tasks may capture aspects of discounting that hypothetical tasks do not. This conclusion is consistent with data produced using other experiential tasks such as the EDT, whereby experiential discounting rates capture the effects of state changes that hypothetical tasks do not (Reynolds et al., 2006; Scheres et al., 2008; Shiels et al., 2009), or capture a degree of discounting that is unprecedented with hypothetical outcomes (Jimura et al., 2009).

Lastly, some studies that have used both hypothetical and real-time tasks have found that discounting rates across the two types of rewards are uncorrelated (e.g. Melanko et al., 2009; Shiels et al., 2009; Paloyelis et al., 2010). This suggests not only that the tasks capture different degrees of discounting, but possibly different types of discounting.

The recent increase in the number of authors who choose to investigate discounting with experiential tasks is evidence of a new phase in the discounting literature. Experiential tasks are being included in work both on their own and in conjunction with hypothetical tasks. Although some authors have investigated ‘basic’ human discounting phenomena, for example by evaluating which function best describes discounting or investigating the magnitude effect (e.g. Jimura et al., 2009), these questions mostly appear to have been left by the wayside in favour of work relating experiential discounting to the more established methods of eliciting discounting and its correlates in every day behaviour (e.g. Reynolds, 2006b; Shiels et al. 2009). With such an overriding force of hypothetical choice tasks in the field, it is perhaps not surprising that the work with experiential discounting tasks has gone through a period in which comparisons to the established methods dominate, and during which conclusions drawn from earlier work with hypothetical tasks are used as benchmarks for these new tasks. But experiential choice tasks should be used in their own right to examine both temporal and probability discounting by capitalising on the aspects of the procedures that set them apart from hypothetical tasks.

Indeed, as already suggested, the particular procedure used to elicit discounting may be influential for the conclusions we draw about discounting processes. For example, Yi et al. (2006) examined hypothetical rewards that were both probabilistic and delayed, phrased in terms of lottery tickets that were delayed and had known probabilities of winning. Across two versions of the task the temporal resolution of the hypothetical ticket was varied. In the immediate resolution scenario, the outcome of the ticket could be known immediately but the (hypothetical) prize would only be collected after a (hypothetical) delay. In the late resolution scenario, both the delivery and determination of the outcome of the ticket were (hypothetically) delayed. In both scenarios the ticket could be sold immediately to a lottery agent for a lesser (variable) amount of money. Yi et al. found that the temporal resolution of the delayed and probabilistic outcome did not affect discounting. In contrast, Rachlin and Siegel (1994) examined the effect of temporal spacing of probabilistic outcomes using all real rewards. In the ‘spaced’ condition participants made a choice between two spinners, the chosen spinner was spun, a token was delivered and two more choices were made following the same procedure before an inter-trial interval of 30 seconds commenced. In the ‘bunched’ condition, the participant made three choices in a row without the spinner being spun. Following the three choices the selected spinner was spun three times, once for each choice, and the inter-trial interval commenced before another set of three

choices were made and three outcomes experienced. Rachlin and Siegel used the point at which participants crossed over from the uncertain to the certain spinner as the measure of risk taking, and found that the mean crossover point differed across conditions. Participants were more risk averse when outcomes were bunched than when they were spaced.

Although the procedures used by Yi et al. (2006) and Rachlin and Siegel (1994) differed in more ways than just the nature of the outcome, the latter experiential study found an effect for the temporal resolution of gambles where the former hypothetical did not, suggesting that the *experience* of the outcome may be central for the effect of temporal resolution to be shown. This comparison across two studies adds to the accumulated evidence found within studies (e.g. Reynolds et al., 2006; Shiels et al., 2009), that the experience of outcomes is indeed important.

Furthermore, the very nature of the procedures determines the types of manipulations that can be made, also evidenced in the comparison between Rachlin and Siegel (1994) and Yi et al. (2006). Because the former study involved real rather than hypothetical outcomes, the choice could be separated from the outcome in a way that is not possible with hypothetical outcomes. In hypothetical choice tasks, it makes no sense to separate the choice from the outcome because there is, in essence, no outcome to be had. This means that, in addition to being crucial to producing an effect, experiential choice tasks may also afford researchers possibilities of investigating questions that are not possible to investigate with hypothetical tasks, alternatively to investigate established phenomena or theory in a novel way.

In conclusion, not only does it appear to be the case that experience makes a difference to different aspects of discounting, but the chosen procedure also dictates what can and cannot be studied. With that in mind, the following section details how experiential choice tasks were used to investigate both temporal and probability discounting in the four experiments of this thesis.

Experiential discounting of delayed and uncertain outcomes

Two major themes in the literature are central to this thesis: First is the importance of experiencing delays and outcomes when examining human discounting; second is the question of whether overlap between temporal and probability discounting is indicative of a single underlying process of delay or uncertainty.

It was not the purpose of the above review to assert that hypothetical choice tasks provide an inaccurate idea of discounting, but instead to suggest that sole reliance on such procedures

produces a limited (and *sometimes* skewed) view of how outcomes lose their value, and that experiential choice tasks can be used to an advantage in examining discounting phenomena from a different light. Research with experiential tasks has already shown for example, that humans are not always as self-controlled as suggested by hypothetical tasks (e.g. Jimura et al., 2009), and that experiential and hypothetical discounting are affected differently by the same manipulations (e.g. Reynolds et al, 2006). This aspect of experiential tasks may also be beneficial in the study of single process accounts.

The question as to whether or not discounting of delayed and uncertain rewards reflects a single underlying process appears to have decreased in prominence in the literature over the last few years. Early experiential discounting work examining this issue seemed to permit greater room for experimentation than later largely hypothetical work. For example, Rachlin et al. (1986) showed that the length of the inter-trial interval had a significant impact on probability discounting rates. As hypothetical tasks have become more commonly used, the discussion has rested primarily on three arguments, two in favour and one against single process views. On the one hand similar functions describing discounting of both delayed and uncertain outcomes and that correlations between temporal and probability discounting rates tend to be positive suggest that one fundamental process may be at work. On the other, opposite magnitude effects and differing outcomes as a result of the same manipulation suggest otherwise. With new experiential tasks, these arguments can be re-explored and experiential task can be used to examine specific assumptions of single process accounts.

The present thesis details the testing of two new experiential tasks, one with uncertain and one with delayed outcomes. Basic discounting phenomena of both delayed and uncertain outcomes were examined in three parts. Study 1a provided an initial examination of the three discounting equations for both delayed and uncertain rewards. In Study 1b, the same data were used to examine the correlations between probability and temporal discounting rates. Lastly, within-subject effects of magnitude were examined in Study 2. These studies would permit comparisons to be made with previous literature using hypothetical and experiential tasks. In Studies 3 and 4, only delay discounting was examined. The nature of the inter-trial intervals of the experiential delay discounting task and participants' prior learning histories of uncertainty were manipulated in Study 3 and Study 4, respectively.

Chapter 2 : Introducing a Novel Experiential Task (Study 1a)

The success of hypothetical tasks in eliciting systematic decreases in subjective value of monetary outcomes (e.g. Rachlin et al., 1991; Critchfield, & Kollins, 2001) and the problem of human insensitivity to short delays in early experiential procedures (Logue et al., 1986; Hyten et al., 1994) provided strong support for the use of hypothetical tasks, in addition to underpinning the claim that while animal discounting occurs over a matter of seconds, subjective value decreases over the range of weeks, months and years in humans. However, more recent experiential tasks capable of capturing human discounting at less than minute long delays (e.g., Reynolds & Schiffbauer, 2004; Scheres et al., 2006; Jimura et al., 2009) are evidence that sole reliance on hypothetical tasks is unwarranted, indeed even objectionable. Not only do experiential tasks bridge the gap between animal and human research so that human discounting can be examined at delays more equivalent to animal tasks, the greater the methodological similarities in procedures used across species the stronger the conclusions drawn about parallels between human and animal discounting processes become. In addition, there is also evidence that experiential procedures may be better suited than hypothetical tasks for measuring temporary effects on discounting rates, such as acute intoxication or drug levels (Reynolds & Schiffbauer, 2004).

Two examples of successful experiential choice tasks are the Experiential Discounting Task (EDT; Reynolds & Schiffbauer, 2004) and the liquid reward task used by Jimura et al. (2009). Each of these tasks incorporates specific adjustments to the standard amount adjusting procedure to capture human discounting over short delays. Noting that ‘coupling uncertainty and delay improves the likelihood of reliable discounting’ (2004, p. 347), Reynolds and Schiffbauer added a constant probability to all delayed outcomes. In contrast, Jimura et al. (2009) targeted the inconsistency between animal and human research in the use of consumable and non-consumable outcomes and, instead of money, used real juice rewards with liquid deprived participants.

Each of these adjustments brings with it its own limitations. In Reynolds and Schiffbauer (2004) the added probability becomes a complicating factor. To account for the effect of adding a constant probability, they calculated the indifference point for an immediate but uncertain outcome and adjusted the indifference points at all delays using this value. Although this approach adjusts for inter-individual variation in the effect of uncertainty on value, it assumes that the effect of probability is constant across all delays. If delay and probability interact

different across delays however, such changes would not be captured in the calculation used by Reynolds and Schiffbauer. Furthermore, this adjustment of the EDT makes it unsuitable for evaluations of single process views of discounting because delay and probability are inherently confounded in the task. In the task used by Jimura et al. (2009), consumable rewards introduce the possibility of satiation effects, even though the likelihood of this was minimized by depriving subjects of liquids prior to participation.

Another limitation of several experiential delay tasks (e.g. Lane et al., 2003; Scheres et al., 2008) is the absence of adjusting inter-trial intervals (ITI). Adjusting inter-trial intervals maintain constant choice rates and/or task durations across extreme impulsive or self-controlled responding. Without adjusting ITIs, impulsive participants have higher choice rates (and shorter task durations, depending on the task) than more self-controlled individuals. To prevent choice rate rather than reward delay from controlling choice, adjusting ITIs should be used^v. Some procedures, such as the EDT (Reynolds & Schiffbauer, 2004) include intervals between blocks of choices rather than each choice. Although these recent experiential choice tasks have been successful in showing that human discounting can be elicited over short delays, there remains a need to explore new procedures that avoid confounding for example probabilistic discounting and choice rates with “pure” delay discounting.

There are fewer experiments investigating human probabilistic choice than delay choice, and very few experiential probability tasks. In one of the first behavioural probability discounting tasks, Rachlin et al. (1986) had participants make repeated choices between two spinners that differed in the probability of a win. Following each choice, a spin produced either a successful or unsuccessful outcome, and in this sense the task was experiential, but the rewards themselves were hypothetical. Other tasks have used both hypothetical delivery of rewards and hypothetical spins. For example, Anderson, Richell and Bradshaw (2003) based their task on the procedure of Rachlin et al. (1986), but participants were shown an image of two spinners and instructed to imagine both the outcomes and the spinning of the wheels. Even less experiential are the hypothetical choice procedures in which participants are given a list of hypothetical outcomes in which the probability is specified as a certain percentage and neither gamble nor rewards are experienced (e.g. Ostaszewski, 1997). There are however, a couple of examples of experiential probabilistic tasks. Rachlin and Siegel (1994) used the same procedure as Rachlin et al, but followed each successful spin with delivery of a chip that was exchanged for money at the end of

the experiment. A computer-based probability discounting task was developed by Scheres et al. (2006) in which participants chose between two piggy banks that were filled with different amounts of money. Participant selected one of the alternatives and a hammer hit the piggy bank. If the hammer broke the piggy bank the money in it was added to the participant's total gain. The probability of success was represented by the thickness of the piggy banks' shells whereby a thicker shell was less likely to break than a thinner shell, and a coloured bar above the piggy bank indicated the hardness of the shell. The total earned in the task was delivered to the participants following task completion.

Like the EDT, both the Rachlin and Siegel (1994) and Scheres et al. (2006) procedures confound delay and probability by withholding actual reward delivery until after all choice have been completed. Consequently, also in the probability discounting research, there is considerable room for further developments of experiential choice procedures.

The first experiment in this thesis introduced two newly developed experiential discounting tasks. One task was designed to investigate temporal discounting and the other probability discounting. The general structure was highly comparable across the two versions; a computer skiing game in which points were gained for skiing over jumps and additional opportunities to gain points were interspersed in the form of standard discounting choices. Both addressed the limitations of experiential discounting tasks described above. Unlike the EDT, with its superimposed probability over all delayed alternatives, discounting choices in the temporal version of the task involved one immediate outcome and one delayed alternative, both of which were 100 percent certain. In the temporal version large delayed outcomes were paired with smaller but immediate outcomes and in the probability version large but probabilistic outcomes were paired with smaller guaranteed gains. In both tasks the value of the smaller option titrated to identify indifference points at a number of delays or probabilities and the outcome of a choice was experienced prior to the next choice. In the probability task all outcomes were immediate, but uncertainties were represented by failed jumps that did not produce additional points. In the temporal version the large alternative required the participant to wait for a specified time before points were delivered whereas a preference for the small option led to an immediate gain of the specified value.

The computer game context meant we could use points as rewards rather than consumable rewards such as those used by Jimura et al. (2009). The context of a game also provided the

additional departure from previous experiential tasks in that points could be delivered as part of the game without necessitating an exchange for money at the end of the experimental session. Because money is not actually delivered to the participant until the whole task has been completed in some experiential discounting experiments, the final delay until receipt of money in these cases is not the delay specified each trial, but the delay until task completion (e.g. Reynolds & Schiffbauer, 2004; Scheres et al, 2006). In an analysis of these types of tasks, Hyten et al. (1994) identified three different delays in such procedures, namely: delay to point delivery, delay to exchange for money, and lastly delay between delivery of money and consumption of a purchased commodity. They established that choice was affected by manipulations to exchange delays (i.e. the delay until points were exchange for money). Therefore, tasks that include exchange delays until the end of the task, do not adequately distinguish between discounting as a result of delays to point gain or delivery of money. Because points were not exchanged for money upon completion of the task in the skiing game, exchange and consumption delays were removed completely, leaving only point delays to be manipulated.

Lastly, discounting choices were presented to the participant at regular intervals, with an adjusting delay in the temporal version. This adjusting ITI maintains a stable choice rate and task duration irrespective of preference for the immediate or delayed outcomes. In the temporal version, the game context also provided a novel way to deal with post-reward delays. Unlike the tasks used by Scheres et al. (2006), in which participants passively waited the duration of the post-reward delay until the next trial, the skiing context was used to incorporate a less apparent post-reward delay, in which alternative reinforcement was none-the-less withheld^{vi}.

The aim of the present study was thus to examine discounting using the two versions of the skiing game task, one on probability and the other temporal discounting. Discounting was examined using both fitted models and an AUC analysis. Consistent with research using both hypothetical and experiential choice tasks in humans and animal studies, it was expected that discounting would be better described by the hyperbolic or hyperboloid functions than the exponential model (e.g. Myerson & Green, 1995).

Method

Participants

Eighty participants were recruited through the Victoria University School of Psychology research participation program. All participants were completing an introductory psychology course in which course credit was given for research participation.

Materials

Experiential discounting tasks

The Visual Basic® computer tasks were both skiing games with the aim of gaining points by skiing over jumps. Both tasks consisted of two components, a free-skiing, or in-game, component, which remained largely the same across the two versions, and a choice component, which differed across the tasks in the types of choices made. Both tasks took approximately 30 minutes to complete, depending on latency of responding.

Probabilistic discounting task

The choice component in the probabilistic discounting task examined choices between two immediate outcomes that differed in size and uncertainty.

Written instructions presented on the screen at the beginning of the session were as follows:

You are a 'ski boarder' competing for points. The object of the task is to gain as many points as possible. You gain points for each jump you make over 'moguls' which look like (*image of a mogule shown here*). You lose points for running in to trees or rocks.

Every so often you get to make a 'free run' at a jump platform. Before making such a jump you must choose ONE of TWO possible jump scenarios. One option results maximum points for a successful jump but there is a chance you will fail in the jump and crash (thereby getting no points) ... The other option will deliver anywhere between 1 and 10 points but there is no chance of the jump failing (a successful jump is guaranteed 100%). Use the mouse to click on the option you wish to choose. You move the player around using the DOWN, LEFT and RIGHT arrows. You can only move left or right, straight down, or at an angle

downwards (make sure you spend some time at the start trying out the keys in order to become familiar with movement).

In addition, participants were informed verbally that they would be given fifty of these ‘free run’ jumps during the game. If the participants had no questions, they clicked a button on the computer screen to start the game when ready. If participants had questions, the written instructions were repeated verbally.

The game commenced with the ‘in game’ context where participants themselves controlled the movement of a centred skier down a slope, over which trees, rocks and jumps were randomly spread (Figure 2.1). Five points were earned for each jump and two points were lost for each collision with a tree or rock. For the duration of the game the total points accumulated was shown and continually updated in a box in the top right corner.

At regular intervals the slope disappeared from view and presented the participants with a ‘free run’ jump, the choice phase (Figure 2.2). At the start of the choice phase a text box at the top of the screen read “Use the mouse to click on 1 of the 2 jump options below”. In the probabilistic version, the instruction also specified that “each option carries a different chance of success and points gained IF successful”. The two alternatives were presented in boxes below this, one to the left and the other to the right. The alternative on the left was always certain but varied in size. The alternative on the right varied in its probability of success, but was always worth the same amount of points. In the current experiment the value of the uncertain amount was 10 points.

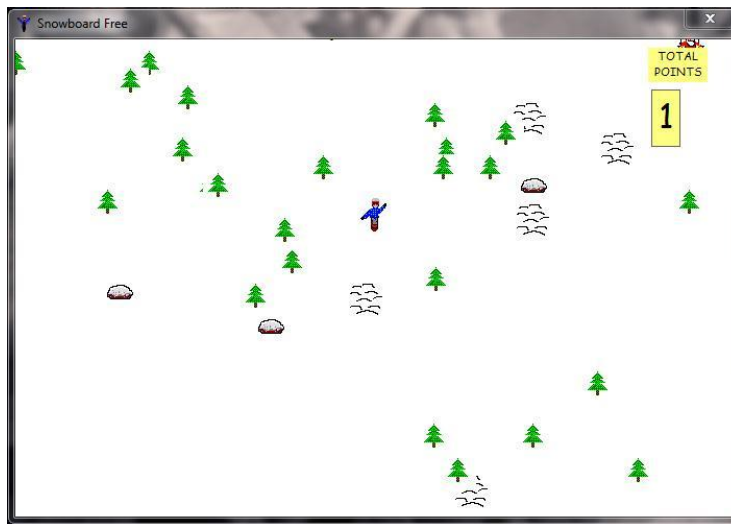


Figure 2.1. Screen capture of the in-game part of the experiential discounting tasks. Participants lost points for crashing into trees and rocks and gained points for skiing over jumps (wavy black lines). The in-game component appeared the same for both the temporal and probability skiing tasks.

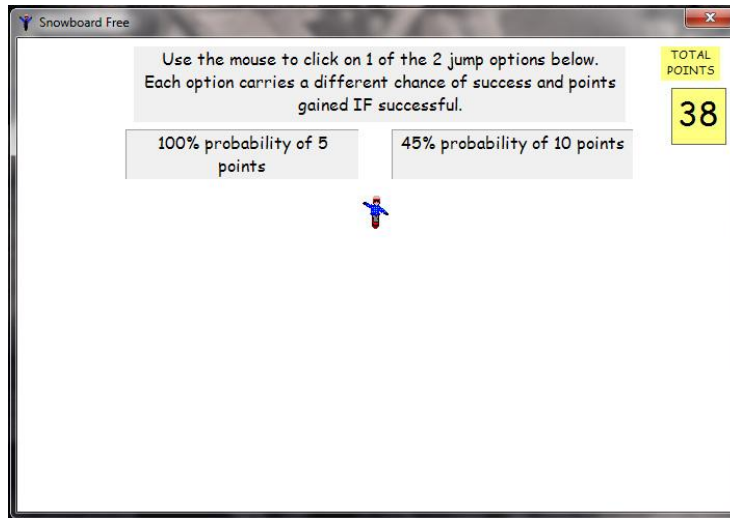


Figure 2.2. Screen capture of choice component in the probability discounting task, presenting the probabilities of the two alternatives for that particular trial. Participants selected one of the options by clicking on the box of the preferred alternative. Choice of the left alternative resulted in certain and immediate outcome delivery. Choice of the right alternative resulted in an immediate but probabilistic outcome

When a choice was made by clicking on the preferred box, the non-chosen alternative disappeared from view and the skier automatically skied over a jump that appeared on the screen. Following a choice of the certain amount, a text appeared at the bottom saying “SUCCESS!!!! You get X more points”. The total points counter was updated immediately, and the screen returned to the in-game view. If the uncertain option was chosen the skier might fail or succeed with the jump, according to the probability level specified for that jump. After a successful jump the text “SUCCESS!!!! You get 10 more points” appeared at the bottom of the screen. After an unsuccessful jump the text ‘Failure!!!! You get NO points” appeared at the bottom of the screen. In both cases the screen returned to the in-game view and the total points counter was updated.

Choices were always made between a guaranteed smaller amount of points and a larger but probabilistic amount of points. The amount of the smaller alternative and the probability of the larger amount varied across trials. Five probabilities were used (15, 30, 45, 65 and 90 percent) and each was presented ten times in a pseudo-random order, for a total of 50 trials. The probabilistic amount was always 10 points. On the first trial of each probability the value of the

guaranteed amount was always half the uncertain amount. On subsequent trials at that probability the value of the certain amount titrated based on the participant's preceding choice. If the guaranteed alternative had been chosen, it decreased in the subsequent trial of that probability. If the uncertain alternative had been chosen, the guaranteed amount increased in the next trial of that probability. The change in the guaranteed amount was adjusted as a proportion of the large uncertain alternative, in increments or decrements of 10%. The minimum was constrained at 10% and the maximum at 100% of the large amount.

The inter-trial interval in the probabilistic task was fixed to 15 seconds. After fifty trials had been completed a 'thank you for participating' text box appeared on the screen and participants alerted the researcher that the game was over.

Temporal discounting task

The in-game component of the tasks did not differ (Figure 2.1), and the objective of both was to gain points by skiing over moguls. Only the nature of the trials and the inter-trial interval differed between the probabilistic and temporal tasks.

Written instructions for the temporal game were as follows:

You are a 'ski boarder' competing for points. The object of the task is to gain as many points as possible. You gain points for each jump you make over 'moguls' which look like (*image of a mogule shown here*). You lose points for running in to trees or rocks.

Every so often you get to make a 'free run' at a jump platform. Before making such a jump you must choose ONE of TWO possible jump scenarios. One option results in maximum points for the jump but it will take longer to do. The other option will give you less points but will be quicker to do. Use the mouse to click on the option you wish to choose. You move the player around using the DOWN, LEFT and RIGHT arrows. You can only move left or right, straight down, or at an angle downwards (make sure you spend some time at the start trying out the keys in order to become familiar with movement).

As in the probabilistic task, participants were told that they would be given fifty 'free run' jumps during the game. If the participants had no questions, they clicked a button on the

computer screen to start the game when ready. If participants had questions, the written instructions were repeated verbally.

Consistent with the probability version, the game commenced with the ‘in game’ context. The points gained and lost for collisions were the same across the tasks; five and two points, respectively.

During the choice phase (see Figure 2.3) a text box at the top of the screen read ‘Use the mouse to click on 1 of the 2 jump options below. Each option gives a different number of points and takes a different amount of time to complete’. The two alternatives were presented in boxes below this. The alternative on the left was always immediate but varied in size. The alternative on the right varied in its delay, between 1.5 and 12 seconds, but was always worth the same amount of points.

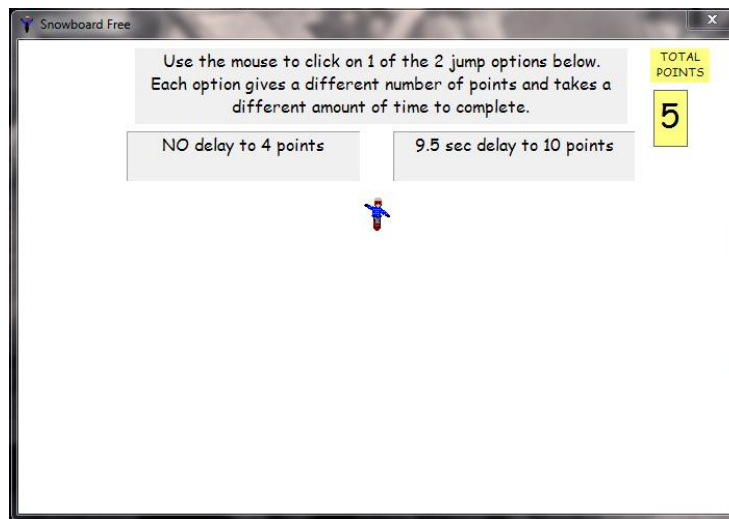


Figure 2.3. Screen capture of choice component of temporal discounting task. Participants selected one of the options by clicking on the box of the preferred alternative. Choice of the left alternative resulted in immediate outcome delivery. Choice of the right alternative resulted in a waiting period and then outcome delivery.

Following a choice of the immediate amount, the other choice box disappeared from view and another box appeared at the bottom of the screen saying ‘You get X more points’. The total points counter was updated immediately, and the screen returned to the in-game view. Following a choice of the delayed amount the immediate choice box disappeared but the screen remained for the given delay. One and a half seconds before the end of the delay a jump appeared over which the skier moved. A text box then appeared at the bottom of the screen saying ‘You get 10 more points’ and the total points tally was updated before the screen returned to the in game context. When fifty trials had been completed a ‘thank you for participating’ text box appeared on the screen and participants alerted the researcher that the game was over.

Choices were always between an immediate smaller amount of points and a larger but delayed amount of points. The amount of the smaller alternative and the delay to the larger amount varied across trials. Five delays were used (1.5, 4, 7, 9.5 and 12 seconds) and each was presented ten times in a pseudo-random order, for a total of 50 trials. The delayed amount was always 10 points. The value of the immediate amount was always half the delayed amount on the first trial of each delay. On subsequent trials at that delay the value of the immediate amount titrated based on the participant’s preceding choice. If the immediate alternative had been chosen, it decreased in the subsequent trial of that delay. If the delayed alternative had been chosen, the immediate amount was increased in the next trial of that delay. Like in the probability task, the change in the small amount was adjusted as a proportion of the large option, in increments or decrements of 10%. The minimum was constrained at 10% and the maximum at 100% of the large amount.

The two tasks also differed in the inter-trial interval. Although the skier was returned to the in-game context following the choice in the temporal task, an adjusting delay commenced during which fewer moguls were available and points could not be gained or lost for skiing over moguls and crashing into trees or rocks. The average number of jumps shown on the screen during the adjusting delay was always reduced from five to one, but the duration of the delay depended on the choice just made. Following an immediate choice the adjusting delay was at its longest, at 15 seconds. Following a delayed choice, this 15 second delay was shortened by the delay specified in the choice. For example, if a participant had chosen the delayed amount of points at 7 seconds, the adjusting delay of 15 seconds was decreased by 7 seconds. The adjusting delay was the shortest, at 3 seconds, following a delayed choice with a 12 second delay.

Once the adjusting delay had elapsed a fixed delay of 17 seconds commenced during which points could once again be gained and lost for moguls and crashes. This combination of an adjusting delay without access to reinforcement and punishment and a fixed delay with access ensured that both overall rate of reinforcement and time in task was kept equal, irrespective of choice patterns.

Preliminary discounting data screening and fitting the functions.

Indifference points were established for both tasks by averaging the values of the immediate or guaranteed amounts of points of the last two trials at each delay or probability. Examination of choice patterns in pilot studies showed that by this number of trials a stable pattern of responding had been reached, indicating indifference between the two alternatives. The choice patterns across each of the delays and probabilities in the current data set were also examined to determine whether indifference points accurately reflected the data.

Microsoft Excel Solver® was used to fit the exponential (Equation 1), hyperbolic (Equation 2) and hyperbola-like (Equation 3) discounting functions to the individual indifference points. Area under the curve was also calculated as described in Myerson, Green and Warusawitharana (2001).

Procedure

Participants completed both the temporal and the probabilistic versions of the experiential choice task, half completed the temporal discounting task first and the other half completed the probability discounting task first.

The data provided by these participants was used in two studies of this thesis, Study 1a and Study 1b. In Study 1a, the model fits of the three most commonly used equations were tested. Participants also completed a hypothetical delay discounting task and completed self-report measures of impulsivity and risk behaviour. These data were used in Study 1b to investigate the relationship between experiential probability and delay discounting, hypothetical discounting and self-reported impulsivity.

Results

Data exclusion

Participants were excluded based on the criteria specified by Johnson and Bickel (2008). If any indifference point was greater than the preceding point by 20% of the delayed outcome (2

points), or if the decrease in value between the first and the last indifference point was less than 10% of the delayed outcome (1 point), the participant was excluded from analysis. Seventeen participants were excluded based on these criteria.

Manipulations to data

Tests of normality (Shapiro Wilk) on discounting parameters of both tasks showed that only the AUC measure in the temporal task was normally distributed (all other $ps < .05$). Log 10 transformations normalized the data of the hyperbolic discounting rates on both tasks, exponential discounting rate on the probabilistic task and the AUCs (all other $ps < .05$). Because normality was not achieved for all variables, all test were conducted on original non-logged data using non-parametric tests.

Testing model fits on the temporal task

Model fits were evaluated on the basis of the adjusted R-square, Mean Squared Error (MSE), and residuals. The MSE was used in addition to R^2 because the latter measure is influenced by the data range and thus correlated with degree of discounting (Johnson & Bickel, 2008). Analysis of all subjects showed significant correlations between discounting rate and R^2 in both the temporal ($r_s(71) = .351, p < .05$) and probability tasks ($r_s(71) = .283, p < .05$). However, because R^2 is the measure of fit most commonly used in the discounting literature, this was included for the sake of comparability to established literature with question based tasks.

Medians and interquartile ranges of the MSEs and adjusted R^2 for each of the functions on the temporal task are shown in Table 2.1. The best fit according to the MSE was achieved by the hyperboloid model, closely followed by the exponential. A Friedman test of the model fits showed a significant difference in MSE in the temporal task, $X^2(2) = 70.483, p < .001$. Post hoc Wilcoxon Signed Ranks Tests showed that the MSE of the hyperbolic function was significantly different from the MSE of the hyperboloid function ($Z = -6.624, p < .001$) and the exponential function ($Z = -5.199, p < .001$) but that the hyperboloid and exponential MSEs were not significantly different, using bonferroni correction for number of tests ($Z = -2.102, p = .036, ns$).

Table 2.1

Medians and interquartile ranges of the Mean Square Errors and adjusted R^2 fits from individual data of hyperbolic, hyperboloid and exponential discounting functions in the temporal task.

	MSE		Adjusted R^2	
	Median	IQ range	Median	IQ range
Hyperbolic	1.907	2.712	.724	.182
Hyperboloid	1.282	2.039	.78352	.208
Exponential	1.329	2.031	.824225	.156

In contrast to the MSEs, the adjusted R^2 of the temporal task showed a superior fit of the exponential model over the other functions. The adjusted R^2 penalises for the addition of a free parameter and because the fits were strikingly similar between the exponential and hyperboloid functions (as shown in Figures 2.4 and 2.5), the adjusted R^2 produced a worse fit for the two parameter model. A Friedman test was significant ($X^2(2) = 51.621$, $p < .001$). With bonferroni correction for number of tests, the difference between the hyperboloid and hyperbolic was not significant ($Z = -2.071$, $p = .038$, ns), but the exponential model had a significantly better fit than both the hyperboloid ($Z = -4.278$, $p < 0.001$) and the hyperbolic functions ($Z = -4.185$, $p < 0.001$).

Examination of the means of individual residuals at each of the five delays (Figure 2.4, left panel) showed that there were systematic variations from all three models. At short delays the functions underestimated subjective value, whereas they overestimated value at the longer delays. The overestimation became progressively worse at longer delays in the hyperbolic function.

Testing model fits on the probability task

Medians and interquartile ranges of the MSEs and adjusted R^2 fits for each of the functions on the probability task are shown in Table 2.2. A Friedman test on this task also showed a significant difference in MSEs across functions, $X^2(2) = 67.483$, $p < .001$. Post hoc Wilcoxon

Signed Ranks Tests showed that the MSEs of the hyperboloid function differed significantly from the hyperbolic ($Z = -6.624$, $p < .001$) and the exponential functions ($Z = -6.275$, $p < .001$), and that the hyperbolic differed from the exponential ($Z = -4.417$, $p < .001$), using bonferroni correction for number of tests.

Table 2.2.

Medians and interquartile ranges of the Mean Square Errors and adjusted R^2 fits of individual data for hyperbolic, hyperboloid and exponential discounting functions in the probabilistic task.

	MSE		Adjusted R^2	
	Median	IQ range	Median	IQ range
Hyperbolic	1.036	1.093	.799751	.230
Hyperboloid	0.508	.899	.85506	.205
Exponential	1.626	1.689	.715222	.525

In the probability discounting task the adjusted R^2 showed a similar pattern to the MSEs. Despite the addition of a free parameter, the hyperboloid function still provided a better fit than the exponential and hyperbolic functions, confirmed with a Friedman test ($X^2(2) = 24.517$, $p < .001$) and post hoc Wilcoxon Signed Ranks tests ($Z = -4.750$, $p < .001$, and $Z = -2.969$, $p < .05$, respectively). In addition, the fit of the hyperbolic function differed significantly from the exponential ($Z = -5.176$, $p < .001$).

Examination of the residuals in the probability discounting task (Figure 2.4, right panel) showed that the exponential function underestimated subjective value at low probabilities, but overestimated value at high probabilities. Note that residuals are presented from low probability to high probability, not ‘high odds against’ to ‘low odds against’, for sake of clarity and comparability with the temporal discounting residuals. The residuals were not as systematic in either the hyperbolic or hyperboloid functions. Both functions underestimated values at the lowest probability, but the hyperboloid also underestimated value of the highest two probabilities, whereas hyperbolic showed very small residuals at these two points.

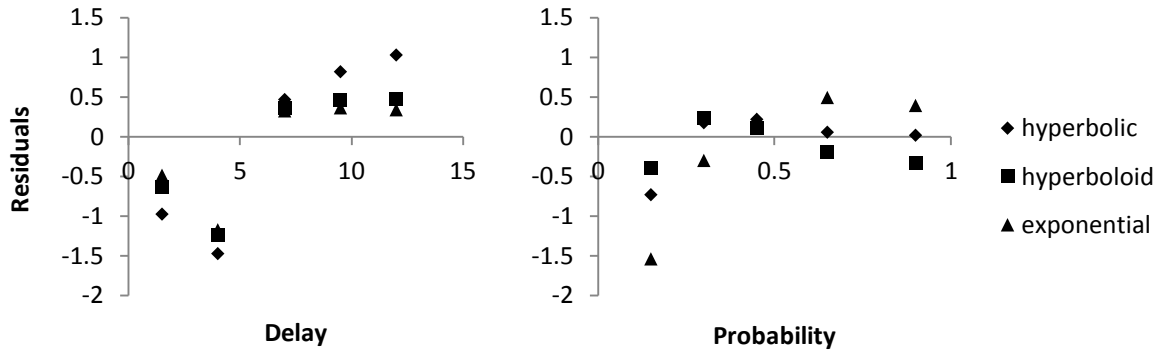


Figure 2.4. Mean residuals as a function of delay on the temporal task (left panel) and probability of success on the probability task (right panel).

Comparisons of the measures of fits and the residuals across the two tasks showed that both hyperboloid and hyperbolic models fit better in the probability version than the temporal version, according to both MSE ($Z = -3.651$, $p < .001$; $Z = -3.225$, $p < .001$) and adjusted R^2 fits ($Z = -3.039$, $p < .05$; $Z = -2.009$, $p < .05$). Fits across the task using the exponential model showed no significant difference in MSEs ($Z = -1.026$, $p = .305$), but a significant difference in R^2 ($Z = -2.567$, $p < .05$). Overall, this suggests that the three models described indifference points of individuals better in the probability task.

Figure 2.5 shows examples of indifference points and the best fitting functions of individuals at the 25th, 50th and 75th quartiles in the temporal (left panels) and probability tasks (right panels). In all cases, these individuals were selected based on the R^2 fit of the hyperboloid function.

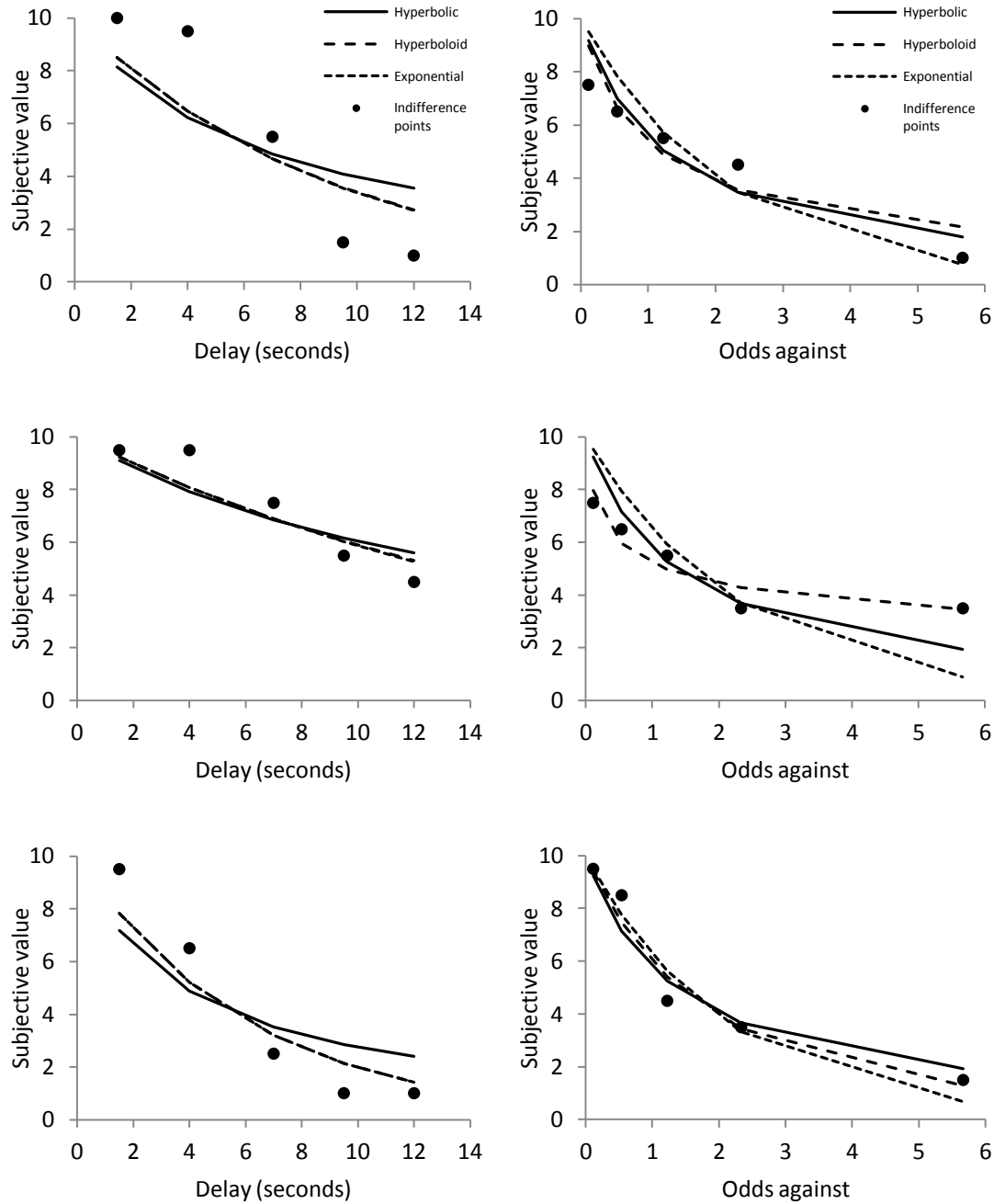


Figure 2.5. Individual indifference points as a function of delay (left panels) and odds against (right panels) and their best fitting functions. The individuals at the 25th (top row), 50th (middle row) and 75th (bottom row) quartiles for the fits of the hyperboloid discounting function are shown.

Group data

Group discounting functions were fit to median individual indifference points. The MSEs and adjusted R^2 fits for both tasks are shown in Table 2.3. Group level analysis revealed similar results to the analysis of individual measures of fit. Fits to the grouped data on the temporal task were best for the exponential function according to both MSE and R^2 measures, although the difference between the hyperboloid and exponential functions were minimal in both cases. In the probability task the hyperbolic and hyperboloid functions performed equally well, and the exponential had a slightly worse fit.

Table 2.3.

Mean Square Errors and adjusted R^2 fits of group hyperbolic, hyperboloid and exponential discounting functions in the temporal and probability discounting tasks.

	MSE		Adjusted R^2	
	Temporal	Probability	Temporal	Probability
Hyperbolic	1.981	.150	.776	.980
Hyperboloid	1.000	.150	.887	.980
Exponential	.993	.684	.888	.910

Median indifference points and best fitting functions for the temporal task are shown in Figure 2.6. There is considerable overlap in the shape of the exponential and hyperboloid functions in this task, accounting for the great similarity in the measures of fit.

Median indifference points and best fitting functions for the probability task are shown in Figure 2.7. The very high overlap between the hyperbolic and hyperboloid functions that produced equivalent fits in both measures is clearly visible.

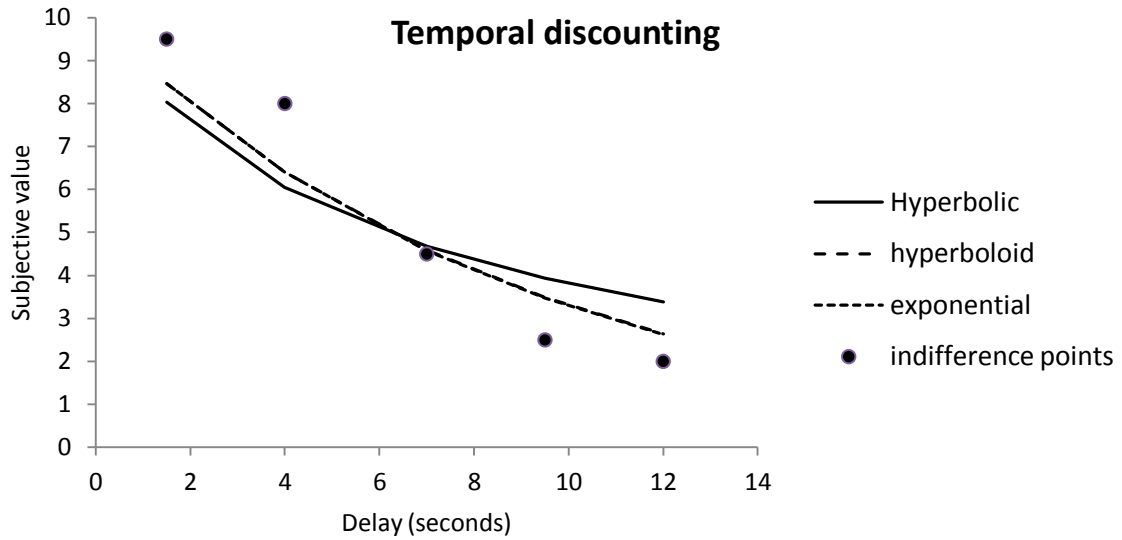


Figure 2.6. Median group indifference points as a function of delay and the best fitting hyperbolic, hyperboloid and exponential discounting functions.

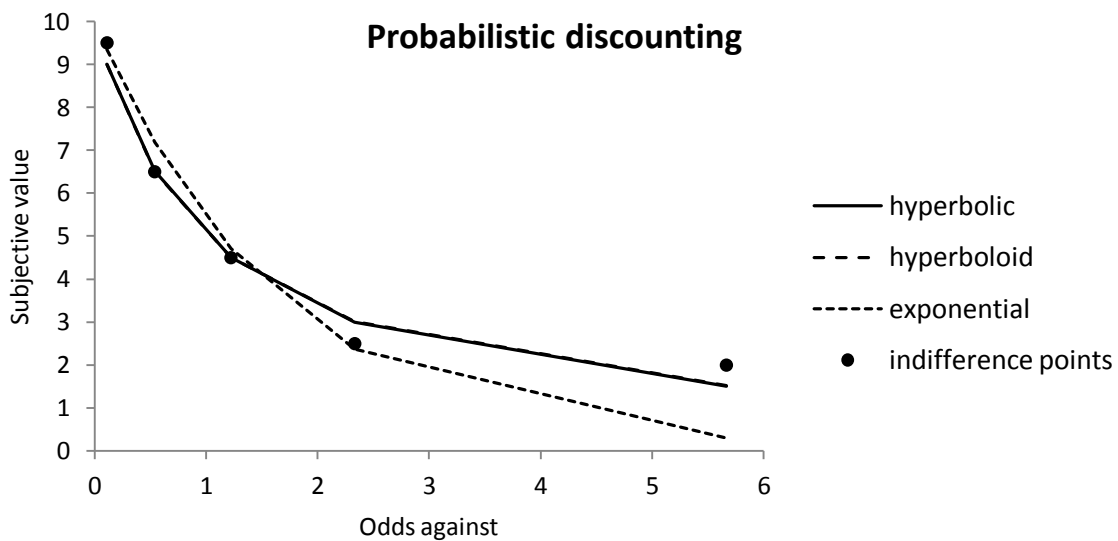


Figure 2.7. Median group indifference points as a function of odds against and the best fitting hyperbolic, hyperboloid and exponential discounting functions.

In conclusion, individual and group level analysis suggested that the hyperboloid model described both types of discounting well, but evaluation of the models on the basis of the residuals, MSE and R^2 fits also showed some interesting differences across tasks in the single parameter model fits. The hyperbolic model provided a good fit in the probability discounting task, whereas it performed slightly worse in the temporal task. Individual data showed that unlike the probability task, in which the hyperboloid performed consistently better than the other two models, the differences between the exponential and hyperboloid models were negligible in the temporal task. Although it provided a good description of the data, the hyperboloid model did not improve the fit over the exponential model enough to warrant the addition of the free parameter in the temporal task. In the probability task, however, the two parameter model provided a much better fit than either of the other two models. Despite differences across tasks in the single parameter model that best described indifference points, further examination of the hyperboloid model suggested that, for the purposes of this thesis, use of a single parameter model would be more appropriate than the two parameter model.

Examination of hyperboloid parameters

Fitted to indifference points of hypothetical choice tasks, dependence between the parameters of the hyperboloid model is often above .80 (Myerson, Green & Warusawitharana, 2001). In the current study, hyperboloid k and s values were very highly negatively correlated in both the temporal ($r_s(56) = -.975, p < .001$) and the probability tasks ($r_s(56) = -.852, p < .001$). The high correlation between parameter estimates prompted further examination of individual data.

Given similar s estimates, as in Figure 2.8, k described the discounting rate well. Indifference points show that Individual 3 clearly discounted delayed rewards to a greater extent than Individual 2 and 1, and that Individual 2, in turn, discounted more than Individual 1. These relative differences are reflected in their k estimates, where k becomes progressively larger from Individual 1 to Individual 3. However, Figure 2.9 illustrates a problem of the hyperboloid k parameter as a measure of discounting rate when s varies. Visual analysis of indifference points of Individual 4 (top panel) indicate steeper discounting relative to Individual 5 (bottom panel) and both AUC values and single parameter models are consistent with this conclusion. The AUC is smaller and both hyperbolic and exponential k values are greater for Individual 4. In contrast, the hyperboloid k parameter, which is meant to capture discounting rate, indicates that Individual 4 discounted less than Individual 5. This occurs because the change in indifference points across

delays is captured differently by the s parameter. For a given k value, an s estimate of less than 1 allows for shallower decreases in subjective value at long delays relative to initial decreases in value, as seen by Individual 5 (bottom panel). Both Individual 4 and 5 show initial drops in value, but Individual 5 shows a smaller decrease in value over subsequent delays, where an outcome even at 12 seconds has a subjective value of almost half the delayed amount. Relative to the outcomes at short delays, where little discounting occurred, Individual 4 on the other hand discounted the outcomes at the long delays close to the point of no subjective value. The minimal k estimate accounts for the initially shallow discounting, while the scaling parameter describes the subsequent relatively steep drop at the longer delays. This illustrates that when s varies, as in Figure 2.9, k on its own is not an appropriate measure of discounting rate.

Degree of Discounting

Medians and interquartile ranges of discounting rate are presented in Table 2.4 and 2.5 for the temporal and probability tasks, respectively. Discounting was steeper on the probability task based on both hyperbolic and exponential measures and had a larger spread. Using only the single parameter models, two Wilcoxon Signed Ranks tests confirmed that discounting was steeper in the probability task than the temporal task as measured by both hyperbolic ($Z = -6.523$, $p < .001$) and exponential k values ($Z = -6.546$, $p < .001$).

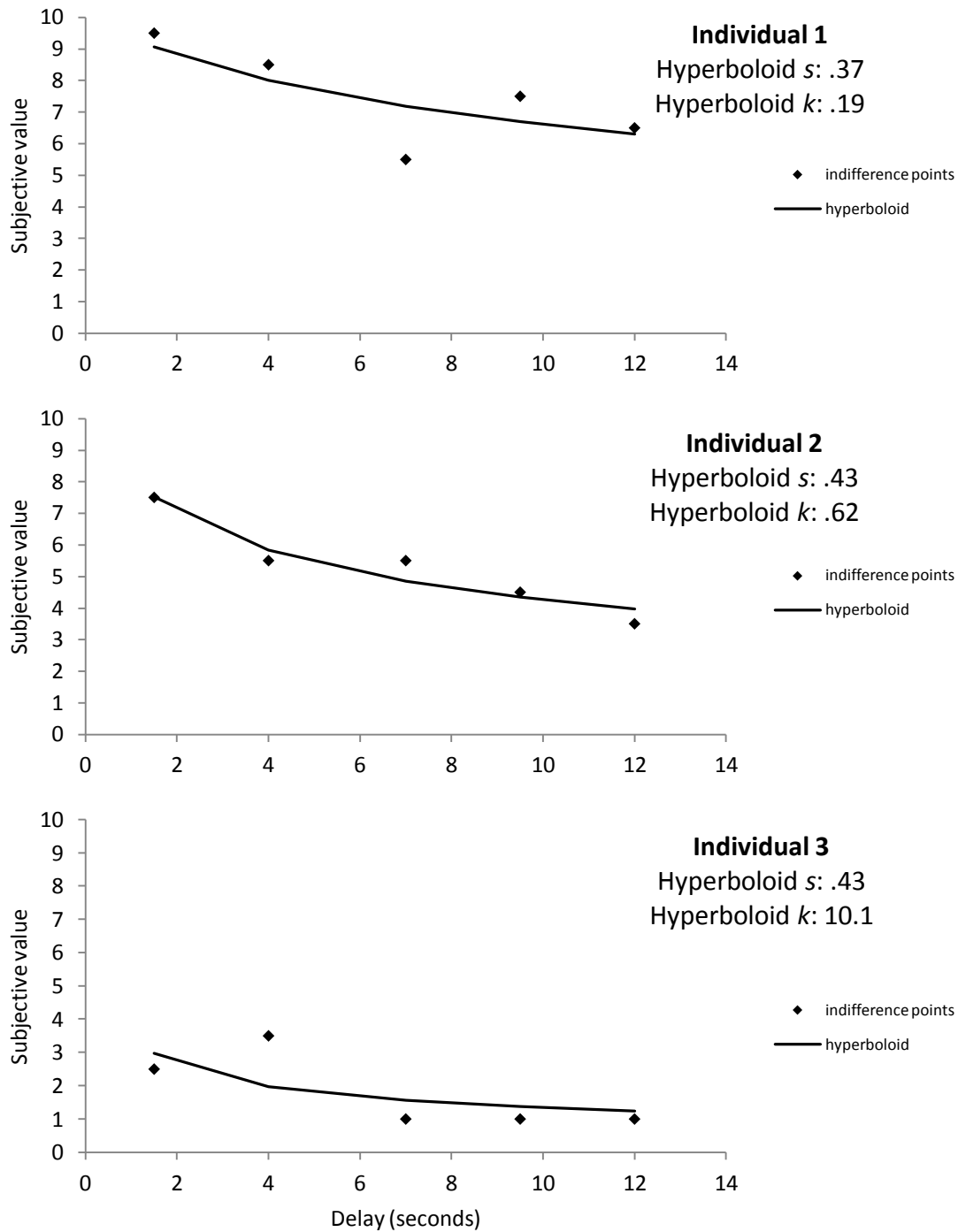


Figure 2.8. Examples of individual indifference points and best fitting hyperboloid model where s values are approximately the same, but estimates of k vary. Top panel shows shallow discounting, middle panel moderate discounting, and bottom panel steep discounting.

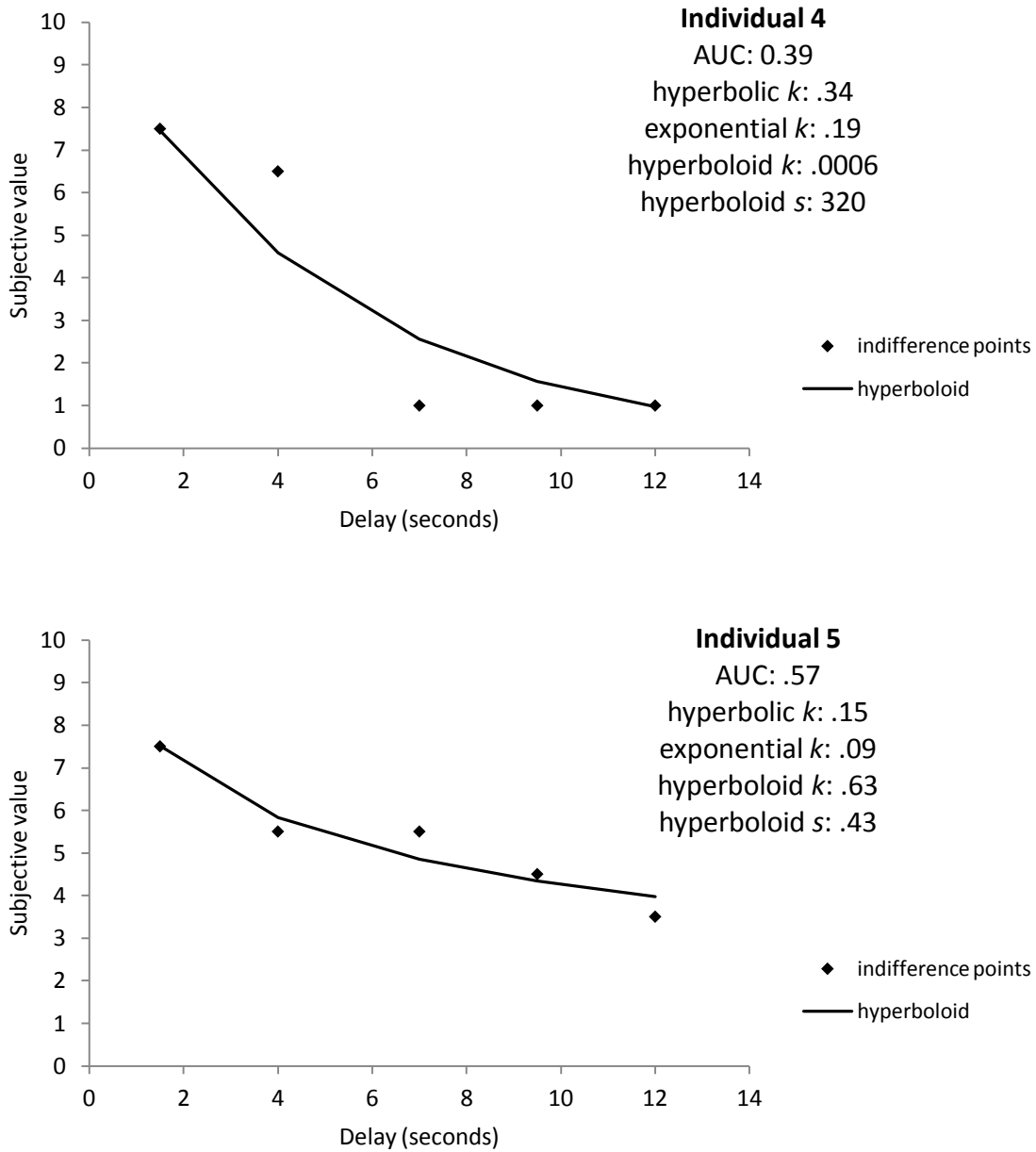


Figure 2.9. Examples of individual indifference points and best fitting hyperboloid model, where both s and k vary such that k on its own is not a good descriptor of discounting rate.

Table 2.4.

Medians and interquartile ranges of individual discounting parameters in temporal discounting task.

	Median	Interquartile range
Hyperbolic k	.171	.157
Hyperboloid k	.0014	.007
Hyperboloid s	59.91	263.391
Exponential k	.116	.080

Table 2.5

Medians and interquartile ranges of individual discounting parameters in probability discounting task.

	Median	Interquartile range
Hyperbolic k	1.047	1.429
Hyperboloid k	1.722	8.088
Hyperboloid s	.650	1.222
Exponential k	.634	.812

Directly comparing discounting rate across conditions using the hyperboloid model is not appropriate because of the parameter interdependence and the influence of s on the discounting rate parameter, as discussed above. However, the descriptive statistics showed that in the temporal task median hyperboloid discounting rate approached zero and the median scaling parameter was greater than 1, with a considerable spread, whereas the median of the scaling parameter in the probability tasks was less than 1 and its spread was much smaller than in the temporal task.

Area under the curve (AUC) analysis

Myerson et al. (2001) developed a theoretically neutral measure of discounting rate based on the area under the indifference points. This area under the curve measure (AUC) avoids the problems of dependent parameters and has been used in addition to parameter estimates as a description of discounting. The AUC has been praised for its theory free and data driven nature, and it is often used because it avoids introducing systematic variation that occurs when fitting

models to data. Residual analyses showed that all three discounting equations underestimated subjective value at short delays and overestimated subjective value at long delays. Because the AUC measure is determined directly by indifference points, systematic deviation such as this does not influence the resulting measure of discounting. Table 2.6 presents the medians and interquartile ranges of AUCs in both tasks. Consistent with single parameter estimates of k , the AUCs show steeper discounting (smaller AUCs) to uncertain outcomes than to delayed outcomes. A Wilcoxon Signed Ranks test confirmed that discounting was steeper in the probability task than the temporal task in AUC ($Z = -5.424$, $p < .001$).

Table 2.6

Medians and interquartile ranges of AUCs in temporal and probability discounting tasks.

	Median	Interquartile range
Temporal task	.569	.228
Probability task	.345	.193

Furthermore, in the current sample AUCs and hyperbolic k values were highly negatively correlated in both the temporal ($r_s(58) = -.997$, $p < .001$) and probability tasks ($r_s(58) = -.947$, $p < .001$), suggesting that AUC captured differences in discounting rate across individuals consistent with model descriptions.

Discussion

This study introduced an experiential discounting procedure in which participants experienced the outcome of each choice prior to making the next choice. Two versions of the task were used, one examining temporal discounting and the other probability discounting, and three commonly used models of discounting were fit to individual and group indifference points. In summary, initial analyses of model fits showed that both probability and temporal indifference points were well described by the two parameter hyperboloid model proposed by Myerson and Green (1995). Further analyses, however, showed that the parameters of the hyperboloid model were not reliable and that use of one of the single parameter models would be more appropriate. Discounting of probabilistic outcomes was well described by the one parameter hyperbolic model whereas discounting of delayed outcomes was well described by the exponential

discounting model. Indifference points were also examined using the AUC analysis, and the AUC measure was correlated with single parameter k values in the current sample.

AUC Analysis

The only study to have examined both temporal AND probabilistic discounting using experiential tasks (Scheres et al., 2006) did not focus on model comparison but used the AUC analysis. This theoretically neutral approach was developed to enable comparisons that avoid introducing error through systematic deviation between indifference points and fitted models, but also to facilitate comparisons of discounting rates when the fitted model includes more than one free parameter, such as the hyperboloid function (Myerson et al., 2001).

AUC analyses were also conducted in the current study, and found to be consistent with estimates of single parameter k values, as evidenced by significant correlations within each task. Despite the consistency between discounting rates and AUC analysis in the current study, the AUC has two limitations. Firstly, although it avoids introducing systematic error, it is a measure purely of area and is therefore insensitive to differences in the *shape* of the indifference points. A continuously decreasing value of indifference points can produce a highly similar AUC value to indifference points that barely change across delays or odds against. Indeed, although it is unlikely to occur, a similar value could be produced by continuously increasing indifference points. This means that the AUCs of two individuals can be nearly identical even though their indifference points, and discounting parameter estimates, differ. This is illustrated in Figure 2.10.

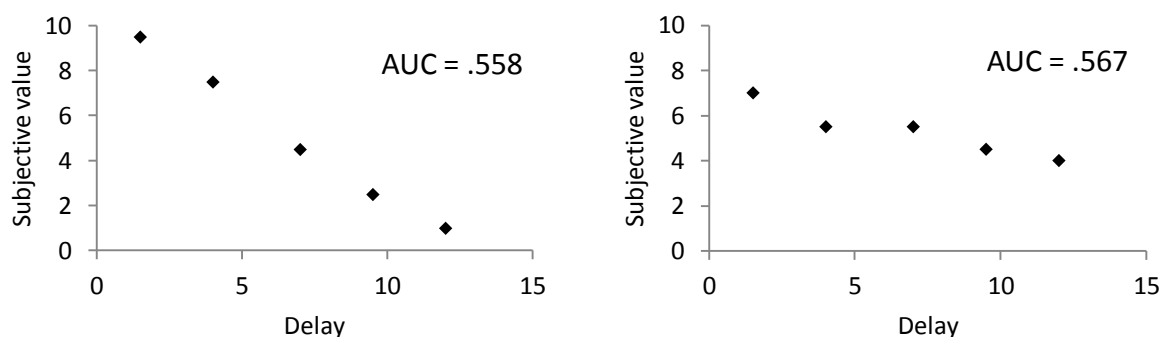


Figure 2.10. Illustration of AUCs insensitivity to shape differences in indifference points.

Another limitation of the AUC is its lack of theoretical strength. By design a theoretically neutral measure, the AUC does not imply theoretically relevant predictions regarding the data.

The exponential, hyperbolic and hyperboloid models all have theoretical boundaries by which they can be tested and compared. For example, the often cited reasons in favour of hyperbolic discounting are the superior fits to both human and animal indifference points, and that a non-constant decrease in value predicts preference reversals without any additional assumptions, which the constant decrease predicted by the exponential function does not. The AUC does not do this, but simply provides a single measure of discounting that can be used to compare individuals and groups.

The strong correlation between discounting rates and AUC suggest that while it does a satisfactory job of describing the decrease in subjective value, its limitations as a theoretical tool make it a rather superfluous measure in addition to fitted models, at least for the purposes of this thesis. In following studies, therefore the AUC measure will not be included in the analysis.

Overall model fits

Residual analysis of the models fit to probabilistic indifference points revealed less systematic error for the hyperbolic and hyperboloid models than the exponential. In contrast, residuals were in favour of the exponential and hyperboloid models in the temporal task. Myerson and Green (1995) and more recently McKerchar et al. (2009) showed that the models (and the exponential function in particular) tend to overestimate value at short delays and underestimate at long values. Contrary to their results all models in the current study underestimated value at short delays and overestimated value at longer delays. This could have to do with the difference in the range of delays used across experiential and question based measures, and illustrates the importance of investigating discounting at shorter delays than what has been done with question based measures.

Comparing across the two tasks, residuals for the hyperbolic and hyperboloid models were less systematic and their measures of fit better in the probability discounting task. This pattern, whereby the exponential model fared worst, is consistent with the literature (Myerson & Green, 1995). However, the ability of the exponential model relative to the others in the delay discounting task was surprising. This will be discussed further below.

Overall, R^2 -values were slightly lower than those produced with question based measures (e.g. Myerson & Green, 1995; Johnson et al., 2007), but in comparison to previous experiential choice tasks the best fits were of comparable size. Reynolds and Schiffbauer (2004) reported

median R^2 -values close to 0.8 using their experiential discounting task, which is slightly lower than those found in the current experiment. Studies that have used both experiential and question based tasks have produced slightly lower fits to the former. Lane et al. (2003) compared responding across three discounting tasks, one experiential and two hypothetical. The hypothetical tasks differed in their delays and reward sizes, with the longest delays 90 days and 25 years in the compressed and standard tasks, respectively, and delayed reward sizes of \$150 and \$1000, respectively. In their experiential task the longest delay was 90 seconds and the delayed reward size \$0.15. They reported a median R^2 in the experiential task of .830, comparable in size to that of the best fitting model in the current study and an R^2 of .9 in their standard hypothetical measure. Similarly, Reynolds et al., (2006) compared discounting in experiential and question based (potentially real) tasks and reported R^2 -values of approximately 0.7 in the experiential and 0.8 in the question based one. Fits in the current study's experiential task were greater than their experiential tasks and comparable to fits in their question based measure.

It should also be noted that the experiments described above used only the hyperbolic equation in their analyses, whereas equations of varying complexity were compared in the current study. Adding a second parameter to a model will increase its ability to account for data and use of the simple R^2 measure would therefore likely favour the hyperboloid model over the two single parameter models. Therefore, we used the adjusted R^2 to account for the addition of the s parameter to the simple hyperbolic model. Previous literature in which equations of different complexity have been compared using the R^2 measure have not indicated whether this approach has been used or not, but some have used other tests of fit such as Aikake's Criteria (e.g. Odum et al., 2006).

In conclusion, visual analysis of individual subjects showed that the subjective value of delayed point gains in the context of a skiing task did decrease systematically. Residual analysis and indicators of fit also demonstrated that established discounting models described this loss of value well and at comparable levels to traditional question based research. This provided initial support for the use of the skiing task as a measure of discounting.

Hyperboloid temporal discounting

The hyperboloid model has been used to describe discounting of both delayed and uncertain outcomes in past research, but primarily using hypothetical outcomes. Jimura, et al. (2011) found that the hyperboloid model fit discounting of real juice rewards, but most other studies using experiential tasks have used the one parameter hyperbolic equation. The behaviour of the model in the probabilistic skiing task was consistent with this prior research, as discussed further in the section on probability discounting below.

In contrast, the temporal discounting data produced some noteworthy results regarding the two parameter model. Firstly, the two parameters in the hyperboloid model were almost perfectly correlated. Although Myerson, Green and Warusawitharana (2001) noted a common interdependence of the estimates, this was done as a justification for using the AUC to investigate changes in discounting rate across conditions, not as a discussion of a problem in the model itself. With two such highly correlated free parameters, the k parameter alone fails to consistently describe relative discounting rate across individuals.

Secondly, estimates of s in the temporal task were different from what is usually found. An exponent greater than 1 is not inconsistent with its interpretations as a psychophysical scaling parameter if, as posited by McKerchar et al. (2010), it represents the ratio of two psychophysical scaling functions. Individually they should be less than 1, but the ratio itself is not constrained. However, estimates of less than 1 are usually reported. McKerchar et al. reported that 36 out of 64 participants showed s values significantly less than 1. In the current experiment, only 8% of individual s values in the temporal task were less than 1. In our temporal task, the indifference points produced large s values and estimates of k very close to 0. An s value of less than 1 steepens the decrease at short delays and shallows the decrease down at long delays for the same value of k , producing a ‘super hyperbolic’ shape. In the current study larger s values and k values approaching 0 accommodated a more exponential shape and, in comparison to the single parameter exponential model, it failed to significantly decrease MSE or increase adjusted R^2 values. This suggested that the addition of a second parameter was not warranted.

Due to the inter-dependence of the parameters in the hyperboloid function, and its otherwise equivalent performance to the single parameter, it was not considered a valid function to use for the current procedure.

Hyperboloid probability discounting

As noted, the data from the probability discounting task showed greater consistency with previous probability discounting literature. The hyperboloid and hyperbolic functions provided good fits to indifference points, and the hyperboloid function performed better than the single parameter models even when the additional free parameter was taken into account.

As with the delayed outcomes, the probabilistic k and s parameters were significantly correlated. However, the strength of the correlation was at the lower end of what Myerson et al (2001, p.238) noted is common for the model. Furthermore, group median estimates of s were less than 1 and 60% of subjects had s values of less than 1, in greater accordance with that found using question based tasks (Green & Myerson, 2004) and consistent with predictions by Green, Myerson and colleagues.

Although the two parameter hyperboloid function performed well with uncertain rewards, its use would limit the comparability with delay discounting, for which it was unsuitable, particularly given the interdependence of the parameters in both outcome types.

Exponential temporal discounting

An unexpected result was the good fit of delay discounting data to the exponential model. Most animal and human discounting literature has favoured the hyperbolic function. But there are two studies that have shown superior performance of the exponential function. Both of these experiments made use of novel procedures to elicit discounting. Schweighofer, Shishida, Han, Okamoto, Tanaka, Yamawaki et al. (2006) measured participants' preferences for one of two boxes that were filled with black and either white or yellow patches. Each box was filled progressively with more non-black patches when a participant selected it and the end of a trial occurred when one of the boxes was completely filled with non-black. A box with white patches represented the small reward (5 Yen) and a box with yellow patches represented the large reward (20 Yen). It took less time to fill the small reward box than the large reward box, but in each case the selection of a box was associated with a 1.5 second delay before the chosen box increased the proportion of white/yellow. Each trial therefore consisted of at least 1 selection step. Once a box was completely filled the reward size was shown during a 1.5 second ITI. The task duration was fixed at 700 steps (including ITIs). Using this novel procedure, Schweighofer et al. found that

participants distributed their choices in a way consistent with the exponential model and by doing so maximized total task reward.

These experiments show that it is not completely without precedent that human discounting could be exponential, but they do suggest that this type of behaviour could be task dependent, or at least that participants sometimes discount exponentially. Schweighofer et al. (2006) suggested that humans discount exponentially when such discounting, rather than hyperbolic discounting, maximizes total gain. In the current experiment however, participants would maximize gain by responding with exclusive self-control. Indeed, prior to exclusion of participants, less than five participants showed this pattern of behaviour. Could it be, alternatively, that experiential tasks such as the skiing game and the box task of Schweighofer et al, result in exponential discounting and that the overwhelming support for hyperbolic discounting is a function of hypothetical choice tasks? No, this does not appear to be the case since other experiential tasks show good fits to non-constant discounting. The EDT (e.g. Reynolds & Schiffbauer, 2004) produced data better fit by the hyperbolic function than the exponential, as did a real reward condition by Lagorio and Madden (2005). Other experiential tasks have been conducted in which tests comparing fits have not been conducted (e.g. Scheres et al. 2006; Jimura et al., 2009). Jimura et al. however, showed that the hyperboloid model fit well to discounting of real juice rewards (median $R^2 = .957$).

There is another possible reason for the superior fit of the exponential function in this particular study, namely the range of delays used. Rachlin et al. (1986) described how probabilistic outcomes can be transformed into average expected delays until successful gambles, using the following formula:

$$D = \frac{(t + c)}{p} - t$$

where D is the average expected delay until a successful gamble, t the delay between choice opportunities, c the duration taken by the actual gamble (duration it takes to make a choice in the case of the skiing game) and p the probability of the outcome. Although Rachlin et al. meant this as a means to calculate the rate of repeated gambles, to find their equivalent delay, it can also be used in reverse to calculate delays equivalent to probabilities. In the probability skiing task we measured discounting at near certainty and near uncertainty (95% to 15%), and we can apply this formula to establish delays equivalent to that range of probabilistic outcomes, given the specific

characteristics of the task. Inter-trial interval (t) in the probability task was 25 seconds and it took participants approximately 2 seconds to respond (c). Applying these figures to the formula, the average expected delay equivalent to the lowest and highest probabilities (15% and 90%) would be 155 and 5 seconds, respectively. In the actual delay discounting task however, the longest delay tested was 12 seconds, equivalent approximately to twice that of the most certain outcome. Therefore, it is possible that the delays were too short to capture the tail end of the hyperbolic function, resulting in a better fit for the exponential model. Determining what range of delays to use in experiential tasks is a balancing act between what is theoretically appropriate and what is practically feasible. The game structure of the skiing task, and the post-reward delays in particular, made use of delays ranging between 5 and 155 seconds impractical. The post reward delay would have to be adjusted for this length, as would the active time in the in-game component, resulting in a very long task. In addition, the longer the post-reward delays the more noticeable they would be, which may have compromised their use.

Although it was unexpected that the exponential model produced a superior fit over the two non-constant models, this finding does not lessen the usefulness of the skiing game as an experiential discounting task. Participants did discount the value of delayed points, and this decrease in value was well captured by a model that has specific theoretical implications. The experiential discounting task can be used to explore these theoretical considerations. For example, the most commonly quoted argument against exponential discounting, aside from the superior fits to discounting data, is that it requires the additional assumption of amount dependence to predict preference reversals (e.g. Green et al., 1994). Question based studies have shown that humans discount smaller rewards more steeply than larger rewards (Green et al., 1997), and Jimura et al. (2009) showed that even consumable rewards produce this effect. What about discounting of points in the experiential skiing task? In the third study of this thesis, the issue of amount dependent discounting was explored further.

Conclusion

This first study established that discounting of both delayed and uncertain point outcomes could be elicited using a task structure in which outcomes were experienced following each choice. The study also revealed differences across the two types of choices. Whereas discounting

of probabilistic outcomes was well described by both non-constant models, delay discounting was best described by a constant decay model.

The second study in this thesis, using the same data as the current experiment, further examined the relationship between value loss of uncertain and delayed outcomes, and whether or not the two were related.

Chapter 3 : Correlation between Temporal and Probability Discounting (Study 1b)

A number of studies have found that probability and temporal discounting rates are positively correlated (e.g. Richards, Zhang, Mitchell de wit, 1999; Crean, de Wit & Richards, 2000), in support of single process views of discounting that posit one fundamental underlying process responsible for discounting of both delayed and uncertain rewards. The specific nature of that process has been debated, and two main accounts have emphasized the role of either risk or delay. Rachlin et al. (1986) described the loss in value of both delayed and uncertain rewards in terms of rate of reinforcement, in that both delayed and uncertain rewards are associated with decreased rates of reinforcement. The opposing view, proposed by Green and Myerson (1996), holds that the fundamental process by which rewards lose their value is through risk. While uncertain rewards are in their nature risky, delayed rewards are risky in that something can occur during the delay to prevent the reward from being delivered.

Both views are supported by evidence. Consistent with the former view, both human and animal subjects are more risk averse with longer inter-trial intervals than with shorter inter-trial intervals (Rachlin et al., 1986; Hayden & Platt, 2007). As inter-trial intervals increase, reinforcer rates decrease, suggesting that the subjective value of repeated uncertain outcomes is indeed influenced by reinforcement rates. In support of the latter account, however, people not only rate delayed rewards as more uncertain than more immediate rewards, but delay discounting rates are positively correlated with uncertainty ratings (Patak & Reynolds, 2007). Uncertainty ratings also differ significantly between smokers and non-smokers (Reynolds et al., 2007), who in turn, differ significantly in temporal discounting rates (Bickel et al., 1999).

Problematic for both accounts are inconsistencies in the magnitude effect across temporal and probability discounting. If a fundamental underlying process underpinned both temporal and probability discounting, the same manipulation should produce similar effects in both. However, whereas large delayed rewards are discounted less steeply than small delayed rewards, large probabilistic rewards are discounted more steeply than small probabilistic rewards (Green et al., 1999).

In light of this inconsistency, positive correlations between probability and temporal discounting rates need to be reevaluated without reliance on single process accounts. One suggestion has been that similarities between temporal and probability discounting tasks, or task spillover effects, have led to an artificially inflated relationship (Myerson et al., 2003; Reynolds

et al., 2003). Indicative of this, significant correlations have mostly been found in studies where temporal and probabilistic choices were either randomly mixed or presented sequentially within a single session (e.g. Reynolds et al., 2003), whereas non-significant results have been produced when discounting rates were elicited in separate sessions (e.g. Crean et al., 2000; Reynolds et al., 2004). The literature review detailed how task structure, such as use of binary, multiple choice or fill in the blank procedures, produced different discounting rates within subjects. Is it possible that some of the overlap between temporal and probability discounting is due to the use of the same format for both types of questions?

Alternatively, it may be the case that the traditional tasks inherently fail to isolate delay from uncertainty due to their hypothetical nature. In these tasks subjects are left to interpret the delay or risk associated with each choice, and at no point do participants have to wait for the delayed reward or experience the outcome of a gamble taken on an uncertain outcome. If progressively more delayed outcomes are viewed as more uncertain and the extent of discounting is related to degree of uncertainty, as shown by Patak and Reynolds (2007), there is already evidence that question based measures fail to disentangle risk from delay. Furthermore, attempts meant to rectify the hypothetical nature of temporal discounting tasks by delivering one real outcome randomly for a number of choices only exacerbates this limitation because doing so explicitly introduces an element of uncertainty into delay discounting tasks. Experiential tasks, in contrast, have the advantage that they do not rely as heavily on participant interpretations of delays and uncertainties. This suggests that experiential tasks may be better suited to investigations aimed at clarifying the relationship between delay and uncertainty.

Although there are a number of experiential tasks, only one study has investigated the relationship between experiential discounting of delayed and uncertain outcomes (Scheres et al., 2006). In the temporal task participants made a choice between two airplanes that differed in the amount of money they carried, and whose height off the ground represented the delays of each alternative; the higher the plane, the longer the delay. Two versions of this task were created, one with adjusting inter-trial intervals and one without. In the probability task, participants made their choices between two piggy banks that differed in the amount of money they contained. The probabilities of each choice were represented by the thickness of the piggy banks shells; the thicker the shell, the lower the probability. The participants consisted of a group of children with ADHD and a control group. A significant moderate positive correlation was found in the ADHD

group, using only the delay task version without the adjusting inter-trial interval. For the control group however, delay and probability discounting rates were uncorrelated.

One problematic procedural characteristic of this study was that rewards were actually delayed in both the temporal and probability tasks because money was delivered only after all trials of the task. Given that adult humans are sensitive to exchange delays over a matter of weeks (Hyten et al., 1994), it is possible that the particularly impulsive ADHD group could have been sensitive even to the short delays involved in waiting for task completion. The experience of a delay even in the probability discounting task leads to the same caveat in this study as in hypothetical or potentially real outcome studies: the significant correlation between discounting of delayed and uncertain outcomes could be the result of confounding delay and uncertainty in task.

In the experiential skiing tasks participants worked solely to gain points within the task, avoiding the confounding factor in Scheres et al. (2006), and the large standard reward was always either delayed or uncertain, never both. Hence, the skiing task was well suited to investigating the relationship between temporal and probability discounting when the two types of outcomes were clearly isolated from each other. The first aim of the current study was to investigate the correlation between temporal and probability discounting using the experiential tasks.

A second aim of the current study was to determine whether or not discounting elicited with the experiential delay task bore any resemblance to discounting using a more traditional question based measure of discounting (Kirby & Marakovic, 1996). In light of Reynolds (2006b), who showed that discounting on the EDT was significantly correlated with question based discounting, discounting rates on the question based measure were expected to correlate with discounting rates on the temporal version of the experiential discounting measure. However, discounting on the probability version was expected to be uncorrelated with question based delay discounting.

Lastly, we also included self-report measures of impulsivity and risk taking. We used the Barratt impulsiveness scale (BIS; Patton et al., 1995) and the Brief sensation seeking scale (BSSS; Hoyle, Stephenson, Palmgreen, Puzles Lorch & Donohew, 2002). A number of studies have already examined the relationship between behavioural and self-report measures of impulsivity and risk-taking, and the data often suggest that they capture different processes or

constructs, (Reynolds, Ortengren, Richards & de Wit, 2006; Dai et al., 2009) but there are also studies that show commonality between discounting and trait measures (Ostaszewski, 1996; Crean et al., 2000; Alessi & Petry, 2003; de Wit et al., 2007).

Method

Participants

Data analysis was conducted on the same data set used in Study 1a. Participants also completed a hypothetical delay discounting task and two self-report measures that were added to the analysis for Study 1b. As a reminder, the eighty participants were recruited through the Victoria University School of Psychology research participation program.

Procedure

A mixed design was used with one within-subject factor of type of discounting (temporal and probabilistic) and one between subject factor of the delay between completion of discounting tasks; half of the participants completed both tasks within one session and the other half completed tasks a day apart. Impulsivity and gambling measures were completed online during the first week of the trimester as part of a larger body of surveys. Participants also completed a money discounting task during this survey session. During the trimester, students signed up to participate in either two half hour sessions or one full hour session. Participants in the former group had to sign up to one session and a follow-up session one week later. In each session they completed either the temporal or probability discounting task. The other participants completed both tasks within the same hour. Half of the participants across the two groups completed the temporal discounting task first and the other half completed the probability task first.

Measures

Barratt Impulsiveness Scale

The 30 item BIS-II is a widely used and validated self-report measure of impulsivity. Factor structure analysis of the measure has identified six first order and three second order factors (Patton et al., 1995). The six first order factors are attention, motor impulsiveness, self-control, cognitive complexity, perseverance and cognitive instability. The second order factors are

attentional impulsiveness, motor impulsiveness and non-planning impulsiveness. Item examples include “I am a careful thinker”, “I am more interested in the present than the future” and “I save regularly”. The BIS-II has previously been used in research specifically related to temporal discounting (e.g. Mitchell, 1999).

Brief sensation seeking scale (BSSS)

This 8 item paper and pencil questionnaire (Hoyle et al., 2002) was based on Form V of the Sensation seeking Scale (SSS-V; Zuckerman, Eysenck & Eysenck, 1978), which comprises 40 items. While attempting to make it suitable to adolescent responders and avoid items that have been criticised for colloquialism, the items included in the BSSS were chosen to represent the four primary dimensions of sensation seeking identified in the SSS-V; thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility. Two items tap each of the four dimensions and, unlike the true and false format of the SSS-V, responses are made on a five-point scale, from “strongly disagree” to “strongly agree”, with a central point of ‘neither disagree nor agree’. The BSSS has been shown to correlate with high risk sexual behaviours in homosexual men (Dudley, Scales Rostosky, Korfhage, & Zimmerman, 2004) and alcohol and marijuana risk behaviours (Miller & Quick, 2010). The SSS-V has previously been used in studies of discounting (Ostaszewski, 1996; Vuchinich & Simpson, 1998; Mitchell, 1999).

Temporal discounting task (Kirby & Marakovic, 1996)

This questionnaire provides a time-efficient measure of temporal discounting. It includes 21 choice pairs of a large delayed and a smaller immediate monetary outcome from which discounting rate can be estimated. The choice pairs are presented to participants in a random order, but are ranked upon data analysis in order to establish extent of discounting. Each choice pair is given a rank and estimated discounting rates associated with each rank decrease the higher the rank. Estimated discounting rates are determined by the point at which participants shift their preference from the delayed to the immediate outcome. Both hyperbolic and exponential discounting rates can be estimated based on the choice pairs. Example items include ‘\$34 tonight or \$35 in 43 days’ and ‘\$32 tonight or \$55 in 20 days’. Choice of the immediate outcome in the former choice pair represents estimated discount rates of both hyperbolic and exponential discounting at 0.0007. The latter represents a hyperbolic rate of 0.0359 and an exponential rate of

0.0271. Although it has been used in potentially real procedures, the format of the questionnaire is suitable for hypothetical choices as well.

Preliminary discounting data screening and fitting the functions.

Experiential choice data were the same as that used in Study 1a. The exponential and hyperbolic discounting functions were used as they provided good descriptions of the temporal and probabilistic discounting data, respectively, but avoided the problems of the hyperboloid function. Ideally only one fitted model would be used, but both were presented to show that the conclusion remained the same, irrespective of the model used.

Results

Comparing discounting across the two tasks

Tests in both tasks of between-subjects effects of order and condition showed no significant main effects or interactions in temporal and probabilistic discounting rates.

Discounting rates on the temporal and probability tasks were uncorrelated according to both models' k values (hyperbolic k : $r_s(58) = .145$, $p = .278$, ns ; exponential k : $r_s(58) = .131$, $p = .328$, ns). Both models suggested that delay and probability discounting in the skiing tasks were independent.

Correlations between experiential and hypothetical tasks

Median estimated hyperbolic discounting rate on the hypothetical task was .036 (IQR .12). Spearman's Rank Order correlations were conducted to determine the relationship between discounting in the two experiential tasks and the hypothetical task. Correlations between the hypothetical task and experiential discounting parameters are shown in Table 3.1. Discounting in the hypothetical task was uncorrelated with discounting rates on the probability task, but significantly correlated with both hyperbolic and exponential k values on the experiential temporal task. This suggests that the loss of value captured in the hypothetical measure overlaps with that of the experiential temporal task, but not the experiential probability task.

Table 3.1

Spearman's Rank Order correlations between estimated hyperbolic discounting rate on the hypothetical measure and fitted hyperbolic and exponential discounting parameters of both temporal and probability experiential tasks.

	Hyperbolic k		Exponential k	
	temporal	probability	temporal	probability
hypothetical k	.466*	.104	.449*	.121

* $p < .05$, all other $ps > .4$

Correlations with self-report measures

Significance level was increased to 0.01 to control for the number of correlations between the self-report measures, their subscales and the behavioural tasks. Results of the correlational analysis are presented in Table 3.2. Spearman's Rank Order correlations between discounting parameters and scores on the BIS, its subscales and the BSSS, did not produce any significant correlations.

Table 3.2.

Spearman Rank Order correlations between discounting parameters on experiential tasks scores on BIS, its subscales and the BSSS.

	Total BIS	Attention	Motor	Self- control	complexity	Perseverance	Instability	BSSS
Hyperbolic k								
Temporal	.082	.018	-.059	-.012	.177	.230	.020	.113
Probability	.046	-.042	-.049	-.020	.274	.225	.052	.032
Exponential k								
Temporal	.076	.006	-.061	-.029	.166	.234	.031	.096
Probability	.042	-.064	-.054	-.025	.279	.235	.064	.028

All $ps > .01$

In task effects

We also examined the relationships between discounting rates and behaviour in the skiing component of the experiential tasks. A significance level of 0.01 was used to control for number of tests. The correlation between number of crashes and discounting rate approached significance in the temporal task, but with the increased criterion, failed to reach a significant level (hyperbolic k : ($r_s(58) = .308, p = 0.018, ns$); exponential k : ($r_s(58) = .298, p = .023, ns$). Likewise, the correlation between the number of jumps made and discounting rates in the probability task approached, but failed to reach significance (hyperbolic k : ($r_s(58) = .327, p = 0.012, ns$); exponential k : ($r_s(58) = .322, p = 0.014, ns$).

Latencies associated with each type of choice, self-controlled or impulsive, did not differ significantly using a Wilcoxon Signed Ranks Test on either the temporal task ($Z = -1.072, p = .284, ns$) or the probabilistic task ($Z = -.040, p = .968, ns$).

Discussion

The second study of this thesis used the same data as the first to examine the relationship between temporal and probability discounting. Discounting rates of uncertain and delayed outcomes were compared to rates on a question based measure of delay discounting and self-report measures of impulsivity and risk taking. Discounting rate in the temporal version was significantly correlated with discounting rate on the question based temporal measure but the correlation between discounting in the two experiential task was not significant, nor were correlations between the experiential tasks and self-reported impulsivity and risk-seeking. Lastly, discounting rates in the tasks were not significantly correlated with behaviour in the skiing component of the tasks.

Correlation between experiential probability and temporal discounting

Unlike several question-based studies (e.g. Richards et al., 1999), the current experiment did not find a significant correlation between discounting of uncertain and delayed outcomes using experiential tasks. The absence of a correlation in the current experiment may be due to the use of experiential tasks that clearly delineated probability from delay and vice versa. However, because some studies using question based discounting tasks have also failed to find the positive correlations (e.g. Ohmura et al., 2006), this remains a tentative explanation.

It is interesting to compare these results with the only other study that has investigated experiential discounting of both uncertain and delayed rewards (Scheres et al., 2006). In that study, participants with ADHD discounted similarly across the probabilistic task and a version of the delay discounting task in which steep discounting decreased task duration. The contrasting results of that and the current study are especially interesting given the greater overlap in the task structure of the latter. In the current study the tasks were as similar as possible; both used the context of a skiing game in which points were gained and lost and within which discounting choices were presented at regular intervals. The task differences in Scheres et al. were comparatively large. Their delay discounting task used aeroplanes that dropped cargo from various heights and the probability task involved breaking the shells of piggy banks that varied in thickness. If spillover effects due to task similarity is part of the underlying reason for positive correlations in question based temporal and probability discounting, and if this applies to experiential tasks as well, one might likely expect the relationship to be stronger across the highly similar skiing tasks than in the Scheres et al. tasks, but the opposite occurred. Perhaps instead the differences across the two studies illustrate the importance of considering exchange delays, inter-trial intervals and specific participant characteristics.

As noted above, Scheres et al. (2006) delivered actual monetary rewards only following completion of each task. Even though an on-screen counter displayed accumulated rewards progressively during the task, the collected total was delivered only once all trials had been completed. Furthermore, in the delay task without adjusting ITIs, impulsive behaviour decreased task duration and participants behaved more impulsively in this task than in the one that included adjusting ITIs. The fact that a significant correlation was found only in participants with ADHD, and only in the no ITI condition, suggests that for these particularly delay-sensitive individuals, the delays and ITIs were sufficient to influence discounting. Indeed, the relationship between probabilistic and temporal discounting rates in control subjects, irrespective of ITIs, was consistent with the results of the current study.

Although it is unfortunate that these two are the only experiential studies to have correlated delay and probability discounting, the results of both imply that the experience of outcomes can be an influential factor to consider when attempting to determine whether or not the loss in value of delayed and uncertain outcomes reflect the same underlying process.

In the current experiment the delay and probability discounting were elicited in separate tasks. Half of the participants completed the two tasks right after each other and the other half completed them a day apart. The delay between the two tasks did not make a significant difference in the current experiment but a possible variation of the procedure would be to present probability and delay trials all within one task. This alteration would approximate the structure of some question-based tasks in which hypothetical delay and probability questions are intermixed in a single scale (e.g. Richards et al., 1999). If the two types of discounting remain uncorrelated, this would add additional evidence for the importance of experiencing outcomes in differentiating between temporal and probability discounting.

Correlation between experiential and question based task

Estimated rate of discounting in the question based delay task was significantly correlated with experiential discounting rate in the temporal discounting task. The extent to which participants discounted delayed hypothetical monetary rewards overlapped with the extent to which they discounted delayed experiential point rewards. However, discounting of hypothetical delayed outcomes did not correlate with discounting of experiential probability discounting. This has two implications. Firstly, the positive correlation across delay discounting tasks shows that despite evidence that manipulations produce diverging effects in the two types of tasks (Reynolds et al., 2006), there is still significant overlap in the discounting processes captured by each. Secondly, the results indicate that there is less overlap between the discounting of delayed hypothetical rewards and probabilistic experiential rewards.

Given the differing correlations for hypothetical delayed rewards on the one hand, experiential delayed and probabilistic on the other, and between delayed and probabilistic experiential rewards, it seems plausible that the difference in overlap is due to the delayed vs. probabilistic nature of the rewards, rather than the experiential vs. hypothetical nature of the tasks. A relevant comparison for this finding comes from a study that produced a significant positive correlation between the EDT and a hypothetical delay measure, but not a hypothetical probability measure (Reynolds, 2006b). Although no question-based probability discounting task was used in the current study, probability discounting elicited with experiential trials did not correlate with hypothetical delay discounting.

Correlation with self-report measures

Like many studies previously, correlational analyses revealed no significant relationships between discounting and self-report measures of impulsivity and risk-taking. Only one subscale of the impulsiveness measure, namely the cognitive complexity subscale, was significantly correlated with probability discounting at the .05 confidence level, but it failed to reach significance at the more conservative .01 level which was used to correct for the number of tests. Previous studies have shown that self-reported impulsivity is only weakly, if at all, correlated to delay discounting (e.g. Crean et al., 2000; Dom et al., 2006; Krishnan-Sarin et al., 2007).

Conclusion

Studies *1a* and *1b* produced a number of findings with implications for single process interpretations of discounting. The two types of outcomes, uncertain and delayed, differed in the model that best described indifference points (study 1a). Whereas the loss in value of delayed points was best described by the constant exponential function, the non-constant models performed significantly better with uncertain outcomes. Single process accounts of discounting rest in part on a similarity in the function that best describes discounting (Myerson & Green, 2004). A further disassociation between delay and probability discounting emerged in that discounting rates of the two types of outcomes were uncorrelated (study 1b). Myerson et al. (2003) argued that positively correlated discounting rates support single process accounts of discounting, but overall the accumulated evidence of correlations is inconsistent.

In Study 2 we explored another discounting phenomenon that has been thoroughly investigated with hypothetical choice tasks, namely the effect of reward magnitude on discounting rates. This also has implications for single process accounts because previous findings have suggested that probability and delay discounting are not affected in the same way by magnitude manipulations.

Chapter 4 : Magnitude effect (Study 2)

Human discounting rates increase as the size of *uncertain* outcome increase but decrease as the magnitude of the *delayed* outcome increases. This has been shown using both single parameter fitted models (Green et al., 1997) and AUC analyses (Du et al., 2002), but almost exclusively using hypothetical choice tasks. The only study to have examined the effect of magnitude manipulations on experiential discounting was conducted by Jimura et al. (2009) using real juice rewards. They compared discounting of a smaller (8 ml) and a larger (16 ml) amount of delayed juice and showed that the former was discounted more than the latter, consistent with hypothetical choice tasks.

Studies of animal discounting however, have failed to show evidence of magnitude effects in for example rat and pigeon discounting (Richards, Mitchell, de Wit & Seiden, 1997; Grace, 1999; Green, Myerson, Holt, Slevin & Estle, 2004). These studies have used different procedures to investigate magnitude effects, some more similar to human research than others, but naturally all non-human animal procedures are experiential. Could the disparity between human and animal magnitude effects be due to the experience of the delay? The study by Jimura et al (2009) suggests that the magnitude effect is found in humans even when the delay is experienced, but as noted the magnitude effect has not been investigated nearly as thoroughly with human experiential tasks as hypothetical ones. Furthermore, no study has yet to investigate the magnitude effect of experienced probabilistic outcomes.

It is particularly important to investigate the magnitude effect using the skiing tasks because delay discounting was better described by the exponential rather than hyperbolic model in Study 1a. The preference for the non-constant models in the behavioural literature is based, to a large extent, on its superior performance in describing both animal and human choice and their ability to account for preference reversals. However, the exponential model can also account for such changes in preference if the magnitude of an outcome influences the rate at which it loses value. Specifically, if discounting rates are steeper for smaller magnitudes than larger ones, an exponential discounting shape is also able to account for preference reversals (Green & Myerson, 1996).

Because preference reversals are an empirically supported phenomenon (Green et al., 1994), with which exponential discounting is inconsistent unless discounting rates are amount dependent, this implies that discounting of the point gains in the delay skiing task would have to

be affected by magnitude manipulations in order to account for preference reversals. In contrast, the reverse magnitude effect would not be necessary (albeit expected) in the probability skiing task because Study 1a showed that uncertain outcomes lost subjective value hyperbolically.

The current study examined magnitude effects in both temporal and probability discounting using the skiing task. Magnitude was manipulated by altering the size of the alternatives given in the choice jumps. In the small magnitude condition the procedure and amounts were exactly the same as that used in study 1a and 1b, with the standard delayed or probabilistic outcome set at 10 points. For the large magnitude condition the standard amount was increased to 50 points. The variable alternative remained the same proportion of the standard across the two magnitudes and the points available for jumps in the skiing part of the game remained the same across the two conditions (5 points gained and 2 points lost). Both delayed and probabilistic outcomes were tested with participants completing both magnitudes of either the probabilistic or the delayed tasks. We expected to find that the magnitude manipulation produced steeper discounting of the small delayed outcome than the large delayed outcome. This expectation was consistent with the findings of Jimura et al. (2009), and would also entail that the exponential form of discounting was not inconsistent with preference reversals. Consistent with the reverse magnitude effect in probability discounting using question based measures (Myerson et al., 2003), we expected to find steeper discounting of large probabilistic outcomes than small probabilistic outcomes.

Method

Participants

Fifty one participants were recruited through the Victoria University School of Psychology research participation program and through posters advertising the study around the Victoria university campus. All participants in the former group were completing an introductory psychology course that required participation in research, and participants in the latter group were primarily university students.

Measures

Experiential discounting tasks

The temporal and probability discounting tasks used in experiment 1 were used again to determine individual discounting rates. The magnitude of the large delayed or probabilistic

standard outcome was manipulated. In the small magnitude condition, it was always worth 10 points, and in the large magnitude condition it was worth 50 points. The small alternative (always immediate and certain) varied in size according to the proportion of the large alternative and the first choice at each delay or probability was between the large standard outcome and a small outcome of half its size. For example, the first choice at each delay in the temporal task would be between 10 points at a delay or 5 points immediately in the small magnitude condition, and between 50 points at a delay and 25 points immediately in the large magnitude condition. The immediate alternative would increase and decrease in increments of 10% of the delayed outcome, depending on the participant's choices.

Procedure

A mixed design was used with one within-subject factor of magnitude (large and small amounts) and one between subject factor of type of outcome; half of the participants completed both temporal tasks and the other half completed both probability tasks.

All participants also completed two self-report measures, but these were not included in this analysis. Participants who participated as part of the Psychology research program completed the BIS-11 and South Oaks Gambling Screen (SOGS) measures in the first laboratory class of the term and these two measures were completed together with a number of other questionnaire measures. Participants in the poster group completed the two pencil and paper measures after having done the two magnitudes of the discounting task.

Results

Data exclusion and manipulation

Participants were excluded based on the criteria specified by Johnson and Bickel (2008). Participants were excluded if they failed to meet the criteria on either or both amounts. This resulted in a sample size of 20 participants in the temporal group, and 24 participants in the probability group.

Subjective value at both magnitudes was transformed into proportions of the large rewards to facilitate comparisons across the two amounts and the exponential function was fit to indifference points (MSE and R^2 analyses, as well as magnitude comparisons using the two non-constant models are included in Appendix A).

Data of the measures of fit, discounting rates and performance in the tasks were not normally distributed according to Shapiro Wilks test for normality (all $p > .05$). Log and square root transformations did not normalize the data, and therefore non-parametric tests were conducted. The exponential function provided good fits to both temporal and probabilistic indifference points. The fits were of equivalent size to those found in experiment 1a for the temporal task, and even higher for the probability task. The adjusted R^2 s are shown in Table 4.1.

Table 4.1

Median and interquartile ranges of adjusted R^2 for the exponential function fit to individual indifference points in two magnitudes of the temporal and probability tasks.

	Temporal		Probability	
	Median	IQ range	Median	IQ range
10 point				
Exponential R^2	.829	.145	.826	.441
50 point				
Exponential R^2	.793	.201	.846	.231

Discounting rates

Medians and inter quartile ranges of discounting rates fit to individual data are shown in Table 4.2. In the delay task, discounting rates in the large magnitude were shallower than discounting rates in the small magnitude condition ($Z = -2.912$, $p < .05$). There was not a significant difference in discounting rates across magnitudes in the probability task ($Z = -.146$, $p = 0.884$, *ns*).

Group discounting rates in the temporal and probability tasks are shown in Figure 4.1 and Figure 4.2, respectively. These functions were fit to median indifference points in each task and each magnitude, and show the same pattern as individual discounting rates. Discounting rate in the small magnitude condition was steeper than in the large magnitude condition only in the temporal task. In the probability discounting task only one indifference point differed between the two magnitudes.

Table 4.2

Medians and interquartile ranges of exponential discounting rates in the experiential temporal and probability discounting tasks for small and large magnitudes of the standard outcome.

	Temporal		Probability	
	Median	IQ range	Median	IQ range
10 point				
Exponential k	.136	.087	.657	.734
50 point				
Exponential k	.069	0.059	.666	.586

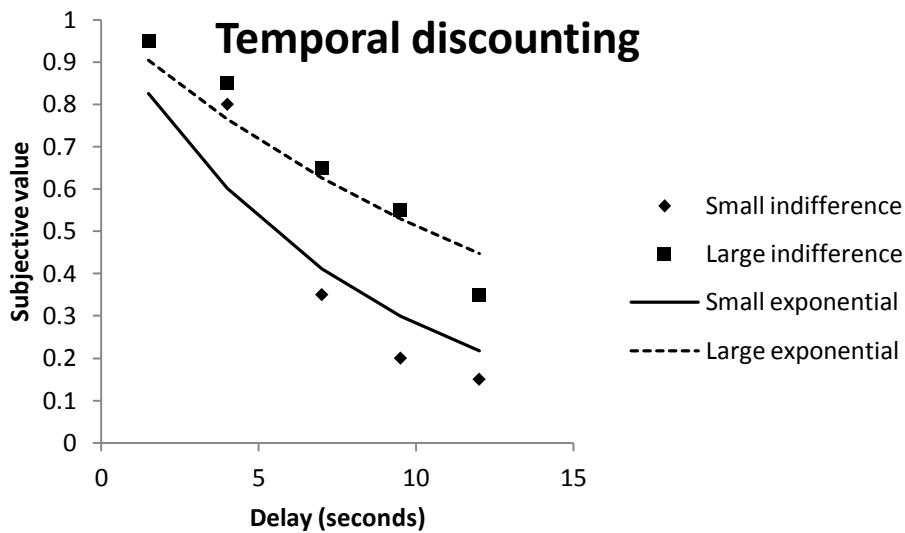


Figure 4.1. Median individual indifference points and best fitting exponential function in the temporal task. The dotted line represents the exponential function fit to the large reward and the solid line the fit to the small reward.

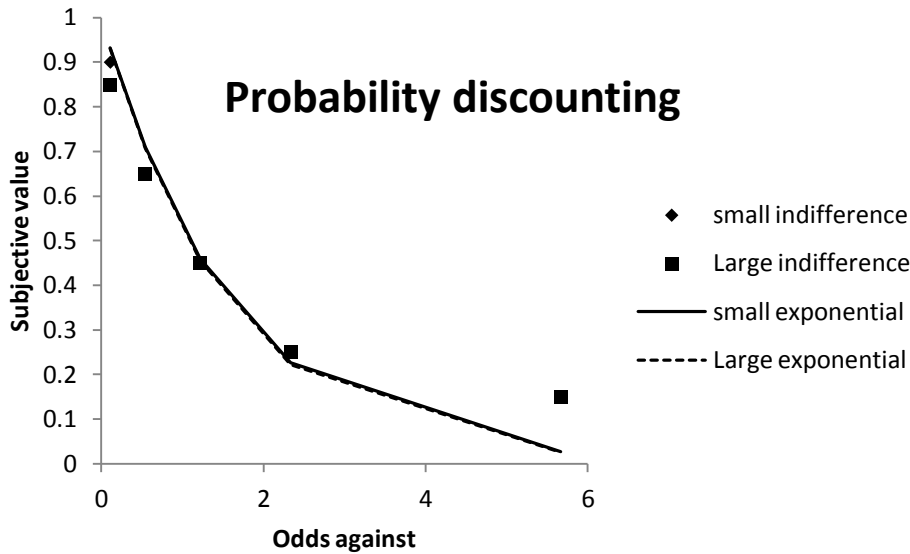


Figure 4.2. Median individual indifference points and best fitting exponential function in the probabilistic task. Dotted line represents the fit to the large magnitude condition and the solid line the fit to the small magnitude condition.

Effect of magnitude on discounting rate using exponential function

The difference in the effect of magnitude across temporal and probability discounting is also shown by plotting the ranked individual discounting rates on the large magnitude condition as a function of ranked individual discounting rates on the small magnitude condition. Figure 4.3 shows this plot for the temporal task, and Figure 4.4 for the probability task. The significant magnitude effect in the temporal task is evident by the clustering of points below the diagonal line. In contrast, the even spread of points both above and below the diagonal illustrate that discounting rates did not differ across magnitudes in the probability task.

Figures 4.3 and 4.4 also suggest that the relationships between discounting of large and small magnitudes differed across delayed and uncertain outcomes. In the probability task the points are clustered closer along the diagonal than in the temporal task, suggesting that as discounting rates on one magnitude increase so do discounting rates on the other magnitude. This pattern does not appear in the temporal task, where steep discounting in the small reward condition is not necessarily associated with steeper discounting in the large. Indeed, discounting rates were significantly correlated in the probability task ($r_s(22) = .758, p < .001$) but not in the temporal task ($r_s(18) = .352, p = .128, ns$).

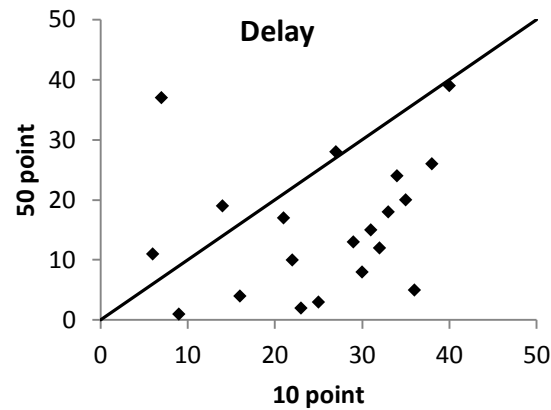


Figure 4.3. Ranked individual exponential discounting rates on the 50 point condition as a function of ranked individual discounting rates on the 10 point condition in the temporal task

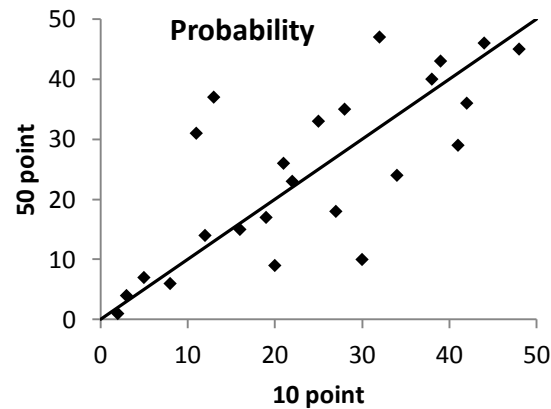


Figure 4.4. Ranked individual exponential discounting rates on the 50 point condition as a function of ranked individual discounting rates on the 10 point condition in the temporal task

Because the hyperbolic discounting function described probabilistic discounting well in study 1a, the tests were also conducted using this function. The conclusions remained the same irrespective of whether the exponential or the hyperbolic function was used (hyperbolic function analyses are found in Appendix A).

Discussion

Having introduced the experiential choice tasks in Study 1, and shown that discounting of delayed hypothetical outcomes was related to discounting of delayed gains but not uncertain gains, the current experiment examined the effect of magnitude manipulations on discounting in both versions of the experiential task. Discounting rates varied inversely with magnitude in the temporal task, consistent with evidence from hypothetical choice procedures, but were unaffected by the magnitude manipulation in the probability task, failing to produce the reverse magnitude effect usually shown.

Effect of magnitude on delay discounting

Elicited through hypothetical or potentially real choice tasks the magnitude effect in temporal discounting is very robust and has been shown using rewards of comparatively small and large magnitudes (e.g. Du et al., 2002; Estle et al., 2006). Kirby and Marakovic (1996) showed significant magnitude effects using potentially real rewards that ranged from \$30-\$35 to \$70-\$85. The effect has also been shown in discounting of other commodities such as hypothetical vacations (Raineri & Rachlin, 1993), health outcomes (Chapman, 1996), and real liquid rewards (Jimura et al., 2009). We were able to extend this research by showing that the temporal magnitude effect also occurs when delays are experienced, when amounts were similarly small (10 and 50 points) and outcomes were point gains not exchanged for money.

Although the magnitude effect is robust, the lack of an effect in animal studies (Grace, 1999; Ong & White, 2004) suggests that it may be sensitive to the way in which discounting is elicited. While the current experiment used of a binary choice procedure similar to other human tasks that titrated the immediate/certain outcome, it differed from for example Kirby and Marakovic (1996) and Green et al. (1999) in that each outcome was experienced following each choice. In this sense it was more similar to animal procedures, in which magnitude effects are not commonly shown. The presence of a magnitude effect in the current study, consistent with Jimura et al. (2009) suggests that despite attempts to keep procedures similar, human and animal discounting processes may fundamentally differ in their sensitivity to manipulations of the magnitude of delayed outcomes.

Jimura et al. (2009) noted that a remaining difference between their task and standard procedures with animals was the symbolic representation of delays and reward amounts. When a reward became accessible to the participant the amount remaining was represented by a

horizontal bar, the length of which corresponded to the amount left, and following choice of the delayed alternative, a timer counted down the delay in seconds until delivery. Jimura et al. suggested that this symbolic representation of delays and amount may have accounted for the presence of an amount effect in a human experiential delay discounting task. In the current task reward amounts were represented by the number of points to be received, but delays were experienced without a counter telling the participant the remaining time. In line with Jimura et al.'s argument, the remaining difference between human and animal procedures lies in the symbolic representation of reward amount.

The current procedure included another feature that may have contributed to the significant magnitude effect: the context in which alternative rewards were provided. In addition to showing the standard delay magnitude effect, Dai et al. (2009) found that discounting of a \$500 reward was greater when choices had previously been made for a \$5000 reward than when the previous choices were made for a \$50 reward, demonstrating a contrast rather than a magnitude effect. A similar contrast effect could be occurring in the current experiment, in which discounting was influenced not by prior choices but by the surrounding context. In both the large and small magnitude conditions, the same amount of points (5) were gained for jumps made during the free skiing part of the game (in-game), and the same amount of points (2) were lost for crashing into trees and rocks. In other words the delayed reward was 10 times the size of the in-game jumps in the large magnitude condition, but only twice the size in the small magnitude condition. If points gained through choices were compared to the points gained in the in-game phase a similar contrast effect as shown by Dai et al. could account for the magnitude effect.

Effect of magnitude on probability discounting

Unlike delayed rewards, discounting of uncertain rewards did not change as a function of magnitude. Reverse magnitude effects, whereby larger probabilistic rewards are discounted more steeply than smaller probabilistic rewards, have been shown in a number of experiments (Du et al., 2002; Yi et al., 2006; Estle et al., 2006, Myerson et al., 2003) and it was surprising that the same was not found in the current experiment.

There are a number of possible reasons for the lack of an effect in the probability task. Notably, magnitude manipulations in previous experiments have often been more extreme than in the current experiment. Du et al. (2002), compared discounting of \$200 to discounting of \$10,000, Yi et al. (2006) compared \$10 and \$1000, and Myerson et al. (2003) compared \$200

and \$40,000. These magnitude differences represent large rewards of 50, 100 and 200 times that of the small rewards, respectively. In the current study however, the large reward was only 5 times that of the small reward. In one study, comparing probability discounting at 9 magnitudes, the smallest comparisons were between \$20 and \$250, still an increase of 12.5 times (Myerson, Green & Morris, 2011). Although the small difference between the two reward magnitudes was large enough to produce a significant magnitude effect in temporal discounting, it is possible that the differences in magnitudes used in the current experiment were simply not large enough to show an effect on probability discounting. Further support for this is the fact that in each of the previously noted experiments examining both temporal and probabilistic magnitude effects, the effect of magnitude on uncertain outcomes was not as strong as that on delayed outcomes. Changes in AUC in delay discounting were twice the size of changes in AUC in probability discounting in both Myerson et al. (2003) and Estle et al. (2006). In addition, Yi et al. (2006) conducted combined delay and probability conditions and found that the delay magnitude effect appeared to dominate over the probability effect, also suggesting that magnitude has a stronger effect on delayed rewards than uncertain rewards.

Correlations between magnitudes

Discounting rates between the two magnitudes of the delayed outcomes were not correlated, but probability rates were. Although large between-subjects variation is commonly reported and within-subject variations occur as a function of magnitudes and commodities (Kirby & Marakovic, 1996; Odum & Rainaud, 2003), the assumption that discounting rate is an individual difference variable implies that discounting across magnitudes should be correlated within-subjects. One would expect that an individual who discounts more relative to someone else in a large magnitude condition would also discount relatively more in a smaller magnitude condition. Such consistency has been shown (Yi et al., 2006; Madden et al. 1997; Charlton & Fantino, 2008), but the non-significant correlation in the temporal task suggests that this was not the case in the current sample. In contrast, discounting rates across the two probabilistic magnitudes were correlated. Interestingly, Yi et al. (2006) found that delay discounting rates were correlated, but that probabilistic rates were not, which is opposite to the findings of the current experiment. With only one previous study reporting correlations across conditions in probability discounting, this is a topic that requires further investigation.

Conclusion

Across two studies the experiential discounting task has shown that delay and probability discounting are not related to each other and that they are affected differently by the same magnitude, even though the difference was a lack of an effect in probability discounting rather than the reverse effect often seen in hypothetical choice tasks.

The following study examined a characteristic of the temporal discounting task that differentiated it from the probability task, namely the inter-trial interval.

Chapter 5 : ITI and Access Adjusting (Study 3)

In a typical experiential delay discounting procedure the trials, or choices, are presented on a concurrent chain with an adjusting delay so that rate of choice presentation is independent of the alternative preferred (e.g. Scheres et al., 2006; Jimura et al., 2009). Without an adjusting delay, preference for the smaller immediate alternative will increase rate of reinforcement within the task and, if the task has a fixed number of trials, decrease task duration (see Lane et al., 2003, for discussion). In such cases, preference for the smaller alternative may be the result of a global maximising strategy rather than a preference for immediate outcomes (Logue et al., 1986; Hyten et al., 1994), and arguably such behaviour is not ‘impulsive’ at all. From an empirical perspective, therefore, the adjusting delay is crucial in avoiding confounding behaviour aimed at increasing reinforcement density and behaviour determined by single trial immediacy.

However, the adjusting delay is problematic in two ways; one in terms of the added difficulty in capturing impulsive behaviour within an experimental setting, and the other in relevance to real-life impulsive behaviour. Firstly, real time studies have shown that human participants are sensitive not only to the delay between choice and delivery, but also to post-reinforcer, inter-trial intervals and exchange delays (Logue et al., 1986; Hyten et al., 1994). Because of this, human participants tend to distribute their choices to maximize reinforcement across the entire task (Logue et al., 1986), making their behaviour exclusively self-controlled. Use of primary consumable reinforcers may alleviate this problem, as shown by Jimura, et al. (2009), but several experiential discounting procedures involve collecting money or points exchangeable for money (e.g. Lane et al, 2003; Scheres et al., 2006), and do not include adjusting ITIs because this encourages exclusive self-control.

Secondly, although the adjusting delay procedure does model some real behaviour, its relevance is limited to everyday choice behaviour in which reinforcement density is stable across preference for the immediate and delayed outcomes. For example, when deciding whether to sleep in or get up in time to get to work and earn money, it does not matter which alternative is preferred, the choice is presented each morning irrespective of preference (even this choice is not actually mirrored in most choice tasks, because the delayed outcome of cash in the bank is often only experienced after multiple choices have been made). Unsurprisingly, there are many intertemporal choice situations in day-to-day life when a higher density *is* associated with preference for the smaller immediate outcome than the larger delayed outcome. For example, when choosing between two products, one cheaper but of lower quality (and shorter life-span) than the other, choice opportunities will arise more often if the cheap product is preferred than if the more expensive and long lasting alternative is preferred. In the long term, purchasing the more expensive product once will be less costly than repeatedly purchasing the cheaper but lower quality product. The concurrent chain adjusting delay procedure fails to model situations such as these, and we know that the presence of adjusting delays produce greater self-control (Scheres et al., 2006).

Similar to other delay discounting procedures, the temporal skiing task used an adjusting delay between trials. In the original procedure, the delay associated with the chosen alternative (ranging from 0 for the immediate outcome to 12 seconds for the longest delayed outcome) was subtracted from the time in-game so that presentation of choices was always separated by the same duration. For study 3 we created a version of the task in which the delay associated with the chosen alternative was added to a fixed duration of time in-game, rather than subtracted from time in-game. The effect of this on the task was twofold. Firstly, rate of choice presentation increased with greater impulsive preferences. If the immediate outcome was preferred, the inter-trial delay was at its shortest, but if the delayed alternative was selected the inter-trial delay consisted of the fixed delay plus the delay until outcome delivery. This is similar to the procedure used by Lane et al. (2003) in their contingent task except that their ‘immediate’ outcome was delayed by 3 seconds. Secondly, total task duration in the new ski task version decreased with greater impulsive preference. In the original task participants always made 50 choices and the adjusting delay ensured that task duration was stable across impulsive and self-controlled responding. With a fixed ITI and a fixed number of trials, total task duration

decreased with greater preference for the immediate outcome. In order to separate the effects of increased choice rate from decreased task duration we created a third skiing task version. This was also a fixed ITI version, but task duration rather than total trial number was specified. In this version greater preference for the immediate rewards would result in more choice opportunities than if the delayed outcome was chosen on all trials, but would last the same length of time irrespective of choices. In all other respects, this task was equivalent to the other fixed ITI version. The two fixed ITI tasks enabled us to investigate the effect of ITI while also ensuring that escape from the task was not influencing participant choices. Given the systematic discounting elicited in the previous experiments, we still expected participants to show discounting in the fixed ITI versions but, consistent with Scheres et al. (2006), we expected that discounting would be steeper in the fixed ITI tasks because impulsive responding decreased overall trial duration (in the fixed total task duration version) or both overall trial duration and task duration (in the 50 trial versions).

In addition to investigating the impact of fixed and adjusting delays, a second aim of Study 3 was to determine whether or not withholding reinforcement during part of the in-game phase influenced participant discounting in the temporal task. Studies 1b and 2 showed that temporal and probability discounting were uncorrelated and differently affected by magnitude, respectively. Although the tasks were highly comparable and we would expect to see significant correlations and corresponding effects if discounting of the two types of outcomes were governed by the same process, the two versions did differ from each other in the nature of the in-game phase and it was possible that this difference accounted for the results of study 1b and 2.

Whereas each choice in the probability version was separated by a fixed duration of play during which jumps and obstacles were always active, the adjusting delay in the original temporal version consisted of the active phase as well as an 'inactive' phase. During the inactive phase neither gains nor penalties were awarded and the number of jumps available on the screen was less than during the active phase. This discrepancy in the in-game structure introduced the possibility that participants reacted differently to the temporal and probability discounting tasks. Hence, we created another delay discounting version in which the whole adjusting inter-trial delay consisted of the active phase. This allowed us to compare temporal discounting with and without the inactive period. No previous experiential discounting task has used a context similar to the skiing game, making predictions based on existing literature difficult. However, to the

extent that participants noticed the inactive phase as a systematic withholding of reinforcement, equivalent to a post-reward delay in more traditional discounting tasks, we would expect participants to be more self-controlled in the original version than the new version.

Method

Participants

One hundred and twelve participants were recruited through the Victoria University School of Psychology research participation program. All participants were completing an introductory psychology course that required participation in research.

Measures

Standard temporal task – adjusting delay without access

In the standard temporal discounting task (the adjusting non-access version) the inter-trial interval was kept constant using a combination of a variable and a fixed duration delay, and trial number was fixed at 50 free run jumps (trials). This ensured that task duration and rate of trial reinforcement was kept constant irrespective of choice patterns. In addition, the reinforcement and punishment that was *usually* contingent on moguls and crashes was made unavailable during the adjusting delay to ensure that impulsive responding did not lead to additional reinforcement during the inter-trial interval. A person who preferred the immediate alternative was not given any more opportunities to gain in-game points than an individual who preferred the delayed alternative. Therefore, controlling for differences in skill level, total reinforcement was dependent only on trial jumps, with increasing reinforcement the more self-controlled the participant. Three other versions of the task were created in which the features of the inter-trial delay and the criteria for task completion were altered, with implications for rate of reinforcement, total reinforcement and task duration.

Adjusting delay with access

The only difference between this version and the standard task was that points could be earned and lost during the entire in-game component. The ITI was composed of the same adjusting and fixed delays of the standard task, but there was no difference between them in terms of the number of moguls available. In this version both the task duration and rate of

reinforcement from trial jumps were fixed, but participants could gain more points by making an impulsive rather than self-controlled choice because moguls were active during the adjusting delay. For example, when the large alternative in trial jumps was worth 10 points at a 12 second delay, the small immediate alternative was 1 point and each mogul was worth 5 points, an ‘impulsive’ participant who preferred the small immediate alternative could make up the difference to the large delayed alternative by making two mogul jumps in the adjusting delay, and would therefore actually benefit from being impulsive relative to being self-controlled.

Non-adjusting 50 trial version

In the non-adjusting 50 trial version the inter-trial interval was fixed to 17 seconds, irrespective of choice. Moguls, trees and rocks resulted in gains and losses during the entire ITI. As in the standard version, the number of trials was fixed to 50, with ten trials per delay. In this version both the duration of the task and the rate of reinforcement gained through trial jumps depended on choice patterns. Impulsive responding increased rate of reinforcement through discounting choices and decreased task duration. However, because access to alternative reinforcement and punishment in-game was constant irrespective of choice, when controlling for skill level, total reinforcement was dependent only on choice, and decreased with increasingly impulsive responding.

Non-adjusting variable trial version

This version was equivalent to the non-adjusting 50 trial version in all details except that task duration, rather than number of trials, was fixed. The duration of the task was set to the approximate time it would take for an exclusively self-controlled individual to complete the task (20 minutes). Similar to the non-adjusting 50 trial version, rate of reinforcement gained through trial jumps increased with impulsive responding and when controlling for skill level total reinforcement was dependent on discounting choices.

Figure 5.1 shows a graphical representation of the four conditions, with passing time represented vertically and each choice opportunity represented by a solid circle. Lines originating from the left of the circles represent self-controlled preferences and lines from the right impulsive preferences. Lines on the far left and far right of each condition represent the experiences of exclusively self-controlled and exclusively impulsive individuals, respectively. For lack of space, not all choice possibilities are shown in condition *d*. As can be seen, in

conditions *a* and *b* choices are presented at equal intervals irrespective of preferences. In conditions *c* and *d*, impulsive preferences result in greater rate of choice presentation. Conditions *c* and *d* differ from each other in task duration. Relative to a more self-controlled individual, an impulsive individual completing condition *c* completes the task faster, as soon as the set number of trials (choices) has been presented. An impulsive individual completing condition *d* however, must complete more choices than a self-controlled individual because a minimum task duration was specified.

Procedure

Each participant completed one of the four versions of the temporal discounting task; the original adjusting active and in-active ITI, the fixed ITI 50 trial, the fixed ITI and duration, and the adjusting and active ITI.

Conditions were assigned pseudo-randomly per session to ensure approximately equal distribution of participants. Up to five participants could complete the task per session. All participants were collected by the experimenter and once informed consent had been given participants began the task at approximately the same time. In all but the variable trial condition participants were informed that there were 50 choice opportunities in the game. All participants were also given the Barratt Impulsiveness scale and the South Oaks Gambling screen following completion of the discounting task.

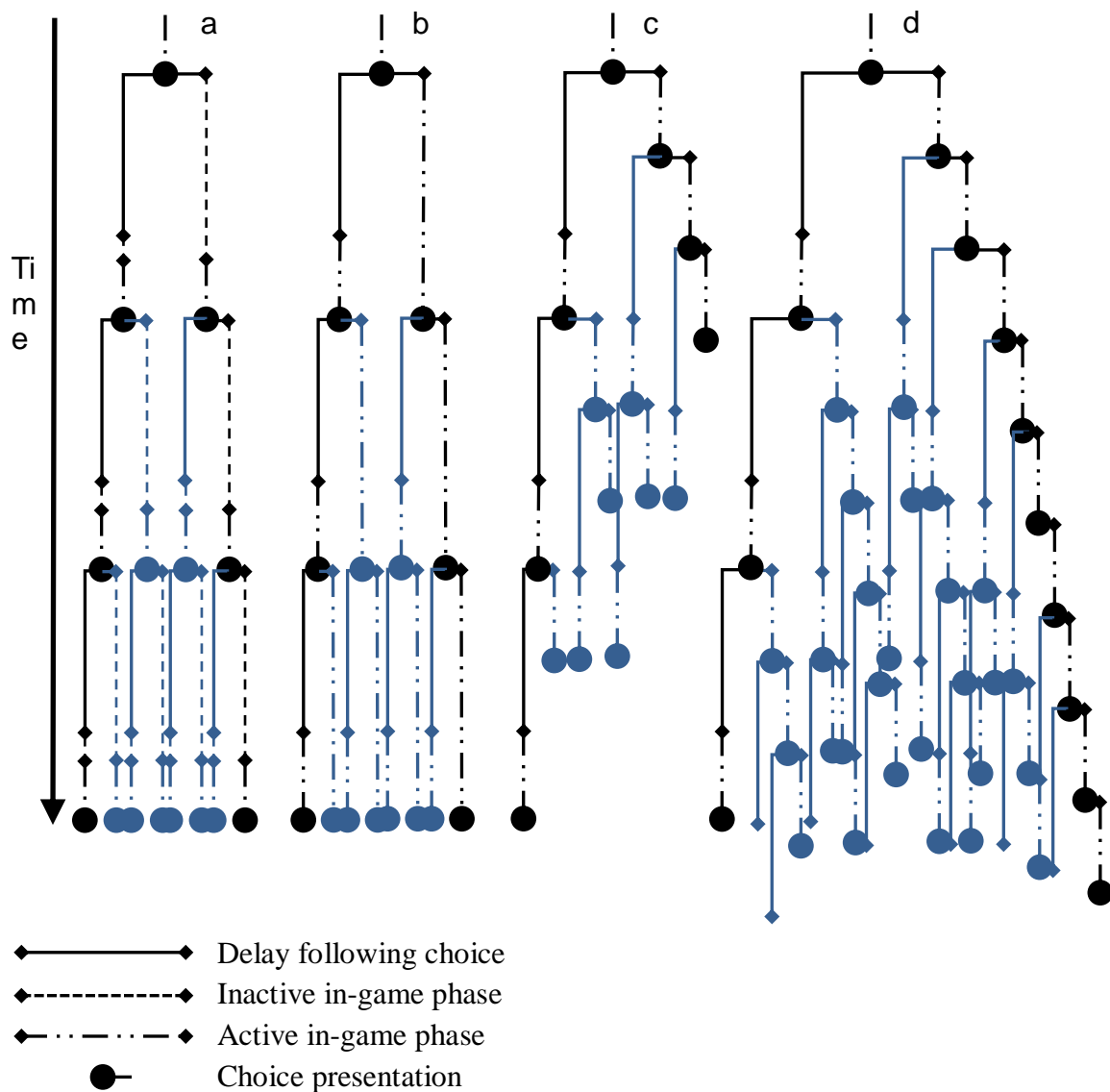


Figure 5.1. Graphical representation of the experiential delay discounting conditions varying in inter-trial interval, task duration and access to alternative reinforcement. Condition *a* is the standard adjusting delay task version, condition *b* is the adjusting delay with active in-game phase, condition *c* is the fixed ITI 50 trial version, and condition *d* is the fixed ITI variable trial version. Black lines represent exclusively self-controlled or impulsive choices and blue lines represent intermediate self-control and impulsivity.

Results

Exclusion of participants

Participants were excluded based on the criteria of Johnson and Bickel (2008). Using these criteria, more participants (11) were excluded from the standard task than from the other conditions. Three participants were excluded from the adjusting delay with access, 5 from the non-adjusting 50 trial version and 4 from the non-adjusting variable trial version. A Chi-square test for association showed that the number of participants excluded across conditions differed significantly ($X^2(3) = 8.365$, $p < .05$)

Visual inspection of the eleven participants excluded from the standard task condition indicated that two failed to meet the criterion that the last indifference point should be 10 percent less than the initial indifference point. Both these participants showed exclusive or near exclusive behaviour, in which subjective value at the longest delay was at its maximum value. Seven participants failed to meet the second criterion that an indifference point be no greater than 20 percent of the preceding indifference point. Although one or more points were greater than the preceding one, subjective value did decrease overall by more than 10 percent from the shortest to the longest delay for these individuals. The remaining two excluded participants failed to meet both criteria. Figure 5.2 shows indifference points of representative examples of these excluded participants. The top four panels show the indifference points of participants who were excluded based on criterion 2. The bottom left panel shows a participant who was excluded based on criterion 1 and the bottom right a participant who was excluded based on both criteria.

Data were not normally distributed, and log10 transformations failed to normalise all variables, therefore non-parametric tests were conducted.

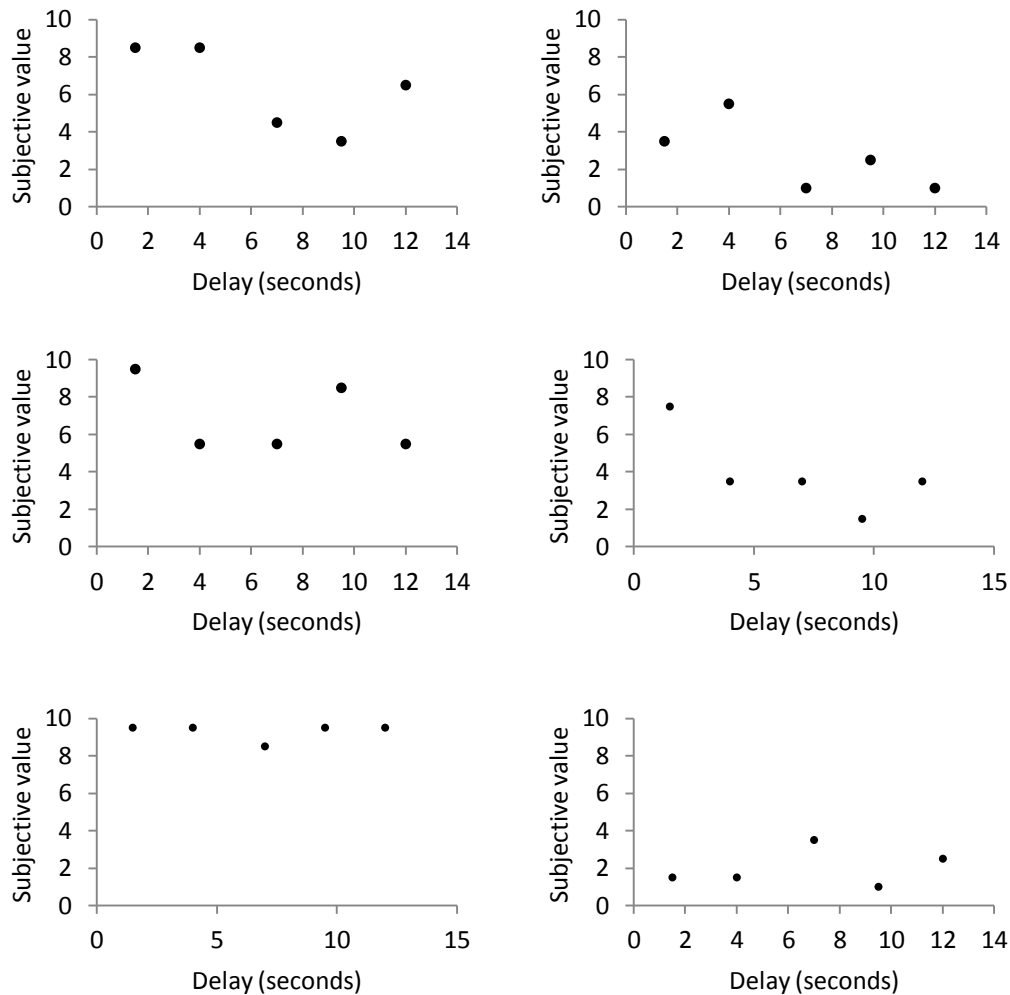


Figure 5.2. Subjective value as a function of delay in six out of eleven individuals excluded from the original task condition based on the criteria specified by Johnson and Bickel (2008).

Measures of fit across conditions

Residual analysis showed similar patterns across all conditions, see Figure 5.3. The residuals tended to be larger for the hyperbolic than the exponential function, similar to study 1a. Both models underestimated subjective value at the two shortest delays and overestimated subjective value at the three longest delays, also consistent with Study 1.

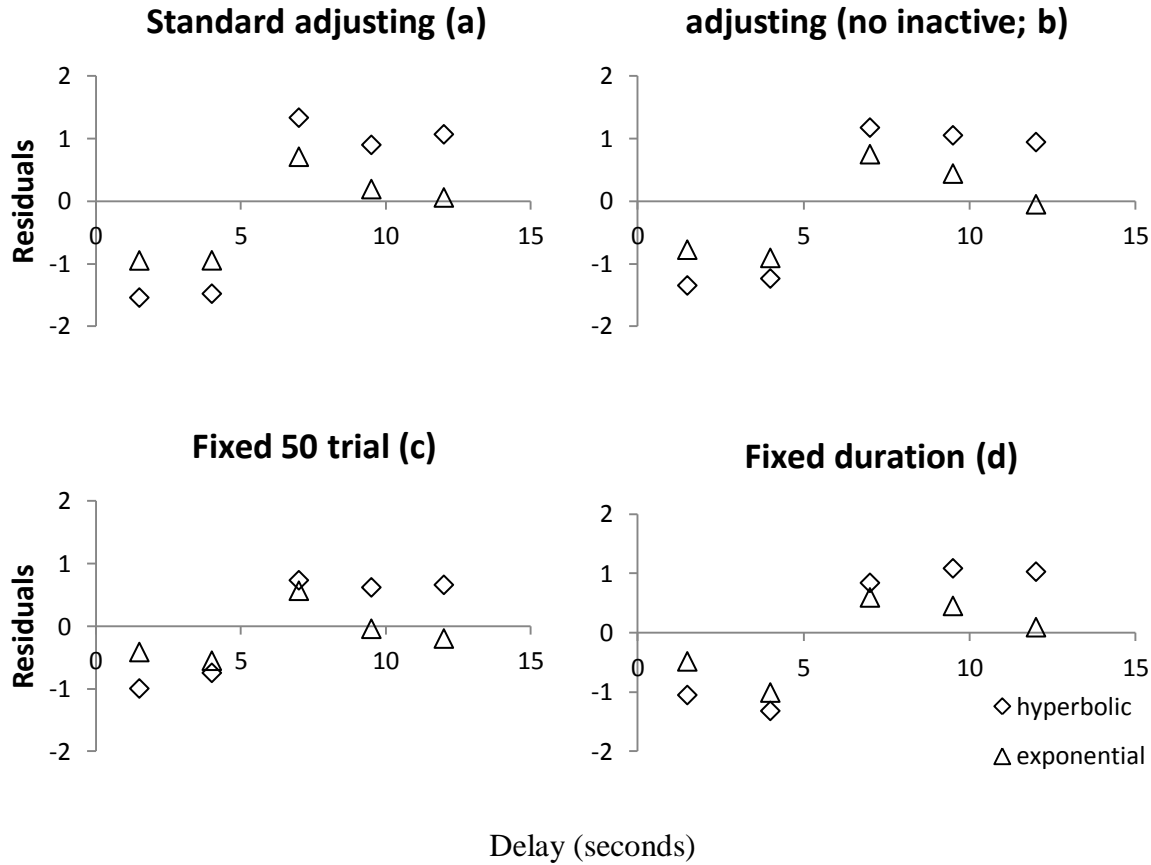


Figure 5.3. Median residuals of individual fits to Equations 1 and 2 as a function of delay, presented by condition.

To examine overall fits, MSE and R^2 measures were examined for differences across conditions. Medians and interquartile ranges of the MSE of the two equations are shown in Table 5.1, and adjusted R^2 fits are shown in Table 5.2. Across all conditions the MSEs of the exponential function were smaller and the R^2 were larger than the hyperbolic. Across all conditions combined, the exponential discounting function performed better than the hyperbolic function in both MSE ($Z = -6.327$, $p < 0.001$) and R^2 fits ($Z = -4.601$, $p < 0.001$).

In summary, both residual analysis and measures of fit indicated that the exponential model performed better than the hyperbolic, consistent with the results of Study 1a.

Table 5.1.

Medians and interquartile (IQ) ranges of the MSEs for the hyperbolic (Eq. 2) and exponential models (Eq 1) across conditions.

	Hyperbolic		Exponential	
	Median	IQ range	Median	IQ range
Adjusting no access	3.003	2.740	1.668	1.663
Adjusting w access	2.346	2.633	1.368	1.563
Non-adjusting 50	1.018	1.604	0.652	1.435
Non-adjusting variable	1.942	2.082	1.109	1.704

Table 5.2

Medians and interquartile (IQ) ranges of adjusted R^2 fits of hyperbolic (Eq. 2) and exponential models (Eq 1) across conditions.

	Hyperbolic		Exponential	
	Median	IQ range	Median	IQ range
Adjusting no access	.699	.127	.803	.152
Adjusting w access	.732	.196	.848	.184
Non-adjusting 50	.808	.189	.845	.180
Non-adjusting variable	.737	.173	.853	.197

In addition to establishing which of the two models fit best, it was also important to examine whether the best fitting model did equally well across all four conditions. MSE and adjusted R^2 measures of the exponential model were used to examine whether this was the case. Two Kruskal Wallis tests showed that neither MSE ($H(3) = 4.405$, $p = .221$, *ns*) nor R^2 fits ($H(3) = .143$, $p = .986$, *ns*) differed significantly across conditions, suggesting that the model described the data equally well across conditions irrespective of the differences in ITIs and access to point gain in the in-game phase.

Discounting rates across the conditions

Having established that the exponential model performed consistently across conditions, it was used to determine whether participants discounted more or less in any of the conditions. Descriptive statistics of individual exponential k values are shown for each condition in Table 5.3.

A Kruskal Wallis test of individual k values showed that discounting did not differ significantly across conditions ($H(3) = .342, p = .952, ns$), suggesting that the delay affected subjective value similarly, despite differences in ITIs and access to point gain in-game.

Table 5.3

Medians and interquartile ranges of individual k values using the exponential function.

	Median	Inter quartile range
Adjusting no access	.170	.094
Adjusting w access	.163	.059
Non-adjusting 50	.173	.152
Non-adjusting variable	.160	.096

Discussion

The influence that ITIs have on discounting rates in experiential tasks has been debated, regardless if they are used or not. Their presence has been criticized because participants tend to be sensitive to post-reward delays, and in their absence they confound preference for immediate outcomes with a greater rate of reinforcement (Logue et al., 1986; Lane et al., 2003). One previous human discounting study that manipulated ITIs showed that they affected discounting rate such that behaviour was more self-controlled when an adjusting delay was used (Scheres, et al., 2006). In contrast, discounting rates in the current study did not change across versions that used either adjusting or fixed inter-trial intervals, and neither were rates affected by the availability of point gain during the adjusting ITI. Indeed, the only significant effect of condition was on the exclusion of participants, whereby a greater number of participants were excluded in the condition with the adjusting delay that withheld point gain and loss immediately following outcome delivery.

There are a number of factors that could have led to the difference in outcome between this and the study conducted by Scheres et al. (2006). Briefly, theirs was a computer task in which outcomes were presented as planes carrying specified amounts of money. The height of the plane represented the delay it took for the reward to be delivered, and outcomes were experienced following each choice. Like the current study it was an adjusting amount procedure and similar trial numbers were used (60 in theirs, 50 in ours). There were also a number of procedural differences. Firstly, discounting choices were the only source of reinforcement. Access to alternative reinforcement provided in the current task might have acted as a buffer on the effect of the ITI on discounting rate. Secondly, their version without an adjusting ITI in fact had no ITI. It was reported that ‘participants did not have to wait for the next trial after receiving the immediate reward’ (Scheres et al., 2006, p. 2096), indicating that the difference between their two versions was much more pronounced than in the current study. Whereas the ITIs in their two versions differed by up to 30 seconds, depending on the delay specified in each specific trial, the difference in ITIs in the current experiment never exceeded 15 seconds, and did not include a no-ITI condition. It is possible that the differences between the versions in the current study, unlike Scheres et al.’s, were not substantial enough to see an effect on discounting rates. In addition, Scheres et al. used a within-subjects design with more power to control for individual variation in discounting rates than the current, between-subjects study.

As touched on briefly above, one potentially significant procedural difference in the skiing task was the provision of reinforcement alongside reinforcers gained from discounting choices. This characteristic marks a significant contrast to most (if not all) human experiential discounting studies to date. Even though no effect was shown for withdrawing point gain and loss during *part* of the ITI, the mere presence of an alternative source of reinforcement may have influenced behaviour.

The results of Studies 1a, 1b and 2 add to the growing evidence that the loss of subjective value of delayed and uncertain outcomes is not governed by one underlying process. Study 3 suggested that these findings were not attributable to the specific differences between the tasks in the nature of the inter-trial interval. Despite the evidence against single process views of discounting, it is reasonable to expect that the perceived certainty of a delayed outcome, in addition to other factors such as rate of inflation, should influence the degree to which delayed outcomes lose value over time. The value of a delayed reward could decrease further (arguably it

should) as a function of probabilistic discounting, be it that this decrease in value is due to a separate process, if the reward is also perceived as uncertain. A crucial distinction between the current real-time and previous hypothetical work therefore, may lie in the extent to which the chosen procedures minimise the influence of these additional factors. Once again, this comes down to experiencing outcomes following choice. Unlike hypothetical tasks, in which outcomes are not experienced at all, the experience gained in playing the temporal skiing task may mean that participants learn that outcomes only differed in respect to delay, and not in probability. This idea was examined in Study 4, in which experience of delayed outcomes was paired with varying degrees of uncertainty.

Chapter 6 : Learning Histories of Risk (Study 4)

According to the account proposed by Green and Myerson (1996), delayed outcomes lose their value because a delay entails a risk that delivery will be interrupted; the longer the delay, the greater the likelihood that something will occur to prevent delivery. By extension, this implies that out of two rewards with equivalent delays, the subjective value will be higher for one than the other, if the delivery of the latter is *perceived* as less certain, irrespective of its actual (or stated) probability, and also that two individuals will have differing subjective values for the same delayed reward if one individual perceives a greater risk of prevented delivery than the other.

Therefore, this account implies that individual differences in temporal discounting may be the result of difference in the degree to which delays are associated with perceived risk of prevented delivery. Patak and Reynolds (2007) and Takahashi, Ikeda and Hasegawa (2007) showed supporting evidence of this using a standard question based discounting task and a certainty rating questionnaire. Following completion of the discounting task participants indicated how certain they were that the rewards at each delay would actually be delivered. Consistent with Green and Myerson's theory, both studies found that participants rated outcomes as less certain the greater their delays. In addition, the decrease in subjective probability of delayed rewards was well described by a hyperbolic function (Takahashi, Ikeda & Hasegawa, 2007). Patak and Reynolds (2007) also showed a positive correlation between the AUCs of delay discounting and degree of uncertainty, further supporting the individual difference view. The

more uncertain a participant perceived the delayed rewards to be, the quicker they lost their value.

In another study to investigate certainty ratings, Reynolds et al. (2007) compared groups of adolescent smokers and non-smokers. Consistent with other research on smokers, they found that smokers discounted more by delay than non-smokers. Moreover, the smokers also rated the delayed rewards as less certain than non-smokers. When certainty ratings were entered as a covariate, the difference in delay discounting between smokers and non-smokers was reduced, although it still approached statistical significance. This finding suggested that the differences in delay discounting between substance abusers and controls could be attributed to differences in the degree of certainty they place on delayed outcomes, and opens up the question as to how such differences appear.

One possibility is that individual differences arise as a consequence of different learning histories. For some individuals, immediate rewards might have been associated with high certainty of reward delivery, whereas rewards with delays were not certain (for example, parents who promised but did not honour a delayed reward for immediate good behaviour). For others, delivery of immediate and delayed rewards might have been equally likely (parents who were consistent in honouring even delayed rewards). Learning histories have been shown to affect impulsivity and self-control in delay discounting procedures in animals (Logue, Rodriguez, Peña-Correal & Mauro, 1984) and in human discounting research the inflation study by Ostaszewski et al. (1998) is relevant. Ostaszewski et al. compared discounting of the highly inflation ridden Polish Zloty and the relatively stable American dollar in a sample of Polish university students who were familiar with both currencies. Analysis revealed that temporal discounting rates were steeper for the Zloty rewards than for the dollar rewards, suggesting an influence of learning histories specific to different currencies. The experience of the Zloty was that its value depreciated quickly over time, whereas the American dollar had been paired with stability over time.

Learning histories may also interact with context, such that steeper discounting can be produced in contexts where outcomes have been less likely to be delivered. Dixon, Jacobs and Sanders (2006) found that discounting rates elicited from gamblers either in an off-track betting facility or a café differed significantly within-subjects. When discounting questions were asked

in the gambling context, discounting rates were steeper than when they were asked in the more neutral café context.

Participants in standard discounting studies come to the experimental session with long learning histories of making choices about money. This, in effect, is why monetary outcomes are so commonly used in discounting research. Not only is money easily quantifiable, but participants are highly familiar with the rewards. Unfortunately, the familiarity with this particular outcome also makes it difficult to control or manipulate learning histories. The skiing discounting task presents a novel approach to investigating individual learning histories and discounting because it uses points rather than money. Although points are similarly pervasive in society, their value is much more context dependent. Points earned through air miles differ from those in computer games, store loyalty schemes or even the points gained in sports events such as tennis. In all these cases, more points hold greater value, but their respective values differ and are learnt specifically within those separate contexts. Indeed, there are contexts in which fewer points are better than many, and examples of these include sports such as in golf, or card games such as hearts, where the lowest score wins.

The advantage of using points to investigate learning histories with the skiing task is that we can manipulate the learning history within that specific context. Indeed we know from the previous experiments that points in the skiing task hold some value, that they lose subjective value as a function of both probability and delay, and that they do so in a systematic way. In Experiment 4, we attempted to manipulate learning histories within the skiing game context to investigate their effect on rates of delay discounting. Specifically, we exposed participants to training phases in which forced choice trials were given. Across different delays these forced choice rewards also differed in their likelihood of receipt. For some participants, rewards with long delays had lower likelihoods of delivery whereas immediate rewards had high likelihoods of delivery. For other participants the opposite was true, immediate rewards were paired with lower likelihood of delivery but long delays with a high likelihood. For a third group, all delays were paired with equally likely delivery. Participants in a control condition completed only the skiing part of the game during the training phase. These participants were not given any experienced with delayed rewards, but were only able to gain points by skiing over jumps. Following completion of the training phase, all participants played the standard delay discounting skiing task used in studies 1 to 3.

We also varied the degree of similarity between the training phase and the main skiing task for the participants in the experimental conditions. Half of the participants were exposed to forced trials only, without the skiing component to separate trials, and the other half were exposed to both forced choice trials and the skiing component.

Consistent with Green and Myerson's theoretical account of temporal discounting, and in holding with Patak and Reynolds (2007) and Reynolds et al. (2007), we expected that participants exposed to the training phases where longer delays were paired with less likelihood of delivery would discount more steeply in the main phase than participants who were exposed to the training phase where long delays were either equally likely as short delays or more likely than short delays, and that the latter group should discount less than the one with the equal likelihoods across delays.

Method

Participants

One hundred and twenty one university participants completed the training and main delay discounting task as part of the laboratory program for a course in behaviour analysis.

Measures

Delay discounting task

The standard delay discounting task used in studies 1, 2 and 3 was used in all conditions. Participants chose between 10 points delayed between 1.5 and 12 seconds, and an immediate amount of points ranging between 1 and 10 points. All participants completed 50 trials, ten at each delay.

Training phases

To manipulate prior experience we created three versions of a training phase. Participants completed one of the versions just prior to the main discounting task. All participants were given the following written instructions before commencing the training phase.

You are a 'ski border' competing for points. The point of the task is to gain as many points as possible. You gain points through going over moguls that look like this: (figure of a mogul presented)

You can also earn points through ‘free run jumps’. The game is divided into two parts, a training phase and a main phase.

Additional instructions for the training phase were specific to the version completed. In the skiing only version participants practiced skiing down the slopes. They collected points by skiing over mogul jumps and lost points by crashing into rocks and trees. The additional instructions provided to participants completing this version were: *‘In the training phase you will get an opportunity to practice skiing down the slope.’*

In the ‘with skiing version’ the participants skied down the slope but were also given forced choice experience with outcomes at three delays. Additional instructions in this version read: *‘In the training phase you will get an opportunity to practice skiing and you will be shown the types of free run jumps you might get in the main game.’*

Lastly, in the no-skiing version the participants were given only forced choice trials, and no skiing practice. These instructions were: *‘In the training phase you will be shown the types of free run jumps you might get in the main game.’*

Participants completing the with-skiing and no-skiing versions completed 30 forced choice trials. During a forced choice trial, a text box showed the amount of points and the delay until the outcome and participants were instructed to: *‘Click on the box below to experience the delay and outcome specified.’* There were 10 forced choices each at 0 seconds delay, medium delay (7 seconds) and long delay (12 seconds). The order of presentation was pseudo-random.

Participants assigned to either of these versions completed one of three conditions. The conditions differed in the pairing of degree of uncertainty and delay. Degree of uncertainty was represented by the proportion of forced choice trials at each delay that gave the participants points. In a successful trial the ski-boarder made the ‘jump’, a text box appeared that read ‘You get ten more points’ and the amount was added to the total points tally. In an unsuccessful trial, the ski-boarder ‘fell’ in the jump, the text-box read ‘Failure! You get no points’ and the points tally did not change. Unlike the delays, which were specified on each trial, the certainty proportions were not known to participants.

Certainty manipulation

The conditions were categorised according to whether they were consistent, neutral or inconsistent with Green and Myerson’s proposal that certainty decreases the longer the delay

until delivery. The proportion of success could be either 3, 7 or 10 out of 10, and the conditions differed as to the ordering of proportions across the three delays.

In the consistent condition, the certainty decreased with delay such that an immediate outcome was 100% certain, and 7 second delayed outcome was 70% certain and a 12 second delayed outcome was only 30% certain. In the neutral condition, all delays were associated with 70% certainty. In the inconsistent condition, certainty *increased* with increasing delays; the immediate outcome was 30% certain, the 7 second delay was 70% certain and the 12 second delay was 100% certain.

Procedure

All participants completed the training phase and main task at the start of a laboratory class. Each class was randomly assigned to one training phase version and condition. Once all students in the class had completed the training phase they were allowed to continue with the main game phase. Participants wore headphones during both training and main game phases. Following completion of the main game phase participants were informed that they would be debriefed the following week in the labs, to prevent the participants in the first labs from telling their classmates with labs later in the week.

Results

Data exclusion and manipulation

Participants were excluded based on the criteria specified by Johnson and Bickel (2008). If any indifference point was greater than the preceding point by 20% of the delayed outcome, or if the decrease in value between the first and the last indifference points was less than 10% of the delayed outcome the participant was excluded from analysis. Forty-two participants completed the skiing only condition, and overall 7 participants were excluded from this condition.

Thirty-seven participants completed the training only condition, of which 9 participants were excluded. Three participants were excluded from the consistent group, 4 from the neutral and 2 from the inconsistent group. Forty-two participants completed the training with skiing condition, of which 13 participants were excluded, with 4 excluded from the consistent, 1 from the neutral and 7 from the inconsistent group.

Measures of fit

As in previous studies, the exponential function provided a good fit to the indifference points. Adjusted R^2 values to the exponential function are shown in Tables 6.1, 6.2 and 6.3 for the only-skiing, no-skiing and with-skiing versions, respectively. All participants in the only-skiing condition completed the exact same task (they did not experience any pairings between delay and uncertainty), therefore Table 6.1. shows the median individual discounting rates of the exponential function for all participants together. Tables 6.2 and 6.3 show median individual discounting rates for the exponential function separately for each group of pairings of delay and uncertainty.

Table 6.1.
Median and interquartile ranges of exponential k and adjusted R^2 values in the only-skiing condition.

	K value		Adjusted R^2	
	Median	IQ range	Median	IQ range
Only skiing training	.123	.101	.858	.162

Table 6.2.
Median and interquartile ranges of k and adjusted R^2 values in the no-skiing version.

	K value		Adjusted R^2	
	Median	IQ	Median	IQ
Inconsistent condition	.0983	.093	.756	.245
Neutral condition	.122	.117	.803	.147
Consistent condition	.149	.098	.864	.073

Table 6.3

Medians and interquartile ranges of k and adjusted R^2 values in the with-skiing version.

	K value		Adjusted R^2	
	Median	IQ	Median	IQ
Inconsistent condition	.134	.056	.786	.122
Neutral condition	.090	.082	.659	1.11
Consistent condition	.130	.068	.838	.126

Differences in discounting rates and measures of fit across conditions

As seen in Table 6.2, and consistent with predictions, discounting rates in the no-skiing training version appeared to increase from the inconsistent, to neutral and consistent conditions. However, a Kruskal Wallis test was not significant ($H(2) = 2.577, p = .276$), indicating that discounting rates did not differ across conditions. A second Kruskal Wallis test of the adjusted R^2 values indicated that fits were equally good across all three conditions ($H(2) = 2.315, p = .314$).

Table 6.3 shows exponential k values across conditions for the participants who completed the with-skiing training phase version. Discounting rates in the neutral condition appeared shallower than in the inconsistent and consistent conditions. A Kruskal Wallis test was non-significant ($H(2) = 5.294, p = .071$). A second Kruskal Wallis test of the adjusted R^2 values for this training version indicated a marginally significant difference in fits across the three conditions ($H(2) = 5.906, p = .052, ns$). Mann Whitney U tests comparing the conditions showed a significant difference between the neutral and consistent conditions ($Z = -2.242, p < .05$). The neutral condition had an average rank of 8.67 and the consistent condition had an average rank of 14.90. Other Mann Whitney U tests, between the neutral and inconsistent conditions ($Z = -1.003, p = .343, ns$), and consistent and inconsistent conditions ($Z = -1.600, p = .122, ns$) were not significant.

Because the training phase only included immediate, 7 second and 12 second delays, but the main game included 1.5, 4.5, 7, 9.5 and 12 seconds, it was possible that the training phase could have affected discounting of only the pre-trained delays. Such selective changes may not be captured with discounting rates that were fit to all delays. Therefore, analyses of individual indifference points were also conducted on the with-skiing and no-skiing conditions.

Differences in indifference points across conditions

Kruskal Wallis tests at each of the indifference points in the no-skiing version were not significant, but in the with-skiing condition indifference points did differ at the three longest delays, as shown in Table 6.4. Correcting for the number of tests with Bonferroni correction, out of these three delays, the only significant result was between the inconsistent and the neutral conditions in the 12 second delay ($Z = -2.472$, $p < .016$). It should be noted however, that for all three delays, the indifference points tended to be larger in the neutral condition than the consistent and inconsistent conditions. These differences were significant at uncorrected statistical significance levels ($p < .05$) in four of the five comparisons, suggesting that participants who had completed the consistent and inconsistent training phases tended to discount more than those who had completed the neutral condition at these longer delays.

Table 6.4.

Kruskall Wallis test statistics of differences in indifference points for each delay across consistent, inconsistent and neutral training conditions for each of the three types of training phases; only skiing, no-skiing and with skiing.

	1.5	4	7	9.5	12
Only skiing	.957	.321	.113	.006	.636
No-skiing	.225	1.029	2.320	3.262	.616
With skiing	3.118	.260	6.933*	6.897*	7.134*

* $p < .05$, All tests $df = 2$

Discussion

The last experiment of this thesis involved an attempt to influence delay discounting by manipulating participant learning histories of certainty and delay. The predictions were based on the assumption that delayed rewards lose value as a result of the uncertainty of their delivery (Green & Myerson, 1996; Patak & Reynolds, 2007) and evidence that learning histories have an effect on degree of discounting in both animals and humans (Logue et al., 1984).; Ostaszewski et

al., 1998). We expected that delay discounting should be steeper for individuals with learning histories in which longer delays were paired with greater uncertainty in comparison to individuals with learning histories in which all delays were equally likely. We also included a condition in which short delays were paired with greater uncertainty than long delays, and expected participants in this group to show shallower discounting than the other two. Although there was some indication that discounting rates increased according to expectations for the groups whose training phase included both practice trials and skiing, the differences in discounting rates were not significant.

No previous experiential study has combined delay and uncertainty in the manner of this study, but two studies have investigated the association between certainty ratings and delay discounting using question based measures. Both studies showed that as delays increased, certainties of receipt decreased, consistent with the view of Green and Myerson (1996). However, the studies differed in their analyses and the results of the correlations between delay and certainty ratings. Patak and Reynolds (2007), who calculated AUCs of discounting and certainty ratings, found that discounting and uncertainty ratings were correlated. The more uncertain the individuals were of receipts, the more the delay affected subjective values. In contrast, Takahashi, Ikeda and Hasegawa (2007), who fit both delay discounting and uncertainty ratings to hyperbolic functions, failed to show the same relationship between uncertainty and delay. The discrepancy between these two studies may be explained in part by the different approaches used to measure discounting. In a group level analysis of probability discounting in smokers and non-smokers, Yi et al. (2007) found that differences between the groups were hidden when overall fitted discounting functions were compared. They showed that indifference points of smokers and non-smokers differed for high probabilities (greater than .5) but not for low probabilities (less than .5), but that when a function was fit to indifference points, these differences were not captured. In the current experiment, there was some evidence that participants in the neutral condition (in which all delays were associated with equal probability) discounted the rewards with long delays less than participants in both the consistent and the inconsistent conditions, but that shorter delays did not differ across groups.

Like Study 3, this experiment used a between-subjects design, and the manipulation may not have been strong enough to outweigh the between-subject variation in discount rates in each group, especially given the small sample sizes. Furthermore, the training phase consisted of only

10 forced choice trials at each delay, which may not have been sufficient exposure to have an effect. It may be interesting to adjust the study such that participants complete multiple free choice sessions where early sessions pair delay and probability similarly to the training phases and later sessions only include delay discounting.

Despite the lack of effect, this study illustrates the benefits of using this novel approach of an experiential game to investigate discounting. In this study, there was a specific benefit in using points as reinforcers in that participants' prior experiences with the particular point structure could be controlled, while at the same time participants' general history with points ensured that the outcomes held some value to be discounted. In comparison, manipulating individual learning histories with monetary outcomes would be much more difficult, even though Ostaszewski et al. (1998) showed that national economic situations could be capitalised on by comparing discounting of two currencies with which all participants had experience.

Chapter 7 : General Discussion

Across four studies, this thesis examined temporal and probability discounting in a novel discounting procedure in which all outcomes were experienced. In Study 1a measures of fit analyses indicated that the exponential function accounted best for indifference points in the temporal task whereas the two-parameter hyperboloid model accounted well for probabilistic indifference points. In Study 1b, the same sample as in Study 1a was used to examine the relationship between probability and temporal discounting. Temporal and probability discounting rates were uncorrelated across the two experiential tasks and probability discounting rates were also uncorrelated with discounting on the question based temporal discounting measure. The two temporal tasks, one experiential and the other hypothetical, were significantly correlated. Study 2 examined the well-established magnitude effect using the experiential tasks. Whereas discounting rates of the delayed outcomes were affected by the magnitude manipulations as predicted, probability discounting rates remained unchanged across conditions. In Studies 3 and 4 the focus was on the experiential nature of the task as a way to examine specific characteristics of experiential discounting, specifically as related to single process views of discounting. In Study 3 the ITI was manipulated, but neither manipulation of the ITI length nor the presence of alternative reinforcement during the adjusting part of the ITI affected discounting rates. Lastly, in Study 4 no significant effect was detected on temporal discounting rates when previous experience with delayed rewards was paired with high or low levels of uncertainty.

The relevance of these results and their implications for discounting research are discussed below, specifically highlighting the use of experiential tasks in discounting research, conceptions of single process accounts of discounting, individual stability and variability of discounting as well as the place of discounting within impulsivity research.

Research with experiential tasks

Across all four samples, the experiential skiing tasks provided not only a consistent picture that decreases in subjective value could be elicited using very short delays, but also that such decreases occurred in systematic (albeit somewhat unexpected) ways. This shows that points accrued in the context of a game can be used as the to-be-discounted reinforcer without necessitating the exchange for money or other backup reinforcers. The main structural characteristics of the tasks were comparable with both established hypothetical and experiential tasks, including the manner in which the small immediate outcomes were titrated to determine indifference points at a number of delays. Many experiential tasks have simply involved the same structure of hypothetical tasks with the addition of an experienced delay (or a combination of delay and probability). Some have presented the alternatives in written form (e.g. Lane et al., 2003; Reynolds & Schiffbauer, 2004), others have represented the alternatives in a more visual form. For example, Jimura et al. (2009) represented the amount of the chosen alternative with a red bar, the length of which corresponded to the amount of reward remaining to be consumed, whereas Schweighofer et al., (2006) represented alternatives both prior to and following choice as boxes to be filled with either white or yellow squares, and Scheres et al. (2006) used the height of aeroplanes off the ground and thickness of piggy bank shells as representations of delay and risk, respectively. The current skiing tasks presented the alternatives in written form similarly to Lane et al., and Reynolds and Schiffbauer, but also introduced features in the inter-trial interval that have not yet been used in experiential discounting research.

Fundamental among the differences between the current and previous studies was the use of a game-context as a means to measure sensitivity to delay or risk. None of the above tasks elaborated on a context in which choices were made because participants accumulated monetary rewards that have real value in society. In the one exception (Jimura et al., 2009), the use of immediate or delayed delivery of consumable amounts of liquids also necessitated no context beyond establishing what the participants preferred to drink normally and ensuring that they

were thirsty. Both such monetary and consumable outcomes have value beyond the particular laboratory background, which differs from the point outcomes used in the current set of experiments. As elaborated on in Study 4, points have generalized value similarly to money, but its value is highly context dependent^{vii}. Therefore, in order to use points as reinforcers (enabling the elimination of point-, exchange- and consumption delays, see Hyten et al., 1994), the specific context of a game was indeed necessary.

The use of a specific context in which to investigate experiential discounting is not completely unprecedented. Like the majority of discounting studies, Lagorio and Madden (2005) used monetary rewards to investigate delay discounting, but they limited the use of this money to purchases in the laboratory shop. Any amount of money accrued to the participant had to be used, and used immediately upon receipt, to purchase items from the experimenter. The laboratory shop therefore, was the context in which the outcomes had value, similarly to the way in which, in the skiing tasks, the game formed the context in which points held value. The two contexts were by no means identical however. Hinvest and Anderson (2010) pointed out that the experimental shop used by Lagorio and Madden may have served to diminish the real value of the monetary rewards because participants could not use the money outside of the laboratory. Because the skiing tasks created a ‘fully-contained’ context with specific reinforcers that were not used outside the laboratory this should not have been a limitation in the skiing task. Participants did appear motivated to gather as many points as possible. Some would look at other participants’ scores or ask at the end of the session how many points the other participants managed to collect. The social aspects of games, and indeed these discounting tasks, present novel opportunities for experiments, rather than limit their use, in that part of the value of points arises as a result of comparisons to other players. In this lies a possible experimental manipulation. A future experiment could vary the level of feedback about other players’ scores through top scorer boards or loud noises when players make successful jumps. Rockloff and Dyer (2007) examined gambling behaviour in participants who were exposed to various levels of feedback cues of other (fake) gambling participants. When both sight and sound cues were presented, participants placed more bets and lost more money than when less information was available. In the skiing tasks, presenting information about other players may make participants act more impulsively, preferring the immediate or uncertain outcome more than when such information is not presented.

Although both involved specific contexts, the Lagorio and Madden (2005) and the current skiing procedures also differed in how reinforcers accumulated over time. Lagorio and Madden specified that participants could not save money in order to make a larger purchase at a later time. In the skiing task, however, not only was the accumulation of points across trials possible, it was the purpose of the game. Lagorio and Madden introduced this restriction noting that participants in earlier versions had explicitly said that they were saving up for a large purchase, meaning they acted with more self-control in such situations. This reasoning implies that the accumulation of points in the skiing tasks might have encouraged greater self-control than if points could not be accumulated. Preventing the accumulation of points however would be counterproductive to the task. Furthermore, although points accumulated across trials, they were not exchanged for other goods at the completion of the task and therefore, a participant would not benefit more by ‘saving’ outcomes.

A second difference between the current task and Lagorio and Madden (2005) was that the skiing tasks involved more than one source of the reinforcers. Whereas the only way to gain reinforcement in the Lagorio and Madden procedure was through trials, participants in the current experiments accumulated (as well as lost) points both during the free-skiing component and through trials. In the delay skiing task, this may have induced greater impulsive responding if a participant believed that an impulsive response would bring about an earlier return to the skiing component, where the difference in points between the large delayed outcome and the small immediate one could be made up. Also in the probabilistic task, this could encourage risk taking if participants believed they could make up the difference in the skiing phase. However, parallels may also be drawn to comparisons of open and closed economies. If the skiing task is treated as an open economy, when points can be gained not only through trials, such access to alternative reinforcers in the inter-trial interval may produce more self-controlled responding compared to a closed economy version in which points can only be garnered through trials.

To my knowledge no studies have examined the effect of alternative reinforcement on discounting in the manner described above, but experiments examining the effects of deprivation on temporal discounting may provide some insight into this issue. For example, Kirk and Logue (1997) showed that food and water deprivation increased impulsive responding for juice rewards, and Mitchell (2004) found that 24 hour nicotine deprivation increased impulsive preferences for cigarettes. In addition, research on risky choice have shown that risk taking increases in negative

energy-budget conditions compared to positive energy-budget situations (Pietras, Locey & Hackenberg, 2003).

All of these studies suggest that we might expect steeper discounting of delayed outcome and shallower discounting of uncertain outcomes if points could not be gathered in the inter-trial interval. Unfortunately the task may not function at all without the in-game component because it provided the context by which the points held any value. Rather than remove the alternative reinforcement completely, another possibility would be to manipulate the accessibility of the jumps, or the number of points gained for each jump during the ITI. According to both the deprivation and energy-budget research (Mitchell, 2004; Pietras et al., 2003) making fewer jumps available during the ITI or providing fewer points for each jump should result in greater impulsivity or risk taking. Initial examinations of this question using the temporal skiing task have indicated however that the opposite effect occurs, whereby discounting rates are steeper when in-game jumps were 100 points than when they were worth 10 points (Hely, Macaskill & Hunt, unpublished data).

While this result is inconsistent with the energy-budget explanation, it is consistent with a contrast, or ‘relative magnitude’, effect because the amount of the free-jump amount can be compared to the amount of points gained through the in-game jumps. The value of the delayed amount of points (100) is *relatively small* in the 100 point condition and *relatively large* in the 10 point condition. According to the magnitude interpretation of these results therefore, discounting should indeed be steeper in the 100 point condition. In the hypothetical discounting literature, experimental contrast manipulations have produced consistent effects with these preliminary results using the skiing task. Dai, Grace and Kemp (2009) showed that discounting rates for an intermediate amount of hypothetical dollars (\$500) was steeper when elicited following a large amount (\$5000) than when elicited following a small amount (\$50). An interesting dichotomy in the literature arises however, when also considering the effect of income on discounting. Conflicting with the contrast effect (according to which one would expect lower income participants to discount the same amount of a delayed reward less steeply than their higher income counterparts), Green, Myerson, Lichtman, Rosen & Fry (1996) showed that lower income older participants discounted more than both higher income older adults and higher income younger adults.

Clearly, the conflicting findings between the energy-budget and income research on the one hand and the skiing task and Dai et al. (2009) on the other, suggest that more attention should be devoted to the question of what effect alternative sources of reinforcement have on discounting rates. This may have highly applicable value if one can shape shallower discounting by capitalising on contrast effects.

The use of a context in which choices are made has the benefit over traditional tasks in that it becomes more analogous to every-day life where people do not make discounting choices in isolation of other events. That said, the skiing task may not have gone far enough to resemble real life discounting choices in that delayed rewards do not tend to be received after a passive wait, as was the case in the skiing game (and other experiential tasks). In many cases outside of the laboratory, delays are either actively or passively filled with distractors of various kinds. In this sense, the Lagorio and Madden (2005) procedure was more true to non-laboratory choices involving delayed outcomes because participants made a choice, went about their day and returned later to collect the delayed reward. This early work with the skiing task has shown that systematic decreases in value can be elicited within a game context using both probabilistic and delayed outcomes. Furthermore, the use of a context opens up a number of new avenues of discounting research.

Implications for single process accounts of discounting

The results of Studies 1a, 1b, 2 and 4 are directly relevant to our theoretical understanding of discounting, most importantly to the two single process views of discounting. Collectively, the results of the first three studies add to the accumulated evidence that delay and probability discounting are not governed by one fundamental process.

As noted by Green and Myerson (2004), the fact that both probability and delay discounting are well described by mathematical functions of the same form '*raises the possibility (although it does not prove) that they both reflect a single discounting process*' (p. 779). Study 1 however, showed that the loss in value of delayed outcomes on the one hand and probabilistic outcomes on the other were best described by functions of different forms. Consistently across the four samples used in this study, temporal discounting was well described by the constant exponential function, whereas indifference points in the probability task were better described by non-constant discounting in both samples tested. This finding is problematic for either of the single

process views (Rachlin et al., 1986; Myerson & Green, 1995). At the very least, even if this result is highly specific to the current task it shows that discounting of delayed and uncertain rewards is affected differently by the parameters in place, be-it the experience of the outcomes, the specific delays and probabilities used or some other characteristic of the task. Most discounting research has been consistent in showing that the *shape* of discounting (but not *degree* of discounting) is stable across different commodities and amounts of rewards, as well as across species, but the present results suggest that even the rather ubiquitous hyperbolic nature of discounting can be altered by the particular method used to investigate decreases in subjective value.

Non-hyperbolic discounting of delayed outcomes is not without precedent. At least two ‘non-traditional’ procedures have produced non-hyperbolic discounting (Read, Frederick, Orsel & Rahman, 2005; Schweighofer et al., 2006). In the former case, delays were framed as the calendar date on which the reward was to be received, and in the latter the delays were composed of a number of steps of equal duration that progressively neared the final receipt.

Exponential discounting may meet with initial resistance due to the dominance of hyperbolic discounting in the established literature, but it is important to note that within the specific framework of the skiing tasks, the results of studies 1a, 1b and 2 together provide a picture that remains consistent with both human and animal delay discounting phenomena (such as preference reversals). An often cited argument in favour of hyperbolic discounting over an exponential form is the consistency between non-constant models and preference reversals. However, as pointed out by Green et al. (1997), exponential discounting is not inconsistent with reversals in preference if degree of discounting is inversely related to magnitude. In Study 1a it was found that delay discounting was best described by exponential discounting, and in Study 2 that degree of discounting was steeper for a smaller magnitude outcome than a larger. These two findings are consistent with the possibility that the skiing task could also produce preference reversals if a constant delay was added to both alternatives. Furthermore, if preference reversals using the skiing task were to be consistent with Green et al. (1994), who showed rapid shifts in preference from the smaller to the larger reward when the inter-reward delays were brief, participants should come to prefer the delayed outcome with very small increases in delays to the more immediate outcome. A future experiment could test how quickly preferences change when equal delays are added to both outcomes.

Interestingly, preference reversals would also be predicted in the skiing probability task. Although there was no significant effect of magnitude on probabilistic outcomes, discounting of these rewards was best described with hyperbolic discounting. Hence, the results of Studies 1a and 2 were also consistent with probability discounting phenomena. As for single process accounts, however, these findings suggest that the pathway by which preference reversals occur differs between experiential temporal and probability discounting. For temporal discounting, sensitivities to changes in magnitudes would allow preferences to shift with delays to both rewards, whereas the decreasing rate of discounting of uncertain rewards permits preference reversals in probability discounting.

The correlational analysis in Study 1b also suggested that temporal and probability discounting are distinct processes. The results were consistent with a number of previous studies that failed to find significant correlations between delay and probability discounting using hypothetical tasks (e.g. Ohmura et al., 2006, Olson et al., 2007). Although the lack of a significant correlation does not preclude the possibility of a single underlying process, and other question-based studies have shown that delay and probability discounting do correlate, the differences in magnitude effects found both in established work and in Study 2, paired with the inconsistent results of correlational analyses (cf. Ohmura et al., 2006; Richards et al., 1999), make this appear increasingly unlikely. Single process accounts of discounting are inconsistent with evidence that delay and probability discounting rates are differentially affected by the same manipulation, of which the most robust finding is the magnitude and reverse magnitude effects (Green & Myerson, 2004). In Study 2, the probability task did not produce a significant reverse magnitude effect, but the fact that a significant effect was detected in delay discounting but not probability discounting points to differences between the two types of outcomes in quantity if not quality of the phenomenon. A manipulation of the same size had an effect on one, but not the other type of outcome. Furthermore, evidence by Isomura and Aoyama (2008) suggests that the reverse magnitude effect in probability discounting is associated subjective estimate differences in the probability of actually receiving the larger or smaller amount. They found that smaller magnitudes are perceived as more likely to be received. In the current experiment, the fact that all outcomes (large and small) were experienced with equal likelihood as each other could have led to a decrease in the disparity in perceived probability, and therefore decreased any magnitude effect of uncertain rewards.

Lastly, the result of Study 4 put into question the specific single process account positing that uncertainty underlies temporal discounting (Green & Myerson, 1996). Using question-based measures of discounting, individual variation in uncertainty ratings of delayed rewards have been shown to correlate with individual variation in delay discounting rates, suggesting that the perceived uncertainty of a delayed reward is influential in determining how quickly delayed rewards decrease in subjective value (Patak & Reynolds, 2007; Takahashi et al., 2007). Keeping in mind that delay and probability discounting appeared independent processes in Studies 1 and 2, Study 4 attempted to elucidate a mechanism by which uncertainty would have an impact on delay discounting, through prior experiences in which delay and uncertainty were variously paired. However, temporal discounting rates did not differ across groups who had prior exposure to delayed rewards that were either more uncertain or more certain than immediate rewards. Although a stronger manipulation may have been required in order to see an effect, these results suggest that the mechanism by which risk would influence delay discounting is not through prior experience pairing the two, and is consistent with the evidence that probability and delay discounting are governed by different processes. These results also have bearings on the conception of temporal and probability discounting as measures of impulsivity, as discussed below.

Impulsivity, experiential discounting and single-process accounts

A range of experimental work suggests that a strong preference for immediate rewards is indicative of impulsivity. Numerous articles have linked steep temporal discounting to impulsive behaviours such as drug taking, and (to a lesser extent) shallow probability discounting to risk taking behaviours such as gambling (Holt et al., 2003). The same participants who exhibit steep temporal discounting also show high levels of impulsivity on self-report measures (Ostaszewski, 1997) and authors have developed models of impulse control fundamentally based on the way in which subjective value decreases as a function of delay (see Ainslie, 1975; Ainslie, 2005).

However, as noted in the introduction, there is limited support for this connection in the research that has directly examined how rates of discounting co-vary with various self-report measures of impulsivity. Although some studies have shown significant correlations between discounting rates and individual sub-scales of self-report measures (Kirby et al., 1999; Petry, 2001b; Petry 2002; de Wit et al., 2007), many others have not (Crean et al., 2000; Dom et al.,

2006; Reynolds et al., 2006; Krishnan-Sarin et al., 2007; Dai et al., 2009). For example, Reynolds et al. (2006) examined responses on the BIS-11 and four behavioural tasks and found only one significant correlation between a self-report subscale and a behavioural measure, namely between the cognitive complexity subscale of the BIS-11 and errors of commission on the Go/No-Go task. The majority of the literature to examine impulsivity using either multiple behavioural tasks or a combination of behavioural tasks and self-report questionnaires shows that these measures capture different aspects of a complex and multi-faceted construct. As reviewed by Evenden (1999), even self-report measures of impulsivity differ in their characterisation of the construct, with consideration taken to functional and dysfunctional aspects; attentional, motor and non-planning factors; or boredom, persistence, decision time and sensation seeking aspects. Likewise, behavioural tasks target specific aspects of impulsivity. The Go/no-go and Go/Stop tasks measure deficits in ability to inhibit responses (Logan, Schachar & Tannock, 1997), the Balloon Analogue Risk Task (BART; Lejuez et al., 2003) and the Bechara card task (Bechara et al., 1994) measure risk taking but also involve aspects of waiting, and lastly delay discounting tasks determine how fast delayed outcomes lose subjective value. As expected, behavioural tasks measuring similar constructs also factor together (Reynolds et al., 2006; Reynolds, Penfold & Patak, 2008). In principle components analyses, Reynolds et al. (2006) found that the Stop task and Go/No-go task factored together, while a hypothetical delay discounting task and the BART task loaded on a separate factor. Reynolds et al. labeled these two factors ‘impulsive disinhibition’ and ‘impulsive decision-making’, respectively. Similarly, Reynolds et al. (2008) tested hypothetical discounting of uncertain and delayed outcomes, experiential discounting using the EDT, the Go/Stop task and the Conners’ continuous Performance Test-11 of sustained attention. Three factors appeared: discounting on the three discounting tasks loaded on one factor, CPT and latencies to bank in the EDT loaded on the second factor, and the Go/stop task on a third. The addition to the factors identified by Reynolds et al. (2006), the CPT and latency to bank factor was labeled ‘impulsive inattention’.

Studies such as these illustrate the complexity of ‘impulsivity’ as a psychological construct, and put into perspective the assumption that self-report measures of ‘general’ impulsivity should correlate with specific measures such as discounting rates. In addition to the inherent bias of self-report measures (in that people, either knowingly or not, report flawed assessments of themselves), it is not surprising that self-report measures of such a multifaceted construct fail to

correlate consistently with behaviour on such a highly specific measure as a temporal or probability discounting task. Perhaps, the more interesting finding is that tasks measuring probability and temporal discounting factor together, when other evidence suggests that the two are governed by different processes.

The factor analyses describe above highlight the need to evaluate how and why decisions involving delayed and uncertain outcomes co-vary if loss in value of these outcomes is governed by different processes. Such examinations may benefit from using experiential rather than hypothetical tasks, in order to clarify if the similarities evidenced in decision making are due to the similarities in the *task structures* or similarities in the *process of de-valuing* uncertain and delayed outcomes. There are empirical reasons to expect that the experience of outcomes could be crucial in uncovering these differences. For example, Reynolds et al. (2008) found that the EDT loaded much less on the ‘impulsive decision-making’ factor than either of the hypothetical discounting measures in confirmatory factor analyses, even though it theoretically measures the same construct.

Furthermore, recent research in temporal discounting suggests a mechanism that does not easily overlap between delay and probability discounting. This research challenges the description of temporal discounting as a measure of impulsivity and instead frames it as a reflection of time sensitivity (Reynolds & Schiffbauer, 2004; Ebert & Prelec, 2007; Zauberman, Kim, Malkoc, & Bettman, 2009). This research shows not only that participants’ sensitivity to time affects discounting, but also that time-sensitivity can be manipulated, with predictable consequences to discounting. In one study, Reynolds and Schiffbauer compared time production and discounting in subjects who were either sleep deprived or well rested. In the time production test, participants were asked to indicate by pressing the mouse button, when 60 seconds had passed since the onset of a stimulus. They found that sleep deprivation led to increases in underproduction of the time duration (i.e. the duration was experienced as being longer than it actually was) and steeper discounting of delayed outcomes, suggesting that the subjective experience of passing time affected how fast delayed rewards lost their value. Zauberman et al. showed that subjective estimation of future durations is insufficiently sensitive to objective duration and that by priming duration, hyperbolic discounting was reduced.

These studies suggest a promising avenue for future discounting research that is more targeted than the ‘discounting as impulsivity’ approach. Furthermore, evidence that the

experience of time influences temporal discounting leads to questions about the discounting of uncertain outcomes, which of course has implications for single process accounts. For example, if sensitivity to time is such a crucial aspect to discounting of delayed outcomes, is there an equivalent mechanism underlying decisions between outcomes varying in uncertainty? A relevant comparison to this idea of sensitivity to duration is found in timing and counting literature which shows that timing and counting are dissociable, if the appropriate tasks to measure them are used (Droit-Volet, Clément & Fayol, 2008). One suggestion draws on the notion that the judgment of value of an uncertain outcome may depend on sensitivity to its frequency because a corresponding construct to individual's subjective experience of duration would be the subjective experience of the likelihood of an uncertain outcome, measured in terms of its frequency. One relevant study of probability discounting showed that even with equal stated probabilities, subjective probabilities can change. Isomura and Aoyama (2008) showed that the size of an outcome affected the subjective estimate of how likely it was to be received. A smaller outcome was judged to be more likely to be received than a larger outcome.

Unfortunately behavioural discounting research at large has been biased towards examinations of temporal rather than probability discounting, with the exception of articles devoted to examining single process accounts of discounting (e.g. Rachlin et al. 1991; Myerson et al, 2003) or comparisons of impulsive/non-impulsive group on the two types of outcomes (e.g. Crean et al., 2000; Reynolds et al., 2004). These articles have either treated delay as fundamental to probability discounting (or vice versa), or have treated both as a reflection of the underlying trait of impulsivity, and although the former has shown that the temporal distance between successful outcomes is important to discounting of probabilistic outcomes (Rachlin et al., 1986), it is possible that this is either secondary or complementary to sensitivity to its frequency.

One way to test these ideas would be to examine the extent of temporal and probability discounting after manipulating either the subjective experience of a duration or the subjective frequency of a probabilistic event. For instance, the subjective duration of an interval could be manipulated by using an engaging task during the interval (e.g. Chaston & Kingstone, 2004). The subjective frequency of a stated probability could be manipulated by arranging positive outcomes in sequence to induce a 'belief of luck' (Yu & Lagnado, 2012). If temporal discounting reflects sensitivity to time and probability discounting reflects sensitivity to frequency, the

former manipulation should affect temporal but not probability discounting, and vice versa for the latter manipulation.

Furthermore, timing and counting research suggests reasons for the contradictory evidence of single process accounts of discounting. Timing and counting processes may variably seem interchangeable or separate from each other, depending on what tasks are used. The similarities seen in temporal and probability discounting may similarly be due to the tasks used, specifically as related to the continued use of hypothetical tasks in discounting research. Although many authors treat real and hypothetical tasks as interchangeable, the question remains whether or not hypothetical tasks adequately capture differences in probability and temporal discounting? The timing and counting literature suggests that task can have a large impact, and Ebert and Prelec (2007) argued that time can easily be ‘pushed into the background or become a key concern, depending on incidental aspects of the choice situation’ (p. 1424) in comparison to other quantities such as money. Perhaps the contradictory findings are a result on relying on tasks that make salient the common processes in decisions making between delayed and uncertain outcomes, respectively, whereas experiential tasks make the differences, i.e. timing and counting, more salient.

A further note on exponential delay discounting

It need hardly be said again that both humans and animals tend to show hyperbolic discounting, contrary to both the rational economic perspective and the data produced using the experiential skiing task. As previously described, the exponential shape paired with a significant magnitude effect means that discounting in the temporal skiing task remains consistent with preference reversals and non-rational decision making. However, possible reasons why discounting was exponential rather than hyperbolic in the delay task remain unclear.

Collectively 363 participants completed the experiential delay task for the current experimental work, and the exponential function performed well across all four studies. Unfortunately indications of fits to the respective equations could not be tested for the hypothetical task because these discounting rates were estimated based on a number of select questions rather than fit to individual indifference points. This prevented tests of whether or not the same subjects who produced exponential discounting to the experienced rewards also did so to hypothetical ones. Given the robustness of hypothetical discounting in previous research, it

seems unlikely however, that the source of this anomalous finding would lie in the particular samples used. The source, as far as can be speculated solely from the research using the skiing task, could be two-fold. It may be a procedural artifact, whereby the choice of points as reinforcers or the particular delays used produced indifference points best described by an exponential decrease in value. Alternatively, the exponential shape of discounting in the skiing task could be a 'true' reflection of discounting at these short delays.

The percentages chosen for the probabilistic task spanned from highly likely to highly unlikely (5 to 95 percent). Using a wide range of probabilities did not present many practical difficulties in terms of designing a task that measured what was intended without being tedious to play. In contrast, selecting the durations of the delays in the temporal task did present with difficulties, and were therefore chosen based on pragmatic reasons rather than with the intention to equate the delays to the chosen probabilities using on the formula proposed by Rachlin et al (1986). The concern was that the longer the delay, the more obvious the inactive phase of the inter-trial interval would be. Study 3 partially confirmed this concern. Although there were no significant differences in the degree of discounting of the included participants, more participants were excluded from the standard task condition than from the others, suggesting that participants may indeed have noticed the inactive phase and responded less consistently as a result. Since this occurred with the chosen relatively short delays, it is likely the problem would have been exacerbated with a longer inactive phase. However, Study 3 also showed that discounting rates of the included participants were unaffected by the inactive phase, suggesting that a variation of the task could be completed without the inactive phase in which the delays were closer approximations of the range covered in the probabilistic task. A future study could test a version of the skiing task in which longer delays are used without an inactive phase, comparing both degree of discounting and measures of fit to discounting elicited using a task with shorter delays. Furthermore, individual indifference points common to both tasks could be compared across tasks to investigate the effect of including longer delays.

Rather than attribute exponential discounting to a procedural artifact of fitting the functions to the particular range of delays, it is also possible that the shape of discounting at such short delays *IS* exponential. It may be that delays this short are processed differently from longer delays. Most human experiential tasks with delays in the seconds range have used delays up to 30 or 60 seconds (e.g. Reynolds & Schiffbauer, 2004; Scheres et al., 2006; Jimura et al, 2009),

whereas the one other experiential task that also found exponential discounting used shorter stepwise delays of 1.5 seconds (Schweighofer et al., 2006). Could it be that the process governing decreases in value at these short delays is different from that governing loss of value at longer delays, or that perception of time within this range differs from the ranges used in prior literature, with the result of exponential discounting?

One reason why discounting might differ at short delays relates to the concept of the *psychological present*. Although the exact duration of the psychological present has been debated, several authors have suggested a range between 2 and 8 seconds (see Bock, 1990). However, Michon (2001) noted that while it usually covers between 2 and 5 seconds, it may last up to half a minute. It is perhaps possible that the shape of discounting was affected because the delays in the skiing task were mostly within the range of what can be experienced as the psychological present. Although the subjective experience of time, either present or passing, is separate from subjective value judgments of delayed outcomes, the decrease in value of rewards that fall within the very close future may not be the same as the decreases in value of rewards that fall further in the future. This interpretation, however, is highly speculative, and as yet says nothing of the mechanism by which the experience of psychological present would influence the decision making regarding outcomes to be experienced in the future.

Another reason why discounting might be exponential at the relatively immediate delays used in the skiing task has to do with the distinction between the subjective experience of time and the objective duration of time. Zauberman, Kim, Malkoc and Bettman (2009) suggested that hyperbolic discounting can result either from decreasing discount rates over time, as usually proposed, or from a subjective time perception that is contracted relative to objective time. As the authors noted, although three years in the future is objectively three times further away than 1 year in the future, it may be perceived as less than this if subjective time is contracted relative to objective time. They proposed that by using subjective estimations of delays rather than objective delays in the hyperbolic function, hyperbolic discounting would be reduced. Using a hypothetical measure, they examined discounting and subjective time estimates over delays lasting from 3 months to 36 months, and found that subjective time was contracted relative to objective time. Furthermore, they showed that when individuals' subjective time estimates were used rather than the objective durations, discounting rates were constant over time. This distinction between objective and subjective estimates of time may account for the anomalous

findings of the present set of studies if the difference between the two measures of duration were not differentiated at the level of seconds. Participants' subjective experiences of the delays measured in the skiing task may not have been contracted relative to the objective delays because they were so short, hence why the use of objective delays in calculating discounting rates resulting in exponential rather than hyperbolic discounting. A future study could examine this explanation by eliciting discounting using the experiential task as well as measuring participants' subjective estimates of the delays used.

Irrespective of the explanation for exponential temporal discount, the fact that discounting of the experiential point outcomes was better described by the exponential function raises the possibility that not only degree of discounting, but also the *shape* of discounting, can change within subjects. A further implication is that multiple processes may be involved in the discounting of delayed rewards, making it seem even less likely that temporal and probability discounting are governed by the same process.

Implications for individual difference interpretation of the k parameter

The results of Studies 1b and 2 are also relevant to the discussion on whether degree of discounting is a state or a trait variable. Odum and Baumann (2010) described a state variable as 'an environmental manipulation affecting behavior over a relatively short time frame' (p. 40) and a trait variable as 'a relatively stable preexisting individual characteristic that affects behavior' (p. 40). Discounting, as reviewed in the general introduction, appears to be relatively stable over time, but is nonetheless affected by environmental manipulations. For instance, while there is a high degree of stability in test-retests of question based discounting (Ohmura et al., 2006), within-subject discounting rates also change as a function of for example, sleep deprivation or nicotine abstinence (Reynolds & Schiffbauer, 2004). In study 1b, within-subject discounting rates were significantly correlated across two types of delay discounting measures, one experiential and one hypothetical, suggesting that degree of discounting was relatively stable within-subjects, despite differences in the procedures that elicited indifference points. Furthermore, although the delays between test occasions were not specifically controlled, some participants completed the two tasks up to three weeks apart, illustrating that discounting rates were stable across time as well as procedures. Previous studies have shown test-retest stability in

discounting rates, but this study also showed stability in discounting rates across hypothetical and experiential tasks.

Study 2 was consistent with other magnitude manipulation studies (e.g. Green et al., 1997) showing that delay discounting rates differed significantly when the size of the delayed outcome was changed, illustrating that within-subject degree of discounting can be relatively easily manipulated. Using question based measures, Yi et al (2006) and Benzion et al. (1989) reported positive correlations between amounts of delayed hypothetical outcomes, indicating that despite absolute changes in rate of discounting across conditions a subject's degree of discounting relative to others remained the same. In contrast, and more problematic for an individual difference approach to discounting, in the skiing task degree of discounting not only differed across the two amounts, but were also uncorrelated. This amount independence of individual discounting rates across magnitude is particularly noteworthy given the stability in Study 1b across the two different discounting procedures, experiential on the one hand and hypothetical on the other. One might expect that with the stability across time and task type implied by Study 1b, discounting should also be related across two magnitudes of the same commodity when elicited within a short duration, using the same experimental procedure. Further studies using the skiing task should examine the stability of discounting rates across time and magnitudes of delayed as well as probabilistic outcomes.

Concluding remarks

The present thesis contributes to the growing body of research on discounting by re-examining and, more importantly, establishing a link between two distinct themes in the established literature; namely the debated importance to behaviour of experiencing the consequences of one's choices, and the question of whether or not different types of discounting are governed by one fundamental process. Although these themes have been explored extensively separately, the significance of the current thesis lies in the suggestion that the answers to the latter question previously revealed in research have been heavily influenced by the (implicit) stance on the former, that experience of outcomes does not matter. However, the introduction highlighted already existing evidence of the impact that experience of outcomes can have on discounting phenomena, in addition to the conflicting findings as regards single process accounts of discounting. This evidence laid the foundation for the presented experimental chapters, which showed that the use of a novel procedure enabled us not only to re-evaluate

robust discounting phenomena in the hypothetical literature, but also allowed us to use novel approaches in the examination of the overlap between risk and delay.

Although the development and use of the skiing task (and other similar ‘dynamic’ discounting tasks) is still in early stages of research, the experiments in the present thesis attempted to show that these two questions are not independent, and also far from fully resolved.

Chapter 8 Appendix A - Further Magnitude Effect Analyses

Measures of fit for Equations 1, 2 and 3

Table 1A shows the medians, standard deviations and ranges of the mean square errors (MSE) and adjusted R^2 fits of the three equations in the two conditions of the temporal task. As in the previous study the exponential model performed well. It performed equally with the hyperboloid function according to the MSE and better than the hyperboloid according to the adjusted R^2 fits.

Table 1A

Median, standard deviations and ranges of the Mean Square Errors and adjusted R^2 fits for hyperbolic, hyperboloid and exponential discounting functions in the small and large condition of the temporal task.

	MSE			Adjusted R^2		
	Median	St. dev	range	Median	St. dev	range
10 point						
Hyperbolic	.017	.025	.086	.736	.106	.378
Hyperboloid	.011	.019	.064	.771	.134	.426
Exponential	.011	.019	.062	.829	.103	.362
50 point						
Hyperbolic	.016	.016	.069	.750	.144	.606
Hyperboloid	.010	.013	.050	.720	.2	.829
Exponential	.010	.013	.049	.793	.147	.597

A Friedman test showed that there were significant differences in MSE depending on function across both the 10 point temporal task, $X_2(2) = 23.7$, $p < .001$, and the 50 point temporal task, $X_2(2) = 29.2$, $p < .001$. Post hoc Wilcoxon Signed Ranks tests of the 10 point condition

showed that the MSE on the exponential and hyperboloid did not differ ($Z = -1.157$, $p = .247$, *ns*) but that the hyperbolic function differed from both the hyperboloid ($Z = -3.92$, $p < .001$) and the exponential ($Z = -3.659$, $p < .001$). In the 50 point condition, with Bonferroni correction for number of tests, all comparisons were significant, all $ps < .017$.

Table 2A shows the descriptive statistics of the measures of fit from the probabilistic task. These are also consistent with the previous study. The hyperboloid discounting function provided a better fit in comparison to the other function, in terms of the MSE in both conditions, and for the adjusted R^2 in the small magnitude condition. In the large magnitude condition the hyperbolic function provided a marginally better fit.

Table 2A.

Median, standard deviations and ranges of the Mean Square Errors and adjusted R^2 fits for hyperbolic, hyperboloid and exponential discounting functions in the probabilistic tasks.

	MSE			Adjusted R^2		
	Median	St. dev	range	Median	St. dev	range
10 point						
Hyperbolic	.007	.009	.035	.891	.444	1.899
Hyperboloid	.004	.005	.023	.923	.129	.506
Exponential	.012	.013	.048	.826	.871	3.73
50 point						
Hyperbolic	.008	.012	.048	.878	.317	1.416
Hyperboloid	.007	.009	.037	.874	.119	.437
Exponential	.010	.014	.049	.846	.608	2.622

Figure 1A shows the residuals of the three models across delays and odds against. Some differences were evident across tasks. Residuals overall appeared smaller and more random in the probabilistic version, at least in terms of the hyperbolic and hyperboloid functions. Furthermore, residuals were similar across the hyperboloid and exponential models in the temporal task, but similar across the hyperbolic and hyperboloid in the probabilistic task.

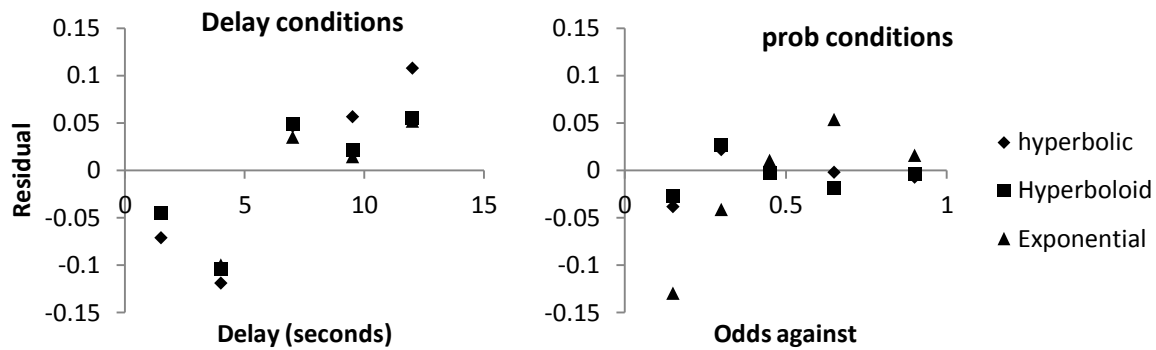


Figure 1A. Median residuals of exponential, hyperbolic and hyperboloid models as a function of delay (left) and odds against (right).

Magnitude effects using hyperbolic and hyperboloid functions

Figure 2A shows hyperbolic function fit to the median individual indifference points for each magnitude in both the temporal and probability tasks. In the temporal task 80% of participants had a larger k value in the 10 point condition than in the 50 point condition according to the hyperbolic function. A wilcoxon signed ranks tests of individual hyperbolic k values confirmed that discounting was steeper in the 10 point temporal condition than the 50 point condition ($Z = -2.949, p < .01$).

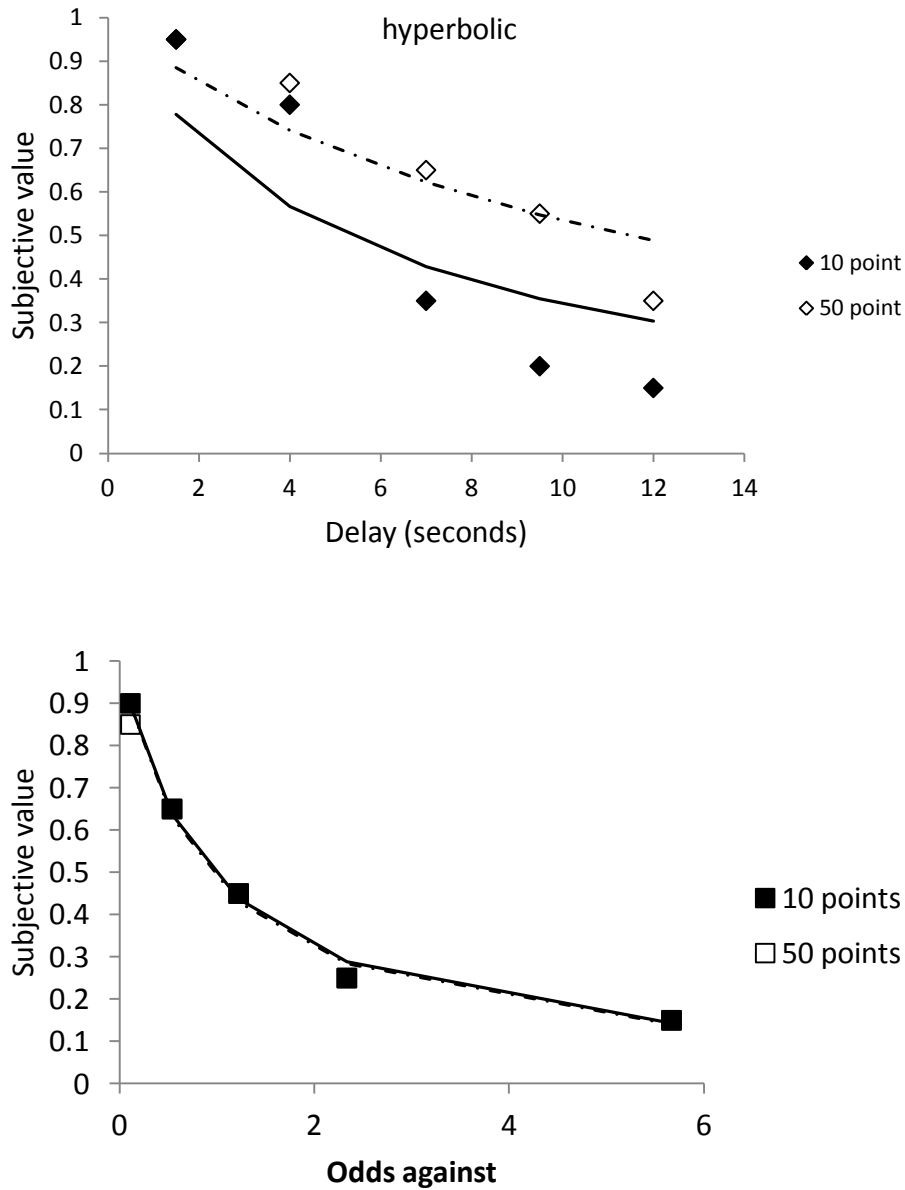


Figure 2A. Median individual indifference points and best fitting hyperbolic discounting function in 10 and 50 point magnitude conditions. Top panel shows the best fitting functions for each amount of the temporal task and the bottom panel for the probability task. Dotted line represents discounting in the 50 point condition and solid line represents the 10 point condition.

In the probability task, 54% of participants had a greater hyperbolic k value in the 10 point condition than 50 point condition. A wilcoxon signed ranks tests of individual hyperbolic k values showed that discounting did not differ significantly between magnitude conditions ($Z = -.308, p = .758, ns$). Figure 3A shows ranked individual discounting rates in the large magnitude condition as a function of ranked individual discounting rates in the small magnitude condition. As with the results using the exponential function, the points cluster below the diagonal line in the temporal task, but are spread evenly above and below the diagonal in the probability task.

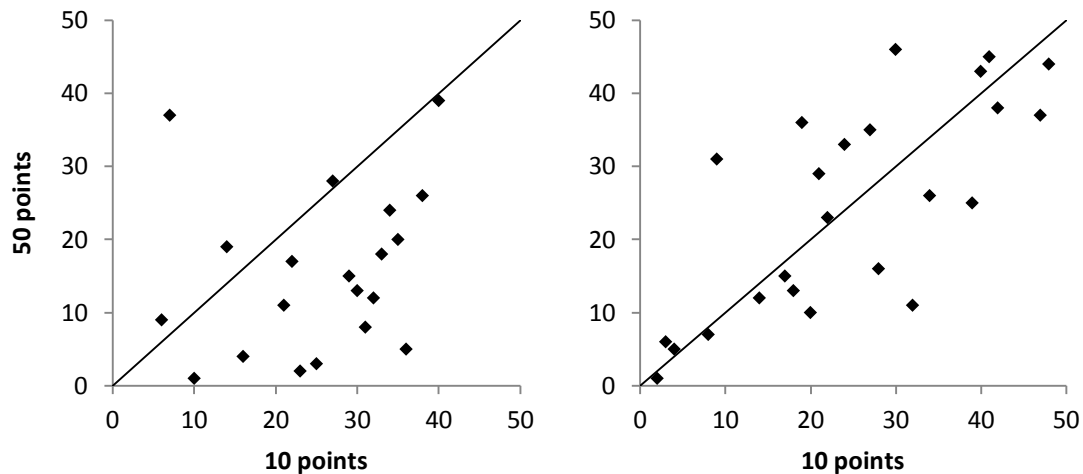


Figure 3A. Ranked individual hyperbolic discounting rates on the 50 point condition as a function of ranked individual discounting rates on the 10 point condition in the temporal task (left panel) and the probability task (right panel).

Figure 4A shows the hyperboloid function fit to median individual indifference points for both magnitudes in both tasks. In the temporal task 60% of participants had a larger hyperboloid k value in the 50 point condition than in the 10 point condition. A wilcoxon signed ranks tests of individual hyperboloid k values showed that the parameter did not differ significantly between magnitude conditions ($Z = -.971, p = .332, ns$). In the probability task 80% of participants had a larger hyperboloid k value in the 10 point condition than in the 50 point condition. A wilcoxon signed ranks tests of individual hyperboloid k values showed that the parameter was greater in the 10 point condition than the 50 point condition ($Z = -2.127, p < .05$).

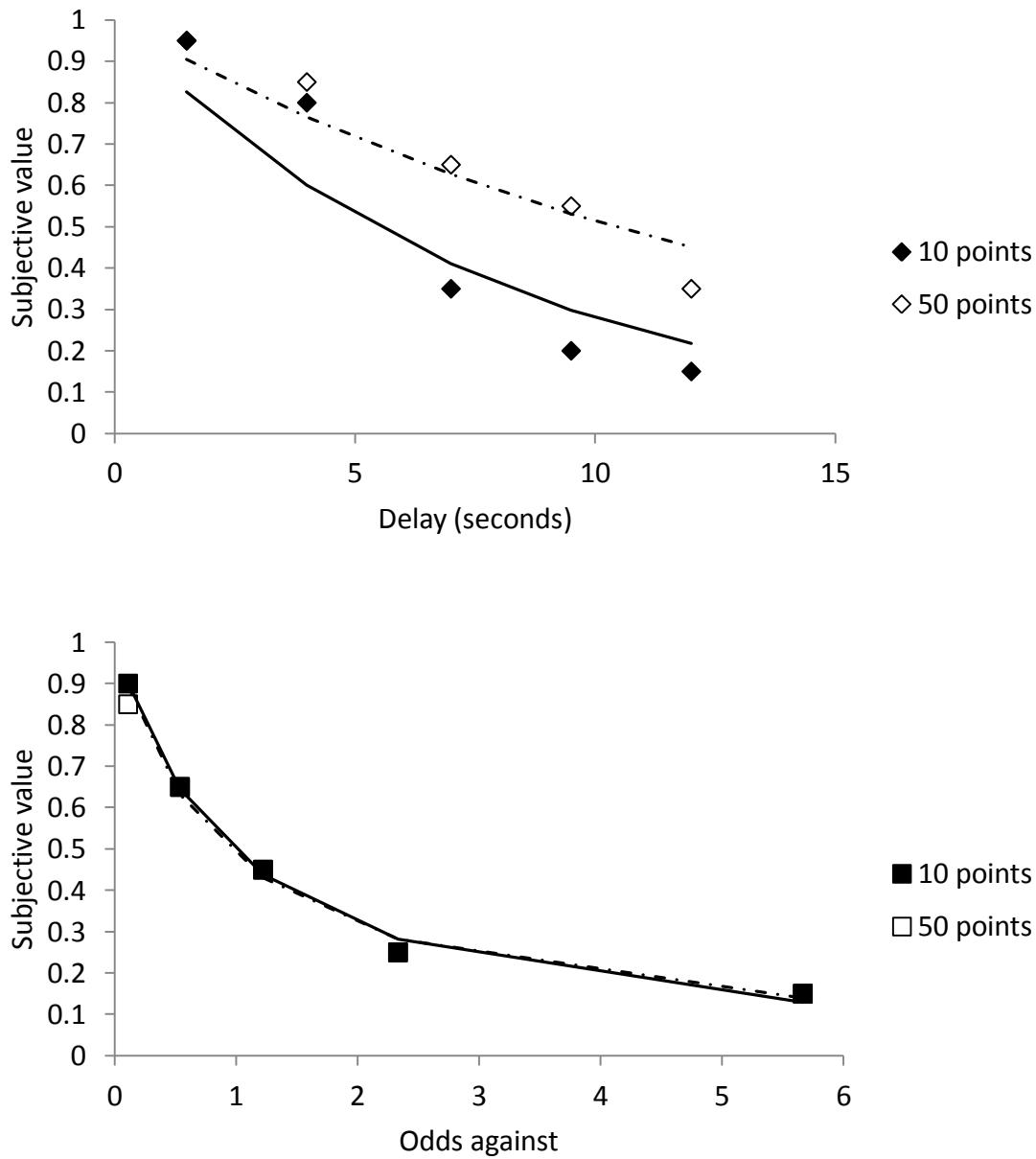


Figure 4A. Median individual indifference points and the best fitting hyperboloid function in the small and large magnitude conditions. Top panel shows temporal discounting task and bottom panel shows probability discounting task. Solid line represent the small magnitude condition and dotted line represent the large magnitude condition.

Figure 5A shows the ranked individual k values on the large magnitude condition as a function of the ranked individual k values on the small magnitude condition in both tasks. The even spread of points across the diagonal show the non-significant effect in the temporal task. The clustering of points below the diagonal in the probability task illustrate the significant effect in which k values were greater in the smaller magnitude condition.

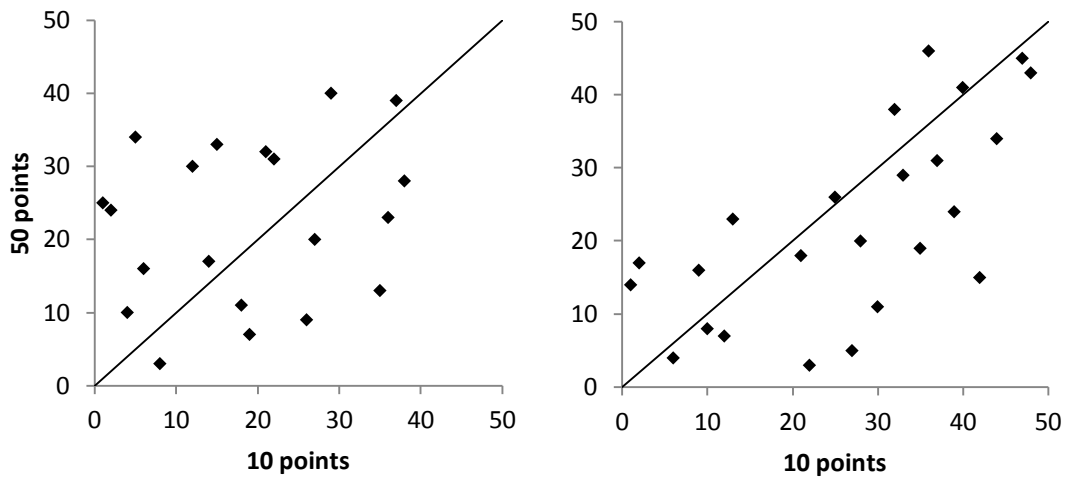


Figure 5A. Ranked individual hyperboloid k values on the 50 point condition as a function of ranked individual hyperboloid k values on the 10 point condition in the temporal task (left panel) and the probability task (right panel).

In the temporal task 75% of participants had a larger hyperboloid s value in the 10 point condition than in the 50 point condition. A wilcoxon signed ranks tests of individual hyperboloid s values confirmed that the scaling parameter was greater in the 10 point temporal condition than the 50 point condition ($Z = -2.277$, $p < .05$). In the probability task 80% of participants had a larger hyperboloid s value in the 50 point condition than in the 10 point condition. A wilcoxon signed ranks tests of individual hyperboloid s values, however, showed that the scaling parameter did not differ significantly between magnitude conditions ($Z = -1.542$, $p = .123$, *ns*).

Figure 6A shows the ranked individual s values on the large magnitude condition as a function of the ranked individual s values on the small magnitude condition in both tasks. Temporal s values are clustered below the diagonal, and a trend is apparent in the probability s values suggesting that they were larger in the large magnitude condition.

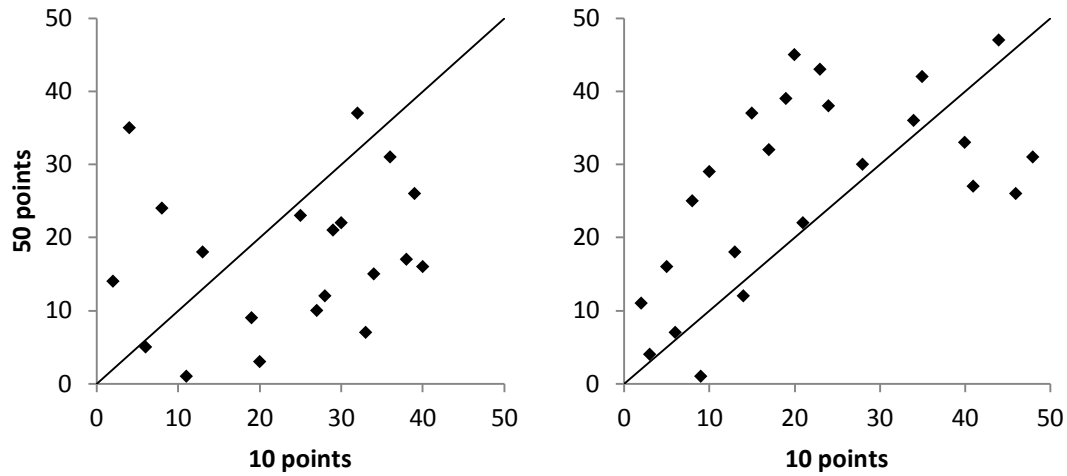


Figure 6A. Ranked individual hyperboloid s values on the 50 point condition as a function of ranked individual hyperboloid s values on the 10 point condition in the temporal task (left panel) and the probability task (right panel).

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ⁱⁱ Although other models have been suggested, e.g. Rachlin (2006, as cited in McKerchar, Green, Myerson, Pickford, Hill & Stout, 2009) these three are the most commonly cited models used in research focused on temporal discounting in humans.

ⁱⁱ Rachlin (2006, as cited in McKerchar, Green, Myerson, Pickford, Hill & Stout, 2009). has also proposed a 2 parameter model in which only the rate parameter is raised to a power. This model has not commonly been used in the literature reviewed. McKerchar et al. (2009) noted that both models perform well in describing delay discounting.

ⁱⁱⁱ For a more thorough description of the mathematical foundations of this theory, see Myerson and Green (1995) or Green and Myerson (1996)

^{iv} Not all real time tasks do, however. As discussed in Study 1b, the EDT also confounds the two.

^v However, adjusting ITIs are also problematic because participants may be sensitive to these, and respond with exclusive self-control upon realizing that impulsive preferences produce the same total inter trial duration as self-controlled preferences.

^{vi} The influence of post reward delays will be further evaluated in Study 3.

^{vii} One might note that the value of money is also context dependent in the exchange and use of different currencies but, excepting Ostasewski et al. (1999), this aspect of monetary value has not been examined in the context of discounting.