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# Rates of Discounting and Errors of Expected Value

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Rates of Discounting and Errors of Expected Value" submitted by Nathaniel Will Shead in partial fulfilment of the requirements for the degree of Master of Science.

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Abstract

This study investigated whether performance on a gambling task was associated with the degree to which delayed and uncertain outcomes were discounted in a sample of college students. Participants ($N = 60$) completed a gambling task that measured preferences for decks of cards that resulted in either net profits or net losses. Repeated selections from decks that resulted in net losses indicated insensitivity to the cumulative negative effects of poor gambling decisions. Participants also completed three discounting tasks in which they made a series of choices between alternatives involving delayed and uncertain outcomes. Degree of discounting for delayed rewards was significantly associated with performance on the gambling task indicating that individuals who preferred larger, delayed rewards over smaller, immediate rewards tended to make decisions on the gambling task that resulted in net losses. Degree of discounting for probabilistic wins and losses was not associated with performance on the gambling task. The results suggest that profitable versus unprofitable gambling decisions may be mediated by temporal considerations rather than consideration of risk.

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LIST OF SYMBOLS & ABBREVIATIONS

AUC – Area Under the Discounting Curve

BIS – Barratt Impulsiveness Scale

CPGI – Canadian Problem Gambling Index

D – Length of delay

EV – Expected Value

h – Rate of probability discounting

k – Rate of delay discounting

p – Probability

s – Scaling parameter (sensitivity to delay or odds against)

V – Value of outcome

$v_d$ – Subjective value (indifference point)

$\Theta$ – Odds against outcome occurring

## EPIGRAPH

What if somebody asked the question he, in idle moments, came perilously close to asking himself: why return to the casino again and again when logic says the house advantage is insurmountable?

Gary Stephen Ross, Stung: The Incredible Obsession of Brian Maloney

# CHAPTER ONE: INTRODUCTION

A common saying associated with gambling is "the house always wins." This saying refers to the fact that the party providing a gambling opportunity (e.g. a casino) has a mathematical advantage over the gambler, thereby ensuring that they will profit on a consistent basis by providing the gambling opportunity. Consequently, it also ensures that the gambler will lose in an expected manner. Certainly, there is the possibility that the gambler will win sometimes, otherwise, the individual would never gamble. However, the "house advantage" dictates that in the long run the gambler will, on average, lose more than he or she wins.

There is no single reason why individuals develop gambling problems (Raylu & Oei, 2002). One explanation may be that some individuals are unable to foresee the cumulative negative consequences of gambling. That is, they may have a deficit in the cognitive processes responsible for considering the potential negative consequences of risky decisions. This study intended to investigate how insensitivity to negative outcomes is associated with other measures that have been shown to be related to problem gambling behaviour.

The following literature review will first examine "expected value," or the average net effect of a particular decision. Next, it will look at the constructs of impulsivity and risk-taking. In subsequent sections, delay and probability discounting will be discussed in detail. Finally, the relationship between rates of discounting and impulsivity/risk-taking will be explored.

### *Expected Value*

As stated above, the "house advantage" dictates that most games of chance will ensure that gamblers tend to lose more than they win in the long run. That is, the expected value (EV) of a particular gamble will take on a negative value. When a particular gamble involves the possibility of either a single event occurring or nothing occurring, the expected value is equal to:

$EV = V \times p$ (1)

where V is equal to the value of the outcome (either positive or negative) and p is equal to the probability of that outcome occurring. For example, if there is a 30% chance of winning $50, the expected value of that gamble is EV = 50(.3) = $15.

When a particular gamble involves the possibility of either a positive outcome (winning) or a negative outcome (losing), the expected value is equal to:

$EV = W(p) - L(q)$ (2)

where W is equal to the value of the positive outcome, p is equal to the probability of the positive outcome occurring, L is equal to the value of the negative outcome, and q is equal to the probability of the negative outcome occurring. In many cases, q will be equal to (1-p), slightly altering equation 2 to take the form:

$EV = W(p) - L(1-p)$ (3)

For example, if there is a 20% chance of winning $30 and an 80% chance of losing $10, the expected value for that gamble is a loss of two dollars -- EV = $30(.2) - $10(.8) = -$2. Another important concept for understanding the house advantage is "odds against winning," which is the average number of losses expected before a win on a particular gamble (Rachlin, Raineri, & Cross, 1991):

$\Theta = (1-p)/p$ (4)

where $\Theta$ is the odds against for a particular gamble and p is the probability of winning. For example, if the probability of winning an amount of money is 25%, the odds against is equal to $\Theta = (1 - .25)/.25 = 3$. Thus, the odds against are 3 to 1; or on average, three losses will occur before a win occurs. A related concept is "odds of winning" which is simply equal to 1/p or ($\Theta$ + 1). Thus, in the previous example, the odds of winning would be 4 to 1; or on average, an individual could expect to win once every four wagers made.

These concepts can be demonstrated using the casino game of roulette. The house advantage in American-style roulette is 5.26% which means that individuals will lose, on average, 5.26% of every wager they place. A roulette wheel consists of 38 numbered sections that have corresponding sections on a separate table. Wagers may be placed on the corresponding sections on the table as to which section a ball will fall into when the wheel is spun. Because there are 38 numbered sections, the probability of betting on the correct number for a given spin is $p = 1/38 = .026$ and the probability of losing is $q = 1-p = .974$. Thus, the odds against winning are 37 to 1 [$\Theta = (1 - .026)/.026 = 37.46$]. However, the casino only pays out 35 to 1 on winning bets (35 times the amount wagered). This difference between odds against winning and amount that is paid out for a win is, in essence, the house advantage. In other words, on a \$10 wager, an individual could expect to lose, on average, 37 times before winning, which would then only pay out \$350. It follows that the expected value for this wager is equal to EV = \$350(.026) - \$10(.974) = -.526 or a loss of about 53 cents. Thus, an average loss of \$0.526 will be incurred every time this wager is made which is 5.26% of the \$10 bet made on each wager.

Of course, if this wager is made only a few times, it is possible that an individual will lose much more than an average of 53 cents or they may even win more than they lose. For example, if they make this wager only three times and do not win on any of the three wagers, they will have an average loss of \$10 per wager or 100%. On the other hand, if they win at least once in less than 35 times the wager is made, they will come out ahead. However, the negative expected value for this wager dictates that the gambler will lose an average amount. The more times this wager is made, the more likely it is that the average amount lost per wager will resemble the expected value and an average loss will almost certainly occur. In other words, in the short term an individual may actually profit from making this wager; however, as the number of times this wager is made increases the more likely it is that his or her average losses will regress towards the expected value.

*Impulsivity & Risk-Taking*

Impulsivity can be defined as behaviour carried out in a spontaneous or unintentional manner without thought or self-control (Raylu & Oei, 2002). This characteristic is associated with problematic behaviours such as substance abuse (Crean, de Wit, & Richards, 2000) and it is a diagnostic feature of several psychological disorders in the Diagnostic and Statistical Manual of Mental Disorders (4$^{th}$ ed. Text rev.; DSM-IV; American Psychiatric Association, 2000). The DSM-IV includes a special category of impulse control disorders. Among these disorders is pathological gambling, which is described as "persistent and recurrent maladaptive gambling behaviour that disrupts personal, family, or vocational pursuits" (p. 671). Recent research has provided increasing evidence that individuals with gambling problems exhibit higher scores on measures of impulsivity (e.g. Petry, 2001a; Petry, 2001b).

One difficulty in studying impulsivity amongst gamblers is the association between impulsivity and risk-taking. Because gambling is, by definition, a risky venture, it makes intuitive sense that people who are risk-takers are more likely to develop gambling problems. Indeed, research has shown that risk-taking is higher among problem gamblers than non-problem gamblers (for a summary, see Raylu & Oei, 2002). More specifically, it has been shown that risk-taking is associated with a loss of self-control in gamblers (Coventry, & Brown, 1993). This loss of self-control, or conscious control over behaviour, in turn, is a defining feature of impulsive behaviour. Direct correlations have also been reported between scores on behavioural tasks that assess risk-seeking and self-report measures of impulsivity (e.g., Breen & Zuckerman, 1999). Thus, there appears to be some overlap between the concepts of risk-taking and impulsivity that can be described by the amount of self-control an individual exhibits which may be a particularly relevant consideration for the study of gambling behaviour.

A major problem with studying impulsivity in individuals has been the lack of consensus regarding the definition of impulsivity (Milish & Kramer, 1984). For instance, some researchers define impulsivity in terms of behavioural characteristics such as an inability to resist temptation, while others define it in terms of cognitive characteristics such as an inability to anticipate adverse future consequences (Crean et al., 2000). Still others have viewed impulsivity as an enduring personality trait that encompasses both behavioural and cognitive deficits (Patton, Stanford, & Barratt, 1995).

These different definitions have led to a divergence in the measurement strategies used to quantify impulsivity in individuals (Lane et al., 2003). Most self-report measures that employ questionnaires (e.g., Patton et al., 1995) are based on very broad operational definitions of impulsivity while some laboratory measures are based on more narrow definitions that only consider specific aspects of impulsivity. For example, an often-noted feature of impulsivity is the inability to delay gratification and a preference for smaller, more immediate rewards over larger, delayed rewards (Rachlin et al., 2000). This feature translates into a more narrow definition of impulsivity which is the basis of a method for measuring impulsivity called delay discounting. This laboratory method is generally supported by research as a valid measure of impulsivity (Crean et al., 2000).

*Delay Discounting*

Delay discounting refers to the tendency for delayed rewards to be considered worth less compared to the value of immediate rewards (Ainslie, 1975; Bickel & Marsch, 2001). As the length of time until receipt of a reward increases, the subjective value of that reward decreases and it becomes less likely that the delayed reward will be chosen among current alternatives (Kirby, Petry, & Bickel, 1999). In the delay discounting paradigm, participants are presented with choices between a reward that is available immediately and a reward that is available after a specified delay. When the two rewards are equal, people will tend to choose the reward that is available immediately because the value of the reward that is to be received later will be discounted by the individual (Kirby, 1997; Mazur, 1987; Mellers, Schwartz, & Cooke, 1998). When the delayed reward is larger than the immediate reward, an individual may still choose the immediate reward, depending on how much the value of the delayed reward has been subjectively discounted by the individual. For example, if given the choice between $100 now or $105 in two months, most people would probably rather have $100 immediately because the extra $5 is discounted over a two-month period. Thus, the subjective value of $100 now is worth more to an individual than $105 dollars in two months. However, if given the choice between $100 now or $200 in two months, most people would wait the two months because they do not discount $200 by more than half of its value over a two-month period. In this case, the subjective value of $100 now is not worth more than $200 in two months.

In the delay discounting paradigm, the amount of the immediate reward is adjusted to identify an individual's subjective value for a delayed reward. This subjective value, or indifference point, represents the point at which an immediate reward and a delayed reward would be chosen equally as often (Crean et al., 2000). In other words, a titration procedure is used to determine how much a given delayed reward is worth to an individual at the present time. Although most of these studies do not usually use real rewards, research has shown that hypothetical rewards can serve as a valid substitute for real rewards in research involving the discounting paradigm (Johnson & Bickel, 2002).

It has been shown that both human and non-human preference between immediate and delayed rewards is well described by the following hyperbolic function (Mazur, 1987):

$v_d = V/(1 + kD)$ (5)

where $v_d$ is equal to the subjective value of a delayed reward, V is equal to the amount of the delayed reward, D is equal to the length of the delay before V is received, and k is equal to the individual rate at which the value of the delayed reward is discounted. Figure 1 illustrates graphically the shape of a delay discount function. As rates of discounting increase, the value of k increases and the discounting curve becomes steeper. Steeper discounting curves describe individuals who prefer smaller, more immediate rewards over larger, delayed rewards. Thus, higher k values are hypothesized to be associated with higher impulsivity.

Several studies have compared discounting rates across groups that are suggested to differ in impulsivity (Baker, Johnson, & Bickel, 2003; Crean et al., 2000; Kirby et al., 1999; Petry & Casarella, 1999; Petry, 2001a; Petry 2001b; Mitchell, 1999; Reynolds et al., 2003, Reynolds et al., 2004). Results show that groups composed of more impulsive individuals demonstrate higher rates of delay discounting (i.e., higher k values) than groups composed of less impulsive individuals. Heroin addicts, for example, are described as impulsive because they cannot control the urge to use drugs even though the long-term health and financial consequences are quite negative. One study did, in fact, show that heroin addicts had higher discount rates for delayed rewards than control participants (Kirby et al., 1999). It can be reasoned from these results that heroin addicts choose to use drugs, even in the face of long-term negative consequences, because the long-term benefits of abstaining from drug use (e.g., good

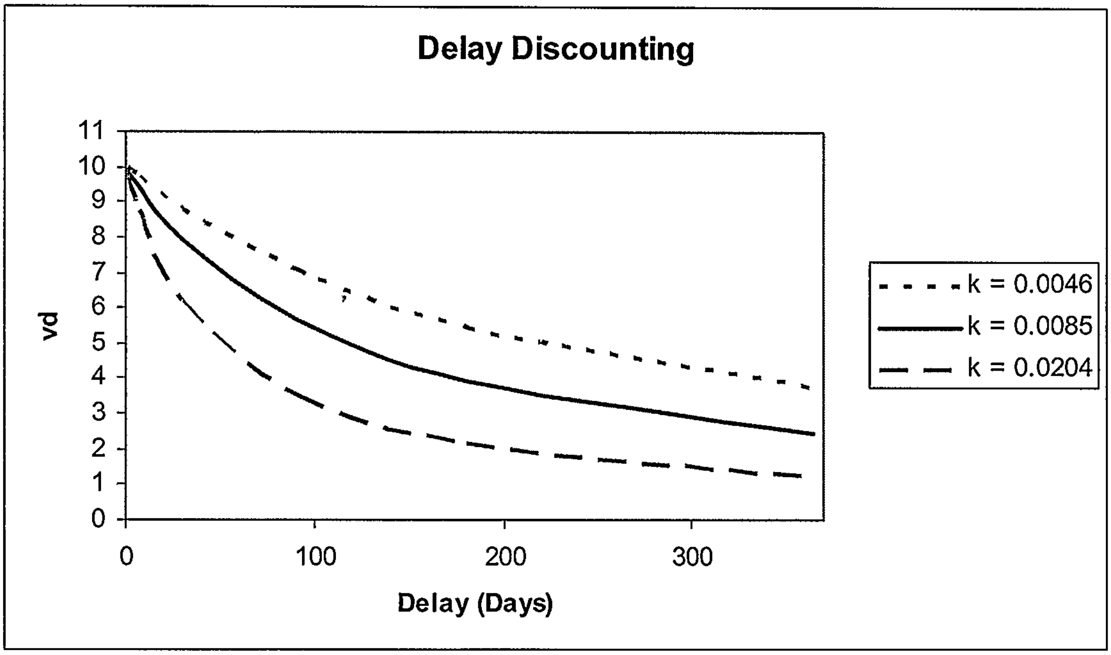


**Figure 1.** Shape of the delay discounting function, $v_d = V/(1 + kD)$, (i.e., subjective value as a function of delay in days) for a delayed reward of \$10. These curves represent the discount functions of three participants in the current study with dissimilar rates of discounting. As the rate of discounting (k) increases, the slope of the curve increases.

health, better financial situation) are discounted such that their subjective value is less than that of the immediate benefits of using drugs.

In a study that involved gamblers, Petry (2001b) compared group k values across three groups: pathological gamblers with substance use disorders, pathological gamblers without substance use disorders, and a control group. She found that pathological gamblers with substance use disorders had the highest group k value, pathological gamblers without substance use disorders had the second highest group k value, and the control group had the lowest group k value. She also found that the two non-control groups had higher impulsivity scores on a self-report measure of impulsivity and higher k values among all participants were correlated with higher scores on the self-report measure. Moreover, in a sample of pathological gamblers, Alessi and Petry (2003) found that gambling severity was the best single predictor of impulsive behaviour in a delay discounting task. Assuming that both pathological gambling and substance use disorder are manifestations of an underlying problem with impulse control, these results strongly support the notion that higher rates of discounting are associated with higher impulsivity.

In summary, behavioural researchers define impulsive behaviour as a preference for small, relatively immediate rewards over a larger but more delayed reward (Ainslie, 1975). Individuals' preferences for smaller more immediate rewards can be expected to change in a predictable way over time. Research has shown that individuals who discount delayed rewards at higher rates are more impulsive.

*Probability Discounting*

Similar to delay discounting is probability discounting, which is the observation that uncertain rewards are considered to be worth less than certain rewards. As the probability of receiving the reward decreases, the subjective value of that reward decreases and it becomes less likely that the uncertain reward will be chosen among alternatives. Recalling the concept of "odds against" (Rachlin et al., 1991), the preceding statement can be changed to read, "as the odds against receiving a reward increases, the subjective value of the reward decreases. . ." (i.e., the value of the uncertain reward is discounted). The probability discounting paradigm is quite similar to the delay discounting paradigm in that participants are asked to choose between sets of certain and uncertain rewards in order to determine an indifference point, or subjective value of the uncertain reward. The subjective value of an uncertain reward is the point at which a certain reward and an uncertain reward would be chosen equally as often (Mellers, Schwartz, & Cooke, 1998). This value represents how much an uncertain reward with a given probability is worth to an individual. Participants choose between a reward that is given for sure and a reward that has a specified chance of either being given or not being given. When the two rewards are equal in value, people will tend to choose the reward that is available for sure because the value of the reward that is uncertain will be discounted by the individual (Rachlin et al., 1991). For example, when given the choice between receiving $20 for sure and a 25% chance of receiving $20, the former reward will invariably be chosen because it is guaranteed whereas the latter reward may or may not be received. As another example, when given the choice between receiving $20 for sure and a 25% chance of receiving $1000, the uncertain reward will probably be chosen because it has not been discounted to the point at which it is worth less than $20 to the individual.

Research has shown that preference between certain and uncertain rewards is well described by the following hyperbolic function (Rachin et al., 1991):

$$v_d = V/(1 + \Theta h) \qquad (6)$$

where $v_d$ is the subjective value of the uncertain reward, V is the amount of the uncertain reward,

$\Theta$ is the odds against receiving the uncertain reward, and h is the rate at which the value of the uncertain reward is discounted. Figure 2 illustrates graphically the shape of a probability discount function which has a similar form to the delay discounting function. Thus, it has been shown that probability discounting is similar to delay discounting in that individuals tend to discount the value of uncertain rewards according to a comparable mathematical function.

*Delay Discounting versus Probability Discounting*

Whereas it is generally agreed that higher rates of delay discounting are associated with more impulsivity, the underlying meaning of different rates of probability discounting has not been theoretically or empirically established. In other words, although the mathematical functions describing probability and delay discounting are isomorphic, the same conclusions about impulsivity cannot necessarily be drawn in relation to the steepness of the discounting curves.

To illustrate, suppose two different individuals were given the option between receiving $500 for sure or a 25% chance of winning $1000. Let's say the first individual decided to take the certain $500 and the second individual decided to take the uncertain $1000. Suppose further that the first individual would be willing to reduce their certain reward to as low as $200 before they would switch their choice and take the uncertain $1000. Additionally, the second individual would choose the uncertain $1000 so long as the value of the certain reward remained below $600. Who is the more impulsive person in this instance?

This scenario allows us to estimate each individual's h value, or rate of probability discounting, based on their preference between these rewards because the subjective value of the uncertain reward is provided for each person. In the first case, the individual's subjective value for the uncertain reward is $200. Thus, this person's rate of discounting can be derived from

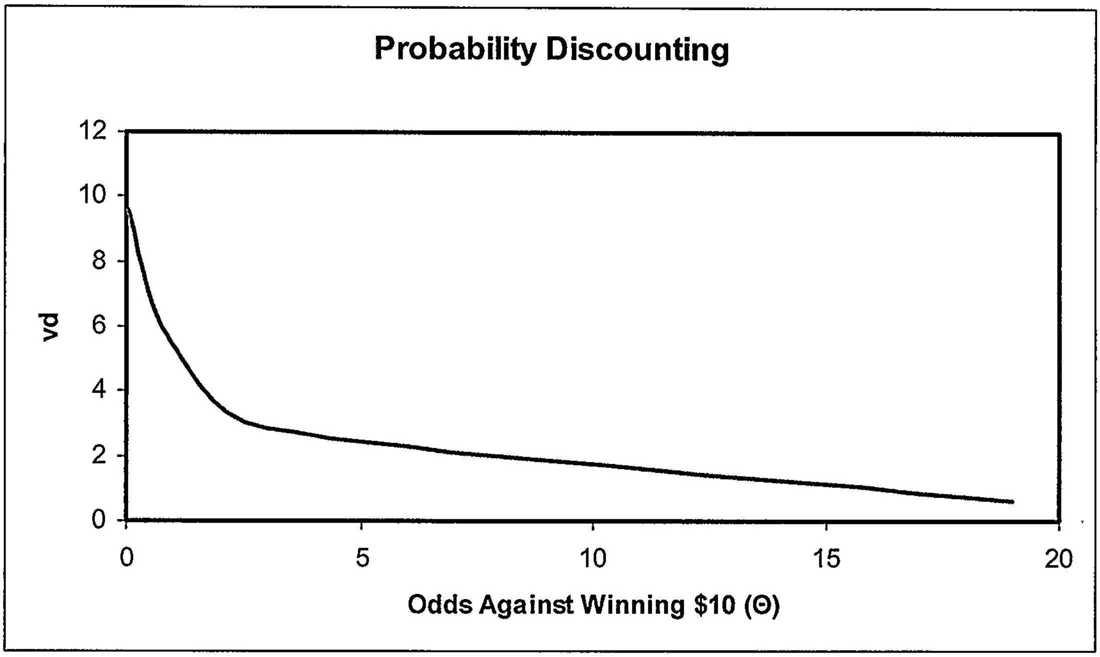


**Figure 2.** Shape of the probability discounting function, $v_d = V/(1 + \Theta h)$, (i.e., subjective value as a function of odds against receiving the reward) for an uncertain reward of $10.

Equation 6:

$200 = 1000/(1 + 3h)$; $h = 1.33$ [note: $\Theta = 1\text{-}.25/.25 = 3$]

In the second case, the individual's subjective value for the uncertain reward is $600. Thus, this person's rate of discounting is:

$600 = 1000/(1 + 3h)$; $h = .22$

Thus, the first individual will have a steeper probability discounting curve because they have a higher h value. However, does this reflect greater impulsivity?

The central question is how to define impulsivity in terms of uncertain outcomes. Is someone more impulsive because they prefer smaller, more certain rewards over larger, uncertain rewards (Rachlin, Logue, Gibbon, & Frankel, 1986) or is someone more impulsive because they prefer larger, more uncertain rewards over smaller, certain rewards (Green & Myerson, 1993)? Two different theories have emerged that take opposing standpoints on this issue. Each theory suggests that delay and probability discounting both involve a single underlying decision processes (i.e., both decisions are based on temporal considerations versus both decisions are based on amount of risk involved).

The first theory, proposed by Rachlin et al. (1986), suggests that delay and probability discounting both involve decisions between alternative rewards that are based on the delay of gratification. Probability discounting is purported to involve decisions based on the delay of gratification because uncertain rewards are treated as repeated gambles wherein the odds against receiving a reward can be considered a measure of delay or waiting time until a win. That is, a reward that is highly improbable has higher odds against and, therefore, a higher average number of losses is expected before a win. Thus, more improbable or uncertain rewards will take longer to be received. It can be argued from this standpoint that individuals with higher rates of probability and delay discounting are more impulsive because they prefer smaller, more certain (and thus more immediate) rewards over larger, more uncertain (and thus more delayed) rewards.

The second theory, proposed by Green and Myerson (1993), suggests that both delay and probability discounting involve decisions based on amount of risk involved. Delay discounting is purported to involve decisions based on amount of risk involved because rewards that are delayed in time are less likely to be received because there is more opportunity for extraneous variables to prevent the reward from being collected. For example, during the period between the selection of the delayed reward and the actual collection of that reward, the receiver may lose contact with the provider. It can be argued from the standpoint of this model that individuals with lower rates of delay and probability discounting exhibit less self-control because they prefer riskier, more uncertain rewards over less risky, more certain rewards.

Certainly, the research described above in the section on delay discounting tends to support the notion that higher rates of delay discounting are associated with impulsivity, but it does not indicate which theory is better able to describe the relationship between probability discounting and impulsivity. Recent research suggests that neither theory provides a suitable explanation for the decision processes involved in both probability and delay discounting and that different underlying processes may be involved for each type of discounting (Green, Myerson, & Ostaszewski, 1999). Green et al. (1999) replicated previous findings that smaller delayed rewards are discounted at proportionally higher rates than larger delayed rewards (e.g., Green, Fry, & Myerson, 1994; Kirby & Marakovic, 1996; Ostawszewski, 1999; Raineri & Rachlin, 1993). However, they found the opposite effect for probability discounting. In other words, individuals discounted large uncertain rewards at proportionally higher rates than smaller uncertain rewards. Thus, although both types of discounting are accurately described by the same hyperbolic function, the underlying decision process appears to be different.

One way to conceptualize the degree of impulsivity associated with rate of probability discounting is to consider the amount of risk involved relative to the expected value. Returning to Equation 6, it can be shown that the subjective value of a reward is equal to the expected value when the rate of discounting is equal to 1 $\{v_d = V/[1 + \Theta h] = V/[1 + \Theta (1)] = V/[1 + \Theta] = V/[1 + (1-p)/p] = V/(1/p) = V(p) = EV\}$. When the expected value of an uncertain reward is plotted as a function of the odds against receiving the reward, the riskiness associated with different rates of probability discounting can be evaluated. Because a discounting rate equal to 1 will result in subjective values equal to the expected value, h =1 reflects an optimal degree of probability discounting. As Figure 3 illustrates, when the rate of discounting is less than 1, larger, less certain rewards are preferred over smaller, certain rewards (above the expected value line). In other words, riskier alternatives are chosen. When the rate of discounting is greater than 1, smaller, more certain rewards are preferred over larger, less certain rewards (below the expected value line). In other words, less risky, more conservative alternatives are chosen.

In the scenario of the two individuals described above, the first individual, who would have taken as little as \$200 rather than take a 25% chance of winning \$1000, would be below the expected value line because the expected value of this uncertain reward is EV = \$1000(.25) = \$250 [Equation 1]. Thus, the decision to take \$200 over a 25% chance of winning \$1000 is less risky and more conservative. The second individual, on the other hand, who would have taken the 25% chance of winning \$1000 over as much as a certain \$600, would be above the expected value line because they are taking a chance that will only yield an average of \$250 when they could be simply taking the certain reward. Thus, the second individual is more risky because they would rather take the chance than take a certain reward that is higher than the expected

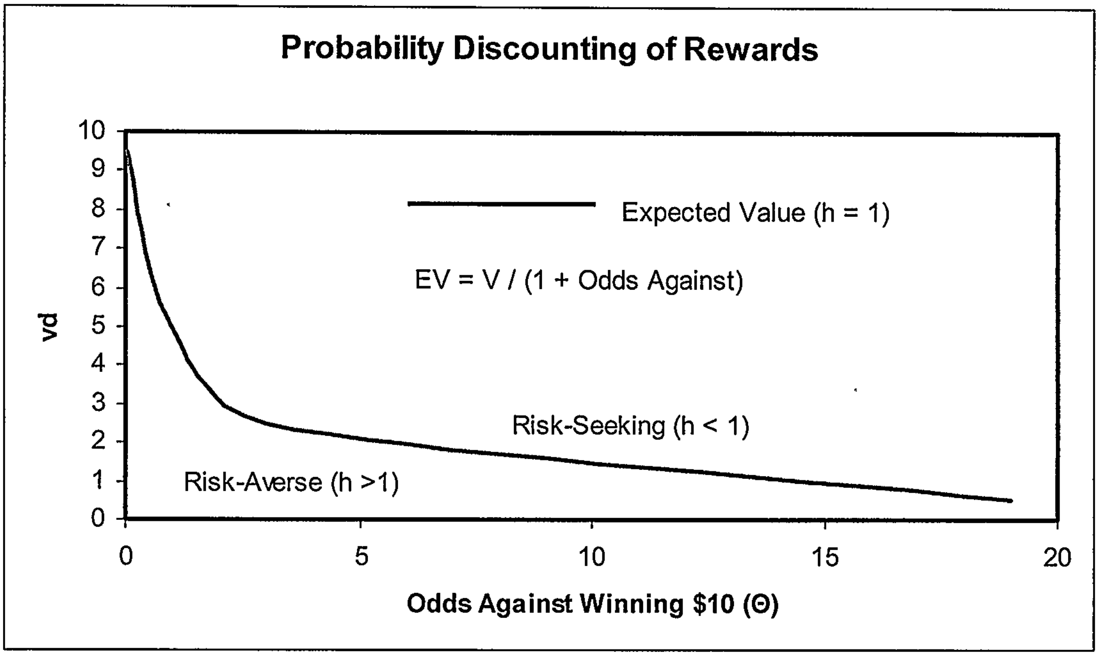


**Figure 3.** Subjective value as a function of odds against receiving $10 relative to expected value. The solid line represents the change in expected value (EV) of a reward as the odds against increase. The expected value function divides the space into two domains: risk-seeking, when the subjective value is greater than expected value ($h < 1$), and risk-aversion, when subjective value is less than expected value ($h > 1$). For the mathematic function $v_d = V/(1+h\Theta)$, expected value is expressed as $EV = V/(1+\Theta)$ because $h = 1$.

value. In summary, lower rates of probability discounting (low h values) appear to be associated with more risky behaviour and less self-control, whereas higher rates of probability discounting (high h values) appear to be associated with less risky behaviour and more self-control.

It can be reasoned that discounting uncertain rewards is perfectly rational. After all, a reward of $100 that has only a .000001% chance of occurring should certainly not be worth $100 to an individual. The same argument, however, might not always be made for a delayed reward. For instance, disregarding factors such as inflation and investment availability, one might contend that $100 today is still $100 tomorrow or the day after. On the other hand, when the reward is uncertain, an element of risk is involved. Common sense would hold that uncertain rewards should be discounted to a point that maximizes outcome. For the present discussion, this rate of discounting corresponds to expected value. When an uncertain reward is discounted more than its expected value, the decision-maker is being too conservative. When an uncertain reward is discounted less than its expected value, the decision-maker is being too risky. A perfect example of this behaviour is when an individual purchases a lottery ticket. The expected value of a one dollar 6/49 ticket is roughly -$.95. In this case, the value of the uncertain million dollar prize is drastically discounted to the point at which the chance at winning the jackpot is worth one dollar to the average lottery player when in fact it should only be worth about five cents. Therefore, someone who buys a one dollar lottery ticket is being too risky. Conversely, if the price of a lottery ticket was reduced to four cents, someone who is unwilling to buy a ticket is being too conservative because they stand to mathematically profit from such a purchase. Thus, it can be seen how central the concept of risk-taking is to probability discounting.

So if amount of self-control is used to describe impulsivity and risk-taking behaviour, the results of Green et al. (1999) indicate that amount of reward has similar effects on self-control regardless of the type of discounting involved. In other words, increasing the amount of reward leads to lowered self-control whether the choices are made between immediate and delayed rewards or certain and uncertain rewards. When the size of the reward was increased for delay discounting, individuals displayed lower discounting rates (lower k values) and an increased preference for large, delayed rewards over smaller, more immediate rewards. When the size of the reward was increased for probability discounting, individuals displayed higher discounting rates (higher h values) and an increased preference for smaller but more certain rewards over larger but more uncertain rewards (Green et al., 1999). Similar findings have been reported in other recent studies (Du, Green, & Myerson, 2002; Holt, Green, & Myerson, 2003; Myerson et al., 2003). Thus, it becomes clear that delay discounting and probability discounting involve somewhat different processes that both incorporate an element of *self-control*.

Studies have shown that delay discounting data fit even better to the function:

$v_d = V/(1 + kD)^s$ (7)

where the exponent *s* is a scaling parameter that provides an index of sensitivity to delay (or odds against) (Du, Green, & Myerson, 2002; Green, Fry, & Myerson, 1994; Myerson & Green, 1995). This hyperbola-like function is derived from the observation that the subjective values (indifference points) of a delayed reward decrease less sharply at long delays than is predicted by equations 5 and 6 (Myerson & Green, 1995). The *s* parameter modifies the form of the original hyperbolic function so that when s is less than 1.0, it flattens the curve causing it to level off as the length of delay increases (see Figure 4).

Green, Myerson, and Ostaszewski (1999) have shown that discounting of probabilistic rewards likewise is better described by a model that includes an exponent:

$v_d = V/(1 + h\Theta)^s$ (8)

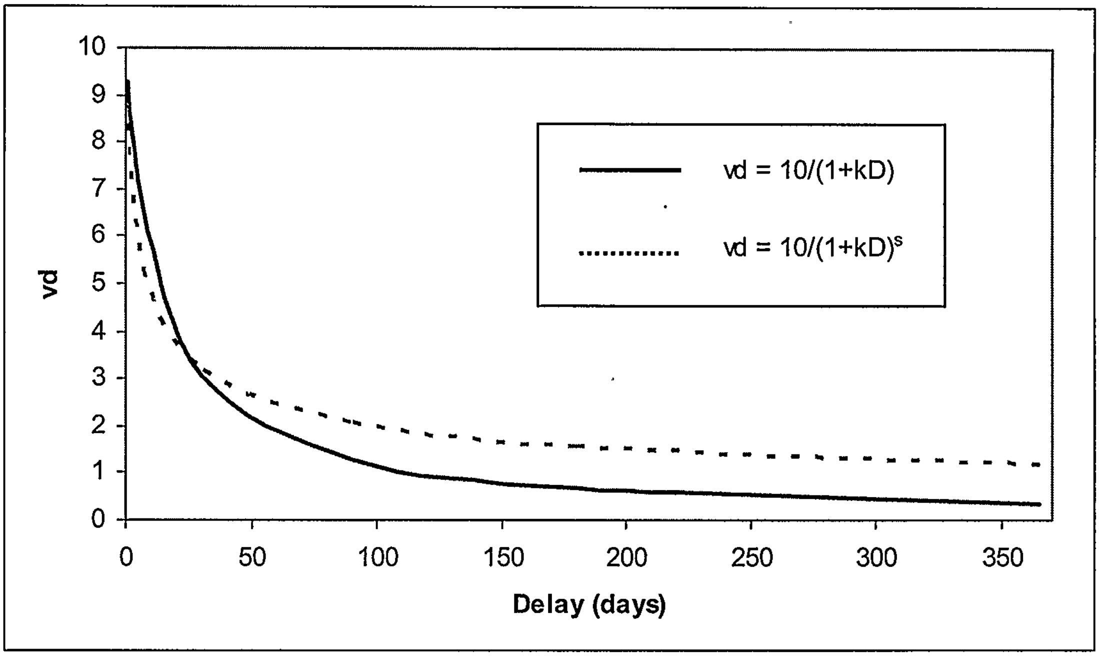


**Figure 4.** Comparison of the hyperbolic discounting function, $v_d = 10/(1+kD)$ (Equation 5), and the hyperbola-like discounting function with an exponent parameter "*s*", $v_d = 10/(1+kD)^s$ (Equation 7) fit to the same set of indifference points. The *s* parameter derived from the hyperbola-like function was less than 1.0 (s = 0.398) which caused the curve to flatten out more rapidly than the hyperbolic function as length of delay increased.

Note that when $s = 1.0$, the above function is reduced to a simple hyperbolic function described by equations 5 and 6. Thus, if the scaling parameter is not estimated to be significantly greater or smaller than 1.0, using Equations 7 and 8 is not justified.

*Relationship between Discounting Rates and Impulsivity*

What unique aspect of impulsivity underlies probability discounting? For researchers studying gambling behaviour, it is important to identify the specific processes that lead to gambling. While it is agreed that problem gamblers are generally more impulsive, this fact does not increase knowledge about the particular cognitive mechanisms at work. As discussed earlier, it is difficult to define accurately impulsivity due to its association with the concept of risk-taking. Although they are often viewed as separate concepts, perhaps there is some overlap between impulsivity and risk-taking that encompasses a cognitive mechanism that is responsible for foreseeing the cumulative negative effects of decisions. And perhaps a deficit in this mechanism suggests a particular vulnerability to engaging in activities that involve negative expected values. One strategy for answering the above question is to measure the association of probability discounting rates with other measures of impulsivity and self-control.

Several studies have correlated rates of probability and delay discounting with various measures of impulsivity and risk-taking (Mitchell, 1999; Ostaszewski, 1997; Richards, Zhang, Michell, & de Wit, 1999). Mitchell (1999) compared discounting rates of smokers and non-smokers and found inconsistent results. Smokers, who had higher scores on self-report measures of impulsivity and risk-taking than non-smokers, also had higher k values (higher rates of delay discounting) than non-smokers. However, the h values of smokers and non-smokers (rates of probability discounting) did not differ. She also found that k and h values did not correlate or correlated weakly with self-report measures of impulsivity and risk-taking. Moreover, a positive correlation was found between k and h values. In the above section, it was predicted that high k values and low h values are associated with higher impulsiveness and higher risk-taking behaviours, respectively. Thus, assuming that high impulsiveness is associated with more risky behaviour, a positive correlation between k and h values is contrary to what would be theoretically expected.

Richards et al. (1999) correlated rates of delay and probability discounting in normal adults with self-report measures of impulsivity and risk-taking. They too found a positive correlation between k and h values. In addition, both k and h values were positively correlated with the disinhibition scale on a scale that measures sensation seeking traits.

Finally, Ostaszewski (1997) compared delay and probability discounting rates between groups of high and low sensation seekers, extraverts and introverts, and high and low impulsive individuals. For delay discounting rates, extraverts and high impulsive individuals had higher k values than introverts and low impulsive individuals and there was no difference in the delay discounting rates between high and low sensation seekers. Contrarily, for probability discounting rates, high sensation seekers had significantly lower h values than low sensation seekers and there were no differences in probability discounting rates between extraverts and introverts, and high impulsive and low impulsive individuals. These results indicate that lower rates of probability discounting are related to high sensation seeking which is consistent with the prediction that lower h values are associated with riskier behaviour. The results may also indicate which unique aspects of self-control underlie probability and delay discounting. That is, delay discounting may tap into the broader construct of impulsivity whereas probability discounting may tap into the propensity to take risks.

Results from studies that have found positive correlations between h and k values

(Mitchell, 1999; Myerson et al., 2003; Richards et al., 1999) provide opposing evidence for the prediction that these discounting rates should be negatively related. Myerson et al. (2003) suggest that such findings are inconsistent with the notion that there is a general "impulsiveness" trait that underlies both an inability to delay gratification and a tendency to gamble and take risks. However, Richards et al. (1999) provide a possible explanation for these results. Earlier it was reasoned that lower h values will be associated with higher risk-taking because a preference for larger, more uncertain rewards entails a greater chance that no reward will be received. But the above-mentioned correlations have demonstrated that participants who preferred smaller, more immediate rewards over larger delayed rewards (more impulsive) were less likely to take risks on probabilistic choices (less risky). To resolve these counterintuitive results, it may be argued that there is no real element of risk in this situation. That is, the two possible outcomes are that a large reward is received or that no reward is received. In other words, the individual does not risk incurring any negative consequences. Thus, Richards et al. argued that impulsive individuals (i.e., those with higher k values) may indeed take more risks but only when there is the possibility of a negative outcome occurring.

This hypothesis is supported by the finding that possible losses are discounted at different rates than are possible gains (Shelley, 1994). Support is also provided by another study that found consumption of alcohol altered people's expectations about potential negative consequences but did not alter their expectations about potential positive consequences (Fromme, Katz, & D'Amico, 1997). Participants had lower estimates of the probability of negative outcomes resulting from engaging in risky activities after consuming alcohol than when they were sober. However, their estimates of the probability of positive outcomes did not change. It is plausible that separate cognitive processes are involved in considering the potential for two different types of uncertain consequences – positive (rewards) and negative (losses). It seems that rates of probability discounting for uncertain rewards may provide a better measure of the processes that consider positive consequences of risky activity whereas rates of probability discounting for uncertain negative consequences may provide a measure of the processes that consider negative consequences of risky activity. These hypotheses may also explain why previous research has not shown a consistent relationship between rates of probability discounting for rewards and measures of impulsivity or risk-taking. These rates only provide an index of insensitivity to the *absence* of possible rewards rather than the *presence* of possible losses. Meanwhile, measures of impulsivity and risk-taking tend to focus on behaviours or traits that generally result in negative outcomes, or losses.

An association between rates of probability discounting and cognitive processes that consider future outcomes would be of particular relevance to the study of gambling behaviour because of the nature of gambling and expected value. Returning to the notion of "the house always wins", recall that the more times a wager with a negative expected value is made, the more likely it is that the average amount lost per wager will resemble this expected value. Thus, the negative financial impact of problem gambling is more likely to emerge as gambling activity increases. The nature of gambling is such that the positive consequences are often more immediate and salient (e.g., a big win) compared to the negative consequences which are usually small and tend to accumulate over time. Therefore, if rates of probability discounting for negative outcomes are able to tap into the cognitive processes that consider the negative consequences of behaviour, h values should be related to scores on measures of errors in anticipating the cumulative effects of risky decisions involving possible negative outcomes. In other words, rates of discounting uncertain losses should be related to errors in identifying situations with negative expected values.

*Present Investigation*

The present study sets a precedent by using the probability discounting paradigm with uncertain negative outcomes. It was hypothesized that individuals would discount uncertain losses in much the same way that they discount uncertain rewards. For example, certain losses are worth less to an individual than uncertain losses of the same amount. That is, as the odds against incurring an uncertain loss or penalty increase (less likely you will lose), the subjective value of the amount to be lost decreases. Participants were asked to choose between either losing a specified amount of money for sure or having the chance at losing either a larger amount of money or losing nothing. This decision-making process is somewhat analogous to deciding whether to temporarily park your car illegally at no cost with the risk of incurring a large parking fine or pay a small fixed fee to park in a lot. Participants' choices were used to determine indifference points, or subjective values of the uncertain loss, and this data was used to plot discounting curves. It was expected that these curves would be described by the hyperbolic function of Equation 6 or hyperbola-like function of Equation 8.

Figure 5 depicts the hypothesized form of the discounting curve for uncertain negative outcomes. As illustrated, higher h values (higher rates of probability discounting) indicate more risky decisions. This makes intuitive sense because someone who is more risky is more likely to take the chance of possibly losing nothing (while also taking the chance that they will lose the entire larger amount) rather than incur a smaller, certain loss. In other words, riskier individuals discount the value of an uncertain loss more (lower subjective values) which means they are not willing to lose as much to ensure that they do not have to lose a larger, uncertain amount. Meanwhile, a more conservative person is more likely to incur the smaller, certain loss rather

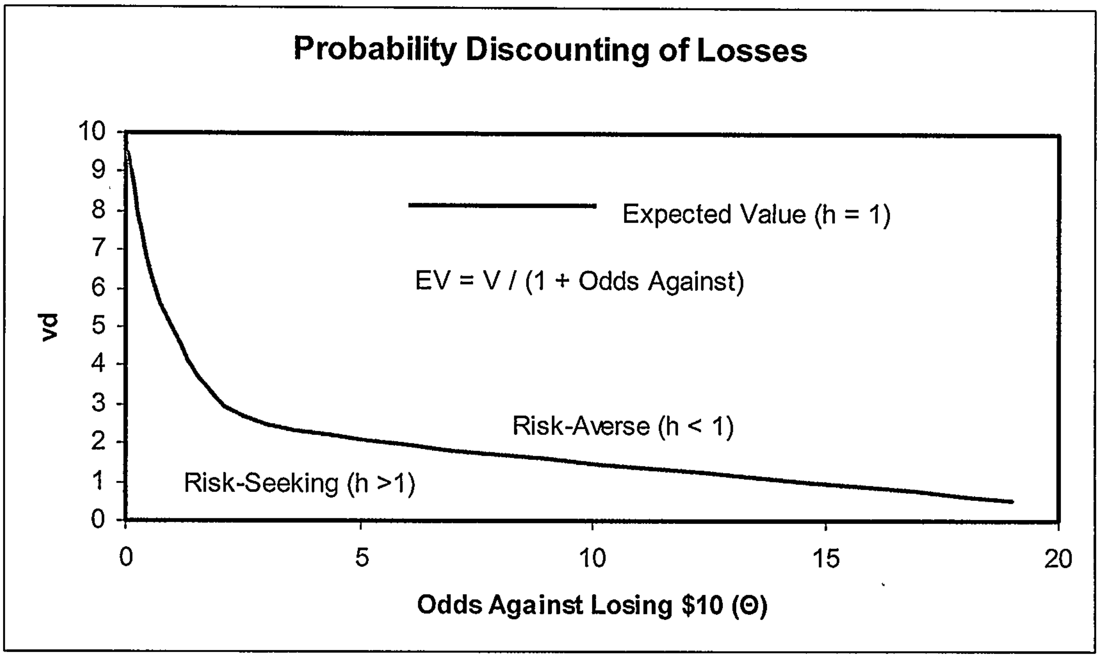


**Figure 5.** Hypothesized form of the discounting curve for uncertain negative outcomes. Subjective value is plotted as a function of odds against losing $10. The solid line represents the change in expected value (EV) of a loss as the odds against increase. The expected value function divides the space into two domains: risk-seeking, when the subjective value is less than expected value ($h > 1$), and risk-aversion, when subjective value is greater than expected value ($h < 1$). For the mathematic function $v_d = V/(1+h\Theta)$, expected value is expressed as $EV = V/(1+\Theta)$ because $h = 1$.

than risk losing the larger, uncertain loss. These individuals do not discount the value of the uncertain loss as much (higher subjective values) and are willing to lose more to ensure they do not have to lose a larger, uncertain amount. It follows that higher discounting rates for uncertain losses were hypothesized to be associated with scores on measures indicating more errors in anticipating cumulative effects of decisions involving possible negative outcomes (negative expected value). Errors of negative expected value were measured using two different methods: a self-report questionnaire and a behavioural task. Specific hypotheses are presented in the Methods section below.

# CHAPTER TWO: METHODS

*Participants*

Sixty participants (14 males and 46 females), aged 18 to 28 ($M = 21.0$) were students from the University of Calgary in the Psychology Department subject pool. All participants underwent the same procedure and they received course credit for their participation. Informed consent, approved by the Department of Psychology Research Ethics Board, was obtained prior to each experimental session.

*Measures*

Participants completed the following measures:

*Demographic characteristics.* Brief demographic information, including age, gender, marital status, education, occupation, and net monthly income, was asked using this questionnaire (Appendix A). No hypotheses were made in terms of differences between groups defined by demographic characteristics.

*Canadian Problem Gambling Index (CPGI; Ferris, Wynne, & Single, 1999).* The CPGI is a nine-item questionnaire used for measuring problem gambling in the Canadian general population (Appendix B). It asks participants how frequently statements apply to them on a 4-point Likert-type scale within the last 12-month period. Items address various aspects of gambling behaviour including extent of involvement, cognitions related to problem gambling, and environmental factors of problem gambling. For example, one question asks, "Have you borrowed money or sold anything to get money to gamble?" Total CPGI scores between 3 and 7 indicate moderate risk gambling behaviour and scores between 8 and 27 indicate problem gambling.

*Barratt Impulsiveness Scale, version 11 (BIS, Barratt, 1985; Patton, Stanford, & Barratt,* *1995).* The BIS is a 30-item self-report questionnaire that asks participants how frequently statements apply to them on a 4-point Likert-type scale (Appendix C). There are three second-order factors that are positively correlated with lack of self-control: attentional impulsiveness (e.g., "I have 'racing' thoughts"), motor impulsiveness (e.g., "I am restless at the theater or lectures"), and non-planning impulsiveness (e.g., "I plan tasks carefully"). The non-planning factor appears to provide a measure of insensitivity to negative consequences or negative expected value.

*Bechara Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara & Damasio, 1997; Busemeyer & Stout, 2002).* The Bechara Gambling Task requires that participants select cards from any of four decks. When a card is overturned, the other side of the card indicates an amount of money that has been won. Some cards also indicate an amount of money that must be paid. Drawing from two of the decks results in net gains while drawing from the other two decks results in net losses. The dependent measure is the number of cards selected from the unfavourable decks.

This task was designed to measure the degree to which an individual fails to anticipate the long-term negative consequences of disadvantageous choices (Bechara et al., 1994). At least two studies have examined whether poor performance on the Bechara Gambling Task is related to impulsivity. Lejuez et al. (2003) found that there was not a significant correlation between percentage of cards selected from the disadvantageous decks and self-report measures of impulsivity and sensation seeking. They also found that smokers and non-smokers did not differ in the percentage of disadvantageous cards selected. Similarly, Petry (2001c) found that number of disadvantageous cards selected did not correlate with scores on an impulse control factor and novelty seeking factor of a self-report measure. However, she did find that substance abusers and substance abusers with gambling problems selected significantly more cards from decks that resulted in large immediate rewards, but resulted in overall net losses. Thus, it appears this task measures preference for immediate rewards and insensitivity to long-term negative consequences rather than overall impulsiveness. In other words, this task provided a behavioural measure of a tendency to make errors in evaluating expected value.

*Discounting tasks*. Three discounting procedures were used to calculate the degree to which each individual discounted: (1) delayed rewards, (2) uncertain rewards, and (3) uncertain losses.

*Procedure*

Each participant completed the experiment individually in a single session. Upon arriving at the laboratory they read and signed a consent form describing the study. At this point they received $20.00 and it was explained that they would be able to keep at the least a portion of this money at the conclusion of the experiment based on their performance in some of the tasks. The allotment of rewards is described in detail below. Then they completed the Bechara Gambling Task. Next, participants completed three discounting tasks. Finally, they completed the biographical information sheet along with the CPGI, and the BIS.

*Bechara Gambling Task.* The procedure for this task was similar to that used by Petry (2001c). Instructions were provided verbally (see Appendix D). In this task, participants were presented with four decks of 60 cards labelled A, B, C, and D that were face-down and equal in appearance. They were instructed to select the top card from any of the four decks. When overturned, the underside of each card indicated an amount of money that was won. Some cards also indicated an amount of money that was to be paid as a penalty. Participants were initially given $2000 in play money. They were told that the objective of the game was to maximize their profit, although they had no knowledge of the reinforcement schedule. They were told to turn over cards from any deck they wished and they were allowed to switch decks at any time and as often as they liked. After each card was overturned, the values were announced for that card and play money was used to distribute the rewards and losses reflected on the card. A running tally of amount won or lost was not kept for the participant. The game was stopped after 100 cards were selected.

All cards in decks A and B yielded a reward of $50. However, a loss of $250 occurred on one of every 10 cards chosen from deck A. Deck B contained losses on 50% of all cards chosen that ranged from $25 to $75 and totalling -$250 for each set of 10 cards. For both decks A and B, wins outweighed losses. For example, for each set of 10 cards in deck A, $500 would be earned and only $250 would be lost. Thus, a net gain of $250 would result from each set of 10 cards in deck A – a positive expected value (+$25/card). Similarly, for each set of 10 cards chosen in deck B, a net gain of $250 would result – also a positive expected value (+$25/card).

All cards in decks C and D yielded a reward of $100. The frequency of losses for decks C and D were the same as decks A and B respectively. However, the size of the losses was larger. A loss of $1250 occurred on one of every 10 cards chosen from deck C. Deck D contained losses on 50% of all cards chosen that ranged from $150 and $350 and totalling $1250 for each set of 10 cards. Because $1000 was rewarded for each set of 10 cards in decks C and D, the total net loss for each set of 10 cards was $250. Thus, both deck C and D had a negative expected value (-$25/card).

To summarize, deck A was a positive expectation deck with lower individual rewards and frequent, small negative consequences; deck B was a positive expectation deck with lower individual rewards and moderate but infrequent negative consequence; deck C was a negative expectation deck with higher individual rewards and moderate but frequent negative consequences; and deck D was a negative expectation deck with higher individual rewards and large but infrequent negative consequences. The number of cards that participants selected from each deck was recorded. Because selecting proportionally more cards from decks C and D compared to decks A and B would result in an overall negative result, the number of cards selected from decks C and D was the dependent measure reflecting degree of "errors of expected value." The number of cards selected from the unfavourable decks (C and D) was inversely proportional to the number of cards selected from the favourable decks (A and B).

*Discounting tasks.* The three discounting tasks followed a procedure similar to that used by Holt et al. (2003). Participants were presented with a series of questions on a computer screen. For each question, participants were required to choose between two alternatives. The participants' responses were used to determine their indifference points and their individual rates of discounting.

Participants were told that they would be asked to make a series of choices between two monetary amounts, and that there would be three types of choice tasks. It was also explained that their performance on these tasks would affect the size of the monetary incentive they would receive for participating in the study. That is, one question from each of the three discounting tasks would be randomly selected at the end of the session and the participant's responses to those questions would be used to determine how much of the $20.00 provided to them at the beginning of the study they would be allowed to keep. By assuring participants that they may receive their preferred alternative for the choices presented to them, this strategy aimed to have participants make every choice as though it were the one they would actually receive (Kirby & Herrnstein, 1995). Instructions for the three discounting tasks were delivered verbally (see

Appendix E) followed by a practice trial for each type. After completion of the practice trials, the experiment began. The order in which the three types of tasks were completed was counterbalanced across participants.

In the delay task, each question asked participants to choose between a reward that was available immediately ("immediate reward") or a reward that was delayed by a specified period of time ("delayed reward"). For example, one question might have asked: Which option do you prefer? (a) $2.50 at the end of this session, or (b) $10 in 30 days? Participants were asked to indicate which of the two alternatives they preferred by pressing "a" or "b" on the computer keypad. The delayed reward was always $10.00 and was available after one of six delays (1, 7, 30, 90, 180, or 365 days). At each of the six delays, six questions were presented sequentially on the computer screen. Each block of six questions required participants to make a choice between an immediate reward and $10.00 at a fixed delay that increased across blocks. That is, the first block of questions contained choices between an immediate reward and $10.00 at a delay of 1 day, the second block of questions contained choices between an immediate reward and $10.00 at 7 days, and so on. The amount of the immediate reward was adjusted across questions within each block. After the first question was answered the amount of the immediate reward was adjusted based on each participant's response to the previous question. The size of this adjustment decreased with successive choices in order to rapidly converge on the individual's indifference point at each delay. The first question in each block asked the participant to make a choice between the delayed reward ($10.00) and an immediate reward whose amount was half that of the delayed reward ($5.00). If a participant chose the immediate reward, then the amount of the immediate reward was decreased on the next choice; if a participant chose the delayed reward, then the amount of the immediate reward was increased on the next choice. Each adjustment was half the difference between the immediate and delayed rewards from the previous question. Thus, the second question in each block contained an immediate reward of $7.50 or $2.50, depending on the participant's response to the first question. That is, half the difference between an immediate reward of $5.00 and a delayed reward of $10.00 is $2.50. So if a participant chose $10.00 in 30 days over $5.00 immediately on the first question, the second question would ask the participant to choose between $10.00 in 30 days and $7.50 immediately ($5.00 + $2.50 = $7.50). Alternatively, if the participant chose $5.00 immediately over $10.00 in 30 days, the second question would ask the participant to choose between $10.00 in 30 days and $2.50 immediately ($5.00 - $2.50 = $2.50). For subsequent questions, the adjustment was half of the previous adjustment. For example, on the second question, if the participant chose $10.00 in 30 days over $2.50 immediately, then the next question would ask the participant to choose between $10.00 in 30 days and $3.75 immediately (i.e., $2.50/2 = $1.25 + $2.50 = $3.75). This procedure was repeated until the participant answered all six questions in the block for the given delay. The immediate amount that would have been presented on a seventh trial, had there been one, was used as an estimate for that participant's indifference point for the given delay. Because there were six delays, each with a block of six questions, six indifference points were obtained for each participant. These points indicate the subjective value of the delayed reward. In other words, it indicates how much the delayed reward is presently worth to them (e.g., the subjective value of $10.00 in 30 days).

In the two probability discounting tasks, an analogous adjusting-amount procedure was employed. Participants answered six questions in each block of questions at each of six different probabilities. For the probability *reward* task, each question asked participants to choose between an amount that could be received for sure ("certain reward") and a larger amount

($10.00) that could be received with a stated probability ("uncertain reward"). For example, one question might have asked: Which option do you prefer? (a) $7.50 for sure at the end of the session, or (b) a 25% chance of receiving $10? The uncertain reward was always $10.00 at six different probabilities (shown on the computer monitor as the percent chance of receiving the reward) presented in the following order: 95, 90, 75, 50, 25, and 5%. At each of the six probabilities, blocks of six questions were presented. The adjusting-amount procedure used in this task was virtually identical to that used in the delay discounting task. The amount of the certain reward across questions within each block was adjusted based on the participant's previous choice according to the same rule used to adjust the amount of immediate rewards. Again, six indifference points were obtained for each participant based on their responses. These points indicate the subjective value of the uncertain reward (e.g., the subjective value of a $10.00 reward with a probability of .75).

For the probability *loss* task, the procedure was similar except that each question asked participants to choose between an amount that could be lost for sure ("certain loss") and a larger amount ($10.00) that could be lost with a stated probability ("uncertain loss"). For example, one question might have asked: Which option do you prefer? (a) $1.25 to be lost for sure at the end of the session, or (b) a 70% chance of losing $10 (30% chance of losing nothing)? The probability of losing nothing was stated in parentheses in order to clarify the difference between the two types of probability discounting tasks. The uncertain loss was always $10.00 at probabilities of 95, 90, 75, 50, 25, and 5%. The adjusting-amount procedure used in this task was similar to that used in the delay and probability reward discounting tasks; however, the amount of the certain loss across questions within each block was adjusted according to the reverse rule used to adjust rewards. That is, if a participant chose the certain loss, then the amount of the certain loss was increased (instead of decreased) on the next question; if a participant chose the uncertain loss, then the amount of the certain loss was decreased (instead of increased) on the next question. Six indifference points were obtained for each participant. These points indicate the subjective value of the uncertain loss (e.g., the subjective value of a $10.00 loss with a probability of .75).

*Allotment of actual rewards.* Whereas most studies use hypothetical amounts of money to determine individual discounting rates, the current strategy to allot actual rewards was used to increase the ecological validity of the discounting tasks. At the end of the experiment, each participant randomly drew three numbers from a hat. The first number corresponded to a question from the delay discounting task, the second to a question from the probability rewards discounting task, and the third to a question from the probability loss discounting task. The participants' responses to each of the three questions determined how much of the $20.00 they were allowed to keep and how much they had to forfeit. For the randomly drawn delay discounting task question, if they chose the immediate reward, they were given credit for the chosen immediate amount. If they chose the delayed reward, they were given an IOU to return to the lab to collect $10.00 on the date when the specified delay had elapsed. For the probability rewards discounting task question, if they chose the certain reward, they were given credit for the certain amount. If they chose the uncertain reward, tokens marked "win $10" and "win $0" were placed in a bag in proportion to the indicated probability. For example, if the probability was .25, 3 out of 4 tokens in the bag were marked "win $0" and 1 out of 4 tokens were marked "win $10." If the participant pulled a token from the bag marked "win $10" they received credit for $10 and if it was marked "win $0" they did not receive any credit. For the probability loss discounting task question, if the participant chose the certain loss, they were required to forfeit the amount indicated. If the uncertain alternative was chosen, a token was once again pulled from a bag. If the token was marked "lose $0" they forfeited nothing. If it was marked "lose $10" they forfeited the full $10. The total amount of money "won" (excluding IOU's) was added up and any amount that was "lost" was subtracted from that total. If this amount was less than $20.00, the participant returned their $20.00 to the experimenter and they were given the appropriate amount. If the total amount allotted (including IOU's) was less than $5.00, the participant was given $5.00 for their participation. Since completion of data analysis, of 21 participants who were provided with IOU's, 20 (95%) of these participants have returned to collect $10. The high percentage of individuals returning after extended delays (as long as 6 months) supports the ecological validity of the choices made in the discounting tasks.

*Data analysis.* Indifference points that were obtained from the adjusting-amount procedure were used to estimate delay and probability discount functions. The hyperbolic delay discounting function (Equation 5) and hyperbola-like delay discounting function (Equation 7) were fit to the six indifference points from the delay discounting task using Microsoft® Excel's SOLVER Add-In for nonlinear curve-fitting (Brown, 2001). This curve-fitting program determined the best fitting values for k (and $s$ for equation 7) using least-squares regression. It also provided the coefficient of determination as an indicator of how much variance in the indifference points was accounted for by each function. Similarly, the hyperbolic probability discounting function (Equation 6) and hyperbola-like probability discounting function (Equation 8) were fit to the six indifference points from both probability discounting tasks to determine the values of h (and $s$ for equation 8) and coefficient of determination. Data for the probability discounting functions were plotted with "odds against winning" (rather than probability or percent chance of winning) on the $x$ axis in order to clarify the hyperbolic form of the discount functions. Using Equation 4, odds against were calculated for each of the six probability values used in this study so that probabilities .95, .90, .75, .50, .25, and .05 were converted to odds against of .053, .111, .333, 1.0, 3.0, and 19.0, respectively.

Group data was analysed to determine how well the data was described by each of the functions. This analysis served two major purposes. One, because previous research has shown that discounting data fits well to hyperbolic functions (e.g., Richards et al., 1999), examination of the coefficients of determination would provide an indication of whether results from the discounting tasks were valid. A low coefficient of determination may suggest that the methodology for the current study was somehow flawed. Two, comparison of the coefficients of determination for the hyperbolic (Equations 5 and 6) and hyperbola-like functions (Equations 7 and 8) would help determine which form of the discounting function provided a better fit to the data. The $R^2$s for fits to individual subjects' data for Equations 5 and 7 were compared using a Wilcoxon matched-pairs signed-ranks test to determine whether one form of the function fit the delay discounting data better than the other. A similar test was performed to compare probability discounting data for Equations 6 and 8.

Of particular interest in the current study was whether group data from the probability discounting of losses task would be described by Equations 6 or 8 because previous research has not tested the discounting paradigm using uncertain losses. Group data was fit to the functions using the group median indifference points for each delay or odds against. The median indifference points were used because the distribution of these points was expected to be skewed (Richards et al., 1999) due to limits imposed on obtained indifference points. That is, no matter how certain the reward, \$10.00 will never be worth more than \$10.00, and no matter how uncertain the reward, \$10.00 will never be worth less than \$0. Therefore, the median is considered the appropriate measure of central tendency.

Values for discounting rates (k and h), scaling parameters (*s* in Equations 7 and 8), and coefficients of determination, were calculated for individual participants. Degree of discounting was established by calculating the area under the discounting curve (AUC). Up to this point, degree of discounting has been discussed in terms of the "rate of discounting" as indicated by k and h values which are indices of the slope of the discounting curves. However, Myerson, Green, and Warusawitharana (2001) suggest that AUC is a more appropriate measure of discounting due to several interpretative and statistical difficulties that are presented by using curve-fitting parameters. The most notable problem is that a two-parameter function (i.e., Equations 7 and 8) is often required to fit individual data. Research has established that a hyperbola-like function with the scaling (*s*) parameter provides a better fit to discounting data (Green, Fry, & Myerson, 1994; Myerson & Green, 1995; Green, Myerson, and Ostaszewski). It has been suggested that it may not always be necessary to use the exponent (*s*) parameter, because the simpler hyperbolic function usually accounts for more than 90% of the variance in group data obtained from human participants (Myerson & Green, 1995). However, individual data is often less reliable than group data and the two parameter function is more likely to provide an adequate fit to an individual participant's indifference points. There are also potential individual and group differences in the exponent (*s*) parameter that make the discounting rate (k or h) parameter inadequate as a measure of individual discounting. To illustrate, using only the discounting rate (k or h) parameter as an index of degree of discounting may be misleading. Two individuals may have the same delay discounting rate (k parameters are equal) but they could appear to differ in the extent to which they discount delayed rewards (lower and higher indifference points) because there is a difference in the scaling (*s*) parameter. Thus, the use and interpretation of discounting parameters are specific to the model and theory from which they are derived. In addition, examination of data sets from previous studies shows that there is considerable variability between participants, and distributions of individual parameter estimates are quite skewed. As a consequence, analysis of k and h values requires techniques to normalize the distributions (such as taking the logarithm of individual k values) or the use of nonparametric tests which are generally less powerful than parametric tests. Research has also shown that the dependence between k (or h) and *s* parameters often exceeds .80 (Myerson et al., 2001). The fact that these parameters may not be independent measures of discounting behaviours means that statistical comparisons may require modelling the dependence between these measures.

To simplify the interpretation and statistical assessment of degree of discounting among individual participants, the current study adopted Myerson et al.'s (2001) theoretically neutral approach to measuring discounting. This approach involves calculating the area under the empirical discounting function (see Figure 6). Higher degrees (rates) of discounting are exemplified by lower subjective values of a delayed or uncertain outcome relative to an immediate or certain outcome. For example, if someone tends to prefer relatively small, immediate rewards over a larger reward at several specified delays, their subjective values of the delayed reward would be reflected by relatively low indifference points when subjective value is plotted as a function of delay. Thus, smaller areas under the curve reflect steeper rates of discounting.

Before AUC was calculated, the subjective values on the $y$ axis, and delays and odds against on the $x$ axis, were normalized for each data point so that they were expressed as proportions of the maximum value (i.e., subjective value divided by $10.00, length of delay divided by 360 days, and odds against divided by 19.0). These normalized values were used to

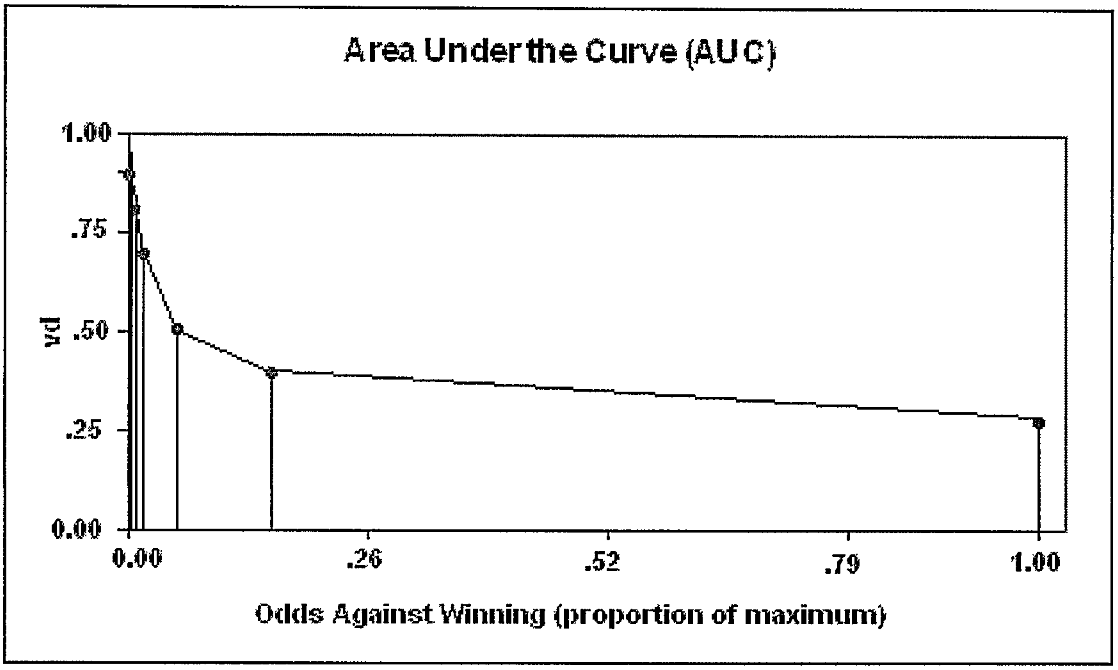


**Figure 6.** Calculation of the area under the empirical discounting function (AUC). Data points are for Participant #10 (probability discounting of rewards).

construct a graph of the discounting data and vertical lines were drawn from each indifference point to the $x$ axis. These lines subdivided the graph into a series of trapezoids and the area of each was calculated using the equation:

$$A = (x_2 - x_1)[(y_1 + y_2)/2] \qquad (9)$$

where $x_1$ and $x_2$ are successive delays or odds against, and $y_1$ and $y_2$ are the associated indifference points. The AUC is equal to the sum of the areas of all six trapezoids. Steeper discounting (i.e., lower indifference points) will be reflected by smaller AUC values. Normalization of $x$ and $y$ values allows AUC values that range between 0.0 (steepest possible discounting) and 1.0 (no discounting). This approach to measuring degree of discounting does not depend on any theoretical assumptions regarding the form of the discounting function because AUC is calculated from the actual data points rather than from a curve fit to the data (Myerson et al., 2001).

*Correlational analyses.* Pearson Product-Moment correlation coefficients were calculated between degree of discounting for each of the three discounting tasks as measured by AUC and scores on the Bechara Gambling Task and the Barratt Impulsiveness Scale. AUC for each of the three discounting tasks were also intercorrelated.

*Hypotheses.* The following results were predicted:

(1) degree of delay discounting would not be correlated with disadvantageous gambling decisions (AUC not correlated with cards from A and B on the Bechara Gambling Task).

(2) degree of discounting for uncertain rewards would be negatively correlated with disadvantageous gambling decisions (AUC negatively correlated with cards from A and B on the Bechara Gambling Task).

(3) degree of discounting for uncertain losses would be positively correlated with disadvantageous gambling decisions (AUC positively correlated with cards from A and B on the Bechara Gambling Task).

(4) degree of discounting for uncertain rewards and losses would be negatively correlated (AUC's negatively correlated).

(5) degree of delay discounting and degree of discounting for uncertain losses would be positively correlated (AUC's positively correlated).

(6) degree of delay discounting would be positively correlated with overall impulsivity (AUC negatively correlated with total BIS score).

(7) degree of discounting for uncertain losses would be positively correlated with impulsive behaviours related to a failure to foresee future outcomes (AUC negatively correlated with scores on the non-planning subscale of the BIS).

# CHAPTER THREE: RESULTS

As expected, the distributions of indifference points were skewed. Thus, median indifference points were used to plot group subjective values as a function of delay and odds against. Figure 7 shows the group delay discounting function when median indifference points are fit to Equations 5 and 7. The curved lines represent the best fitting discounting functions. The proportion of variance accounted for by the hyperbola-like model with the scaling parameter (Equation 7) was .99 versus the hyperbolic model (Equation 5) which accounted for .96 of the variance. For the hyperbolic function, k = .00536, and for the hyperbola-like function, k = .00014 and $s$ = 27.20. Note that the scaling parameter, $s$, for the hyperbola-like function is greater than 1.0 which prevents the curve from flattening off at longer delays and fits the data better than the hyperbolic function (Equation 5) for which $s$ = 1.0.

Figure 8 shows the group probability reward discounting function when median indifference points are fit to Equations 6 and 8. The hyperbola-like model (Equation 8) accounted for a higher proportion of variance than the hyperbolic model (Equation 6), .99 versus .94. For the hyperbolic function, h = 1.08, and for the hyperbola-like function, h = 4.45 and $s$ = .55. In this case, because the scaling parameter, $s$, is less than 1.0, the curve flattens off at higher odds against and fits the data better than the hyperbolic function (Equation 6) for which $s$ = 1.0.

Figure 9 shows the group probability loss discounting function when median indifference points are fit to Equations 6 and 8. Once again, the hyperbola-like model (Equation 8) fit the group data better than the hyperbolic model (Equation 6), $R^2$ = .99 versus $R^2$ = .97. For the hyperbolic function, h = .91, and for the hyperbola-like function, h = 2.36, and $s$ = .55. Similar to the probability reward discounting data, the scaling parameter, $s$, is less than 1.0 which flattens out the curve at higher odds against.

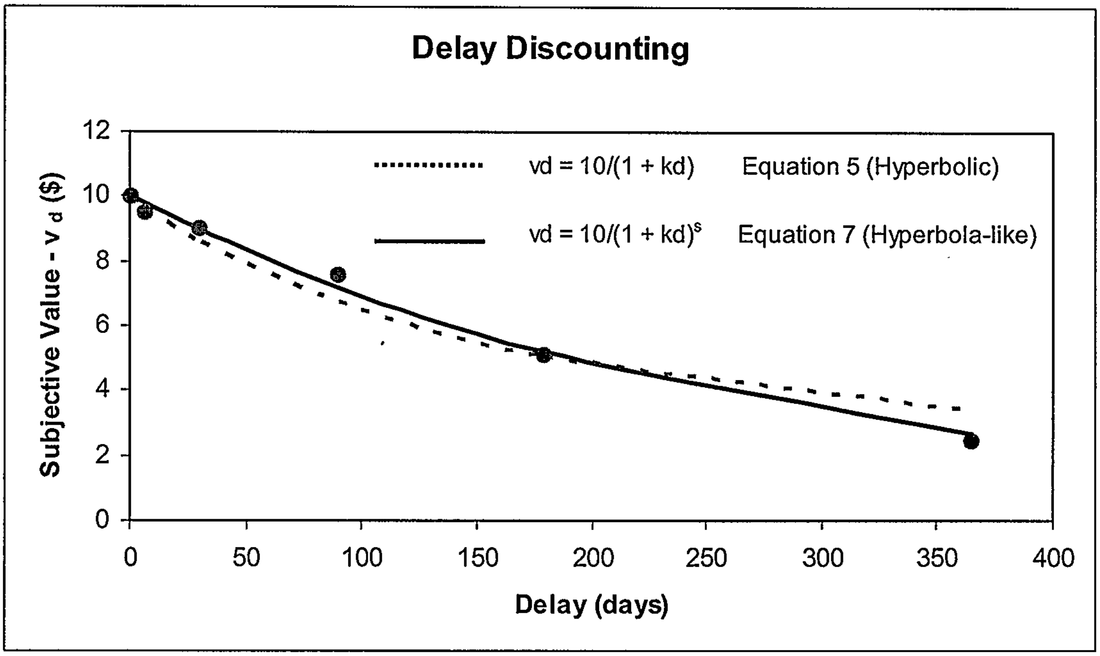


**Figure 7.** Subjective value as a function of delay until receipt of $10.00. Data points represent the group median indifference points. The solid curve represents the best-fitting curve for the function $v_d = 10/(1 + kD)^s$, where k = .00014, $s = 27.20$, $R^2 = .99$. The dashed curve represents the best-fitting curve for the function $v_d = 10/(1 + kD)$, where k = .00536, $R^2 = .96$.

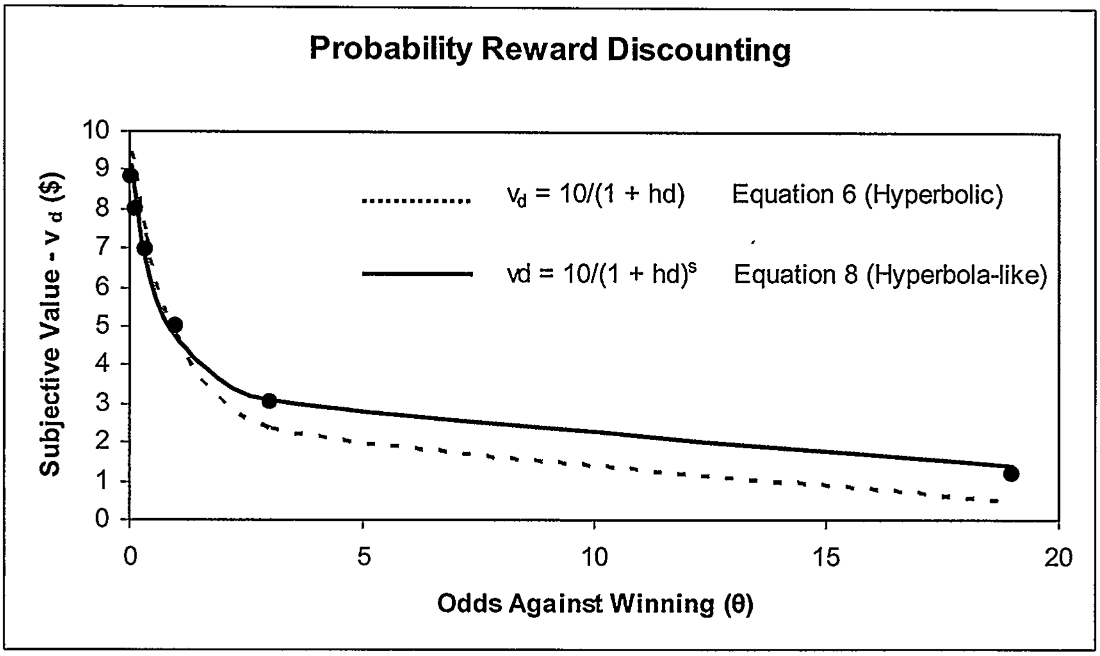


**Figure 8.** Subjective value as a function of the odds against receiving $10.00. Data points represent the group median indifference points. The solid curve represents the best-fitting curve for the function $v_d = 10/(1 + h\Theta)^s$, where h = 4.45, $s$ = .55, $R^2$ = .99. The dashed curve represents the best-fitting curve for the function $v_d = 10/(1 + h\Theta)$, where h = 1.08, $R^2$ = .94.

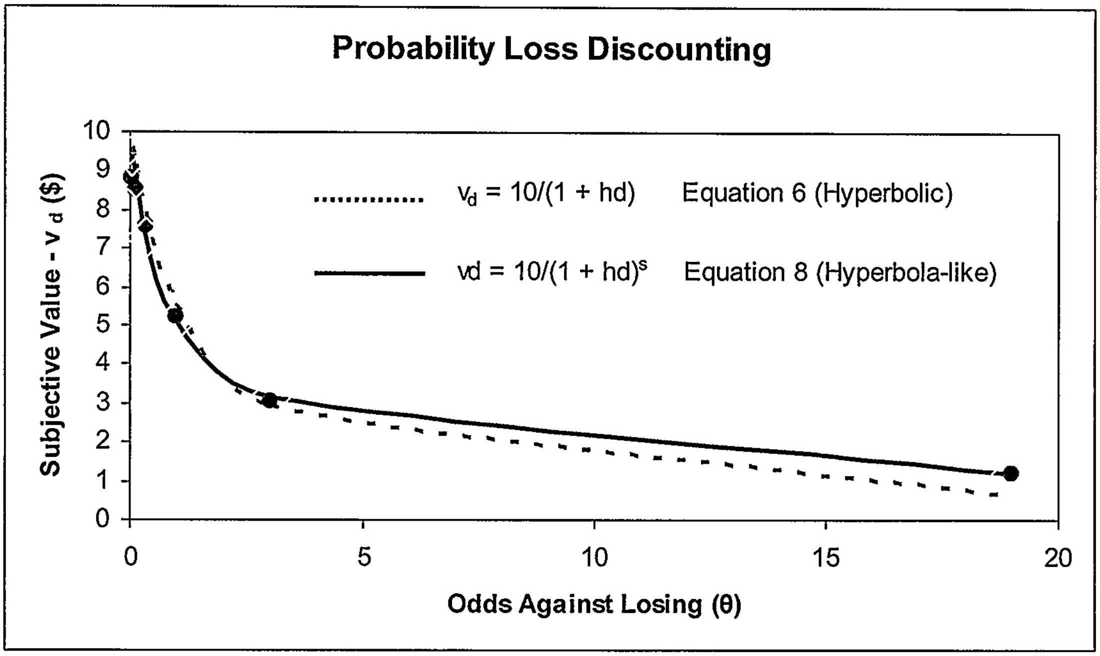


**Figure 9.** Subjective value as a function of odds against losing $10.00. Data points represent the group median indifference points. The solid curve represents the best-fitting curve for the function $v_d = 10/(1 + h\Theta)^s$, where h = 2.36, $s = .55$, $R^2 = .99$. The dashed curve represents the best-fitting curve for the function $v_d = 10/(1 + h\Theta)$, where h = .91, $R^2 = .97$.

The above findings indicate that the hyperbola-like function (Equations 7 and 8) provided a superior model for fitting group discounting data. In order to discern whether this model was better for fitting individual discounting data, individual coefficients of determination were examined. Measures of central tendency and variability for the discounting parameters and $R^2$ values for the three discounting tasks are presented in Table 1.

For the delay discounting task, the median of the $R^2$s for the fits to the individual participants' indifference points was .84 for the hyperbolic function (Equation 5) versus .89 for the hyperbola-like function (Equation 7). When the $R^2$s obtained with Equations 5 and 7 were compared using a Wilcoxon matched-pairs signed-ranks test, the hyperbola-like function with the scaling (*s*) parameter proved to be significantly better, $z = -5.88, p < .001$. A similar comparison based on the data from the probability reward discounting task again revealed that the median of the $R^2$s for the hyperbola-like function (Equation 8) was greater than that for the hyperbolic function (Equation 6), .94 versus .85. Moreover, the fit of Equation 8 with the scaling (s) parameter was significantly better based on a Wilcoxon matched-pairs signed-ranks test, z = -6.28, p < .001. Finally, the median of the $R^2$s from the probability loss discounting task was .90 for the hyperbolic function (Equation 6) versus .93 for the hyperbola-like function (Equation 8). The Wilcoxon matched-pairs signed-ranks test revealed that the hyperbola-like function with the scaling (*s*) parameter (Equation 8) proved to be significantly better, $z = -6.33, p < .001$. Thus, the hyperbola-like functions described by Equations 7 and 8 clearly provide the best model for fitting both group and individual discounting data (see Appendix I for individual values of $R^2$ and AUC for the entire sample).

Because the hyperbola-like function was found to be the best model for fitting indifference points, the coefficients of determination for individual data fit to Equations 7 and 8

Table 1

*Central Tendency and Variability for Discounting Parameters*

| Discounting task | Function | $N$ | Parameter | Median | Interquartile range |
|---|---|---|---|---|---|
| Delay | $v_d = 10/(1 + kD)$ | 49 [a] | k | .0054 | .0028–.0146 |
| | | | $R^2$ | .85 | .74–.93 |
| | $v_d = 10/(1 + kD)^s$ | 58 [a] | k | .0061 | .0001–.4241 |
| | | | $s$ | .83 | .18–51.39 |
| | | | $R^2$ | .89 | .78–.95 |
| | | | AUC | .58 | .41–.77 |
| Probability (rewards) | $v_d = 10/(1 + h\Theta)$ | 52 [a] | h | .97 | .52–1.75 |
| | | | $R^2$ | .85 | .68–.94 |
| | $v_d = 10/(1 + h\Theta)^s$ | 59 [a] | h | 6.49 | 1.04–26.88 |
| | | | $s$ | .40 | .24–.82 |
| | | | $R^2$ | .94 | .86–.97 |
| | | | AUC | .30 | .18–.40 |
| Probability (losses) | $v_d = 10/(1 + h\Theta)$ | 53 [a] | h | .89 | .41–1.78 |
| | | | $R^2$ | .90 | .85–.95 |
| | $v_d = 10/(1 + h\Theta)^s$ | 59 [a] | h | 2.20 | .53–8.96 |
| | | | $s$ | .60 | .36–1.23 |
| | | | $R^2$ | .93 | .90–.96 |
| | | | AUC | .29 | .17–.39 |

[a] The different values of $N$ reported in the table were the result of participants whose data were not adequately described by Equations 5, 6, 7, or 8 (i.e., $R^2 \approx 0$).

were used to determine whether a participant's data was included in correlational analyses. That is, if any individual's data was found to not be described well by this model (as indicated by a low $R^2$), their data for that discounting task was excluded from the analysis. A low $R^2$ suggests that the decisions they made on the particular task were highly irregular compared to other participants. For example, multiple switches between immediate and delayed rewards such as choosing \$5.00 now over \$10.00 in 30 days and then choosing \$10.00 in 90 days over \$5.00 now would lead to an *increase* in subjective value of delayed rewards over time, which cannot be described by the model. Low $R^2$s also resulted from exclusive responding to one alternative. Because assessing the relation between degree of discounting and gambling judgements would be meaningless in the absence of a reasonable fit of the function to the data, participants with zero or relatively poor fitting data sets were omitted. Individual participants' data were excluded if their $R^2$ was equal to zero or was an extreme outlier based on a boxplot analysis. Extreme cases had $R^2$s with values more than three times the length of the interquartile range smaller than the lower edge of the interquartile range.

Once the appropriate participants were excluded, correlational analyses were conducted to test the hypotheses outlined in the above section. For delay discounting, four participants were excluded from further analyses (Participants 26, 33, 36, and 47) which made the lowest $R^2$ = .32 (Participant 51) among the remaining sample. Pearson product-moment correlation coefficients were calculated between AUC and number of cards selected from the favourable decks (A and B) on the Bechara Gambling Task. A two-tailed significance test was performed on the correlation between AUC on the delay discounting task and number of favourable selections because this correlation was not hypothesized to be significant in either direction (Hypothesis 1). However, the resulting negative correlation proved to be significant, $r(54)$ = -

.30, $p = .028$ (two-tailed). Thus, Hypothesis 1 was not supported.

For probability reward discounting, two participants were excluded (Participants 24 and 47) which made the lowest $R^2 = .55$ (Participant 18) among the remaining sample. A one-tailed significance test was performed on the correlation between AUC on the probability rewards discounting task and number of favourable selections because these variables were hypothesized to be negatively correlated. The resulting correlation was not significant, $r(56) = .06, p = .635$ which did not support Hypothesis 2 that AUC and selections from A and B would be negatively correlated.

For probability loss discounting, five participants were excluded (Participants 1, 18, 47, 51, and 57) making the lowest $R^2 = .73$ (Participant 35) among the remaining sample. A one-tailed significance test was performed on the correlation between AUC on the probability loss discounting task and number of favourable selections because these variables were hypothesized to be positively correlated. The resulting correlation was not significant, $r(53) = -.12, p = .401$ which did not support Hypothesis 3 that AUC and selections from A and B would be positively correlated.

To test the reliability of these results, an alternative correlational analysis was performed with "money remaining" as the dependent measure for the Bechara Gambling Task. Recall that participants were provided with $2000 at the beginning of the task and their objective was to maximize their profits. Obviously, choosing proportionally more cards from Decks A and B would increase the chance of having a higher amount of money at the end of the task; however, participants who correctly stuck with Decks A and B for the majority of their selections may have taken occasional "calculated risks" by choosing from Decks C and D in an attempt to fulfil their main objective of increasing their profits. Selections from A and B and "money remaining" were significantly correlated [$r(58) = .78, p < .001$]. Results from the alternative correlational analysis were consistent with the original findings. The correlation between AUC on the delay discounting task and "money remaining" was significant, $r(54) = -.28, p = .040$ (two-tailed). The correlations between AUC on the two probability discounting tasks and "money remaining" were not significant; $r(56) = .02, p = .880$ (one-tailed) for the probability rewards discounting task, and $r(53) = -.02, p = .866$ (one-tailed) for the probability loss discounting task.

Table 2 reports the intercorrelations between AUC for the three discounting tasks, selections from Decks A and B, and BIS scores. Note that among the three discounting tasks, the only significant correlation is between AUC for probability discounting of rewards and AUC for probability discounting of losses, $r(52) = -.26, p = .031$. This result was predicted as per Hypothesis 4 and indicates that individuals who discounted uncertain rewards at higher rates tended to discount uncertain losses at lower rates. Also note that the correlation between degree of delay discounting and degree of discounting for uncertain losses was not significant, $r(50) = .16, p = .27$ which does not support Hypothesis 5. The correlation between AUC for delay discounting and AUC for degree of probability reward discounting was not significant, $r(53) = .15, p = .129$ (one-tailed) which is not consistent with previous research that has found positive correlations between rates of delay and probability discounting of rewards (e.g., Mitchell, 1999; Holt et al., 2003; Richards et al., 1999). None of the correlations between AUC on the three discounting tasks and BIS scores were significant. A separate analysis of correlations between AUC on the three discounting tasks and each of the three BIS Factor Scores revealed no significant relationships. Thus, Hypotheses 6 and 7 were not supported. That is, degree of delay discounting was not positively correlated with overall impulsivity scores on the BIS (Hypothesis 6) and degree of discounting for uncertain losses was not positively correlated with scores on the

Table 2

*Intercorrelations between AUC's, Selections from A and B, and BIS Scores*

| Measure | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Cards from A & B | -- | .23* | -.30* | .06 | -.12 |
| | | $n = 60$ [a] | $n = 56$ [a] | $n = 58$ [a] | $n = 55$ [a] |
| 2. BIS Score | | --- | .01 | .13 | -.01 |
| | | | $n = 56$ [a] | $n = 58$ [a] | $n = 55$ [a] |
| 3. AUC – Delay | | | -- | .15 | .16 |
| | | | | $n = 55$ [a] | $n = 52$ [a] |
| 4. AUC – Probability (reward) | | | | -- | -.26* |
| | | | | | $n = 54$ [a] |
| 5. AUC – Probability (loss) | | | | | -- |

[a] The different values of *N* reported in the table were the result of participants whose data were not adequately described by Equations 5, 6, 7, or 8 (i.e., $R^2 \approx 0$).

*p < .05, one-tailed.

non-planning subscale of the BIS (Hypothesis 7). Interestingly, number of selections from favourable decks on the Bechara Gambling Task and scores on the BIS were positively correlated, $r(58) = .23, p = .041$ (one-tailed). This relationship indicates that more impulsive individuals actually performed better on the Bechara Gambling Task which is consistent with the present findings that AUC for delay discounting is negatively correlated with selections from A and B.

*Supplementary Analyses*

Although there was not expected to be a high proportion of problem gamblers in the current sample, an analysis was conducted to see if there were differences among participants identified as non-problem and problem gamblers. The mean CPGI score for all participants ($N = 60$) was 1.42 ($SD = 2.51$; $Mode = 0$). Half of the participants were classified as non-gamblers (score of 0) on the CPGI ($n = 30$) and one third were classified as low risk gamblers (score of 1 or 2, $n = 20$). Eight participants were classified as moderate risk gamblers (score of 3 to 7) and only two were classified as problem gamblers (score of 8 or above). Participants classified as non-gamblers and low-risk gamblers ($n = 50$) were grouped together (non problem group) and participants classified as moderate risk and problem gamblers (problem group) were grouped together in order to compare these groups on various measures.

First, comparisons were made between the two groups for each type of discounting. Figure 10 shows the mean AUC for both groups on the three discounting tasks. The two groups did not significantly differ in degree of discounting on the delay, $t(54) = 1.04, p = .153$, probability reward, $t(56) = 1.40, p = .084$, or probability loss discounting tasks, $t(53) = .18, p = .427$. Note that the non-significant difference in delay discounting is in the hypothesized direction in that problem gamblers discounted at a higher rate than non-problem gamblers

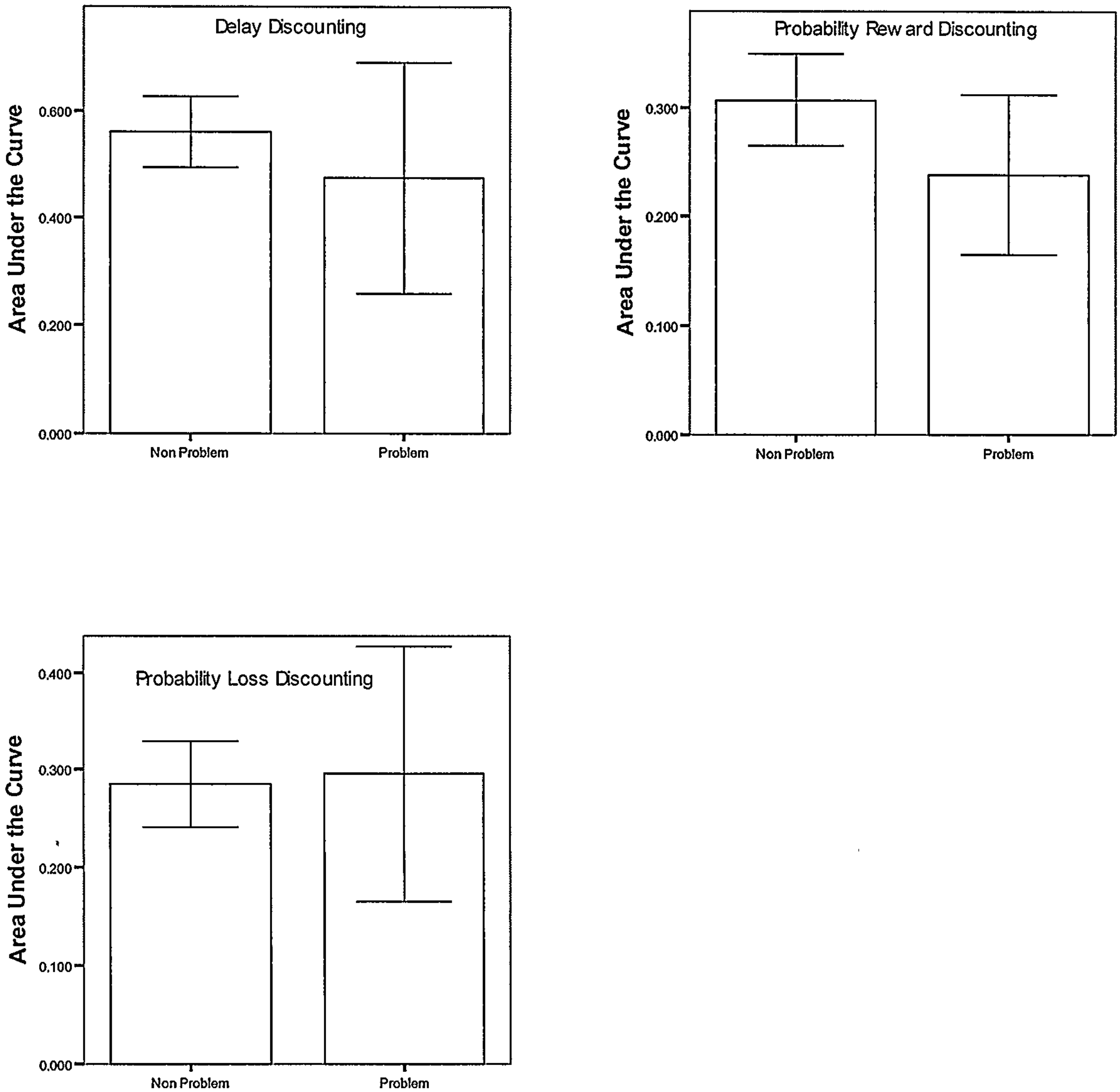


**Figure 10.** Mean values of AUC estimated from each group for each of the discounting tasks. Error bars represent the 95% confidence interval.

(smaller AUC). The error bars show that there is a relatively large amount of variability in AUC values for the problem gambler group. This error, which is present in all comparisons, can mostly be attributed the smaller sample size of the gambling group ($n$ = 10 versus $n$ = 50). The non-significant difference in probability reward discounting is in the opposite direction to that expected based on assumptions about problem gamblers. That is, problem gamblers appear to discount uncertain rewards at a higher rate (lower AUC) and recall that higher rates of this type of discounting reflect less risky decision-making (i.e., prefer smaller, certain rewards over larger, uncertain rewards).

The two groups were also compared on performance on the Bechara Gambling Task. There was not a significant difference between the two groups in number of cards selected from Decks A and B, $t(58) = 1.16$, $p = .126$. Finally, groups were compared on BIS scores. It was predicted that the problem gamblers would have higher BIS scores so a one-tailed test was performed. Surprisingly, this result was significant in the opposite direction $t(58) = -1.77$, $p = .041$, indicating that non-problem gamblers actually had higher BIS scores. However, because this difference was not predicted, the result is not considered significant because it would not have reached significance in a two-tailed test ($p = .082$).

# CHAPTER FOUR: DISCUSSION

The major goal of the present study was to test the hypothesis that rates of discounting for uncertain negative outcomes are related to errors of expected value. This hypothesis was not supported. Correlations between degree of discounting and performance on the Bechara Gambling Task revealed that only degree of delay discounting was related to errors of expected value, as indicated by performance on the gambling task. The results showed that individuals who discounted delayed rewards at a higher rate tended to make more favourable deck selections. In other words, more "impulsive" individuals, in the sense that they preferred smaller, immediate rewards over larger, delayed rewards, made decisions on the gambling task that resulted in more positive cumulative outcomes (more cards from Decks A and B). On the other hand, less "impulsive" individuals made decisions on the task that resulted in more negative cumulative outcomes. Similarly, more impulsive individuals, as indicated by their score on the BIS, performed better on the gambling task. These results are surprising because they suggest that less impulsive individuals are more susceptible to making errors of expected value.

Degree of probability discounting, for both uncertain rewards and losses, was not related to performance on the Bechara Gambling Task. In addition, degree of discounting on each of the three discounting tasks was not related to total score on the BIS or any of the three factor scores on the BIS. No relationships were found amongst degree of discounting on the three different discounting tasks apart from a significant negative correlation between degree of probability reward discounting and probability loss discounting. This result was predicted (Hypothesis 4) and indicates that individuals who discounted uncertain rewards at lower rates tended to discount uncertain losses at higher rates. That is, individuals who took more risks when making decisions involving uncertain rewards (preferred larger, more uncertain rewards over smaller, certain rewards) also took more risks when making decisions involving uncertain losses (preferred larger, more uncertain losses over smaller, certain losses). This negative correlation is to be expected because more risky choices are associated with overvalued *rewards* and undervalued *losses*. In other words, individuals who discount uncertain rewards to a lesser degree will value them more and take greater risks to obtain them (prefer chance at full reward versus smaller, certain reward). Similarly, individuals who discount uncertain losses to a greater degree will undervalue the potential detriment they pose and will be willing to take greater risks to avoid them altogether (prefer chance at no loss versus "insurance policy" of smaller, certain loss).

Although most hypotheses were not supported, the current results have important implications for future discounting research. Particularly promising was the finding that the discounting paradigm can be used with uncertain losses. Group and individual data clearly show that the hyperbola-like function described by Equation 8 provides an adequate fit to indifference points for uncertain losses. However, results of correlational analyses did not show that degree of discounting uncertain losses was related to major dependent measures that were examined in the current study. The fact that rates of probability discounting were not found to be related to poor gambling decisions suggests that the processes involved in discounting uncertain outcomes are independent of processes involved in sustained gambling behaviour. Contrarily, profitable versus unprofitable gambling decisions seem to depend more on temporal discounting.

The purpose of this study was not to examine the characteristics of individuals who are at risk of developing gambling problems, but to examine the processes involved in gambling that make it a potentially addictive activity. Gambling in its most popular form (e.g., casino gambling) is a losing proposition, yet individuals continue to gamble in the face of losses that inevitably accumulate over time. One possible explanation for this irrational behaviour is that gamblers, in the midst of a gambling session, gain the perception that they have a mathematical advantage over the house. This study did not intend to identify the individuals who are prone to such errors in judgement, but to see if there is a relationship between errors in judging expected value and the degree to which an individual discounts rewards and losses. Rate of discounting was deemed an important correlate of expected value judgements because of the established relationship between various types of discounting and risky or impulsive behaviour (Baker, Johnson, & Bickel, 2003; Crean et al., 2000; Kirby et al., 1999; Petry & Casarella, 1999; Petry, 2001a; Petry 2001b; Mitchell, 1999; Reynolds et al., 2003). It was hypothesized that individuals who discount uncertain losses at a greater rate would make more errors of expected value. This hypothesis was not supported. However, it was found that individuals who discounted delayed rewards at a greater rate made fewer errors of expected value. On the other hand, participants who preferred larger, delayed rewards over smaller, immediate rewards tended to lose money on a gambling task wherein there was actually the possibility of winning money.

These results may be specific to the gambling task used in this study. The Bechara Gambling Task provided an estimate of an individual's ability to make profitable gambling decisions based upon knowledge of past outcomes. If more cards were selected from Decks A and B (positive expected value) the individual would most likely achieve a profit. However, if more cards were selected from Decks C and D (negative expected value) the individual would be more likely to achieve a net loss. Ideally, an individual completing the task would eventually learn that choosing from only Decks A and B would result in a certain net gain as the number of total selections increases. Although choosing from Decks C and D offered greater wins per card ($100 versus $50), and could even result in a relatively large net profit for the first few cards, continued selection from Decks C and D resulted in a certain net loss as the number of total selections increased. Thus, this task measures how quickly an individual can learn to identify alternatives that have the best prospective value. Conversely, it also measures the extent to which an individual prefers alternatives that have poor prospective value even though more profitable alternatives are available. In this sense, decisions on the Bechara Gambling Task that result in a cumulative net loss reflect an insensitivity to the "long term" consequences of an individual's choices. In other words, the cumulative effect of one's decisions in this task takes on a temporal connotation. A cumulative win represents a long term win and an immediate win represents a short term win. Poor performance on this task is reflected by a preference for immediate, large rewards (Decks C and D) over immediate, small rewards (Decks A and B). The net effect of poor decision making on this task is a long term loss.

The above discussion leads to a possible explanation for why the results showed that individuals who discounted delayed rewards to a greater degree tended to perform better on the Bechara Gambling Task. Recall that higher rates of delay discounting represent a preference for smaller, immediate rewards over larger, delayed rewards. In the Bechara Gambling Task, the favourable decks (A and B) offered participants smaller, immediate rewards coupled with smaller losses versus the unfavourable decks (C and D) which offered participants larger, immediate rewards coupled with larger losses. Thus, individuals with higher rates of delay discounting were able to identify rapidly the more favourable decks and continued to choose from them because they had a natural tendency to discount the long term value of the unfavourable decks. In other words, the participants who preferred smaller rewards versus waiting a period of time to collect a larger reward also preferred smaller rewards in the Bechara Gambling Task. They were less susceptible to "chasing" after a greater net profit via Decks C and D.

This process can be demonstrated by a brief analysis of the typical mindset of an individual completing the task. Initially, the participant will choose from each of the decks to determine what rewards are offered by each. After it is determined that Decks A and B offer $50 each time while Decks C and D offer $100 each time, the participant will tend to choose from C and D. However, they eventually discover that the cumulative losses that appear intermittently on these cards are outweighing the cumulative wins. At this point, they switch back to choosing from Decks A and B to eventually discover that the smaller wins outweigh the cumulative losses on these cards. The difference between good and poor performance on this task is the rate at which an individual can discern the cumulative effect of their choices. The results of this study suggest that people who discount delayed rewards at a high rate are better able to discern the cumulative effect of their choices. On the one hand, these results seem counterintuitive because it would be assumed that individuals who discount delayed rewards would also discount long term profits (achieved via more selections from favourable Decks A and B) and therefore would make more selections from Decks C and D. However, after sustaining a few relatively large losses on cards from Decks C and D, these individuals would have a greater tendency to discount rapidly the long term rewards possible in Decks C and D and quickly switch to Decks A and B that allow them to obtain smaller rewards with less concern for long term value. In other words, it may be easier for delay discounters to "let go" of the potentially big payouts offered by Decks C and D because they are content with smaller, immediate rewards. According to this analysis, delay discounters do not perform better on the Bechara Gambling Task because they consider the net effects of their choices; rather, they perform better because they have an affinity for immediate payouts and stay away from choices that present long term uncertainty.

The Bechara Gambling Task was not originally intended to measure gambling behaviour per se. Its authors (Bechara et al., 1994) aimed to create a task that could measure real-life decision-making defects in individuals with damage to the ventromedial prefrontal cortex. It was found that prefrontal patients were insensitive to the future consequences of their actions and seemed to base their decisions on immediate prospects only. In other words, they selected more cards from Decks C and D than control participants because, the authors concluded, selecting from Decks C and D offered higher immediate rewards. The authors went on to suggest that it is not possible for subjects to "perform an exact calculation of the net gains or losses generated from each deck as they play" (pp. 13). They found that a group of control subjects with superior memory and IQ could not provide accurate figures of the net gains or losses from each deck. They concluded that performance on the task depended on participants' ability to estimate which decks yielded a profit or loss in the long run. This ability, or lack thereof, is precisely what the present study attempted to correlate with various rates of discounting.

The authors made another interesting conclusion. They considered three possibilities to explain why individuals who performed poorly on this task preferred high immediate rewards that also resulted in long term punishment: (1) they are so sensitive to reward that immediate gains subjectively outweigh the prospect of future punishment; (2) they are insensitive to punishment so the highest rewards offered will naturally take precedence; or (3) they are insensitive to both positive and negative future consequences, so their decisions are influenced most by immediate prospects. When the authors altered the task so that Decks A and B had $50 losses on each card along with small, intermittent wins (resulting in a net loss), and Decks C and D had $100 losses on each card along with large, intermittent wins (resulting in a net gain), the participants who had performed poorly on the original task continued to choose from the unfavourable decks (A and B this time) on the modified task. That is, they chose from the decks with smaller immediate losses and therefore were more influenced by immediate punishment rather than by delayed reward. Thus, the authors concluded that poor performance on the Bechara Gambling Task reflects unresponsiveness to future consequences and oversensitivity to immediate consequences (whether positive or negative).

The authors suggested that this deficit in decision-making is due to faulty representations of future outcomes that are either: (1) unstable and cannot be held in working memory long enough to be acted upon, or (2) not marked with a negative or positive value and thus cannot be easily rejected or accepted. The hypothesis that representations of future outcomes are unstable would suggest that these representations are easily discounted. However, the results of the current study do not support that hypothesis because a negative correlation was found between preference for higher immediate rewards (Decks C and D) and rate of delay discounting. According to the unstable representations hypothesis, individuals who perform poorly on the Bechara Gambling Task should also discount delayed rewards more rapidly which was not supported by the current findings.

The marked value hypothesis may have more merit and could also explain the current findings. According to the marked value hypothesis, individuals who perform poorly on the Bechara Gambling Task are unable to label the cumulative effects of their decisions as either positive or negative so they resort to relying on immediate consequences to guide their decision-making. In contrast, individuals who do well on the task can effectively place a positive or negative value on the net effects of their decisions so they are better able to use future representations to influence accurately their current decisions. If this hypothesis is correct, the results of the current study would suggest that participants who discounted delayed rewards at a higher rate were better able to mark their future representations as positive or negative. Emphasizing the fact that these participants rapidly discounted delayed *rewards*, this higher rate of discounting may reflect a more *rapid labelling* of future representations. Assuming these participants were better able to label future representations than participants who performed poorly on the task, their higher rate of delay discounting appears to be an indicator of a higher readiness to eliminate or disregard unfavourable long term outcomes. In other words, those individuals who rapidly discount delayed outcomes are better at discounting alternatives that result in long term losses (Decks C and D). Put simply, delay discounters are more rapid labellers of future representations because they can "let go" of future alternatives more quickly. This suggests that individuals who perform well on the Bechara Gambling Task should also discount delayed *losses* at a higher rate. Thus, if a similar delay discounting paradigm were administered using delayed losses (e.g., would you prefer to lose $5 now or lose $10 in 30 days?), number of selections from Decks A and B would be expected to be positively related to degree of discounting of delayed losses (negatively related to AUC).

An interesting excerpt from the mind of a gambler lends some credibility to this notion that individuals who discount delayed rewards at a lower rate may not be able to "let go" of future possibilities:

> . . . the odds at roulette stink. ("Smart gamblers" never touch the game; they play cards or dice—much better odds.) But I fell in love with roulette the first time I sat down to it, and if I had the money and the drinking capacity I'd probably live at a roulette table and let my life go to hell. . . Okay, that's my game, and I'm playing the three. Losing $180-odd is losing 30 more dollars than I ever made in a week before the age of thirty two. . . The number three hasn't come up in what

> seems like three-thousand years, a period with the slow-motion intensity of a car crash . . . Then three hits! Well, it was bound to hit once. But it keeps on hitting. It's like I've finally broken through to the wheel—finally, this once, had what every roulette player sits there for, a hotline to the wheel. (Ventura, 1993, pp. 85-86)

This passage proposes that perhaps individuals who continue to make poor gambling decisions in the midst of a gambling session (i.e., continue to gamble), do so because they do not discount the long term possibility of a big payout. They cannot "let go," so to speak. They are waiting for their own "hotline to the wheel."

Unfortunately, methodological limitations of the current study prevent definitive conclusions to be made regarding the exact decision-making deficit present in individuals who performed poorly on the Bechara Gambling Task. For instance, the current study did not include a delay discounting task for delayed losses. Because this study allotted actual rewards for decisions made on the discounting tasks, it was not practical to include a delay discounting task wherein participants would be presented with choices between losing money immediately or returning to the laboratory at a later date to "lose" a larger amount. Future studies could test this "let go" theory by including a delay discounting procedure for losses, possibly using hypothetical outcomes.

As mentioned earlier, the Bechara Gambling Task was not specifically designed to study gambling behaviour (Bechara et al., 1994). At least one study has examined performance on the Bechara Gambling Task as an indicator of decision-making processes amongst gamblers (Petry, 2001c). The current study used this task as a direct measure of profitable or unprofitable gambling decisions in order to examine the decision processes that make gambling a potentially addictive activity. However, the Bechara Gambling Task may not adequately simulate true gambling experiences for several reasons. First, play money was used and the main objective of the task, to maximize profit, may not have been taken seriously by participants who were indifferent to the consequences of their decisions because their own money was not at risk. Future studies with this task may be able to increase ecological validity by having participants use real money. Second, contrary to earlier discussions that most gambling activities have a negative expected value, the Bechara Gambling Task has both positive and negative expected value possibilities. Thus, a fundamentally maladaptive aspect of gambling, that it is an activity that will almost certainly result in long term losses, is absent from the Bechara Gambling Task. It would be interesting to conduct an experiment that uses a variant of this task wherein all four decks have negative expected values, but to varying degrees. Third, the size of the rewards available did not vary which is not the case in many forms of gambling. Decks A and B offered \$50 per card and Decks C and D offered \$100 per card. Although some forms of gambling offer what is essentially a fixed reward – for example, apart from "blackjacks" that pay two-to-one, a player can only win as much as he or she bets in the game "21" – most forms offer rewards of variable size. Slot machines offer wins that range in size from very small to enormous jackpots. In roulette, a player may bet on even-money propositions (e.g., black or red) or single numbers for 35 to 1 payouts. This aspect of gambling is not captured well by the Bechara Gambling Task because the only outcome that varies across decks is the size of the loss. In fact, real-life forms of gambling tend to operate in an opposite fashion – the size of the potential loss is known before the wager is placed, and the size of the reward is unknown. Future versions of the Bechara Gambling Task that aim to study gambling behaviour should vary the size both wins and losses. After all, the type of wager a gambler makes from one bet to the next in a real-life situation will depend on various factors such as amount of money they have remaining, size of the bet, and potential size of win. For instance, a player who has already lost a large sum of money may try to win it back by making a bet with poor odds but a high payout. Thus, choice of wager is inevitably related to the expected values of the gambling alternatives being offered.

On a related note, another limitation of the current study is the potential effect that the sequencing of tasks may have had on the results. All participants completed the Bechara Gambling Task before the discounting tasks which may have influenced the types of decisions they tended to make, depending on how well they performed on the gambling task. Participants who did poorly on the Bechara Gambling Task (took a net loss as indicated by ending up with less play money than they started with) might have made more risky decisions on the discounting tasks (e.g., choosing larger, more uncertain rewards) in order to make up for a lack of success at the preceding task. Conversely, participants who did well on the Bechara Gambling Task may have made more conservative decisions in order to maintain a certain level of success. Future studies that examine performance on these tasks should account for this possibility by controlling for performance across tasks.

Of course, the current findings do not suggest that problem gamblers discount delayed rewards to a lesser degree than non-problem gamblers. On the contrary, several studies have found that problem gamblers tend to discount delayed rewards at a higher rate than control participants (Alessi and Petry, 2003; Dixon, Marley, and Jacobs, 2003; Petry, 2001b). Indeed, when degree of discounting was compared between sub-groups of problem gamblers and non-problem gamblers in the current study, a non-significant difference was found in the hypothesized direction showing that problem gamblers discounted at a higher rate than non-problem gamblers. However, a disproportionately small sub-sample of problem gamblers prevented a comparison with adequate power. Most of the participants in the current study received a score of 0 on the CPGI (non-gambler classification). So while the main findings do not suggest that low rates of delay discounting lead to problem gambling, they may help explain the decision-making processes that occur when an individual is actually gambling.

Two separate choice patterns, both characterized by a high degree of delay discounting, may be responsible for the development of gambling problems. It may be that problem gamblers exhibit molar choice patterns that result in the impulsive decision to begin a gambling session wherein the value of avoiding gambling and having money saved for the future is discounted to the point that the immediate prospect of gambling and possibly winning money is worth more to that individual. However, once a gambling session has begun, more impulsive individuals (i.e., problem gamblers) exhibit molecular choice patterns that result in more profitable play. Consequently, they may experience more frequent winning sessions compared to less impulsive individuals which allows them to rationalize future decisions to gamble. Unfortunately, as already discussed, gambling is an inherently negative expected value activity and no matter how optimal one's decisions are, cumulative losses are inevitable. This analysis allows degree of delay discounting to be an indicator of both a general trait of impulsivity and sensitivity to cumulative outcomes. Hence, the rate at which an individual discounts delayed outcomes may provide an index of their susceptibility to developing a gambling problem.

Future studies could test this hypothesis by comparing rates of delay discounting between large samples of problem gamblers and controls over long periods of time. It would be interesting to note changes in rates of discounting as non-problem gamblers become more involved in gambling activities and problem gamblers begin to abstain. In addition, profitability of play over gambling sessions could be compared between the groups. It would also be beneficial to examine the various coping mechanisms individuals might use to influence the rate at which they discount delayed outcomes. At least four strategies (extrapsychic mechanisms, control of attention, preparation of emotion, and personal rules) have been proposed to help individuals make more "self-controlled" choices in terms of reducing the rate at which they discount future outcomes (Ainslie & Monterosso, 2003). It would be informative to examine which strategies, if any, are most helpful in changing gambling behaviour. The current study served as an important first step in this investigation by examining the unique underlying processes involved in different discounting tasks. The results suggest that profitable versus unprofitable gambling decisions are not related to how uncertain outcomes are discounted but may be related to how delayed outcomes are discounted.

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## Appendix A

## BACKGROUND INFORMATION QUESTIONNAIRE

The following questions ask for background information. All responses will be kept confidential.

**Date:** __________

**Age:** __________

**Gender:** male ___ female ___

**Marital Status:**

single ___ married ___ common law ___ separated ___ divorced ___ widowed ___

**Education:**

Highest grade complete: ___

Number of years of post-secondary education: ___

Title of degree (if any): _____________

**Occupation:**

Position/ title: ___________________

If student: full time ___ part time ___

**Your approximate net monthly income:** _______________

## Appendix B

## CANADIAN PROBLEM GAMBLING INDEX

*Some of the questions in this questionnaire may not apply to you but please attempt to be as accurate as possible. Please circle the answer that best describes your experiences over the past 12 months.*

1. Have you bet more than you could really afford to lose?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

2. Still thinking about the last 12 months, have you needed to gamble with larger amounts of money to get the same feeling of excitement?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

3. When you gambled, did you go back another day to try to win back the money you lost?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

4. Have you borrowed money or sold anything to get money to gamble?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

5. Have you felt that you might have a problem with gambling?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

6. Has gambling caused you any health problems, including stress or anxiety?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

7. Have people criticized your betting or told you that you had a gambling problem, regardless of whether or not you thought it was true?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

8. Has your gambling caused any financial problems for you or your household?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

9. Have you felt guilty about the way you gamble or what happens when you gamble?
   a) Never
   b) Sometimes
   c) Most of the time
   d) Almost always
   e) Don't know

Scoring: Score 1 for each response of "sometimes", 2 for each response of "most of the time" and 3 for each "almost always"

## Appendix C

## BARRATT IMPULSIVENESS SCALE

This questionnaire consists of thirty questions that ask you to rate how well certain statements apply to you. To answer these questions, please determine to what degree each of these statements applies to you and choose the appropriate response.

How well does each of these statements describe you?

1. I plan tasks carefully.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

2. I do things without thinking.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

3. I make-up my mind quickly.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

4. I am happy-go-lucky.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

5. I don't "pay attention."
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

6. I have "racing thoughts."
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

7. I plan trips well ahead of time.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

8. I am self-controlled.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

9. I concentrate easily.
   a.) Never
   b.) Occasionally
   c.) Often
   d.) Always

10. I save regularly.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

11. I "squirm" at plays or lectures.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

12. I am a careful thinker.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

13. I plan for job security.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

14. I say things without thinking.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

15. I like to think about complex problems.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

16. I change jobs.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

17. I act "on impulses."
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

18. I get easily bored when solving thought problems.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

19. I act on the spur of the moment.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

20. I am a steady thinker.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

21. I change residences.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

22. I buy things on impulse.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

23. I can only think about one problem at a time.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

24. I change hobbies.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

25. I spend or charge more than I earn.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

26. I often have extraneous thoughts when thinking.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

27. I am more interested in the present than the future.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

28. I am restless at the theater or lectures.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

29. I like puzzles.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

30. I am future oriented.
    a.) Never
    b.) Occasionally
    c.) Often
    d.) Always

## Appendix D

## BECHARA GAMBLING TASK

**Instructions:**

*Participants will be presented with four decks of 60 cards labeled A, B, C, and D that are face-down and equal in appearance. The student researcher will read the following set of instructions to each participant prior to beginning the Bechara Gambling Task:*

The underside of each of these cards indicates an amount of money that has been won. Some cards will also indicate an amount of money that must be paid as a penalty. You are to select the top card from any of the four decks. The objective is to maximize your profits. However, you will not receive or pay any amount indicated on these cards. You may select cards from any deck you wish and you may switch decks at any time and as often as you like. After each card is overturned, the values will be announced for that card. Continue to select cards until I instruct you to stop. Try to end up with more money than the $2000 you started with by choosing from the best decks.

## Appendix E

## DISCOUNTING TASKS

**Instructions:**

*The student researcher will read the following set of instructions to each participant prior to beginning the discounting tasks:*

Now I am going to ask you to make some choices involving money. You are to make decisions about which of two consequences you prefer. There will be three types of questions. One set of questions will have you choose between different amounts of money available immediately or after different delays. For example, you may be asked the following: Which option do you prefer? (a) $2 at the end of this session, or (b) $10 in 30 days. A second set of questions will have you choose between different amounts of money available for sure or with a specified chance. For example, you may be asked the following: Which option do you prefer? (a) $7 for sure at the end of the session, or (b) a 25% of receiving $10. A third set of questions will have you choose between different amounts of money that must be paid for sure or with a specified chance of being paid. For example, you may be asked the following: Which option do you prefer? (a) $4 to be lost for sure at the end of the session, or (b) a 70% chance of losing $10 (30% chance of losing nothing). These questions will appear on the computer screen and you will be asked to indicate your preference by pressing the corresponding key on the keyboard (i.e., [a] or [b]). At the end of the session, one question from each of these three sets of questions will be selected at random and you will receive/lose whatever you chose in response to those 3 questions. For the set of questions involving delayed amounts, if on that trial you selected an immediate amount of money [option (a)], you will keep that amount of the $20 given to you at the onset of the session. If you selected the delayed amount of money [option (b)], you will be required to forfeit that amount of the $20 given to you and it will be placed in an envelope with your name on it, and it will be available to you when the time has elapsed. For the set of questions involving certain/uncertain amounts to be received, if on that trial you selected a certain amount [option (a)], you will keep that amount of the $20 given to you at the beginning of the study. If on that trial you selected a chance of winning $10 [option (b)], you will select a token from a bag containing "win $10" tokens and "win $0" tokens in the proportion that reflects the probability. For example, if the trial you selected was $10 with a 25% chance, you will select one token from a bag containing 1 "win $10" token and 3 "win $0" tokens. You will keep that amount of the $20 given to you at the onset of the session if you draw a "win $10" token and you will forfeit $10 of the $20 if you draw a "win $0" token. For the set of questions involving certain/uncertain amounts to be lost, if on that trial you selected a certain loss [option (a)], you will forfeit that amount of the $20. If on that trial you selected an uncertain payment [option (b)], again you will select one token from a bag with "lose $10" and "lose $0" tokens and either forfeit $10 or $0, depending on which token you pick. If it turns out that you lose more money than you are allowed to keep, you will not be required to pay any money. You will be entitled to a minimum of $5 of the $20 provided to you at the beginning of the study. Remember that each of these three questions will be randomly selected so please answer each question during this task according to your actual preferences. Please feel free to answer any questions at this point.

## Appendix F

### DEBRIEFING SCRIPT

Gambling is an activity that normally involves a situation in which the "player" is at a statistical disadvantage. Often termed "the house advantage," the nature of gambling is such that each wager takes on a "negative expected value." In other words, in the long run, a person can expected to lose an average amount for each bet that is placed. It may be theorized that people with gambling problems are unable to foresee the cumulative negative effects of gambling. The current study aims to investigate whether "errors of expected value" are associated with how they discount the value of uncertain losses.

Individuals discount the value of a reward that is delayed. For example, $10 in one year is worth less than $10 available immediately. Likewise, the value of an uncertain reward is discounted. That is, $10 with a 25% chance is worth less than $10 for sure. Researchers have found that delayed and uncertain rewards are discounted according to a hyperbolic function which allows calculation of an individual's rate of discounting. Research has also shown that higher discounting rates of delayed rewards are associated with higher rates of impulsivity. However, it is not clear whether varying discounting rates of uncertain rewards is associated with increased impulsivity or the related construct of risk-taking. The literature suggests that discounting rates of uncertain losses (rather than rewards) may be associated with increased risk-taking. However, the standard discounting paradigm has not been conducted using uncertain losses. The current study endeavors to apply the standard discounting paradigm using uncertain losses in order to establish whether the same hyperbolic function used for rewards can be used to describe how individuals discount uncertain losses. The current study also hypothesized that higher discounting rates of uncertain losses is associated with increased risk-taking – specifically risk-taking that results in long-term cumulative losses.

This project aims to accomplish the following three goals: 1) determine whether people discount the value of uncertain negative outcomes according to the same hyperbolic function that describes the discounting of delayed rewards and uncertain rewards; 2) determine whether more impulsive individuals take more risks when uncertain outcomes are negative; and 3) determine the association between rates of discounting and insensitivity to the cumulative negative effects of decisions.

The results of this experiment may be useful in developing the discounting paradigm as a measure of susceptibility to developing a gambling problem. Future studies could test this hypothesis by comparing rates of probability discounting across groups of problem gamblers and controls.

## Appendix G

## RECRUITMENT NOTICE

Notice to be posted on http://experimentrix.com/uc

Research Project: PROBABILITY DISCOUNTING AND RISKINESS, Time Required: 60 min, Bonus Credits: minimum of $5, maximum of $20, Description: You will be asked to make choices between monetary alternatives. You will be asked to make choices between unknown monetary alternatives. You will also be asked to provide background information and complete questionnaires regarding risk-taking, impulsivity, and gambling. THIS IS A NON-BONUS CREDIT RESEARCH PARTICIPATION OPPORTUNITY.

## Appendix H

## UNIVERSITY OF CALGARY
## INFORMED CONSENT FORM

Research Project Title: Rates of Probability Discounting and Errors of Expected Value

Investigators: N. Will Shead, B.A. Hons., Clinical Psychology Student, Department of Psychology, University of Calgary, and David C. Hodgins, Ph.D., Professor, Department of Psychology, University of Calgary.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this carefully and to understand any accompanying information.

The results of this study may be useful in enhancing knowledge about how people make decisions, particularly when there is an element of risk involved. You will be asked to provide background information (age, gender, education, etc.) and then complete four decision-making tasks. These tasks involve making decisions between monetary alternatives. The outcomes of some of these decisions will be uncertain. Next, you will complete three questionnaires. One questionnaire asks questions about your gambling habits, and the other two questionnaires ask questions about risk-taking and impulsivity. Some of these questions may be personal, but you are free to refuse to answer any questions that you do not wish to answer. At the beginning of the study you will be awarded $20 for your participation. However, you will only be entitled to keep a portion of this amount at the conclusion of the study. The amount that you must give back will depend on your decisions during the decision-making tasks. This will be explained in more detail during the experiment; however, if you have any questions about this aspect of the study that you would like answered now, feel free to ask them at this point.

All of your individual results from this study will be completely confidential and your name will not be used on any of your responses. Information from this study will not be made public in any form in which you personally can be identified as a participant. Your data will be identified using an arbitrary participant number. Research materials and data from this study will be stored in a locked cabinet at the University of Calgary.

The results of this study will be completely confidential and your name will not be used on any of your responses. Information from this study will not be made public in any form in which you personally can be identified as a participant. Data from this study will be stored on computer disks that will be stored in a locked cabinet at the University of Calgary.

In signing this form I fully understand that I am participating in this study as part of my educational experience in the Department of Psychology. In exchange for my time I expect to gain some understanding of research and some of the ideas currently being explored in psychology. If, after the study, I feel I have not gained sufficient educational benefit, or have other concerns regarding this experience, I may register my concerns with Dr. M. Boyes, Chair: Department of Psychology Research Ethics Board. He will ensure that my comments are acted upon with no fear that I will be identified personally. Dr. Boyes can be reached at A230, 220-7724, boyes@ucalgary.ca.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to not answer specific items or questions in interviews or questionnaires. You are free to withdraw from the study at any time and still receive the one bonus credit. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact Will Shead at 210-9500 or nwshead@ucalgary.ca.

If you have any questions concerning your participation in this project, you may also contact Mrs. Patricia Evans, Research Services Office, Room 602 Earth Sciences, telephone: 220-3782. If you have concerns regarding your gambling, help is available from the problem gambling helpline at 1-800-665-9676 and AADAC at 297-3337.

| | |
|---|---|
| ______________________ | ______________________ |
| Participant | Date |
| ______________________ | ______________________ |
| Investigator | Date |

A copy of this consent form has been given to you to keep for your records and reference. This research has the ethical approval of the Conjoint Faculties Research Ethics Board.

**Appendix I**

*Individual Values of Proportions of Explained Variance ($R^2$) for the Hyperbola-like Function (Equations 7 and 8) and Area Under the Empirical Discounting Curve (AUC)*

| Participant | Delay | | Probability (reward) | | Probability (loss) | |
|---|---|---|---|---|---|---|
| | $R^2$ | AUC | $R^2$ | AUC | $R^2$ | AUC |
| 1 | .981 | .526 | .939 | .480 | .000[a] | --[b] |
| 2 | .988 | .636 | .949 | .330 | .942 | .333 |
| 3 | .968 | .148 | .939 | .168 | .980 | .220 |
| 4 | .793 | .677 | .625 | .522 | .776 | .285 |
| 5 | .810 | .616 | .974 | .215 | .892 | .390 |
| 6 | .980 | .433 | .893 | .174 | .915 | .468 |
| 7 | .596 | .823 | .971 | .205 | .956 | .339 |
| 8 | .919 | .627 | .989 | .128 | .926 | .246 |
| 9 | .959 | .564 | .957 | .182 | .902 | .557 |
| 10 | .948 | .485 | .995 | .366 | .980 | .335 |
| 11 | .923 | .535 | .876 | .558 | .941 | .171 |
| 12 | .865 | .146 | .961 | .226 | .961 | .234 |
| 13 | .920 | .418 | .946 | .393 | .914 | .244 |
| 14 | .641 | .719 | .908 | .174 | .934 | .379 |
| 15 | .954 | .611 | .947 | .227 | .956 | .205 |
| 16 | .846 | .445 | .892 | .586 | .955 | .369 |
| 17 | .967 | .260 | .925 | .122 | .984 | .354 |
| 18 | .761 | .092 | .553 | .352 | .557 | .500 |
| 19 | .872 | .457 | .952 | .396 | .898 | .301 |
| 20 | .682 | .781 | .978 | .207 | .864 | .212 |
| 21 | .585 | .829 | .990 | .314 | .846 | .409 |
| 22 | .977 | .285 | .858 | .208 | .958 | .547 |
| 23 | .945 | .778 | .942 | .145 | .972 | .184 |

| Participant | Delay | | Probability (reward) | | Probability (loss) | |
|---|---|---|---|---|---|---|
| | $R^2$ | AUC | $R^2$ | AUC | $R^2$ | AUC |
| 24 | .648 | .794 | .450 | .361 | .987 | .368 |
| 25 | .358 | .983 | .966 | .183 | .849 | .315 |
| 26 | .000[a] | --[b] | .839 | .514 | :903 | .057 |
| 27 | .949 | .707 | .958 | .507 | .979 | .060 |
| 28 | .987 | .109 | .965 | .089 | .982 | .121 |
| 29 | .927 | .697 | .937 | .351 | .963 | .164 |
| 30 | .847 | .562 | .928 | .302 | .913 | .104 |
| 31 | .890 | .875 | .859 | .585 | .936 | .081 |
| 32 | .872 | .561 | .967 | .206 | .930 | .145 |
| 33 | .000[a] | --[b] | .797 | .527 | .932 | .121 |
| 34 | .936 | .777 | .970 | .178 | .831 | .293 |
| 35 | .646 | .578 | .689 | .510 | .727 | .116 |
| 36 | .039 | .942 | .989 | .327 | .836 | .539 |
| 37 | .546 | .149 | .751 | .417 | .921 | .310 |
| 38 | .896 | .178 | .682 | .136 | .923 | .360 |
| 39 | .806 | .867 | .946 | .156 | .876 | .549 |
| 40 | .893 | .678 | .820 | .080 | .927 | .426 |
| 41 | .943 | .579 | .856 | .559 | .970 | .194 |
| 42 | .969 | .100 | .969 | .118 | .926 | .272 |
| 43 | .834 | .370 | .973 | .199 | .910 | .166 |
| 44 | .971 | .884 | .945 | .311 | .966 | .196 |
| 45 | .950 | .507 | .939 | .098 | .997 | .500 |
| 46 | .801 | .477 | .837 | .298 | .957 | .162 |
| 47 | .091 | .932 | .000[a] | --[b] | .634 | .475 |
| 48 | .446 | .981 | .974 | .419 | .975 | .489 |
| 49 | .979 | .329 | .996 | .400 | .931 | .152 |
| 50 | .939 | .731 | .976 | .319 | .973 | .247 |
| 51 | .318 | .211 | .865 | .332 | .287 | .369 |

| Participant | Delay $R^2$ | Delay AUC | Probability (reward) $R^2$ | Probability (reward) AUC | Probability (loss) $R^2$ | Probability (loss) AUC |
|---|---|---|---|---|---|---|
| 52 | .926 | .766 | .852 | .382 | .931 | .633 |
| 53 | .917 | .259 | .872 | .162 | .919 | .044 |
| 54 | .420 | .461 | .852 | .179 | .898 | .233 |
| 55 | .789 | .639 | .862 | .173 | .954 | .473 |
| 56 | .887 | .606 | .960 | .276 | .954 | .363 |
| 57 | .892 | .586 | .970 | .397 | .454 | .289 |
| 58 | .863 | .301 | .701 | .228 | .752 | .125 |
| 59 | .928 | .821 | .995 | .221 | .994 | .118 |
| 60 | .872 | .537 | .882 | .345 | .912 | .522 |

[a] $R^2$ of .000 indicates that the function could not describe any variance in indifference points.

[b] The value of AUC is omitted because the poor fit made the measure meaningless (see above).

UNIVERSITY OF CALGARY

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**CERTIFICATION OF INSTITUTIONAL ETHICS REVIEW**

This is to certify that the Conjoint Faculties Research Ethics Board at the University of Calgary has examined the following research proposal and found the proposed research involving human subjects to be in accordance with University of Calgary Guidelines and the Tri-Council Policy Statement on *"Ethical Conduct in Research Using Human Subjects"*. This form and accompanying letter constitute the Certification of Institutional Ethics Review.

| | |
|---|---|
| File no: | **CE101-3715** |
| Applicant(s): | **Nathaniel Will Shead** |
| Department: | **Psychology** |
| Project Title: | **Probability Discounting and Riskiness** |
| Sponsor (if applicable): | |

***Restrictions:***

**This Certification is subject to the following conditions:**

1. Approval is granted only for the project and purposes described in the application.
2. Any modifications to the authorized protocol must be submitted to the Chair, Conjoint Faculties Research Ethics Board for approval.
3. A progress report must be submitted 12 months from the date of this Certification, and should provide the expected completion date for the project.
4. Written notification must be sent to the Board when the project is complete or terminated.

Janice Dickin

**Janice Dickin, Ph.D, LLB,**
**Chair**
**Conjoint Faculties Research Ethics Board**

2 October 2003
**Date:**

**Distribution**: (1) Applicant, (2) Supervisor (if applicable), (3) Chair, Department/Faculty Research Ethics Committee, (4) Sponsor, (5) Conjoint Faculties Research Ethics Board (6) Research Services.