5-2012

Exploring the Reliability and Validity of the Experiential Discounting Task

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EXPLORING THE RELIABILITY AND VALIDITY OF

THE EXPERIENTIAL DISCOUNTING TASK

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Psychology

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UTAH STATE UNIVERSITY
Logan, Utah

2012

ABSTRACT

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Delay discounting (the devaluation of rewards delayed in time) has been studied extensively using animal models with psychophysical adjustment procedures. Similar procedures were soon developed to assess delay discounting in humans. Although across species the same mathematical function relates discounted value to imposed delay, several methodological concerns have been implicated in human delay discounting procedures. A procedure recently developed to address these concerns is the Experiential Discounting Task (EDT). This task arranges experienced delays and rewards that humans make decisions regarding—experiencing the outcomes of their choices within session before making additional choices. The popularity of this procedure has been fueled by reports of its sensitivity to acute experimental manipulation, and that it has been predictive of treatment success. Similar sensitivity results have not been found when a traditional delay discounting task (DDT) has been used. Though the EDT appears useful for a variety of reasons, it has not been subjected to the same rigorous internal validity and reliability tests that traditional DDTs have. In two experiments we examined the test-retest reliability of the EDT (Experiment 1) and the way in which choice trials are regulated (Experiment 2). Results demonstrate that the EDT is reliable across time and choice is insensitive to trial regulation differences. We conclude with a critique of the EDT as a procedure for assessing delay discounting and hypothesize other processes it may be measuring.

(80 pages)

PUBLIC ABSTRACT

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Delay discounting is the devaluation of rewards that are delayed in time. This phenomenon was first studied with animals in controlled laboratory environments and later translated to human procedures. Though the decrease in value of outcomes as the delay to receipt increases is the same across species (money for humans, food for animals), a number of methodological concerns have been raised about the procedures used to study delay discounting in humans.

The Experiential Discounting Task (EDT) was recently developed in order to study delay discounting in humans in a way that is more similar to that used with animals. That is, humans make repeated decisions concerning outcomes they experience within session (delays and rewards). The EDT has proven useful for a variety of reasons including its ability to detect changes in how delayed rewards are discounted as a function of acute alcohol where traditional measures have not. However, this measure has yet to undergo rigorous tests of internal validity and reliability that previous measures of delay discounting have.

In two experiments we tested the reliability and internal validity of the EDT. First we assessed the test-retest reliability across seven days. Next we tested whether the way in which choices are presented in the EDT affects choice. In addition, all participants completed a traditional delay discounting task, boredom proneness scale and probability discounting task.

Experiment 1 resulted in good test-retest reliability for all tasks, including the EDT and the traditional measure of delay discounting. In Experiment 2 we found that individual performance did not change as a function of how choices were presented. Across both experiments we found no evidence for a correlation between discounting in the EDT and the traditional measure. Though reliable across time we contend, based on the relation to a traditional delay discounting task and the reviewed literature that there is little evidence that the EDT is a valid measure of delay discounting and call for more research to determine what process underlies decision-making in the EDT.

DEDICATION

I can say with sincerity that this document and all of the work that it signals has been the most rewarding project I have completed in my short time on this earth. I can only thank those in my environment who have provided the motivation, skills, opportunities, and much needed distractions that have enabled me to accomplish this achievement. Namely, my academic advisors who have inspired me and given me the tools to do research effectively (Drs. Greg Madden and Daniel Holt); my fellow lab members with whom I have had countless thought-provoking conversations (Patrick Johnson, Jeff Stein, Monica Francisco, Adam Brewer); my family for always encouraging me to learn and grow and to challenge and for providing opportunities to do so (Tony and Rita Smits); and my friends who have given me priceless distractions from academia to keep me grounded in the real world (Caralee Applequist and Jessica Pernsteiner). Finally, I have been eternally blessed with a supportive, loving, and patient boyfriend who has supported and challenged me through this process (TJ Seemann).

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CHAPTER I

INTRODUCTION

Delay discounting is the systematic decrease in the subjective value of an outcome as the delay to its receipt increases (for review see Madden & Bickel, 2010). Delay discounting is thought to underlie a specific type of impulsivity (Ainslie, 1975) – one characterized by preference for a smaller-sooner (SS) reward over an objectively larger but delayed reward with a present (discounted) value below that of the SS reward. For example, pay-day loan services profit from those who choose to obtain a small amount of cash now (SS) over a larger amount of money dispersed later (LL) when the next paycheck arrives. The choice provides evidence that the value of the LL payment is discounted below the undiscounted value of immediate cash.

Review of Delay Discounting

The seminal work in delay discounting was conducted in nonhuman animal labs and used titrating procedures borrowed from psychophysics (e.g., Mazur, 1987). In these studies, the shape and steepness of the delay discounting function were investigated by giving animals (such as rats or pigeons) repeated choices between SS and LL amounts of food at a range of delays. At each delay, the animal's choices were used to quantify the subjective (discounted) value of the LL reward. One commonly used method for accomplishing this is to make choice-dependent adjustments to the amount of the immediate reward until the animal is indifferent between the LL and SS rewards (e.g., Green, Myerson & Calvert, 2010; Richards, Mitchell, de Wit, & Seiden, 1997). Figure 1 shows two hyperbolic discounting functions that well characterize animal choices under this procedure. The steepness of the curve reflects the rate at which delayed rewards are discounted and is quantified as the *k*-parameter in the hyperbolic discounting equation proposed by Mazur (1987):

$$V = \frac{A}{(1+k\,\mathrm{D})} \tag{1}$$

where *V* is the present value of a reward of amount (A), available after a delay (D). Higher *k* values reflect steeper discounting as illustrated in Figure 1.

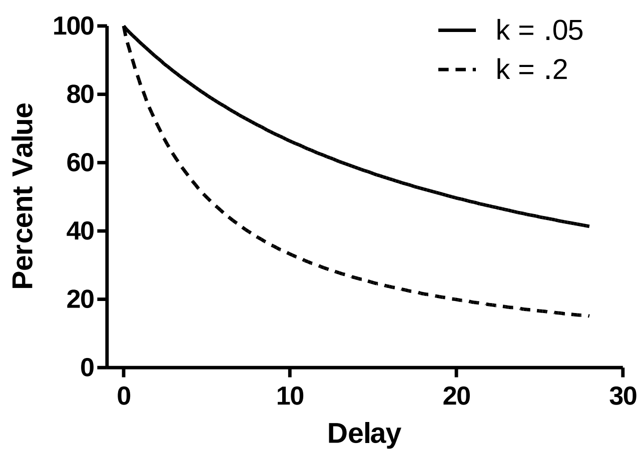

Figure 1. Two illustrative discounting curves.

In the last 20 years, a considerable amount of research has explored variants of these methods to examine the shape and steepness of the delay discounting function in humans. Most of these studies employ hypothetical monetary outcomes and an adjusting-amount procedure similar to the one described above (e.g., Rachlin, Raineri, & Cross, 1991). The vast majority of research suggests that Equation 1 provides a better fit of human delay discounting than does a normative exponential equation that was favored by economists for a majority of the 20th century (Samuelson, 1937).[1] This finding suggests that a comparable behavioral/cognitive process underlies human and animal discounting of delayed rewards.

That being said, four concerns have often been raised about the procedures used to study delay discounting in humans: a) the vast majority, if not all, of the rewards used in these studies are hypothetical prospects rather than real consequences of choice (Lawyer, Schoepflin, Green, & Jenks, 2011), b) the delays to the LL reward are verbal descriptions of delays rather than real delays that will be experienced (Lagorio & Madden, 2005), c) steady-state procedures characterizing the animal literature are not used with humans (Lagorio & Madden, 2005), and d) variables that would appear to affect impulsive decision-making in natural environments (e.g., opportunity costs, probabilistic delayed outcomes) are not represented in these discounting tasks (Reynolds, 2006).

Each of these concerns appears to have motivated the development of the Experiential Discounting Task (EDT) as an alternative method of assessing human delay discounting (Reynolds & Schiffbauer, 2004). In the EDT, humans make choices involving real SS and LL rewards and real delays to their delivery. The EDT uses an adjusting amount procedure similar to that used with nonhumans; that is, the amount of the SS reward is incremented (decremented) on trial t_{i+1} after this alternative was chosen (forgone) on trial t_i. Monetary rewards, and delays to these rewards, are experienced for each choice made in the EDT and before additional choices are made. Finally, choices

[1] See Green & Myerson (2004) for evidence that a hyperbola-like equation provides a better fit to human, but not animal delay discounting data.

continue to be made at a single delay until a stable pattern of decision making is detected (Reynolds, Penfold, & Patak, 2008; Reynolds, Richards, & de Wit, 2006; Shiels et al., 2009; Voon et al., 2010). An attractive feature of the EDT is that multiple indifference points are obtained in a single session; making it possible to derive a *k*-value in approximately 20 minutes. Thus, the procedure appears ideal when studying experimental manipulations anticipated to produce time-limited effects on delay discounting (e.g., sleep deprivation or drugs; Reynolds & Schiffbauer, 2004; Voon et al., 2010).

A second apparent benefit of the EDT is that choice under this procedure is sensitive to acute experimental manipulations, whereas choices made in discounting tasks using hypothetical rewards and delays are largely insensitive to these manipulations (see review by de Wit & Mitchell, 2010). For example, Reynolds et al. (2006) found that alcohol consumption increased the steepness of delay discounting curves when these curves were assessed with the EDT, whereas choice in a hypothetical-rewards delay discounting task was unaffected by alcohol (see also Richards, Zhang, Mitchell, & de Wit, 1999). Choices made in the EDT have also proven sensitive to sleep deprivation (Reynolds & Schiffbauer, 2004); the dopamine D_2/D_3 agonist, pramipexole (Voon et al., 2010); and, methylphenidate in children diagnosed with attention deficit hyperactivity disorder (Shiels et al., 2009). This point is illustrated in Table 1 which summarizes effect sizes from the small number of studies that have used both the EDT and a delay discounting task (DDT). An effect size is a standardized mean difference between experimental and control group/condition; positive effect sizes indicate that the experimental manipulation increased impulsivity. Table 1 illustrates that the EDT has produced larger effect sizes than the DDT (Mann-Whitney U = 3.5, $p < .05$).

Table 1

EDT and DDT Effect Size Comparison for Studies that Evaluated Experimental Manipulations

	EDT	DDT
Acheson et al. (2006)		
Diazepam	0	0
Acheson et al. (2007)		
Sleep Deprivation	.27	-.55
Reynolds et al. (2006)		
High dose alcohol	18.33	.01
Low dose alcohol	1.67	.05
Shiels et al. (2009)		
High dose MPH	.31	0
Low dose MPH	.25	0

Another benefit of the EDT is that at least one study suggests it better differentiates those who will succeed in drug-treatment from those who will not. Krishnan-Sarin et al. (2007) reported that adolescent smokers who discounted less steeply in the EDT were more likely to be abstinent at the end of a smoking-cessation treatment interval. A hypothetical-rewards DDT failed to differentiate between these treatment-seeking smokers.

Because the EDT has proven to be convenient, sensitive to acute experimental manipulations, predictive of a treatment outcome, and differentiates addicted from control samples (Fields, Collins, Leraas, & Reynolds, 2009; Reynolds, 2006) the EDT (or a similar procedure) has been used as a measure of delay discounting in several research laboratories in the US and UK.

Unique Characteristics of the EDT

The EDT contains three procedural components that differ from commonly used DDTs. To better understand the apparent benefits of the EDT, we describe and consider the pros and cons of each of these unique procedural characteristics in the sections that follow.

Delayed-Probabilistic Rewards

Reynolds (2006) noted that in extra-laboratory contexts delayed rewards are often probabilistic. For example, when a trusted friend asks to borrow $100 to be paid back in one year, one knows that the probability of receiving nothing in return is greater than zero. Likewise, in the natural environment of nonhumans, delayed rewards may never come to fruition if any of a number of interruptions comes to pass (Stevens & Stephens, 2010). For example, the LL reward may be consumed by a conspecific or the organism awaiting the LL may be consumed by a predator. To model this, following the delay interval, the EDT delivers the LL reward with a probability of .35.

Introducing probabilistic outcomes in a discounting task is potentially problematic if one is interested in quantifying delay discounting. To address this, Reynolds and

Schiffbauer (2004) suggested that the probabilistic-reward effect could be removed from EDT measures of delay discounting through a normalization procedure. Specifically, in one condition of the EDT participants choose between a smaller-certain and a larger-probabilistic reward (p = .35). The subjective value of the probabilistic reward (i.e., the indifference point) in this condition is then used as the normalized value of the probabilistic LL rewards arranged in the other EDT conditions.

The EDT's normalization technique assumes that the effect of probability on reward value is constant across the range of delays arranged in the EDT (0-60 s). Such an assumption is consistent with the hypothesis that delay- and probability-discounting are a single process. For example, Rachlin, Logue, Gibbon, and Frankel (1986) suggested that delay discounting is the fundamental process underlying probability discounting because decreasing the probability of obtaining a reward in a repeated gambles experiment increases the average delay to collection (see also Rachlin et al., 1991). Consistent with this, Yi, Piedad, and Bickel (2006) found that a single hyperbolic discounting function could be fit to indifference points when the rewards were both delayed and probabilistic. However, the delays employed in the Yi et al., experiment were not within the range of delays arranged in the EDT and the Yi et al., delays and probabilities (and rewards) were hypothetical rather than experienced, as they are in the EDT. Thus, the assumption that using a probabilistic LL reward in the EDT does not affect the estimate of delay discounting has not yet been established. Because a considerable amount of evidence suggests that delay and probability discounting are separate processes (Estle, Green, Myerson, & Holt, 2006; Estle, Green, Myerson, & Holt, 2007; Myerson, Green, &

Morris, 2011; Ostaszewski, Green, & Myerson, 1998) there is reason to question this assumption.

Opportunity Costs

Reynolds (2006) argued that outside the laboratory, choosing a LL reward often involves opportunity costs; that is, time spent waiting for the LL reward is time in which other (SS) rewards may not be pursued. For example, amusement park rides differ in quality and in the time that must be spent waiting in line to access the ride. If one is waiting in a long line, the opportunity cost is the cumulative benefits that could have been obtained by riding several lower quality rides. To model these costs, sequential choices in the EDT are not separated by a post-reward ITI. Thus, participants may obtain several SS rewards in the period required to obtain a single LL reward.

If the EDT is being used as a tool to quantify delay discounting (e.g., Krishnan-Sarin et al., 2007) then omitting the ITI may raise concerns. When real rewards and real delays are employed in non-EDT studies of delay discounting (most of which involve animals and food rewards), a post-reward ITI is almost always programmed (e.g., Evenden & Ryan, 1996; Mazur, 1988; Richards, Mitchell, de Wit, & Seiden, 1997). The duration of the ITI in these experiments is dynamic such that the interval between choice opportunities is constant regardless of the alternative chosen. If the ITI were omitted, then the organism could select and obtain several SS rewards in the time it takes to obtain a single LL reward. Such choices could not be described as “impulsive” (i.e., a maladaptive choice) if they allow the organism to maximize local *and* overall rates of reward (Logue, Peña-Correal, Rodriguez, & Kabela, 1986).

Omitting ITI's complicates estimation of the discounted value of the LL reward. In a nonhuman DDT, when the organism is indifferent between a single SS and a LL reward, the value of the latter is the former. However, if multiple SS rewards are obtained during the delay (as in the EDT), then at indifference how should the discounted value of the LL reward be quantified? It might be the sum the SS rewards or the sum of the discounted values of each SS reward in the sequence separating LL rewards (Mazur, 1986). The EDT takes neither approach. Instead, the average SS reward value over the last six choices is taken as the discounted value of the LL reward.

Omitting ITIs may also have the unintended effect of allowing participants to end more quickly the portion of the EDT that requires sustained attention. EDT sessions are composed of several trial-blocks with a different delay to the LL reward arranged in each. The duration of each trial block allows for 20 LL choices to be completed. If fewer than 20 LL choices have been made when the stability criterion is met, then the remainder of the trial block is spent in a waiting period until the next trial block begins. Under this arrangement, each SS choice shortens the portion of the session in which participants are required to pay attention to the task. Given that humans often find operant tasks boring (Galizio & Buskist, 1988), this escape contingency may increase the probability of SS choices and contaminate the quantification of delay discounting. Consistent with this hypothesis, children made more LL choices when an ITI was programmed than when it was omitted in an EDT-like procedure in which LL rewards were obtained 100% of the time (Scheres et al., 2006). If this escape contingency increases SS choices, and escape from an attention-demanding task is a more powerful reinforcer when the participant is sleep deprived or intoxicated (Reynolds et al., 2006; Reynolds & Schiffbauer, 2004) then the steeper EDT discounting functions reported by Reynolds and Schiffbauer (2004) and Reynolds et al. (2006), respectively, may have more to do with escape-maintained behavior than to greater impulsive choice.

Point-Delays

Unlike animal studies of delay discounting that involve real delays to real consumable rewards, the EDT arranges real rewards to real monetary allocations. A difference between these reward types is that the consumable reward mildly alleviates the animal's state of deprivation, whereas the monetary allocation cannot be spent within the EDT session to alleviate a present need. Hyten, Madden, and Field (1994) referred to the delay to a non-consumable reward as a "point delay." Hyten et al. reported that humans exclusively preferred the LL monetary reward when point delays were in the range used in the EDT (see also Belke, Pierce, & Powell, 1989; Flora & Pavlik, 1992; Hyten et al., 1994; Logue, King, Chavarro, & Volpe, 1990; Logue et al., 1986). From the participant's perspective, if the SS reward is selected, it is obtained immediately but it cannot be spent until the session ends and the participant travels to an outlet where goods and services are sold. If the LL reward is selected, more money is obtained and the delay to spending the money on something that may be consumed is the same. When Jackson and Hackenberg (1996) arranged point delays to food rewards, pigeons strongly preferred the LL reward (see also Hackenberg & Vaidya, 2003). These findings suggest that humans should exclusively prefer the LL alternative under the point-delays arranged in the EDT.

Why humans appear to discount monetary rewards across point delays arranged in the EDT is unclear. Reynolds and Schiffbauer (2004) suggested that arranging probabilistic rewards engenders delay discounting when point delays are arranged. However, the normalization process discussed above was supposed to subtract the effects of reward probability from measures of delay discounting. This inconsistency led us to question if the EDT measures delay discounting (as suggested by Reynolds & Schiffbeaur, 2004 and Krishnan-Sarin et al., 2007) or a separate, and potentially important process.

Does the EDT Assess Delay Discounting? A Literature Review

To objectively evaluate the EDT literature we conducted a systematic review of the methods and results of all the studies that have used the EDT. All peer reviewed articles, published prior to December, 2011 that have used the EDT as described by Reynolds and Schiffbauer (2004) were found via citation webs using ISI Web of Science and Google Scholar. Tables 2 and 3 show the 13 articles identified. Each study was evaluated according to several variables we deemed important in assessing trends in methodology and results in the EDT literature. Cohen's *d* effect sizes were calculated for all studies using means and standard deviations or the reported statistics (Cohen, 1988).

In assessment of whether the EDT assesses delay discounting we will consider four categories of data presented in Tables 2 and 3. First, and most obvious, measures of delay discounting obtained from the EDT should be positively correlated with measures obtained from other well-established DDTs. As shown in the final column of Tables 2 and 3, seven studies reported correlation data, with two reporting significant positive correlations (Reynolds, 2006, r = .52; Reynolds et al., 2008, r = .26) and five reporting no significant correlation. These findings suggest the EDT does not provide a valid measure of delay discounting.

Second, if the EDT provides a valid measure of delay discounting, then when indifference points are plotted against the range of point delays at which they are assessed in the EDT, Equation 1 should provide a good fit of these data. Of the 13 EDT studies published to date, 5 have reported how well Equation 1 (or any other equation) has fit the obtained indifference points. Across these five studies the average R^2 value was .79; a value lower than typically reported with either nonhuman (e.g., R^2 = .98, Richards et al., 1997) or human subjects (e.g., $R^2 \geq .85$, Bickel, Odum, & Madden, 1999; median R^2 = .915, Richards et al., 1999; see also DDT R^2 column in Table 2). When interpreting these R^2 values it is important to consider the proportion of participants excluded because of unsystematic data. In the five EDT studies that reported R^2 values, three excluded between 12.5 and 40% of the participants because of unsystematic data. This is surprising considering it is rare for researchers to report excluded data from discounting experiments (e.g., Epstein, Richards, Saad, Paluch, & Roemmich, 2003; Richards et al., 1999). Thus, on this second category by which the validity of the task may be evaluated, the evidence does not strongly support the position that the EDT measures the same delay discounting as other DDTs.

Table 2

Summary of EDT Studies That Have Examined an Experimental Manipulation

Study	Subjects	Independent Variable	Time between assessments	EDT Exclusion Criteria	Percent (n) excluded	EDT R^2 M (SD)	DDT R^2 M (SD)	EDT Effect Size	DDT Effect Size	EDT/DDT Correlation
Acheson et al. (2006)	18 community (18-45y)	Diazepam (20 mg)	> 1 week (random order)			.75 (.06)	.8 (.23)	0	0	—
Acheson et al. (2007)	20 community (18-45y)	Sleep deprivation	1 week (counterbalanced)	"poor fits" in both sessions	40% (8)	.7 (.45)	.5 (1.19)	0.27	-0.55	—
Reynolds et al. (2006)	24 community (av 25 y)	Alcohol	> 1 week (counterbalanced)	*k* not determined	12.5% (9)	.71 (.2)	.83 (.188)			NS (rho)[a]
		High Dose (.4 g/kg)						18.33[b]	0.01	
		Low Dose (.8 g/kg)						1.67	0.04	
Reynolds & Schiffbauer (2004)	12 undergraduates (18-23 y)	Sleep deprivation	1 week (counterbalanced)	EDT $R^2 < .30$	27 % (3)	.68 (.24)	—	0.65[b]	—	—
Shiels et al. (2009)[c]	49 children with ADHD (9-12 y)	Methylphenidate	24 hrs (random order)			—	—			NS[a]
		High Dose (Av 39mg)						0.31[b]	0	
		Low Dose (Av 73 mg)						0.25[b]	0	
Voon et al. (2010)	44 NIH clinic (with parkinsons, and with ICD)	Dopamine agonist (161, 155 LEDD mg/day)	> 1 week			.7 (.25)		0.92[b]		

A dash indicates that the data were not reported. Except where otherwise specified, when a delay discounting task was used it was that described by Richards et al. (1999)
[a] Statistics not reported.
[b] Statistically significant difference according to reported inferential statistics.
[c] Modified Barkley et al. (2001)
LEDD = L-Dopa Equivalent Daily Dose.

Table 3

Summary EDT Studies That Have Examined Group Differences

Study	Subjects	Quasi-Independent Variable	EDT Exclusion Criteria	Percent (n) excluded	EDT R^2 M (SD)	DDT R^2 M (SD)	EDT Effect Size	DDT Effect Size	EDT/DDT Correlation
Fields et al. (2009)	14-17y	Smoking (n = 50) Control (n = 50)			—	—	0.39[a]		
Krishnan-Sarin et al. (2007)[b]	av 16.7y	Abstinent (n = 16) Non-Abstinent (n = 14)			—		5.00[a]	-1	-0.24
Meda et al. (2009)	av 30y	At-risk/Addicted (n = 87) Controls (n = 89)			—		.38[a]		
Melanko et al. (2009)	Community av 15y	Control (n = 25) Smoking HP (n = 25) Smoking LP (n = 25)			—	—	.53[a]	.44[a]	0.105
Paloyelis et al. (2010)	11-20y	ADHD-CT (n = 36) Controls (n = 32)			—	—	0.32	.61[a]	-0.12
Reynolds (2006)	Community av 36 and 28 y	Smokers (n = 15) Controls (n = 15)	$R^2 < .30$	.03% (1)	—	—	cannot compute[c]	cannot compute[c]	.52 (rho)**
EDT in a Factor Analysis									
Reynolds et al. (2008)	Community av 15 y	Component analysis			—	—			0.26**

** $p < .01$. A dash indicates that the data were not reported. Except where otherwise specified, when a delay discounting task was used it was that describe

[a] Statistically significant difference according to reported inferential statistics.

[b] Kirby et al. (1999)

[c] Effect size could not be computed because only non-parametric statistics were reported.

ADHD-CT = Attention Deficit/Hyperactivity Disorder-Combined Subtype, HP = High Pathology, LP = Low Pathology

Third, an extensive body of research has demonstrated that substance-dependent individuals tend to more steeply discount delayed monetary rewards than matched controls (see MacKillop, Amlung, Few, Ray, Sweet, & Munafò, 2011 for a review). If the EDT measures delay discounting, then we would expect it to differentiate these populations in the same direction and by the same magnitude (i.e., co-variance of effect size). Those studies for which co-variance may be assessed are those in which substance dependent and matched control groups completed the EDT and the DDT (Table 2). For ease of comparison, effects sizes are displayed in Table 4. There is no clear relation between the effect sizes of the two measures across these experiments. Additional data are required to make a more definitive statement in either direction.

Table 4

EDT and DDT Effect Size Comparison for Group Differences

	EDT	DDT
Krishnan-Sarin et al. (2007)	5.00	-1
Melanko et al. (2009)	.53	.44
Paloyelis et al. (2010)	.32	.61

Finally, traditional measures of delay discounting used with humans suggest that discounting rate is stable across retesting intervals ranging from 1 week to 1 year (Kirby, 2009; Ohmura, Takahashi, Kitamura, & Wehr, 2006; Simpson & Vuchinich, 2000). If the EDT provides a valid measure of delay discounting then one would expect EDT outcomes to be similarly stable over time. To date, only one study has assessed the test-retest reliability of the EDT. Acheson, Richards, and de Wit (2007) asked 20 community members to complete the EDT in the morning and return to the lab approximately 10 hours later to complete it again. No significant difference in rate of discounting was detected. Clearly, the test-retest validity of the EDT must be assessed across longer intervening periods so as to decrease concerns that participants' choices during the afternoon EDT session were influenced by choices made in the morning.

In sum, these four categories of data provide very limited support for the EDT as a valid measure of delay discounting. The correlation between traditional delay-discounting task performance and discounting under the EDT is most often not observed. EDT indifference points are not as well described by Equation 1 as data from a hypothetical-reward DDT, and the co-variance of performance in the EDT and DDT by different populations has yet to be definitively established. Finally more data are needed to determine if EDT performance is reliable across time and repeated testing.

So, What Does the EDT Measure?

Given the limited data for the EDT as a valid measure of delay discounting, are there reasons to continue using it? As noted above, the EDT appears to be more sensitive to acute experimental manipulations than is the DDT. Of course this is useful only if we understand what the EDT measures. In addition, a small literature suggests the EDT differentiates groups (Table 3) and, in at least one study, predicts treatment success (Krishnan-Sarin et al., 2007). Should additional studies demonstrate that EDT performance is correlated with addictive behavior and success in treatment, a greater premium would be placed on understanding what behavioral process is quantified by the EDT.

One possibility is that the EDT provides a measure of sensitivity to delays involving opportunity costs (Reynolds, 2006). Most delay discounting tasks used with humans arrange long delays to hypothetical rewards (e.g., $100 in 1 year) and the participant is free to pursue other sources of the same reward during the delay. Human choice may be sensitive to the brief delays arranged in the EDT because these delays involve forgoing SS reward opportunities. Reynolds (2006) reported that participants who reported a stronger motivation to earn money were more likely to choose the SS reward; thereby suggesting a role for opportunity costs.

A second, related possibility is that EDT choices may be affected by a participant's willingness to tolerate a period devoid of stimulation (i.e., the delay to the LL reward). Individuals prone to boredom or less able to entertain themselves during stimulus-free periods may be more likely to choose the SS alternative. Likewise, a subject wishing to escape from the attention-demanding portion of the EDT session may learn that the waiting period that follows all choices made within a block of trials (leisure) may be produced more quickly by frequently choosing the SS reward.

A third possibility is that the EDT measures sensitivity to an internality of the task that some participants detect and exploit while others do not. Specifically, rewards on the LL alternative are probabilistic with an expected value less than 11 cents. Given this, participants should never choose the LL when the SS amount is above 11 cents. However, participants frequently do. This may reveal a strategy of exploiting the internality – by repeatedly choosing the LL reward the SS amount is driven up. Detecting this, some participants may increase the SS amount to a value far higher than its discounted value so they may obtain a series of large-certain rewards. Heyman and Dunn (2002) arranged a procedure containing a similar internality. Choosing the right-now best alternative decreased overall income by gradually increasing the interval between choice opportunities, whereas choosing the worse right-now alternative had the opposite effect on inter-choice intervals. Heyman and Dunn reported that years of drug use was negatively correlated with global maximizing. Perhaps the EDT measures one's ability to exploit the EDT's internality and maximize total earnings. This may account for the correlation between steep EDT discounting (a failure to exploit the internality) and substance abuse. Likewise, acute experimental manipulations like intoxication or sleep deprivation may decrease one's ability to exploit (or detect) the internality.

Conclusion

Delay discounting is of societal importance because of the relation between steep discounting and a variety of impulse-control disorders. There has been growing interest in the discounting community in an experiential task that is sensitive to acute changes in discounting and the EDT has, thus far, captured most of this attention. Since its development, the EDT has been used to study state changes (e.g., alcohol administration) as well as group differences (e.g., smokers v. nonsmokers) in rates of delay discounting in humans. A review of the EDT procedures and a critical examination of EDT and other discounting-task outcomes offers inadequate support for the validity of the EDT as a measure of delay discounting. Based on the extant use of the EDT as a measure of delay discounting and the paucity of basic validation research, the current report investigated the reliability and validity of the EDT by assessing test-retest reliability, evaluating performance on several secondary measures (including a DDT), and evaluating the effects of the implementation of a choice-regulating delay (i.e., ITI).

CHAPTER II

METHOD

Experiment 1: Test-Retest Reliability

Participants

Twenty-nine undergraduate students and community members (18 female) participated in Experiment 1 (M = 21 years, SD = 2.9). Participants were recruited for the two 1-hour sessions (separated by 7 days) using the SONA recruiting website. Participants were compensated between $7 and $15 (amount dependent upon performance) for each session. Compensation was given following all behavioral and self-report tasks at the end of each session. All procedures were approved by the Utah State University Institutional Review Board (IRB).

Procedure & Apparatus

Sessions were completed in a small room (113” x 79.5”) containing two tables, one chair, and a desktop computer. Participants completed four different behavioral and self-report tasks in both sessions. Sessions began with either the Experiential Discounting Task (EDT) or the delay/probability discounting tasks (DDT/PDT); the order in which these tasks were completed was counterbalanced across participants and was the same across sessions. These tasks were completed on the computer using applications programmed in Visual Basic 2008. The remaining tasks were paper and pencil questionnaires and were completed in a fixed order: Boredom Proneness Scale (BPS) and

Monetary Motivation Scale (MMS). At the completion of the entire session participants were paid their EDT earnings in cash.

Experiential Discounting Task (EDT). Prior to the EDT session, the experimenter read the instructions appearing in Appendix A. The experimenter remained in the room to provide standard answers (see Appendix B) to questions arising as the participant completed one practice trial block (ranging from 16 to 40 trials) for which they received no money. Each trial began with the screen display shown in Figure 2. Choices were made by pressing one of the on-screen light-bulb buttons. The alternative on the left is referred to as the standard alternative because it always arranged a $0.30 reward (displayed below the button) delivered probabilistically after a delay. When the participant pressed the standard-alternative button, the light bulbs darkened (signaling that further button presses had no programmed consequences), the delay interval was initiated, after which the reward was either available (p = .35) or the next trial began with the illumination of the light bulbs. When a reward was available, the bank icon button was illuminated; clicking this button once added $0.30 to the earnings display.

The right button is referred to as the adjusting alternative because the amount available for pressing this button was adjusted between trials dependent on the participant's choices. Pressing the adjusting-alternative button illuminated the bank icon immediately (p = 1.0). Pressing the bank icon added the adjusting amount of money (displayed below the right button) to the earnings display. This sequence of events was programmed to operate exactly as described by Reynolds and Schiffbauer (2004).

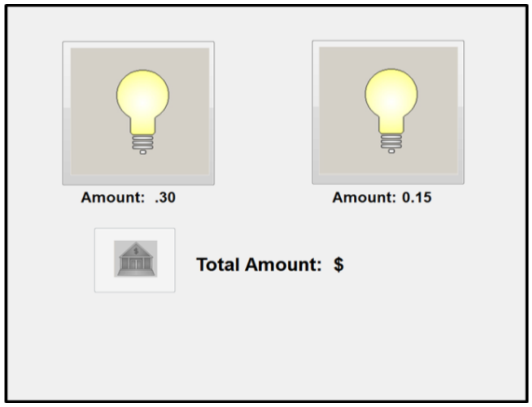

Figure 2. Screen shot of the Experiential Discounting Task.

After the practice trials the experimenter provided a final opportunity for the participant to ask questions and then left the room until the EDT was completed. The EDT was composed of 4 trial-blocks, each arranging a different delay to the standard-alternative (0, 7, 14, or 28 seconds); delays were completed in ascending order.

Each trial-block included a minimum of 16 choice trials. Following each trial the monetary amount displayed below the adjusting-alternative was increased (decreased) if the participant selected the standard (adjusting) alternative on the preceding trial. The amount of the adjustment was initially 15% of the $0.15 adjusting amount ($0.0225; rounded to the nearest penny on the visual display). If the same alternative was chosen on two consecutive trials the amount of the adjustment decreased by 2% (13% of $0.15; $0.0195). If the participant then chose the previously dis-preferred alternative, the adjustment increased by 2% until the adjusted amount returned to $0.15 (and adjustment percentage to 15%). In this way, the adjusting amount adjusted symmetrically away from, and back to, the original $0.15. Figure 3 displays how the adjusting amount changes given SS (negative x-axis values) or LL (positive x-axis values) choice for any point in the session (any value of the SS). In addition, Figure 3 shows that if the participant exclusively selects the LL throughout the session the SS amount increases by a decreasing percentage following each successive choice (producing a positively decelerating function to the right of 0 on the x-axis). Conversely, if exclusive SS preference is demonstrated, the amount of the SS decreases by a decreasing percentage (producing a negatively decelerating function to the left of 0 on the x-axis). If one alternative was selected four consecutive times, participants were forced to select the dis-preferred alternative (i.e., only one choice button was presented). The adjusting amount in the EDT was titrated following forced choices (based on the EDT program provided by Reynolds' lab).

This titration procedure was designed to find a stable point of indifference between the adjusting (SS) and standard (LL) amounts. Stability was evaluated following trial 16 and after each subsequent free choice. Stability was defined as three of the previous six free choices were for the standard alternative. When stability was achieved all buttons were darkened for the remainder of the programmed trial-block duration. The duration of each trial block was equal to the delay to the standard alternative (e.g., 30 s) times 20 (e.g., 600 s). The timer controlling trial-block duration elapsed only during delays to the standard alternative. If the participant reached stability before making 20 LL choices, they spent the remainder of the time with the buttons darkened (signally that no options were available). If participants made 20 or more LL choices, trial blocks were terminated immediately. After each trial block a message informed participants how much they earned in that trial block and required them to press “OK” to continue. Following the last trial block (including time-out period) an on-screen message showed the amount earned in each trial block, the total amount earned in the session, and a message to alert the researcher that the session was over.

Delay and Probability Discounting Task (DDT/PDT). The discounting task replicated the procedures used by Richards et al. (1999; see also Baker, Johnson, & Bickel, 2003). This was the most commonly used procedure in studies comparing EDT, DDT, and PDT performance, as well as the task used when a positive relation was found between EDT and DDT performance (e.g., Acheson et al., 2006, 2007; Melanko, Leraas, Collins, Fields, & Reynolds, 2009; Paloyelis et al., 2010; Reynolds, 2006; Reynolds, et al., 2006, 2008). Before the task began the experimenter read aloud the on-screen instructions and answered participant questions (Appendix C). The participant was then left alone to complete the task. On each trial, the participant chose one of two alternatives presented on the computer screen. On DDT trials, the standard alternative was described as $10 to be delivered after a delay (1 day, 2 days, 1 month, 6 months and 1 year). On PDT trials, the standard alternative was described as $10 delivered probabilistically (for sure, 90%, 75%, 50% or 25%). The standard alternative was presented on the left side of the screen on all trials. DDT and PDT trials were presented randomly and trials were separated by one second.

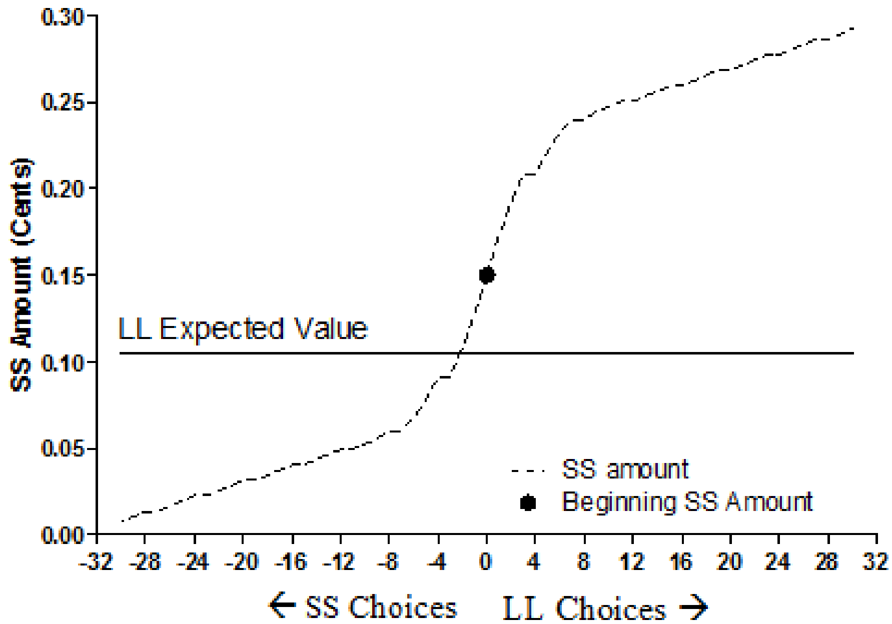

Figure 3. Plot of the changing SS amount as a function of choice. Movement right along the x-axis depicts LL choices and movement left indicates SS choices. Note that due to the adjusting algorithm a participant can move left or right along the curve in any way. The limits of the x-axis denote when the trial-block is ended due to the SS amount reaching $0.30 or $0.00. The horizontal line at .105 is the expected value of the LL amount (.30 × .35). The dashed line is the obtained SS amount given forced choices. The solid line is the best-fitting sigmoidal function.

The amount of the adjusting alternative (SS or smaller-certain reward) was displayed in $0.50 increments. On any given trial the amount of the adjusting alternative was randomly chosen from a range of values. The upper and lower limits of this range were adjusted between trials. Four limits (2 upper and 2 lower) were used in this “double-limit” procedure. The maximum-upper limit and minimum-upper limit began at $10. The maximum-lower limit and minimum-lower limits began at $0. Thereafter, at a particular delay (probability) the limits were adjusted, based on participant choices, according to the following rules:

1. If the standard alternative was chosen:
    a. If the SS was greater than the minimum-upper limit, then this limit was set equal to the SS, and the maximum-upper limit was reset to $10 (this choice is inconsistent with a previous choice).
    b. If the SS was greater than the minimum-lower limit and less than the minimum-upper limit, the minimum-lower limit was set equal to the SS and the maximum-lower limit was set equal to the previous minimum-lower limit (all other values were unchanged).
    c. If the SS was less than the minimum-lower limit, then the maximum-lower limit was set equal to the SS amount.
2. If the SS alternative was chosen:
    a. If the SS was greater than the minimum-upper limit, then the maximum-upper limit was set to the SS amount.
    b. If the SS was less than the minimum-upper limit and greater than the minimum-lower limit, then the minimum-upper limit was set equal to the SS amount and the maximum-upper limit was set to the previous minimum-upper limit (all other values remained unchanged).
    c. If the SS was less than the minimum-lower limit, then the minimum-lower limit was set equal to the SS amount and the maximum-lower

limit is reset to $0.00 (this choice is inconsistent with a previous choice).

The limits (for each delay and probability) adjusted until the maximum-upper and maximum-lower limits (the two extremes) were within $0.50, the average of which was then taken as the indifference point. When an indifference point had been determined at a given delay (or probability), choices were no longer presented from that delay (or probability). In order to disguise the adjustment algorithm, after 70 choices were made half of the questions were distractor questions. Distractor questions consisted of randomly chosen amounts, delays or probabilities and did not affect indifference points.

Boredom Proneness Scale (BPS). The BPS is a 28-item true/false questionnaire that measures propensity toward boredom and need for stimulation (Farmer & Sundberg, 1986; Appendix D). The BPS has good internal consistency and test-retest reliability (Farmer & Sundberg, 1986; Watt & Davis, 1991). We used a 7-point Likert-scaled version of the BPS as this increases the sensitivity of the scale without loss of reliability (Vodanovich & Kass, 1990; Watt & Blanchard, 1994; Watt & Ewing, 1996). Vodanovich and Kass reported that BPS items clustered into 5 factors (see Table 5): external stimulation (the environment lacks variety), internal stimulation (the inability to entertain oneself produces boredom), perception of time (boredom occurs because time is perceived to pass slowly), constraint (the inability to do what one wishes, or the obligation to do something one does not wish to do), and affective responses (emotional responses to the environment).

Table 5

Factors of the Boredom Proneness Scale

Factor	Items
External Stimulation	6, 19-21, 25-28
Internal Stimulation	7, 8, 11, 13, 18, 22-24
Perception of time	3, 4, 14, 16
Constraint	15, 17
Affective Responses	2, 4, 5, 9, 11, 12

Monetary Motivation Scale (MMS). The MMS is a 2-item paper-and-pencil questionnaire designed to assess participants' current motivation to earn small amounts of money (see Appendix E).

Data Analysis

The indifference point for each trial block in the EDT was the average adjusting amount over the last six choices. Indifference points from all trial blocks of the EDT were normalized by dividing by the indifference point in the 0-s delay block (Reynolds & Schiffbauer, 2004). For the DDT and PDT, indifference points were the average of the maximum-upper limit and maximum-lower limit from each delay and probability value and then divided by $10 to express as a proportion of the standard alternative. Normalized and proportional indifference points were then fit with Equation 1 to determine best-fitting *k*-values for individual participants in each task. In addition, the area under the empirically determined indifference points was calculated for individual participants (AUC; Myerson, Green, & Warusawitharana, 2001). AUC is a theory-free method of quantifying rate of delay discounting and can range from 0 (strict preference for smaller rewards) to 1 (rewards are not devalued regardless of delay).

Several dependent measures deviated significantly from normality. Logarithmic and square root transformations failed to improve the distribution for a majority of the dependent measures. Therefore nonparametric difference tests were used.

Test-retest Reliability. Correlational analyses were conducted between all dependent measures (between sessions) using either Pearson or Spearman's correlation. Pearson's r was used unless the distribution of scores violated homoscedasticity, in which case Spearman's ρ was calculated. Correlation coefficients are the recommended method for analyzing test-retest data, with follow-up tests to assess systematic variation that cannot be detected by correlations (Rousson, Gasser, & Burkhardt, 2002). Wilcoxon signed-rank tests were conducted to test for differences in performance between sessions one and two for all dependent measures as well as Cohen's d, a measure of effect size that expresses mean-differences in standard deviation units. Analyses were conducted using GraphPad software (Ver. 5.01) and SPSS 19.

Between-Measure Correlations. Summed BPS scores, separate BPS factor scores, and summed MMS scores were correlated with the discounting measures produced by the EDT, DDT, and PDT. Pearson's r was calculated except when there were significant violations of homoscedasticity in which case Spearman's ρ was calculated. For the MMS, items were quantified as distance from the left (in centimeters), with a lower bound of .01 and upper bound of 16.1. Item 2 was reverse coded, then averaged with item 1.

Experiment 2: Inter-Trial Interval

Participants

Twenty undergraduate students and community members (15 female) participated in Experiment 2 (M = 21.8 years, SD = 3). As in Experiment 1, participants were recruited via an online recruiting website (SONA). Participants signed up for one 90 minute session and were informed they would be compensated $15-$40 in cash at the conclusion of the session (amount dependent on performance). All procedures and recruitment materials were approved by the Utah State University IRB.

Procedure

The procedures were identical to those used in Experiment 1 except that participants also completed a modified version of the EDT (EDTmod). The EDTmod was identical to the EDT except that an ITI was imposed following trials on which the adjusting alternative (SS reward) was selected. The duration of the ITI was equal to the duration of the delay interval experienced after choosing the standard alternative. The ITI ensured that the time between choice opportunities was constant within a trial block, regardless of the alternative chosen. The ITIs imposed in the EDTmod took the place of the period of time during which participants were not allowed to make any responses at the conclusion of each trial block. The order of EDT and EDTmod was counterbalanced across participants. Between EDT tasks, participants completed the DDT/PDT, BPS and MMS (in that order).

Data Analysis

All data were analyzed as in Experiment 1 with the exception of a second session's data for the DDT/PDT, MMS and BPS. All analyses were conducted using GraphPad software (Ver. 5.01) and SPSS 19 as in Experiment 1.

CHAPTER III

RESULTS

Experiment 1: Test-Retest Reliability

Two participants did not complete the second session and data from one participant was lost due to computer malfunction. Therefore data are reported for 16 individuals. Table 6 shows individual participant's *k* and R^2 values obtained when indifference points were fit with Equation 1. Median individual fits for the DDT and PDT were greater than EDT fits (.84 and .94 compared to .49). A Friedman's test comparing R^2 values across tasks revealed a significant main effect ($\chi^2(3)$) = 35.08, p < .0001). Dunn's multiple comparison analysis revealed significant differences in R^2 values between the EDT and PDT (p < .05), and DDT and PDT (p < .05). The low R^2 values in the EDT may be an artifact of shallow discounting (i.e., little variance in y to be accounted for by x). Inconsistent with this hypothesis, an ANOVA comparing mean square error (a measure of the deviation from the best-fitting curve) revealed no significant difference across the three tasks or the two sessions (F(5) = 1.307, *p* = .26). That is, the difference in R^2 values across tasks cannot be due to differences in steepness of discounting.

Test-Retest Reliability

Individual participants' data for all dependent measures are shown in Figure 4. As shown in Table 7, between-session test-retest correlations were positive and significant except for EDT and PDT AUC scores, which achieved only a trend level of significance.

Table 6

Individual Best-Fitting k Parameters (and R^2 Values) From Experiment 1

	EDT		DDT		PDT	
ID	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
1	.01 (-)	.01 (.68)	18 (.94)	41 (.97)	.36 (.97)	.27 (.98)
2	.04 (.19)	0 (0)	88 (.46)	37 (.91)	1.2 (.84)	1.1 (.65)
3	.01 (-)	.59 (.42)	.52 (.30)	.33 (.72)	.21 (.99)	1.1 (.89)
4	.52 (.46)	.06 (.01)	24 (-)	45 (.91)	.26 (.99)	.81 (.82)
5	.17 (.85)	.03 (.66)	.43 (.14)	1.6 (.95)	.65 (.99)	.89 (.89)
6	1.5 (.11)	.63 (-)	11457 (0)	11457 (0)	3602 (.99)	23520(.96)
7	.01 (.92)	.51 (.52)	2.0 (.43)	.80 (-)	1.2 (.91)	.77 (.68)
8	2.1 (.95)	2.0 (.94)	.15 (-)	.17 (.73)	1.6 (.94)	.70 (.77)
9	.48 (.95)	1.0 (.21)	2.3 (.98)	6.5 (.89)	1.2 (.90)	3.2 (.77)
10	1.5 (.52)	1.3 (.17)	43 (.93)	49 (.95)	3.5 (.81)	.16 (.96)
11	.12 (.22)	.62 (.10)	3.1 (.97)	1.3 (.69)	.13 (.99)	.10 (.99)
12	3.2 (.99)	.74 (.79)	.39 (.23)	3.8 (.97)	.10 (.99)	.26 (.98)
13	.34 (.63)	.09 (.29)	1.2 (.19)	.15 (.82)	.17 (.90)	2.7 (.93)
14	.47 (.98)	.55 (.90)	.45 (.92)	.51 (.97)	2.2 (.69)	4.2 (.67)
15	.13 (-)	.04 (-)	.51 (-)	.32 (-)	1.7 (.90)	.46 (.96)
16	.05 (.70)	.09 (-)	.03 (0)	.57 (.49)	1.3 (.93)	.64 (.95)
17	.13 (-)	-.47 (-)	.17 (.10)	.08 (.14)	.34 (.78)	.22 (.96)
18	.11 (.06)	3.2 (.93)	.79 (.89)	1.1 (.94)	1.1 (.95)	.60 (.98)
19	.13 (.57)	-.07 (-)	.46 (.77)	1.2 (.93)	.54 (.95)	.43 (.95)
20	.19 (.38)	.22 (-)	2.6 (.87)	3.1 (-)	.42 (.85)	.63 (.81)
21	.83 (.87)	1.1 (.99)	.59 (.87)	.15 (.82)	.44 (.97)	1.4 (.92)
22	.58 (.54)	.74 (.53)	23 (.98)	38 (.93)	.56 (.98)	.74 (.98)
23	.10 (-)	.24 (.54)	33 (.97)	31 (.97)	20 (.87)	7.0 (.74)
24	.28 (.80)	.05 (-)	.39 (-)	.40 (.93)	.20 (.95)	.09 (.97)
25	5.0 (.88)	4.0 (.87)	6.0 (.97)	13 (.98)	.98 (.91)	1.4 (.94)
26	.40 (.80)	-.01 (-)	1.3 (.97)	.58 (.92)	.46 (.97)	.83 (.83)
Median:	.2617 (.49)		1.271 (.84)		.7532 (.94)	

Note. R^2 values of 0 or marked as (-) were treated the same (as zeros), and this did not affect medians nor Freidman's test.

Table 7

Wilcoxon Signed-Rank Tests and Correlation Coefficients for Between Session Differences in Experiment 1

	Session 1	Session 2	Rank differences			Correlation	
	M (SD)	M (SD)	W	*p*	*d*	ρ/*r*	*p*
EDT (AUC)	.82 (.19)	.88 (.26)	-117	.14	.27	**.32**	**.06**
EDT k	.70 (1.1)	.65 (.97)	51	.52	-.05	.66	<.01
DDT (AUC)	.56 (.29)	.53 (.33)	43	.57	-.10	.86	<.01
DDT k	459 (2244)	467 (2243)	-89	.23	.004	**.78**	**<.01**
PDT (AUC)	.41 (.13)	.47 (.15)	-143	.07	.41	**.38**	**.06**
PDT k	140 (706)	910 (4632)	-49	.54	.29	**.52**	**<.01**
BPS	94 (19)	94 (17)	4	.96	.02	.89	<.01
MMS	9.3 (4.8)	8.2 (4.3)	141	.06	-.24	.73	<.01

Note. *n* = 26. **Bold** indicates that Spearman's ρ was used.

In addition, the Wilcoxon's rank differences tests revealed no statistically significant differences between matched pairs (i.e., across sessions) for any dependent measures, indicating no systematic change in performance across sessions.

As seen in Table 6, 14 of the 52 EDT R^2 values were ≤ 0, meaning that a horizontal line at the mean of the indifference points accounts for as much as, or more, of the variance than the hyperbolic model. Given this, AUC may be more appropriate for assessing test-retest reliability; however, a limitation of AUC, as described by Myerson et al. (2001) is that the same AUC can be generated from potentially very different patterns of indifference points.

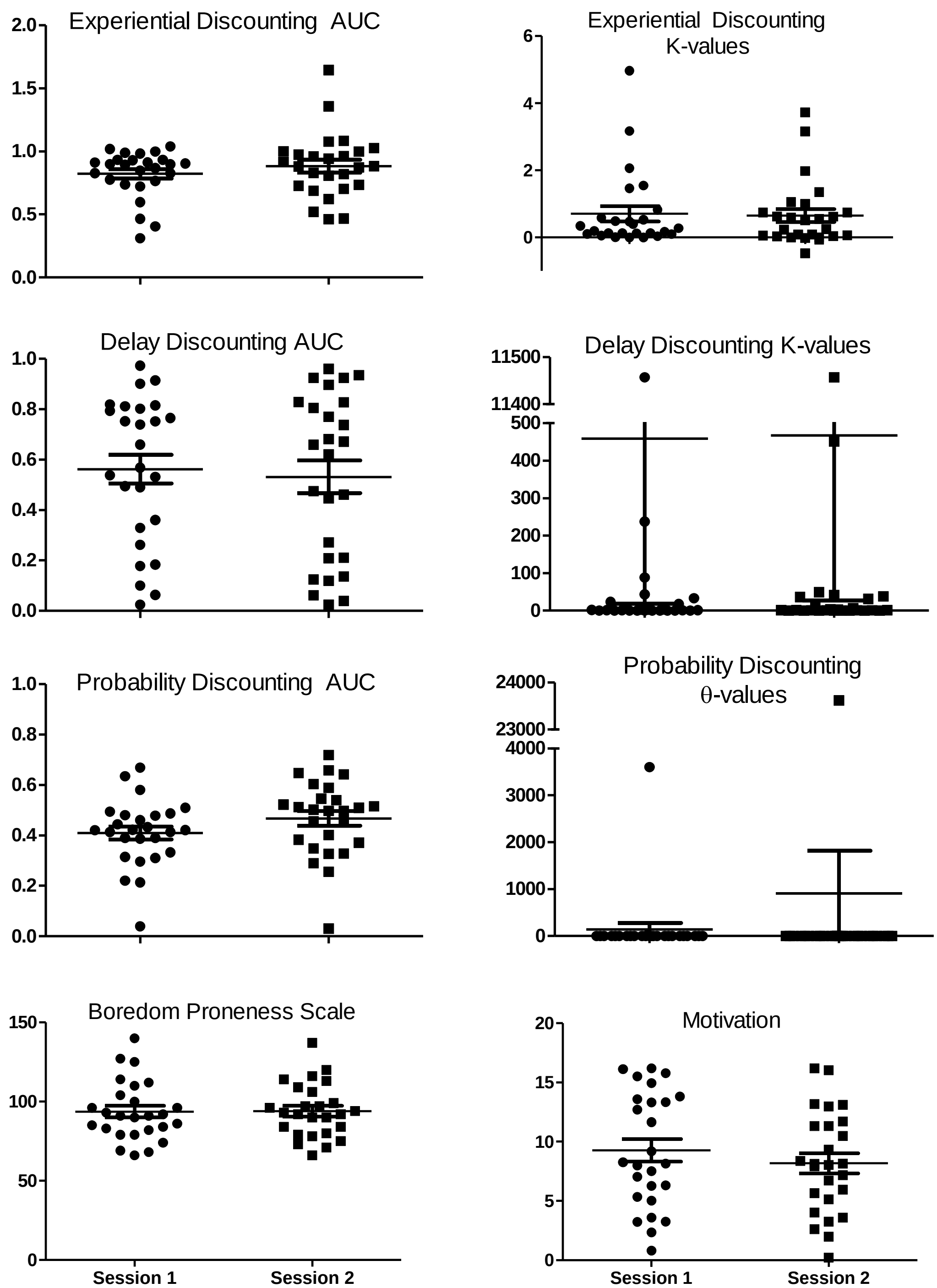

Figure 4. Individual values from each assessment for each session in Experiment 1.

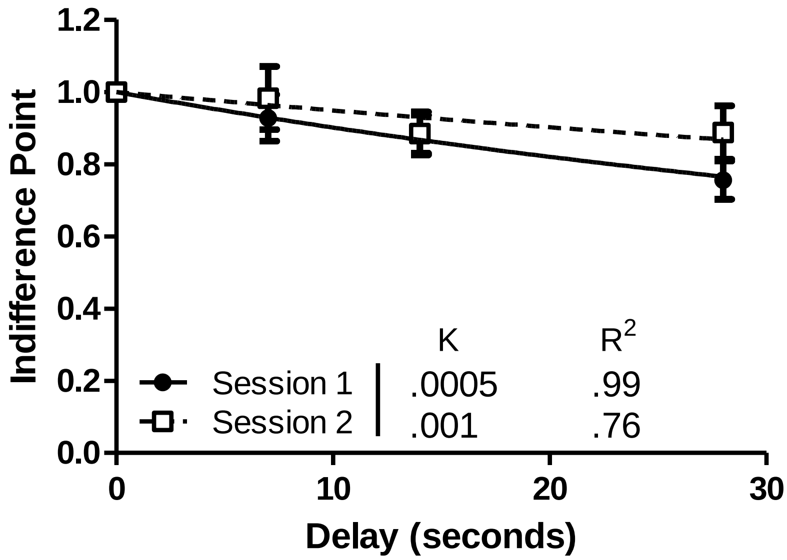

Figure 5. Median normalized indifference points from the Experiential Discounting Task in Experiment 1. Error bars depict standard error of the mean (*n* = 29).

For these reasons, we tested for time effects on normalized or proportional indifference points using a 2 (session) by 4 (indifference point) repeated measures ANOVA. The Greenhouse-Geisser correction on degrees of freedom was used when there were violations of sphericity. Figure 5 shows normalized indifference points as a function of delay in the two EDT sessions. There was a significant main effect of delay (F(2.029) = 7.8, $p < .001$), no main effect of session (F(1) = 1.391, $p = .249$), and no session by delay interaction (F(3) = 1.1, $p = .352$). Delay and probability task indifference points are shown in Figure 6. For the DDT there was a significant main effect of delay (F(1.605) = .89, $p < .001$), no main effect of session (F(1) = .989, $p = .33$), and no interaction (F(2.698) = .89, $p = .44$). For PDT there was a main effect of probability (F(2.2) = 180.346, $p < .001$) no main effect of session (F(1) = 2.067, $p = .163$), but there was a marginally significant interaction (F(4) = 2.609, *p* = .056). Though there was a marginally significant interaction, θ-values did not differ significantly between sessions (W = -49, *p* = .54).

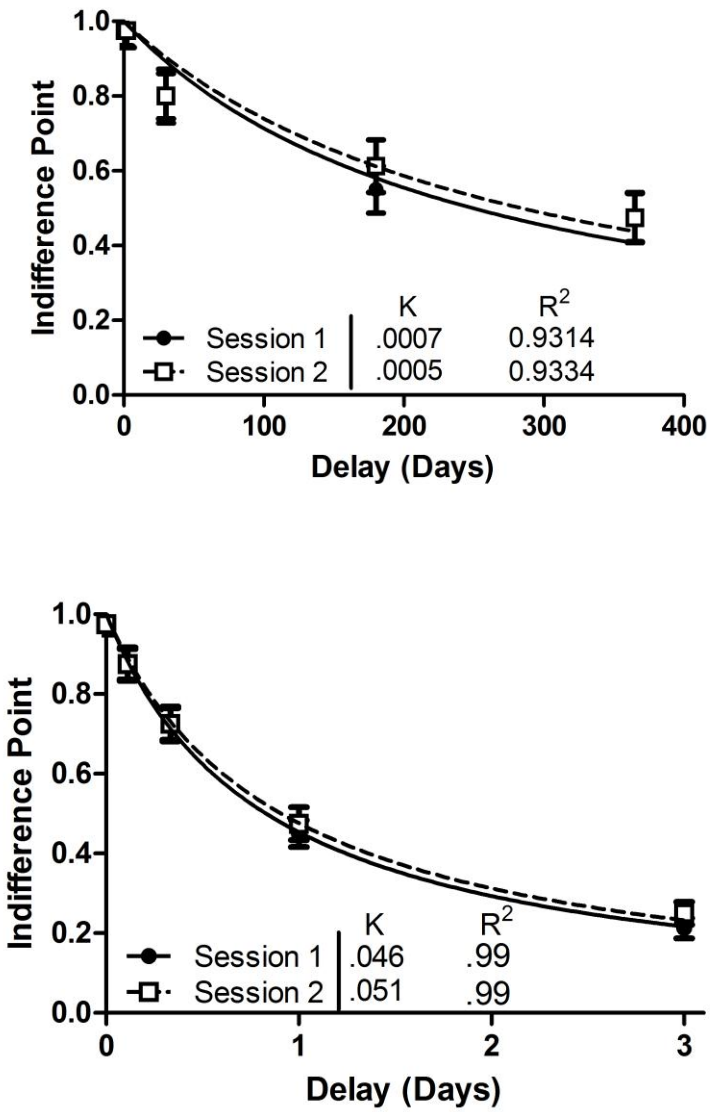

Figure 6. Delay (top) and probability discounting group median indifference functions in Experiment 1. Error bars depict standard error of the mean.

Covariance of Dependent Measures

As no statistically significant differences were detected across sessions, data were averaged across sessions for the remaining analyses. Table 8 shows the correlation matrix among AUC values generated by the EDT, DDT, and PDT; it also shows correlations between these measures and the BPS and MMS. The only significant correlation was a positive relation between DDT and PDT AUC values. Thus, those who steeply discounted delayed rewards also tended to be risk averse. Importantly, AUC from the EDT and DDT were not significantly correlated, suggesting that the two tasks measure different processes.

Table 8

Correlation Matrix for Dependent Measures in Experiment 1

	1	2	3	4	5	M	SD
1. EDT AUC	1					.85	.19
2. DDT AUC	**.01**	1				.55	.29
3. PDT AUC	**.21**	.41*	1			.44	.12
4. BPS	**-.01**	-.08	.19	1		94	17
5. MMS	-.34	.39	-.09	**.13**	1	8.7	4.2

Note. n = 26. Because differences between sessions were not detected, data for each dependent measure were averaged across sessions. **Bold** indicates Spearman's ρ was used. ***** $p < .05$.

Experiment 2: Inter-Trial Interval

Table 9 shows k- and R^2 values for individual participants across the four tasks in Experiment 2. Friedman's test revealed no significant difference across tasks despite the range of median values (.44 for EDTmod to .88 for PDT; Table 9; $\chi^2(3)) = 0.33$, p =.85).

In addition, no differences in deviation from the hyperbolic curve were detected (mean square error; F(3) = .3382, *p* = .80).

The primary question of Experiment 2 was whether the addition of an ITI would systematically affect choice. The median of all participants' indifference points for the EDT and EDTmod are shown in Figure 7. A matched-pairs *t* test revealed no significant effect of adding an ITI regardless of whether AUC or *k*-value was used to quantify discounting (*t* = .86, *p* = .40; *t* = .97, *p* = .34, respectively). A 2 (task) by 4 (delay) repeated measures ANOVA using individual indifference points revealed no main effect of delay (F(3) = 1.641, *p* = .19), task (F(1) = .526, *p* = .477) nor interaction (F(3) = .646, *p* = .588).

As in Experiment 1, correlation coefficients were calculated using either Pearson's *r* or Spearman's ρ and these are reported in Table 10. The correlations between discounting measures across the two EDT tasks were not statistically significant. Upon further examination of the data there was one outlier, with an AUC value from the EDT session of 1.68 and only .78 in the EDTmod. AUC values exceeding 1 are possible in the EDT because indifference points are normalized to the indifference point obtained in the first trial block (0-s delay). If indifference points in subsequent trial blocks exceed this first indifference point, AUC may be > 1. Excluding this participant produced a strong, positive correlation between EDT tasks regardless of the way in which discounting was quantified (AUC *r* = .74, *p* < .01; *k*-value *r* = .90, *p* < .01). The BPS was negatively correlated with EDT AUC indicating that individuals who are less prone to boredom discount less steeply in the EDT. The MMS did not significantly correlate with any dependent measure.

Table 9

Individual Best-Fitting k Parameters (and R^2 Values) From Experiment 2

ID	EDT	EDTmod	DDT	PDT
1	.28 (.01)	.13 (.21)	257 (.96)	8.0 (.80)
2	-.01 (.88)	.05 (-)	.62 (.59)	10 (-)
3	.93 (.51)	.59 (.79)	.61 (.47)	5.1 (.93)
4	-.04 (.08)	.14 (.94)	2.0 (.60)	2.2 (.99)
5	.39 (.07)	.55 (.78)	6.1 (.97)	1.6 (.69)
6	.05 (.70)	.25 (.83)	.54 (.73)	4.0 (.97)
7	.06 (.11)	.16 (.78)	.47 (-)	.83 (.62)
8	-.73 (.93)	.41 (-)	152 (.96)	48 (.99)
9	.26 (.54)	.06 (.69)	.44 (.49)	.74 (-)
10	.47 (.68)	.13 (.35)	.36 (.91)	3.838 (.98)
11	0 (0)	0 (0)	.30 (.15)	1.7 (.84)
12	.80 (.94)	.20 (-)	10 (.94)	1.6 (.93)
13	.16 (.84)	-.01 (-)	57 (.51)	2.2 (.69)
14	.05 (.52)	.32 (.57)	6.0 (.87)	1.2 (.92)
15	.22 (.64)	.53 (.87)	.22 (.21)	7.5 (.99)
16	.32 (.86)	.21 (.53)	6.3 (-)	3.8 (.72)
17	0 (0)	0 (0)	.03 (0)	4.8 (.94)
18	-.07 (.26)	.13 (-)	.03 (0)	.08 (.75)
19	14 (.98)	1.8 (.88)	.03 (0)	12 (.90)
20	.97 (.11)	-.16 (-)	39 (.95)	5.0 (.85)
Median:	.14 (.59)	.15 (.44)	.59 (.59)	3.8 (.88)

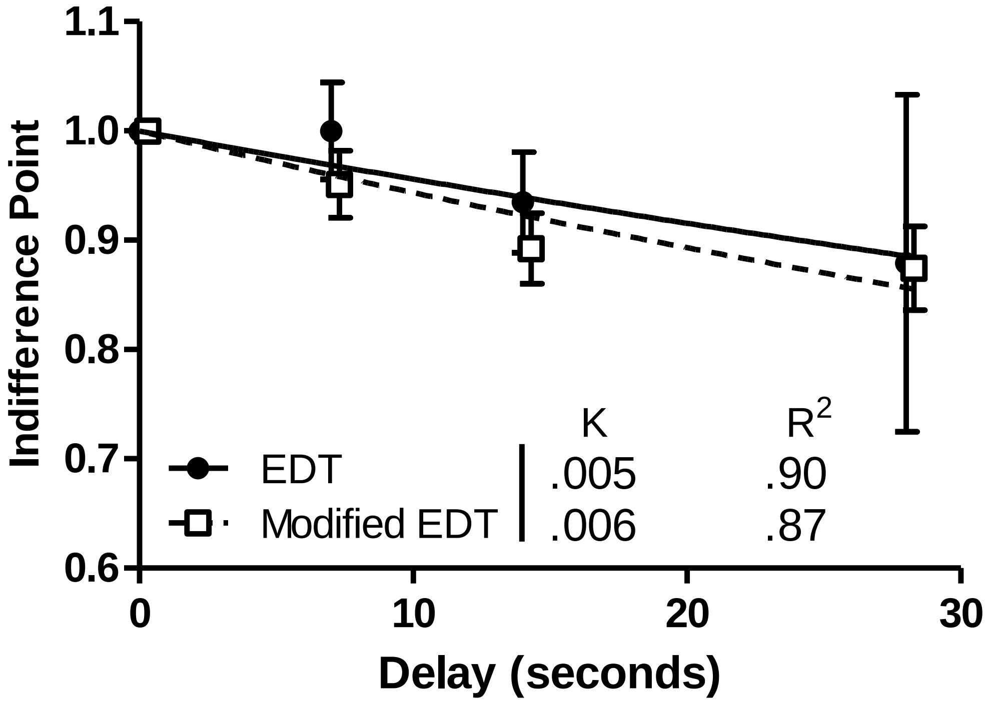

Figure 7. Median normalized indifference points from the EDT in Experiment 2. Error bars depict standard error of the mean (n = 20).

Table 10

Correlation Matrix and Descriptive Statistics for Dependent Measures in Experiment 2

	1	2	3	4	5	6	M	SD
1. EDT auc	1						.92	.25
2. EDTmod	.33	1					90	.12
3. DDT auc	-.34	-.10	1				.61	.32
4. PDT auc	-.18	.19	.27	1			.49	.20
5. BPS	**-.45***	**-.29**	**.07**	.37	1		82	16
6. MMS	-.28	.13	.22	.34	-.23	1	8.7	5.0

Note. *n* = 20. Only AUC values were used for the discounting assessments. **Bold** indicates Spearman's ρ was used. ***** *p* < .05.

Combined Analyses

Because several of the tasks were identical in both experiments a number of questions can be addressed using the data from both experiments. Four overall correlations are of interest: the correlation between discounting as assessed by the EDT and DDT, how both of these correlate with probability discounting, and how the 0-second indifference points on the EDT (a putative measure of sensitivity to probability) correlate with probability discounting. Figure 8 shows the absence of a correlation between AUC values obtained in the EDT and DDT across both experiments (ρ = .01, p = .94).

We combined the delay and probability discounting data from both experiments (averaging the values across sessions in Experiment 1). Figure 9 shows that there was a significant positive correlation between AUC across these two tasks (r = .33, $p < .05$). Figure 10 shows that there was no significant correlation between EDT and probability discounting. Note that there were two participants excluded from this analysis based on a z-scores greater than 3 (one for EDT AUC, and the other for PDT AUC).

One assumption of the EDT is that the indifference point in the 0-second delay block is a measure of sensitivity to probability (because the delayed option is probabilistic). In order to test this assumption, in Figure 11 we assessed the correlation between the 0-second indifference point in the EDT with AUC from the PDT. Figure 11 reveals a significant positive correlation. Note one participant was excluded as an outlier (z-score >3) based on PDT AUC.

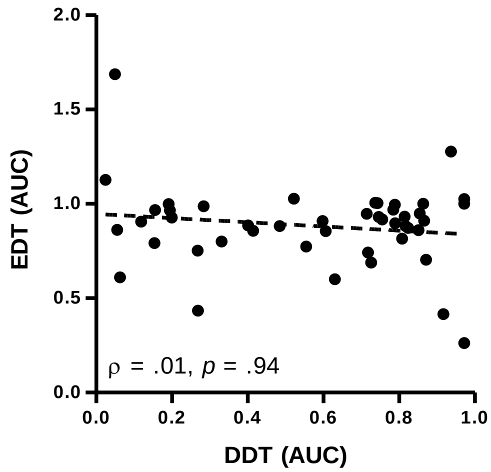

Figure 8. Correlation between delay discounting and experiential discounting area under the curve. Dotted line depicts the best-fitting regression line (n = 46).

Finally, we examined correlations between the three discounting assessments and the five factors of the BPS (Vodanovich & Kass, 1990). There were no significant relations between the discounting measures and the BPS items (Table 11).

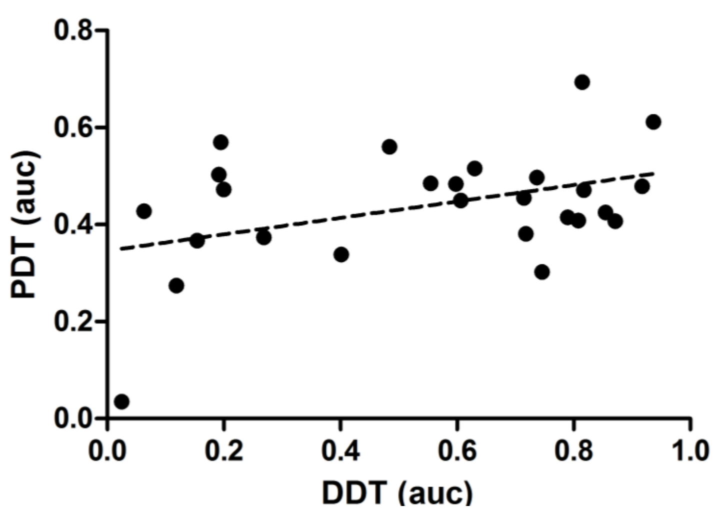

Figure 9. Correlation between delay discounting and probability discounting area under the curve. Dotted line depicts the best-fitting regression line (n = 46).

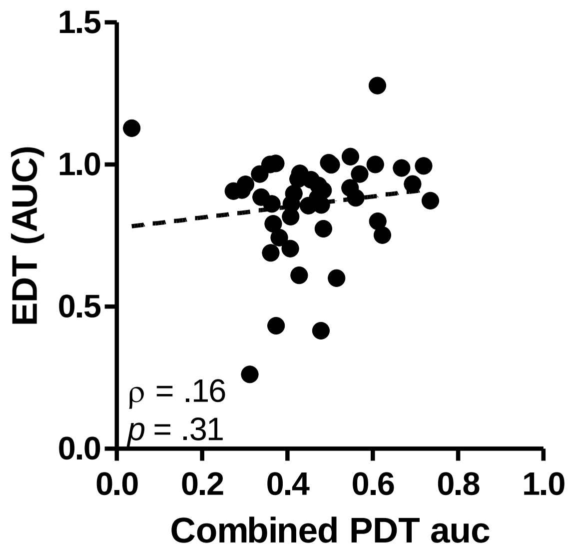

Figure 10. Correlation between experiential discounting and probability discounting area under the curve. Dotted line depicts the best-fitting regression line (n = 44).

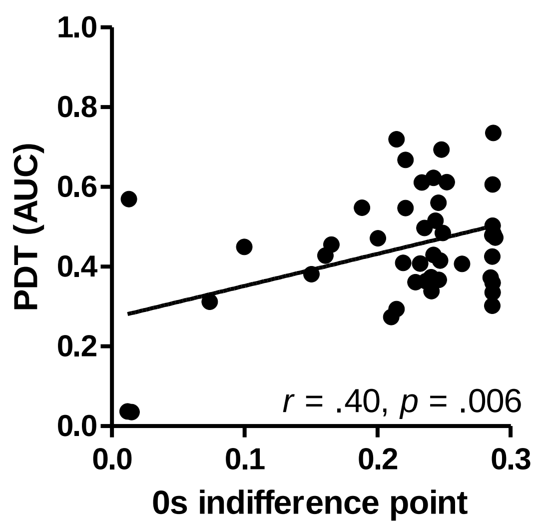

Figure 11. Correlation between probability discounting AUC and the 0-second indifference point from the EDT. Indifference points were used from Experiments 1 and 2; Session 1 in Experiment 1 and the EDT from Experiment 2. Dotted line depicts the best-fitting regression line (n = 45).

Table 11

Correlations Among BPS Subscales and Experiential, Delay, and Probability Discounting

	EDT	DDT	PDT
External Stimulation	-.03	.001	.12
Internal Stimulation	-.24	.05	-.09
Perception of Time	-.25	.07	.02
Constraint	.07	-.06	.001
Affective Responses	-.25	.04	.09

Note. $n = 59$

Another Hypothesis

To further investigate the behavioral processes underlying the EDT, we investigated a model that calculates discounted value for rewards that are both probabilistic and delayed. Yi et al. (2006) proposed the following equation in which probability is included in the hyperbolic equation as a cost variable that combines additively with the delay:

$$V = \frac{A}{1+k\,(d+R\,\theta)} \quad (2)$$

In Equation 2, R is a scaling parameter for the odds against obtaining the delayed reward (θ); all other parameters are as in Equation 1. Rachlin et al. (1991) calculated a scaling parameter for odds against by having participants make decisions about delayed and probabilistic rewards. In their experiments with human subjects, an R of 35.3 provided the best between-subjects fit. We used this R-value and Equation 2 to fit non-normalized

EDT indifference points (data were non-normalized because reward probability was now included in the discounting equation). At this value of *R*, Equation 2 provided poor fits (median R^2 = .18; see the frequency distribution in Figure 12). Next we allowed *R* to vary between participants and, not surprisingly, obtained better fits (as seen in Figure 12).

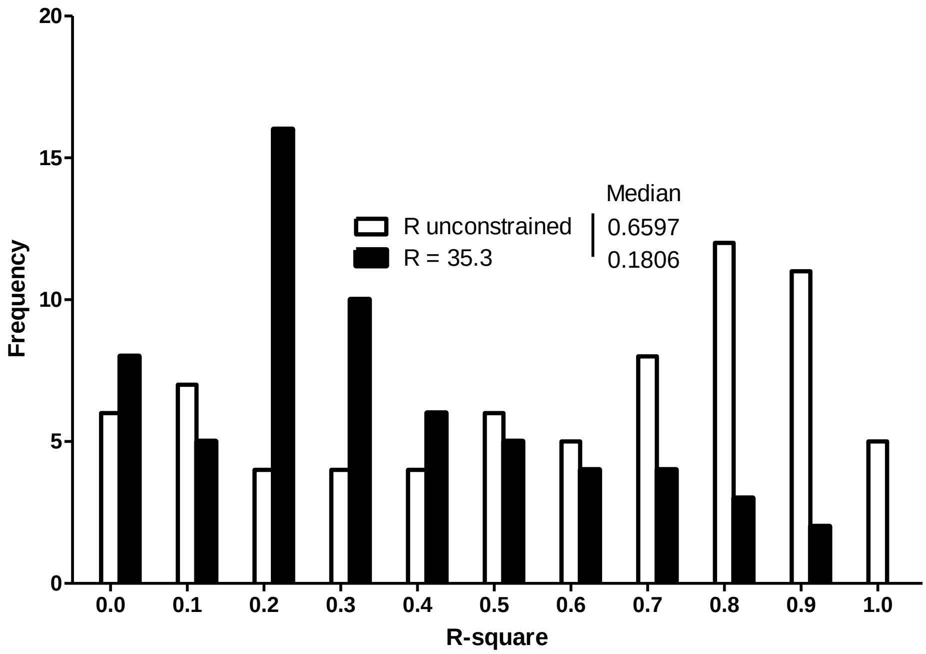

Figure 12. Distribution of R^2 values from equation 2 based on various constraints of the parameter *R*. All negative R^2 values are included in the 0 bin.

Using this arrangement of free-parameters, the estimates of *k* and *R* putatively account for individual variation in sensitivity to delay and probability, respectively. With sensitivity to reward probability removed from the EDT estimate of delay discounting, one would now expect EDT *k*-values derived from Equation 2 to correlate with AUC from the DDT. Figure 13 shows that there was no correlation between the two.

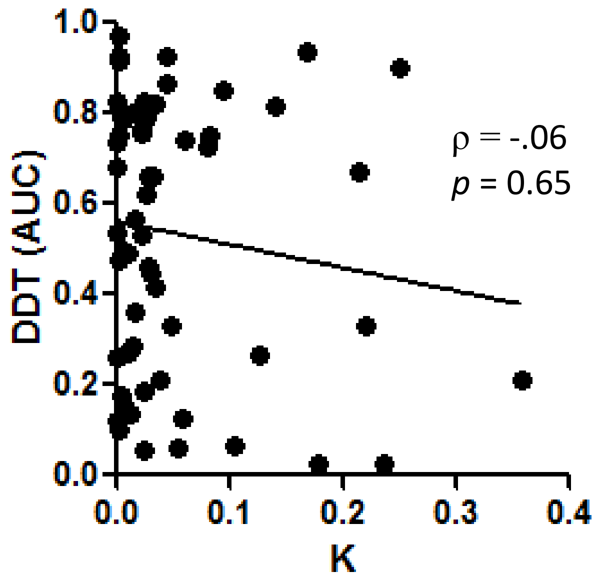

Figure 13. Correlation between best-fitting *k*-values when R was unconstrained and delay discounting AUC.

CHAPTER IV

DISCUSSION

The goals of the present set of experiments were to (a) assess the test-retest reliability of the EDT, (b) determine if adding an ITI to the EDT would systematically affect choice, and (c) evaluate its validity against a DDT with good test-retest reliability and internal validity. Experiment 1 demonstrated that the EDT had good test-retest reliability over a period of seven days. Experiment 2 demonstrated that adding an ITI to trials in which the SS reward was selected did not affect choices made in the EDT.

The EDT was developed to provide a measure of delay discounting that addresses concerns about more typical procedures used to assess delay discounting in humans; it arranges real instead of hypothetical rewards and delays, and estimates discounting from a stable pattern of choice. As noted earlier, the real rewards arranged in the EDT are different from those arranged in nonhuman experiments because monetary rewards cannot be spent (consumed) when delivered. Because previous research with pigeons (e.g., Hackenberg & Vaidya, 2003) and people (Hyten et al., 1994) suggests delayed non-consumable rewards are not discounted over the range of delays arranged in the EDT, it is surprising that delay discounting is observed in the EDT.

The present studies were designed to test one of the procedural concerns associated with the EDT—the omission of ITIs. Although not using an ITI allows for opportunity costs of choosing the LL that often occur in our everyday lives, it is difficult to dissociate the effects produced by opportunity costs versus the effects of the delay. However, when we imposed an ITI in Experiment 2 we found no change in performance from the EDT without ITIs. These data suggest that inclusion of opportunity costs associated with LL choice is a nonfunctional procedural characteristic of the EDT. Thus, it appears that the EDT does not capture the effect of opportunity costs.

Does the EDT Assess Delay Discounting?

The present findings reveal (a) DDT and EDT measures of delay discounting were uncorrelated; (b) the hyperbolic model (Equation 1) provided poorer fits to EDT than DDT indifference points; (c) EDT choice (like DDT choice) does not systematically change over a period of 7 days; and (d) when sensitivity to reward probability was separated from EDT estimates of *k*, these estimates were not correlated with the DDT assessment of delay discounting. Together with the literature summarized in the Introduction, very little evidence supports the EDT as a valid measure of delay discounting.

What Does the EDT Measure?

Given these findings, what does the EDT measure? Here we will consider four possibilities. First, the EDT may provide a measure of sensitivity to opportunity costs. Traditional delay discounting tasks use hypothetical rewards and delays which do not arrange opportunity costs associated with choosing the delayed reward (i.e., one is free to pursue other rewards during the delay). By contrast, in the EDT one is unable to obtain the SS alternative for the duration of the delay to the LL reward. In this way, performance in the EDT may be determined by one's sensitivity to opportunity costs. If this is so, then EDT performance should not be related to a task that assesses the devaluation of a reward delayed in time (namely a DDT). Perhaps sensitivity to opportunity costs co-varies with substance use disorders and may be affected by experimental manipulations such as sleep deprivation (e.g., Reynolds & Schiffbeaur, 2004) and alcohol (Reynolds et al., 2006). However, if this were the case, then we should have seen a significant difference in EDT performance when the ITI was excluded, as in Experiment 2.

Second, the EDT may measure intolerance for periods devoid of stimulation. In the EDT, one can avoid no-stimulation periods by choosing the SS reward. If this were the case we would expect BPS scores to negatively correlate with EDT performance. We did find a negative relation between overall BPS scores and EDT performance in Experiment 2 indicating that this might be a mechanism behind EDT performance. However, this relation was not seen when Experiments 1 and 2 were combined. Further evidence against this hypothesis is that the internal stimulation subscale of the BPS (inability to entertain oneself) was not significantly correlated with EDT scores. More data will be needed to further explore this relation.

Third, the EDT may measure subjective perception of the passage of time. If a participant's internal clock ran quickly, the delay to the LL reward in the EDT (a delay actually experienced during the EDT) would be subjectively experienced as longer than by a participant with a slower clock. The BPS includes a perception of time subscale, which quantifies the extent which boredom occurs because time is perceived as passing slowly. However, EDT scores were not correlated with this subscale of the BPS.

Finally, the EDT might be affected by participant's ability to discriminate and strategically exploit the EDT's adjusting-amount algorithm used to determine an indifference point (i.e., the internality). In animal adjusting-amount tasks the choice is between small amounts of food or liquid, each consumed upon delivery. By contrast, in the EDT, money is accumulated, either on screen or in a glass jar, which may facilitate discrimination of the algorithm by which the amount of the adjusting alternative changes depending on choice. Participants who discriminate this algorithm may be more likely to choose the LL reward in an effort to strategically increase the amount of the SS reward. This may be followed by a series of choices in which participants "cash in" by repeatedly choosing the SS (for sure) reward. Figure 3 depicts the adjusting-amount algorithm by plotting the SS amount (dashed line) as a function of choice. Assuming maximization of amount, participants should never choose the LL reward when the SS exceeds the expected value of the larger alternative; i.e., 11 cents. However we often found indifference points between 21 and 25 cents. If LL choices are made to exploit the adjusting-amount algorithm and increase the amount of the SS reward, then the slope of the curve in Figure 3 depicts the decreasing benefit of each additional LL choice (in increasing the SS amount).

In a procedure designed to test the extent to which individuals exploit an adjusting algorithm, Heyman and Dunn (2002) reported that in comparison to matched controls, substance abusers did not learn to exploit the internality. Substance abusers may similarly not learn to exploit the internality in the EDT causing their performance to be significantly different from controls (Fields et al., 2009; Meda et al., 2009; Melanko et al., 2009). Similarly acute effects of sleep deprivation or alcohol may dampen an individual's ability to detect and exploit this internality. In order to test this assumption, future research should directly compare EDT performance to performance in a task that is designed to specifically test sensitivity to an internality.

An important further consideration for future research is the experiential nature of the EDT. That is, how might choice in the EDT be affected if either the delays, rewards or both were not experienced, but were conveyed verbally? Interestingly, there does not seem to be a difference in EDT results when the money is delivered via a coin dispenser immediately when the reward is earned versus when the amount accumulates on-screen and delivered in one lump sum following completion of the session.

Conclusion

The EDT is a procedurally complicated task in which choices are made between SS and probabilistic LL rewards. Given the numerous potentially interacting procedural variables, it is difficult to say what the EDT measures. However, the results of our experiments provide very limited evidence supporting the contention that the EDT measures delay discounting.

Because choice in the EDT is sensitive to acute experimental manipulations, group differences, and may be predictive of drug-taking, it is important to know what the EDT measures. Future research might benefit from systematically asking participants to report why they make the choices they make. Such self-reports may provide evidence for one of the controlling variables discussed above, or they may suggest a new variable that could be experimentally manipulated in future research.

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APPENDICES

APPENDIX A

Experiential Discounting Task Instructions

"This first portion is a practice portion, you will not receive any money from this portion. You will receive, in cash, the amount you earn during the portions you complete while I am out of the room."

a. Point to the left light bulb and say: *"This is the delayed option."*

b. Point to the right light bulb and say: *"This is the immediate option."*

c. Point to the Total Amount Area and say: *"This is the amount that you will receive in cash."*

d. Read:

"*You will have the opportunity to make multiple choices between a delayed and probabilistic 30 cents or an adjusting immediate and for sure amount of money to be deposited into the bank.*

… as you are making choices with this task, the adjusting amount will adjust *according to certain rules. For every choice to the delayed 30 cents on the left…*

e. Point to the left light bulb and continue:

"…the adjusting amount on the right…

f. Point to the right light bulb and continue:

"…will go up in value for the next choice. For every choice to the adjusting immediate amount on the right…

g. Point to the right light bulb and continue:

"*...the amount on that side will go down in value for the next choice. There are no right or wrong ways to do this task, just do what you prefer. You will be completing several portions, all of which will differ in length of time—from short to long. Proceed through the portions at your own pace. A box will pop up signaling the end of the task. You will know this is the end because it requires a password to continue.*

At this point, you will signal for me and I will record how much money you have earned in this task.

h. To demonstrate how the program works, run the practice portion, having the participant make choices for each option.

i. point out: **The bank button must be clicked when it illuminates and that the amount of money on the right side is adjusting based on the previous choice.**

i. Following the completion of the practice session ask the participant if he/she has any questions. After any questions have been answered, leave the room until they signal for you to return.

APPENDIX B

Answers to Commonly Asked Questions in the EDT

Commonly asked questions (*with responses in italics*):

If the participant does not readily click on the bank button when it illuminates.
Response: [point to the bank button] *You need to click this to deposit the money into your bank.*

"Why are the buttons not available?"
Response: *Sometimes you just need to wait.*

"Is it broken?"
(at the end during the long waiting period)
Response: *It is working properly, you just have to wait longer sometimes.*
(When only one alternative becomes available)
Response: *Sometimes this happens, you simply have to choose the available one.*

Adjusting amount (confusion or misunderstanding)
Response: (refer to the appropriate sections on the previous page).

"Will I get credit for my psychology course for completing this study?"
Response: *No, the only form of compensation is the cash we will pay you at the end of the session.*

APPENDIX C

Delay and Probability Discounting Task Instructions

In this task you will choose between different amounts of money.
All of these outcomes are hypothetical (you will not actually receive the money).

Use the computer mouse to make your decisions.
Please make your decisions as if you were really going to receive the money.

There are no correct or incorrect choices; just make our choices so they reflect what you really want.

APPENDIX D

Boredom Proneness Scale

Before each statement below please rate the extent to which the statement applies to you using the following scale:

1	**2**	**3**	**4**	**5**	**6**	**7**
Highly Disagree						**Highly Agree**

______ 1. It is easy for me to concentrate on my activities. (Reverse)
______ 2. Frequently when I am working I find myself worrying about other things.
______ 3. Time always seems to be passing slowly.
______ 4. I often find myself at "loose ends", not knowing what to do.
______ 5. I am often trapped in situations where I have to do meaningless things.
______ 6. Having to look at someone's home movies or travel slides bores me tremendously.
______ 7. I have projects in mind all the time, things to do. (Reverse)
______ 8. I find it easy to entertain myself. (Reverse)
______ 9. Many things I have to do are repetitive and monotonous.
______ 10. It takes more stimulation to get me going than most people.
______ 11. I get a kick out of most things I do. (Reverse)
______ 12. I am seldom excited about my work.
______ 13. In any situation I can usually find something to do or see to keep me interested. (Reverse)
______ 14. Much of the time I just sit around doing nothing.
______ 15. I am good at waiting patiently. (Reverse)
______ 16. I often find myself with nothing to do, time on my hands.
______ 17. In situations where I have to wait, such as a line I get very restless.
______ 18. I often wake up with a new idea. (Reverse)
______ 19. It would be very hard for me to find a job that is exciting enough.
______ 20. I would like more challenging things to do in life.
______ 21. I feel that I am working below my abilities most of the time.
______ 22. Many people would say that I am a creative or imaginative person. (Reverse)
______ 23. I have so many interests, I don't have time to do everything. (Reverse)
______ 24. Among my friends, I am the one who keeps doing something the longest. (Reverse)
______ 25. Unless I am doing something exciting, even dangerous, I feel half-dead and dull.
______ 26. It takes a lot of change and variety to keep me really happy.
______ 27. It seems that the same things are on television or the movies all the time; it's getting old.
______ 28. When I was young, I was often in monotonous and tiresome situations.

APPENDIX E

Monetary Motivation Scale

Participant ID: ____________ Gender: M / F

Please rate your current financial state by placing an X across the line or filling in the blank.

1. I don't have any spare cash to buy small items (such as snacks or movie rentals):

Strongly Disagree		Strongly Agree

2. I have spare cash to buy small items (such as coffee or snacks):
   (Place an "X" on the line to describe how well this statement describes you)

Strongly Disagree		Strongly Agree